Province of British Columbia
Ministry of Energy, Mines
and Petroleum Resources
Hon. Anne Edwards, Minister

MINERAL RESOURCES DIVISION
Geological Survey Branch

SELECTED BRITISH COLUMBIA MINERAL DEPOSIT PROFILES

Volume 1 - Metallics and Coal

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OPEN FILE 1995-20

1895 - 1995
100 YEARS OF GEOLOGICAL SURVEYING

1895 - 1995

100

YEARS OF GEOLOGICAL SURVEYING

1995 is the 100th anniversary of the British Columbia Bureau of Mines, the predecessor to the present Mineral Resources Division. The Bureau brought together into one Department all government offices that dealt wholly with mining, including the Gold Commissioners, the Government Assay office, the Inspector of Mines and the newly created Provincial Mineralogist.

The Provincial Mineralogist, later known as the Chief Geologist, was charged with the collection of information on the geology and various mining projects in the Province, for the publication of such information to make the mineral wealth of the Province more widely known, and also for promoting the development of the mining industry. These are the origins of the British Columbia Geological Survey Branch.

In 1995 we celebrate 100 years of geological surveying; dedication and progress.

Individual deposit profiles should be quoted by referencing the author or authors. The following is the recommended format for referencing individual deposit models contained in this publication:

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BRITISH COLUMBIA GEOLOGICAL SURVEY

VICTORIA
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Table of Contents

British Columbia Mineral Deposit Profiles

INTRODUCTION

The British Columbia Geological Survey Branch (BCGS) started a mineral potential assessment in 1992 utilizing deposit models for defining and characterizing mineral and coal deposits which exist, or for which favourable geological environments could exist, in the province. The current methodology for this resource assessment process is described by Grunsky *et al.* (1994), Kilby (1995) and Grunsky (1995). A fundamental part of this process is compilation of information about mineral deposits including descriptions, classification and resource data (Lefebure *et al.*, 1995a). The resulting deposit models are being used to classify known deposits and occurrences, to guide experts in their estimation of the number of possible undiscovered mineral deposits, and to group deposits to allow compilation of representative grade and tonnage data.

The Branch initially relied on mineral deposit models published by the United States Geological Survey (USGS) and Geological Survey of Canada (GSC). However, it became apparent that some models needed revision, and that there are British Columbia deposit types lacking published models. This work is proceeding using the Branch's considerable in-house expertise (McMillan *et al.*, 1991) with assistance from economic geologists of the GSC, USGS, industry and academia.

These deposit models are called 'deposit profiles' to distinguish them from other published descriptions, such as the USGS 'deposit models'. One value of the profiles is that they will provide geologists and prospectors with a reference guide to deposits with which they have little familiarity. In some cases they may encourage consideration of new exploration targets within the province (Lefebure, 1995).

This open file is the first of several reports planned to publish the working drafts of the deposit profiles. The ultimate objective is to publish all the deposit profiles in a single volume.

CITATION

This report reflects the contributions of many individuals, particularly the authors of the individual deposit models. It would be appreciated if the individual authors could be cited whenever appropriate rather than the entire Open File.

BACKGROUND

"An ore deposit model is a conceptual and/or empirical standard, embodying both the descriptive features of the deposit type, and an explanation of these features in terms of geological processes."

Hodgson, 1993

In recent years there has been considerable discussion of the importance and dangers of deposit models and their relevance to exploration (Cox, 1993). One of the points underscored by this debate is that while models are an extremely useful method of organizing data, they may lead to over simplification of complex natural phenomena. Important data may be ignored because it does not fit the model. Every model has limitations, particularly those attempting to portray the essential features of natural phenomena.

Interactions between the constructors of models, who are often government and academic geologists, and the explorationists who use them, are critical to the evolution of more accurate and useable models (Hodgson, 1993). Often it is the deposits that can not be classified, or the observation that can not be explained by an existing model, which lead to an advance in our understanding of ore-forming processes or products.

Critical elements of mineral potential assessments are standard deposit-type descriptions that are used to group similar deposits. These standard descriptions can then be used as "deposit definitions" for expert analysis of the mineral potential of geological tracts and provide the basis for selecting resource data for quantitative assessments, such as tabulations of grade and tonnage data (Grunsky, 1995).

Complete suites of deposit models are desirable, even though mineral assessments and exploration programs tend to focus on a restricted number of deposit types at any given time. For government, it is important to assess the resource values with an eye to future exploitation of resources. The mineral potential of some land tracts will be increased if deposit types of little significance today can be identified as possible mines of tomorrow. For industry, it is critical to be able to decide whether a particular occurrence belongs to a deposit type that is economically interesting at the present time. This helps focus exploration efforts on targets with a greater chance of economic return.

The USGS published the first comprehensive set of mineral deposit models and related grade and tonnage probability curves (Cox and Singer, 1986). They present 85 mineral deposit models and 60 associated grade and tonnage curves. Almost all the deposits described contain metallic commodities. Since then the USGS has produced a number of other publications containing summary deposit models, including two significant Open File reports with a large number of industrial minerals models (Orris and Bliss, 1991, 1992). The USGS continues to work on deposit models, however, it has yet to publish models for some deposits that have been found, or could exist, in British Columbia.

B.C. MINERAL DEPOSIT PROFILES

Mineral deposit profiles are concise descriptions tied to a series of headings which will fit on two or three pages. This format is similar to those of deposit models published by the GSC and the USGS (Eckstrand, 1984; Cox and Singer, 1986). They are designed to be primarily descriptive because the ore-forming processes are sometimes poorly understood. As with the USGS models, the profiles are intended to be global models with sufficient information to describe the deposit type anywhere in the world. However, they incorporate more information specific to British Columbia with respect to tectonic setting, age of mineralization, examples, references, resource data and economic factors. The guidelines given to the authors for the profiles are presented in Appendix I.

As part of the British Columbia mineral resource assessment process more than 9900 of the MINFILE occurrences in the province were classified by detailed deposit type. This assisted the analysis of the mineral potential of individual geological tracts by identifying all the deposit types that are known to exist within the tract. It also provided a check on the effectiveness of existing deposit models to adequately describe the complete array of mineral occurrences in British Columbia. Geologists classifying occurrences quickly pointed out that there were a number that did not fit any of the existing profiles and some that did not fit any of the USGS models either. In some cases this reflected the difficulty of classifying poorly described showings and prospects. However, it also identified more deposit models that needed to be written. This exercise should be completed for any area where mineral potential is being assessed as it provides a very useful check on the applicability and completeness of global models being applied.

A number of deposit types that are not thought to be relevant to British Columbia have not been addressed by completing profiles. For example, there seems very little likelihood of Bushveld type Fe-Ti-V or komatiitic nickel deposits occurring in the province. In some cases very specific deposit models have been combined to provide a more general model that better meets the needs of the mineral potential assessment process.

Profiles are based on a combination of published information and the personal knowledge of the authors and, in many cases, information provided informally by industry geologists. More than 140 general deposit models are thought to be relevant to British Columbia, including more than 75 metal, 70 industrial mineral and four coal profiles. The Branch is currently working towards completing descriptions for approximately 100 of these deposit models. We are also compiling grade and tonnage data for selected models.

With new data being produced every day by industry and research geologists, it is expected that some of today's models will be out-of-date tomorrow. The BCGS profiles will change as we receive more information from industry and research geologists. Better models assist both the exploration community and resource assessment geologists.

One of the objectives of this Open File is to elicit comments and criticisms from readers which can assist the authors and editors to improve the deposit profiles. Branch staff can be contacted at the following addresses:

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CLASSIFICATION

The different methods of grouping of the different deposit types has generated considerable discussion. This reflects the difficulties in any subdivision of complex natural phenomena, particularly when some deposit types are end members of a continuum. The many classification systems developed since Agricola are testimony to the elusive nature of a satisfactory classification scheme for mineral deposits. This is not surprising given ongoing advances in our understanding of ore-forming processes. The reader is directed to summaries by Jensen and Bateman (1979) and Peters (1978) for a review of different classification systems.

With our profiles, the approach has been to regard the deposit models as the key element and any classification system as merely an index for placing the models into a useful context for the user. Profiles will be published with multiple indexes, such as by deposit examples, commodity and host lithology. An example of providing indexes to mineral deposit types is Laznicka's text (1985); this reference proved invaluable in researching international examples of deposits similar to those in British Columbia.

Two classification schemes for British Columbia deposit profiles are presented in this open file. The first is organized by deposit groups (Appendix II, Table 3) which uses a combination of characteristics to separate deposits into groupings frequently used by geologists. This is a single entry listing with headings, such as porphyry, industrial rocks, organic and placer deposits, divisions which relate well to areas of expertise of economic geologists. The second classification system classifies profiles according to the most commonly associated host lithologies. This is a multiple entry index (Appendix II, Table 4). It is particularly useful for mineral potential assessments where the bedrock geology is the most important criterion for estimating the number of undiscovered deposits.

The two tables in Appendix II provide some related information that may be of use to the reader. Alternate deposit model names are included under synonyms. In many cases example deposits from British Columbia, Canada and the world are listed for each profile. These are meant to provide knowledgeable readers with suitable reference points. There has been considerable effort put into checking that the examples are representative of the deposit type, however, we are aware that some of the deposits, particularly those from outside the province, may be incorrectly classified. The BCGS alphanumeric reference code for the deposit profiles is recorded in both tables. This is a single letter followed by a two digit number which is used in MINFILE and provides a short exact code for the profiles. If the BCGS does not yet have an existing draft profile for a deposit type, this is indicated by an asterisk after the code (e.g. B01*). For the convenience of readers familiar with the USGS models published by Cox and Singer (1986) and Orris and Bliss (1991, 1992), the relevant numbers of USGS models are listed in Table 4. Note that we have included codes for deposit types listed by Orris and Bliss (1991, page 66) that have not yet been published. As with the BCGS profiles, these codes are indicated by an asterisk (39f*). Readers who are interested in using Tables 3 and 4 might be interested in purchasing the BCGS Open File 1995-8 (Lefebure *et al.*, 1995b) which presents the same information in wall-sized poster format.

Within the two classification schemes of deposit types for British Columbia (Tables 3 and 4), the reader will notice several new deposit types that reflect the influence of new discoveries or new data. For example, there is a deposit model for "Shallow Subaqueous Hot Spring Au-Ag". This is based on the Eskay Creek deposit and recent research results from the southeast Pacific (Hannington, 1993) documenting shallow, precious metal rich, exhalative sulphide deposits. As more data are collected on these new deposits our increased understanding may allow them to be merged with an existing deposit model.

ACKNOWLEDGMENTS

The authors would like to thank all the economic geologists who have contributed their input to the deposit profiles as this is truly a team effort. Branch staff have contributed the majority of the deposit models and participated in number of meetings to determine which deposit types should be included. The work of Chris Ash, Neil Church, Tim Giles, David Grieve, Kirk Hancock, Dan Hora, Nick Massey, JoAnne Nelson, Graham Nixon, Tom Schroeter and Paul Wilton is much appreciated.

A number of geologists from government, universities and industry have also written or co-authored profiles allowing us to tackle more deposit models. Staff of the Geological Survey of Canada have been particularly helpful. Tyson Birkett, Tomas Feininger, Suzanne Paradis, Ann Sabina and Don Sangster have contributed profiles or acted as co-authors. Ian Knuckey and Christopher Pilarski of Baymag; Peter Cerny of the University of Manitoba; Wilfred Kenan of Asbury Graphite Mills Inc.; and Eric Force, Greta Orris and Richard Sheppard of the United States Geological Survey have willingly shared their expertise by co-authoring profiles.

Nick Carter and Ron McMillan of the Stonehouse Group and Robert Brown and Robert Helgason of Quest Canada Resources Corporation were among the first users of the draft profiles and related indexes as they classified the MINFILE occurrences. They provided key insights into the choice of deposit models.

Many people have made useful suggestions; including Dennis Cox and Ted Theodore of the USGS, Ken Dawson and Rod Kirkham of the GSC, and John Thompson of the University of British Columbia. Editorial comments from John Newell were most helpful.

REFERENCES

Cox, D. P. (1993): Mineral Deposit Models, Their Use and Misuse - A Forum Review; *Society of Economic Geologists,* Newsletter No. 14, pages 12-13.

Cox, D.P. and Singer, D.A., Editors (1986): Mineral Deposit Models; *U.S. Geological Survey,* Bulletin 1693, 379 pages.

Eckstrand, O.R., Editor (1984): Canadian Mineral Deposit Types: A Geological Synopsis; *Geological Survey of Canada*, Economic Geology Report 36, 86 pages.

Grunsky, E.C., Kilby, W.E. and Massey, N.W.D. (1994): Resource Assessment in British Columbia; Nonrenewable Resources, Volume 3, No. 4, pages 271-283.

Grunsky, E.C (1995): Grade-Tonnage Data for Mineral Deposit Models in British Columbia; *in* Geological Fieldwork 1994, Grant, B. and Newell, J.M., Editors, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1995-1, pages 417-423.

Hannington, M. D. (1993): Shallow Submarine Hydrothermal Systems in Modern Island Arc Settings; *Geological Association of Canada, Mineral Deposits Division Newsletter*, The Gangue, No. 43, pages 6- 9.

Hodgson, C.J. (1993): Uses (and Abuses) of Ore Deposit Models in Mineral Exploration; *Geoscience Canada*, Reprint Series 6, pages 1-11.

Jensen, M. L. and Bateman, A. M. (1979): Economic Mineral Deposits; *John Wiley & Sons*, New York, 593 pages.

Kilby, W. (1995): Mineral Potential Project - Overview; *in* Geological Fieldwork 1994, Grant, B. and Newell, J.M., Editors, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1995-1, 411-416.

Laznicka, P. (1985): Empirical Metallogeny - Depositional Environments, Lithologic Associations and Metallic Ores, Vol. 1: Phanerozoic Environments, Associations and Deposits, *Elsevier*, New York, 1758 pages.

Lefebure, D.V. (1995): Two Intriguing Mineral Deposit Profiles for British Columbia, *in* Geological Fieldwork 1994, Grant, B. and Newell, J.M., Editors, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1995-1, pages 491-499.

Lefebure, D.V., Alldrick, D.J, Simandl, G.J. and Ray G.E. (1995a): British Columbia Mineral Deposit Profiles; *in* Geological Fieldwork 1994, Grant, B. and Newell, J.M., Editors, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1995-1, pages 469-490.

Lefebure, D.V., Alldrick, D.J and Simandl, G.J., (1995b): Mineral Deposit Profile Tables - Listed by Deposit Group and Lithological Affinities; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1995-8.

McMillan, W.J., Höy, T., MacIntyre, D.G., Nelson, J.L., Nixon, G.T., Hammock, J.L., Panteleyev, A., Ray, G.E. and Webster, I.C.L. (1991): Ore Deposits, Tectonics and Metallogeny of the Canadian Cordillera; *B. C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1991-4, 276 pages.

Peters, W. C. (1978): Exploration and Mining Geology; *John Wiley & Sons, Inc.*, New York, 696 pages.

Orris, G.J and Bliss, J.D. (1991): Some Industrial Mineral Deposit Models - Descriptive Deposit Models; *U.S. Geological Survey*; Open-File Report 91-11A, 73 pages.

Orris, G.J. and Bliss, J.D. (1992): Industrial Mineral Deposit Models: Grade and Tonnage Models; *U. S. Geological Survey*; Open-File Report 92-437, 84 pages.

LIGNITE A02

by Barry Ryan

IDENTIFICATION

SYNONYM: Brown coal.

COMMODITIES (*BYPRODUCTS*): Coal, coal liquids, (*tar, gas, leonardite*).

EXAMPLES (British Columbia - *Canada/International*): Hat Creek (092INW047); Skonun, Queen Charlotte Islands; Coal River (mapsheet 94M10W*); Estevan (Saskatchewan); Texas (USA)*.

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Seams of brown to black coal hosted by clastic sedimentary rocks. It can still contain some imprints of the original vegetation. Wet and dense with a dull lustre. Slacks (disintegrates) on exposure to air.

TECTONIC SETTINGS: Stable continental basins; shelves on the trailing edge of continents; foreland (molasse) basins; back-arc basins; fault blocks, often associated with strike-slip movement to limit sediment influx.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: An area of slow sedimentation, in fresh water, with few or no marine incursions. Delta; shoreline swamp; raised swamp; lake; floating vegetation mats.

AGE OF MINERALIZATION: Quaternary; Tertiary; occasionally older.

ASSOCIATED ROCK TYPES: Sedimentary rocks exhibiting evidence of fresh and or shallow water deposition; carbonaceous mudstones; siltstones and sandstones, often with cross-stratification and other sedimentary structures of shallow water origin.

DEPOSIT FORM: Lignite seams generally conform with regional bedding; sometimes seams are deposited in areas of local subsidence such as fault-controlled blocks or sink holes in karst topography, in which case deposits may be lens shaped. Occasionally seams can be thickened/deformed by surface slump, glacial drift or faulting. Seams may pinch out or split on the regional scale.

TEXTURE/STRUCTURE: Lignite retains a dull matted appearance and is composed mainly of the lithotype huminite. It is banded and jointed. Footwall sediments are often penetrated by roots or weathered to clay (seatearth).

COAL SEAMS / ASSOCIATED MINERAL MATTER: Lignite is defined as coal with an R_{max} value of less than 0.4 %. In outcrop it contains between 30 to 40 % moisture. It usually contains a high percentage of the maceral vitrinite and lower percentages of fusinite and liptinite. Mineral matter occurs in the lignite seams as bands, as finely intermixed material of authogenic or detrital origin (inherent mineral matter) and as secondary material deposited in fractures and open spaces. Inherent mineral matter includes pyrite, siderite and kaolinite. It may be dissimilar to that of the surrounding rocks.

LIGNITE A02

WEATHERING: Weathering of lignite reduces the calorific value by oxidizing the carbon-hydrogen complexes. Minerals such as pyrite oxidize to sulphates. Secondary carbonates are formed.

ORE CONTROLS: The regional geometry of coal seams is controlled by sedimentary features such as extent of the delta, trend of the shoreline, and trend of sand-filled river channels. Subsequent deformation, such as faulting and folding, is important for higher rank coals.

ASSOCIATED DEPOSIT TYPES: Peat (A01), sub-bituminous coal (A03), paleoplacers (C04).

COMMENTS: Lignite has the lowest rank of all classes of coal (R_{max} less than 0.4 %).

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Geochemistry is generally not used as a prospecting tool for lignite.

GEOPHYSICAL SIGNATURE: Lignite has a low density. Resistivity is variable but can be low for lignite. Surface geophysical techniques include direct-current profiling, refraction and reflection seismic and gravity. Subsurface or bore-hole techniques include gamma logs, neutron logs, gamma-gamma density logs, sonic logs, resistivity logs and caliper logs.

OTHER EXPLORATION GUIDES: Presence of: a down-slope coal bloom; nonmarine sediments; coal spar in the sediments; small oily seeps. Presence of lignite seams can also be detected by methane escaping through the surrounding sediments and burn zones where the lignite outcrop has burnt, baking the surrounding sediments.

ECONOMIC FACTORS

TYPICAL GRADE AND TONNAGE: The heat value of lignite is low. Gross heating value on a moist ash-free basis is 15 to 20 MJ/kg. Net useable heat will be lower because of the high moisture content and included mineral matter. Mine reserves range from tens to hundreds of million tonnes.

ECONOMIC LIMITATIONS: Lignite is a bulk commodity which is expensive to transport. The low heating value and tendency for spontaneous combustion usually restrict lignite to local uses. The ratio of tonnage to useable heat is low so that there is a large amount of waste material generated.

END USES: Steam generation in turbines for electrical generation. Feed for liquefaction and gasification.

IMPORTANCE: Major source of fuel used for local electrical power generation. Approximately 10 to 20 Mt of lignite per year are required to support 1 MW of power generation capability.

LIGNITE A02

REFERENCES

Armstrong, W.M., Fyles, J.T., Guelke, C.B., Macgregor, E.R., Peel, A.L., Tompson, A.R. and Warren, I.H. (1976): Coal in British Columbia, A Technical Appraisal; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Coal Task Force, 241 pages.

Cope, J.H.R., Duckworth, N.A., Duncan, S.V., Holtom, J.E.B., Leask, A.L., McDonald, K.A. and Woodman, S.P. (1983): Concise Guide to the World Coalfields; *compiled by Data Bank Service, World Coal Resources and Reserves, IEA Coal Research.*

Matheson, A. (1986): Coal in British Columbia; *; B.C. Ministry of Energy, Mines and Petroleum Resources,* Paper 1986-3, 169 pages.

Smith, G.G. (1989): Coal Resources in Canada; *Geological Survey of Canada,* Paper 1989-4, 146 pages.

SUB-BITUMINOUS COAL A03

by Barry Ryan

IDENTIFICATION

SYNONYMS: Steam coal, thermal coal, black lignite.

COMMODITIES (*BYPRODUCTS*): Coal, coal liquids, (*tar, gas*).

EXAMPLES (British Columbia - *Canada/International*): Princeton (092HSE089), Tulameen (092HSE209), Quesnel (093B036), Tuya River (104J044); *Whitewood and Highvale mines (Alberta, Canada), Powder River Basin (USA).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Seams of black to brown coal hosted by clastic sedimentary rocks. The coal is banded dull and bright. Generally hard, sometimes the texture of the original vegetation is partially preserved.

TECTONIC SETTINGS: Stable continental basins; shelves on the trailing edge of continents; foreland (molasse) basins; back-arc basins.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: An area of slow sedimentation in fresh water with few or no marine incursions. Can be produced by fault blocks associated with strike-slip movement to limit sediment influx. Delta; shoreline swamp; raised swamp; lake; floating vegetation mats.

AGE OF MINERALIZATION: Often Tertiary but can be older.

HOST/ASSOCIATED ROCK TYPES: Sedimentary rocks exhibiting evidence of non-marine deposition. Carbonaceous mudstones, siltstones and sandstones are the most common, often with cross-stratification and other sedimentary structures formed in shallow water.

DEPOSIT FORM: Coal seams generally conform with regional bedding; sometimes seams are deposited in areas of local subsidence, such as fault-controlled blocks or sink holes in karst topography, in which case deposits may be lens shaped. Occasionally seams can be thickened/deformed by surface slump, glacial drift or faulting. Seams may pinch out or split on a local or regional scale.

TEXTURE/STRUCTURE: Sub-bituminous coal is usually composed mostly of clarain and vitrain. Footwall sediments are often penetrated by roots or weathered to clay (seatearth).

COAL SEAMS/ASSOCIATED MINERAL MATTER: Sub-bituminous coal has R_{max} values in the range of 0.4 to 0.6 %. In outcrop it can contain up to 30 % moisture. It usually contains a high proportion of vitrinite and lesser amounts of fusinite and liptinite. Mineral matter is in the coal as rock bands, as finely intermixed material of authogenic or detrital origin (inherent mineral matter) and as secondary material deposited in fractures and open spaces. Inherent mineral matter includes pyrite, siderite and kaolinite.

SUB-BITUMINOUS COAL A03

WEATHERING: Weathering of sub-bituminous coal reduces the calorific value by oxidizing the carbon-hydrogen complexes. Minerals in the mineral matter will also oxidize. Pyrite oxidizes to sulphates. Secondary carbonates are formed.

ORE CONTROLS: The regional geometry of the seam/seams is controlled by sedimentary features, such as the extent of the delta, trend of the shoreline, and trend of sand-filled river channels. Deformation (faulting and folding) is important in some deposits.

ASSOCIATED DEPOSIT TYPES: Lignite (A02); bituminous coal (A04), Shale-hosted Ni-Zn-Mo-PGE (E16), Phosphate - upwelling type (F07).

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Geochemistry is generally not used as a prospecting tool for coal.

GEOPHYSICAL SIGNATURE: Coal has a low density. Resistivity is variable to high. Surface techniques include direct-current profiling, refraction and reflection seismic, and gravity. Subsurface or bore-hole techniques include gamma logs, neutron logs, gamma-gamma density logs, sonic logs, resistivity logs and caliper logs.

OTHER EXPLORATION GUIDES: Presence of: a down-slope coal bloom; coal spar; small oily seeps or methane escaping through the surrounding sediments. Zones where the coal outcrops have ignited and burnt to some depth underground.

ECONOMIC FACTORS

TYPICAL GRADE AND TONNAGE: Gross heating value on an ash-free moist basis is 20 to 27 MJ/kg. Net useable heat will be lower because of the high moisture content and the presence of ash. Mine reserves range up to hundreds of millions of tonnes. The sub-bituminous coal resources of B.C. Tertiary coal basins commonly range up to 200 Mt (Hat Creek exceptional with 1000 Mt).

ECONOMIC LIMITATIONS: Coal is a bulk commodity which is expensive to transport. The moderate heating value and tendency for spontaneous combustion means that sub-bituminous coal is usually used locally for electrical power generation. The ratio of tonnage to useable heat is low so that there is a larger proportion of waste material (water, fly ash and slag) generated when burnt than for higher rank coals.

END USES: Steam generation in turbines for electrical generation. Feed for liquefaction or gasification.

IMPORTANCE: Approximately 8 to 10 Mt of sub-bituminous coal is required to generate 1 MW per year.

SUB-BITUMINOUS COAL A03

REFERENCES

Armstrong, W.M., Fyles, J.T., Guelke, C.B., Macgregor, E.R., Peel, A.L., Tompson, A.R. and Warren, I.H. (1976): Coal in British Columbia, A Technical Appraisal; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Coal Task Force, 241 pages.

Cope, J.H.R., Duckworth, N.A., Duncan, S.V., Holtom, J.E.B., Leask, A.L., McDonald, K.A. and Woodman, S.P. (1983): Concise Guide to the World Coalfields; *compiled by Data Bank Service, World Coal Resources and Reserves, IEA Coal Research.*

Matheson, A. (1986): Coal in British Columbia; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1986-3, 169 pages.

Smith, G.G. (1989): Coal Resources in Canada; *Geological Survey of Canada*, Paper 1989-4, 146 pages.

BITUMINOUS COAL A04

by Barry Ryan

IDENTIFICATION

SYNONYMS: Metallurgical coal, coking coal, humic coal.

COMMODITIES (*BYPRODUCTS*): Coal, coke, (*coal liquids, tar, gas*).

EXAMPLES (British Columbia - *Canada/International*): Line Creek (082GNE020), Quintette (093I010, 011, 019, 020); *Sydney coalfield (Nova Scotia, Canada), Sydney coalfield (Australia).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Seams of black coal hosted by clastic sedimentary rocks. Coal is banded bright and dull. Generally hard with well developed cleats.

TECTONIC SETTINGS: Stable continental basins; shelves on the trailing edge of continents; foreland (molasse) basins; back-arc basins.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: An area of slow sedimentation in fresh water with few or no marine incursions. Can be produced by fault blocks associated with strike-slip movement to limit sediment influx. Delta; shoreline swamp; raised swamp; lake; floating vegetation mats.

AGE OF MINERALIZATION: Generally older than Tertiary; major deposits are Cretaceous, Permian or Carboniferous in age.

ASSOCIATED ROCK TYPES: Sedimentary rocks exhibiting evidence of non-marine deposition; carbonaceous mudstones; siltstones and sandstones often with cross-stratification and other sedimentary structures of fluvial/alluvial or deltaic origin.

DEPOSIT FORM: Coal seams generally conform with regional bedding; sometimes seams are deposited in areas of local subsidence, such as fault-controlled blocks. Seams may be thickened/deformed by faulting, folding and shearing. Seams may pinch-out or split on a local or regional scale.

TEXTURE/STRUCTURE: Bituminous coal is usually composed mostly of clarain and vitrain. Footwall sediments are often penetrated by roots or weathered to clay (seatearth).

COAL SEAMS/ASSOCIATED MINERAL MATTER: Bituminous coal has R_{max} values in the range of 0.5 to 2.0 %. In outcrop it can contain up to 15 % moisture. It usually contains a high percentage of the maceral vitrinite; at higher ranks liptinite is difficult to detect; the amount of fusinite is variable. Mineral matter is in the coal seams as rock bands, as finely intermixed material of authogenic or detrital origin (inherent mineral matter) and as secondary material deposited in fractures and open spaces. Inherent mineral matter includes pyrite, siderite and kaolinite. It may be dissimilar to that of the surrounding rocks.

BITUMINOUS COAL A04

WEATHERING: Weathering of the bituminous coal reduces the calorific value by oxidizing the carbon-hydrogen complexes. It also destroys the agglomerating (coke making) properties. Minerals such as pyrite oxidize to sulphates. Secondary carbonates are formed. These transformations may further damage the coking properties.

ORE CONTROLS: The geometry of the seam/seams is controlled by sedimentary features, such as extent of the delta, trend of the shoreline, and trend of sand-filled river channels. Deformation (faulting and folding) is also important.

ASSOCIATED DEPOSIT TYPES: Sub-bituminous coal (A03), anthracite (A05), Shale-hosted Ni-Zn-Mo-PGE (E16), Phosphate - upwelling type (F07).

COMMENTS: Bituminous coal is widely used for coke making by the steel industry because of its agglomerating properties.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Geochemistry is generally not used as a prospecting tool for coal.

GEOPHYSICAL SIGNATURE: Bituminous coal has a low density. Resistivity is variable to high. Surface techniques include direct-current profiling, refraction and reflection seismic, and gravity. Subsurface or bore-hole techniques include gamma logs, neutron logs, gamma-gamma density logs, sonic logs, resistivity logs and caliper logs.

OTHER EXPLORATION GUIDES: Presence of: a down-slope coal bloom; nonmarine sediments; coal spar. Presence of methane escaping through the surrounding sediments.

ECONOMIC FACTORS

TYPICAL GRADE AND TONNAGE: Numerous tests quantify the coking ability of bituminous coal, they measure rheology, melting and petrographic properties of the coal as well as the chemistry of the ash. The gross heating value of bituminous coal is 27 to 33 MJ/kg on an ash-free moist basis. Net useable heat will be lower because of the presence of ash. Mine tonnages generally range from 10 to 1000 Mt.

ECONOMIC LIMITATIONS: Coal is a bulk commodity which is expensive to transport. Bituminous coal has a high market value because of its coking properties and high heating value. The ratio of tonnage to useable heat is good so that there is a lower proportion of waste material (such as water, fly ash and slag) generated than for other ranks of coals.

END USES: Coke; steam generation in turbines for electrical generation.

IMPORTANCE: Generally bituminous coal is used for coke making, weathered and non-agglomerating bituminous coal is utilized for power generation. Only source for coke used in the steel industry.

BITUMINOUS COAL A04

REFERENCES

Armstrong, W.M., Fyles, J.T., Guelke, C.B., Macgregor, E.R., Peel, A.L., Tompson, A.R. and Warren, I.H. (1976): Coal in British Columbia, A Technical Appraisal; *B.C. Ministry of Energy, Mines and Petroleum Resources,* Coal Task Force, 241 pages.

Cope, J.H.R., Duckworth, N.A., Duncan, S.V., Holtom, J.E.B., Leask, A.L., McDonald, K.A. and Woodman, S.P. (1983): Concise Guide to the World Coalfields; *compiled by Data Bank Service, World Coal Resources and Reserves, IEA Coal Research.*

Matheson, A. (1986): Coal in British Columbia; ; *B.C. Ministry of Energy, Mines and Petroleum Resources,* Paper 1986-3, 169 pages.

Smith, G.G. (1989): Coal Resources in Canada; *Geological Survey of Canada,* Paper 1989-4, 146 pages.

ANTHRACITE A05

by Barry Ryan

PROFILES

IDENTIFICATION

SYNONYMS: Hard coal, stone coal, smokeless fuel.

COMMODITIES: Coal, carbon.

EXAMPLES (British Columbia - *International/Canada*): Klappan (104H020,021,022), Panorama South (104A082); *Canmore (Alberta, Canada), Pennsylvania coalfields (USA).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Seams of black coal hosted by clastic sedimentary rocks. Coal is well cleated with bright and dull bands. Anthracite often exhibits a high lustre and is not dusty.

TECTONIC SETTINGS: Stable continental basins; shelves on the trailing edge of continents; foreland (molasse) basins; back-arc basins.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: An area of slow sedimentation in fresh water with few or no marine incursions. Can be produced by fault blocks associated with strike-slip movement to limit sediment influx. Delta; shoreline swamp; raised swamp; lake; floating vegetation mats.

AGE OF MINERALIZATION: Generally older than Tertiary; major deposits are Cretaceous, Permian or Carboniferous in age.

HOST/ASSOCIATED ROCK TYPES: Sedimentary rocks exhibiting evidence of non-marine deposition; carbonaceous mudstones; siltstones and sandstones often with cross-stratification and other sedimentary structures formed in fluvial/alluvial deltaic settings.

DEPOSIT FORM: Anthracite seams generally conform with regional bedding. Seams are often thickened/deformed by faulting, folding, shearing and thrusting. Seams may pinch-out or split on a local or regional scale.

TEXTURE/STRUCTURE: Anthracite is usually composed mostly of the lithotypes clarain and vitrain.

COAL SEAMS/ASSOCIATED MINERAL MATTER: Anthracite has R_{max} values over 2.0 %. In outcrop anthracite can contain up to 5 % moisture. It usually contains a high percentage of the maceral vitrinite but because of the high rank the rheological and chemical differences between vitrinite and the inert macerals are small. Liptinite is difficult to identify at the anthracite rank. Mineral matter is in the coal seams as rock bands, as finely intermixed material of authogenic or detrital origin (inherent mineral matter) and as secondary material deposited in fractures and open spaces. Inherent mineral matter includes pyrite, siderite and kaolinite. It may be dissimilar to that of the surrounding rocks.

ANTHRACITE A05

WEATHERING: Weathering of anthracite reduces the calorific value by oxidizing the carbon-hydrogen complexes. Minerals in the mineral matter will also oxidize. Pyrite oxidizes to sulphates. Secondary carbonates are formed.

ORE CONTROLS: Deformation (folding, faulting and thrusting) is very important. The regional geometry of the seam/seams may also be influenced by sedimentary features, such as extent of delta, trend of the shoreline, and trend of sand-filled river channels.

ASSOCIATED DEPOSIT TYPES: Bituminous coal (A04), Shale-hosted Ni-Zn-Mo-PGE (E16), Phosphate - upwelling type (F07).

COMMENTS: Anthracite is the highest rank coal. At this rank agglomerating properties have been destroyed and heating value decreased somewhat from the maximum obtained by low-volatile bituminous coal. Anthracite releases little smoke when burnt.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Geochemistry is generally not used as a prospecting tool for anthracite.

GEOPHYSICAL SIGNATURE: Anthracite has a low density. Resistivity is variable to high. Surface techniques include direct-current profiling, refraction and reflection seismic, and gravity. Subsurface or bore-hole techniques include gamma logs, neutron adsorption logs, gamma-gamma density logs, sonic logs, resistivity logs and caliper logs.

OTHER EXPLORATION GUIDES: Presence of down-slope coal bloom; fresh water depositional structures; coal spar. Presence of anthracite seams can also be detected by escaping methane.

ECONOMIC FACTORS

TYPICAL GRADE AND TONNAGE: The heat value of anthracite is good and similar to that of medium-volatile bituminous coal. Gross heating values are 30 to 33 Mj/Kg on an ash-free moist basis. Net useable heat will be lower because of the presence of ash. The mine reserves of anthracite generally range from 10 to 100 million tonnes. They are generally smaller than the strip or open pit thermal or metallurgical coal mines.

ECONOMIC LIMITATIONS: Anthracite is a bulk commodity which is expensive to transport. Anthracite as low-ash lumps can be more than twice as valuable as bituminous coal, in which case it is shipped widely. Sold as fine anthracite briquettes with a moderate ash content, it has about the same dollar value as bituminous thermal coal.

END USES: Source for carbon. Specialized smelting applications, smokeless fuel for heating.

IMPORTANCE: As low-ash large lumps it is an important source of carbon in the chemical industry.

ANTHRACITE A05

REFERENCES

Armstrong, W.M., Fyles, J.T., Guelke, C.B., Macgregor, E.R., Peel, A.L., Tompson, A.R. and Warren, I.H. (1976): Coal in British Columbia, A Technical Appraisal; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Coal Task Force, 241 pages.

Cope, J.H.R., Duckworth, N.A., Duncan, S.V., Holtom, J.E.B., Leask, A.L., McDonald, K.A. and Woodman, S.P. (1983): Concise Guide to the World Coalfields; *compiled by Data Bank Service, World Coal Resources and Reserves, IEA Coal Research.*

Matheson, A. (1986): Coal in British Columbia; ; *B.C. Ministry of Energy, Mines and Petroleum Resources,* Paper 1986-3, 169 pages.

Smith, G.G. (1989): Coal Resources in Canada; *Geological Survey of Canada,* Paper 1989-4, 146 pages.

SURFICIAL PLACERS C01

by Victor M. Levson

IDENTIFICATION

SYNONYMS: Holocene placer deposits; terrace placers; fluvial, alluvial, colluvial, eolian (rare) and glacial (rare) placers.

COMMODITIES (*BYPRODUCTS*): Au, PGEs and Sn, {locally Cu, garnet, ilmenite, cassiterite, rutile, diamond and other gems - corundum (rubies, sapphires), tourmaline, topaz, beryl (emeralds), spinel - zircon, kyanite, staurolite, chromite, magnetite, wolframite, sphene, barite, cinnabar}. *Most of the minerals listed in brackets are recovered in some deposits as the principal product.*

EXAMPLES (British Columbia - *Canada/International*): Fraser River (Au), Quesnel River (Au), Tulameen district (PGEs); *North Saskatchewan River (Au, Alberta, Canada), Vermillion River (Au, Ontario,Canada), Rivière Gilbert (Au, Québec, Canada), Klondike (Au, Yukon, Canada), Rio Tapajos (Au, Brazil), Westland and Nelson (Au, New Zealand), Yana-Kolyma belt (Au, Russia), Sierra Nevada (Au, California, USA), Goodnews Bay(PGE, Alaska, USA), Emerald Creek (garnet, Idaho, USA), Rio Huanuni and Ocuri (Sn, Bolivia), Sundaland belt (Sn, Thailand).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Detrital gold, platinum group elements and other heavy minerals occurring at or near the surface, usually in Holocene fluvial or beach deposits. Other depositional environments, in general order of decreasing importance, include: alluvial fan, colluvial, glaciofluvial, glacial and deltaic placers.

TECTONIC SETTINGS: Fine-grained, allochthonous placers occur mainly in stable tectonic settings (shield or platformal environments and intermontane plateaus) where reworking of clastic material has proceeded for long periods of time. Coarse, autochthonous placer deposits occur mainly in Cenozoic and Mesozoic accretionary orogenic belts and volcanic arcs, commonly along major faults.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: Surficial fluvial placer concentrations occur mainly in large, high-order, stream channels (allochthonous deposits) and along bedrock in high-energy, steep-gradient, low-sinuosity, single-channel streams (autochthonous deposits). Concentrations occur along erosional surfaces at the base of channel sequences. Alluvial fan, fan-delta and delta deposits are distinct from fluvial placers as they occur in relatively unconfined depositional settings and typically are dominated by massive or graded sands and gravels, locally with interbedded diamicton. Colluvial placers generally develop from residual deposits associated with primary lode sources by sorting associated with downslope migration of heavy minerals. Glaciofluvial and glacial placers are mainly restricted to areas where ice or meltwater has eroded pre-existing placer deposits. Cassiterite, ilmenite, zircon and rutile are lighter heavy minerals which are distributed in a broader variety of depositional settings.

AGE OF MINERALIZATION: Mainly Holocene (rarely Late Pleistocene) in glaciated areas; generally Tertiary or younger in unglaciated regions.

HOST/ASSOCIATED ROCK TYPES: Well sorted, fine to coarse-grained sands; well rounded, imbricated and clast-supported gravels.

DEPOSIT FORM: In fluvial environments highly variable and laterally discontinuous; paystreaks typically thin (< 2 m), lens shaped and tapering in the direction of paleoflow; usually interbedded with barren sequences.

SURFICIAL PLACERS C01

TEXTURE/STRUCTURE: Grain size decreases with distance from the source area. Gold typically fine grained (< 0.5 mm diameter) and well rounded; coarser grains and nuggets rare, except in steep fluvial channel settings where gold occurs as flattened flakes. Placer minerals associated with colluvial placer deposits are generally coarser grained and more angular.

ORE MINERALOGY (principal and *subordinate*) : Au, PGE and cassiterite (*Cu, Ag and various industrial minerals and gemstones*).

GANGUE MINERALOGY: Quartz, pyrite and other sulphides and in many deposits subeconomic concentrations of various heavy minerals such as magnetite and ilmenite.

ALTERATION MINERALOGY: Fe and Mn oxide precipitates common; Ag-depleted rims of Au grains increase in thickness with age.

ORE CONTROLS: In fluvial settings, placer concentrations occur at channel irregularities, in bedrock depressions and below natural riffles created by fractures, joints, cleavage, faults, foliation or bedding planes that dip steeply and are oriented perpendicular or oblique to stream flow. Coarse-grained placer concentrations occur as lag concentrations where there is a high likelihood of sediment reworking or flow separation such as at the base of channel scours, around gravel bars, boulders or other bedrock irregularities, at channel confluences, in the lee of islands and downstream of sharp meanders. Basal gravels over bedrock typically contain the highest placer concentrations. Fine-grained placer concentrations occur where channel gradients abruptly decrease or stream velocities lessen, such as at sites of channel divergence and along point bar margins. Gold in alluvial fan placers is found in debris-flow sediments and in interstratified gravel, sand and silt. Colluvial placers are best developed on steeper slopes, generally over a weathered surface and near primary lode sources. Economic gold concentrations in glaciofluvial deposits occur mainly along erosional unconformities within otherwise aggradational sequences and typically derive their gold from older placer deposits.

GENETIC MODEL: Fluvial placers accumulate mainly along erosional unconformities overlying bedrock or resistant sediments such as basal tills or glaciolacustrine clays. Basal gravels over bedrock typically contain the highest placer concentrations. Overlying bedded gravel sequences generally contain less placer minerals and reflect bar sedimentation during aggradational phases. Frequently the generation of more economically attractive placer deposits involves multiple cycles of erosion and deposition.

ASSOCIATED DEPOSIT TYPES: Fluvial placers commonly derive from hydrothermal vein deposits and less commonly from porphyry and skarn deposits. PGE placers are associated with Alaskan-type ultramafics. Allochthonous fluvial placers are far traveled and typically remote from source deposits.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Anomalous concentrations of Au, Ag, Hg, As, Cu, Fe, Mn, Ti or Cr in stream sediments. Au fineness (relative Ag content) and trace element geochemistry (Hg, Cu) of Au particles can be used to relate placer and lode sources.

GEOPHYSICAL SIGNATURE: Ground penetrating radar especially useful for delineating the geometry, structure and thickness of deposits with low clay contents, especially fluvial terrace placers. Shallow seismic, electromagnetic, induced polarization, resistivity and magnetometer surveys are locally useful. Geophysical logging of drill holes with apparent conductivity, naturally occurring gamma radiation and magnetic susceptibility tools can supplement stratigraphic data.

OTHER EXPLORATION GUIDES: Panning and other methods of gravity sorting are used to identify concentrations of gold, magnetite, hematite, pyrite, ilmenite, chromite, garnet, zircon, rutile and other heavy minerals. Many placer gold paystreaks overlie clay beds or dense tills and in some camps these 'false bottom' paystreaks are important.

SURFICIAL PLACERS C01

ECONOMIC FACTORS

TYPICAL GRADE AND TONNAGE: Deposits are typically high tonnage (0.1 to 100 Mt) but low grade (0.05-0.25 g/t Au, 50-200 g/t Sn). Placer concentrations are highly variable both within and between individual deposits.

ECONOMIC LIMITATIONS: The main economic limitations to mining surficial placer deposits are typically low grades and most deposits occur below the water table. Environmental considerations are also an important limiting factor as these deposits often occur near, or within modern stream courses.

IMPORTANCE: Placer gold deposits account for more than two-thirds of the world's gold reserves and about 25% of known total production in British Columbia. Recorded placer production has represented 3.5% of B.C.'s total gold production in the last twenty years. Prior to 1950, it was approximately 160 000 kg. Actual production was significantly larger. Placer mining continues to be an important industry in the province with annual average expenditures of more than $30 million over a survey period from 1981 to 1986. Shallow alluvial placers also account for a large part of world tin (mainly from SE Asia and Brazil) and diamond (Africa) production.

REFERENCES:

Boyle, R.W. (1979): The Geochemistry of Gold and its Deposits; *Geological Survey of Canada*, Bulletin 280, 584 pages.

Giusti, L. (1986): The Morphology, Mineralogy and Behavior of "Fine-grained" Gold from Placer Deposits of Alberta, Sampling and Implications for Mineral Exploration; *Canadian Journal of Earth Sciences*, Volume 23, Number 11, pages 1662-1672.

Herail, G. (Editor) (1991): International Symposium on Alluvial Gold Placers, Abstract Volume; La Paz, Bolivia.

Levson, V. M. and T.R. Giles. (1993): Geology of Tertiary and Quaternary Gold-bearing Placers in the Cariboo Region, British Columbia. *B. C. Ministry of Energy, Mines and Petroleum Resources*, Bulletin 89, 202 pages.

Levson, V.M. and Morison, S.R. (in press): Geology of Placer Deposits in Glaciated Environments; in Glacial Environments - Processes, Sediments and Landforms, Menzies, J., Editor, *Pergamon Press*, Oxford, U.K., 44 pages.

Minter, W.E.L. (1991): Ancient Placer Gold Deposits; *in* Gold Metallogeny and Exploration, Foster, R.P. , Editor, *Blackie*, pages 283-308.

Morison, S.R. (1989): Placer Deposits in Canada; *in* Quaternary Geology of Canada and Greenland, Fulton, R.J., Editor, *Geological Survey of Canada*, Geology of Canada, Number 1, pages 687-694.

Sutherland, D.G. (editor) (1991): Alluvial Mining; Institution of Mining and Metallurgy, *Elsevier Applied Science*, London, 601 pages.

BURIED-CHANNEL PLACERS C02

by Victor M. Levson and Timothy R. Giles

IDENTIFICATION

SYNONYMS: Paleoplacer deposits; paleochannel deposits; fluvial and alluvial placers.

COMMODITIES (*BYPRODUCTS*): Mainly Au and PGE {also Cu, Ag, garnet, cassiterite, rutile, diamond and other gems: corundum (rubies, sapphires), tourmaline, topaz, beryl (emeralds), spinel; zircon, kyanite, staurolite, chromite, magnetite, ilmenite, barite, cinnabar}. *Most of the minerals listed in brackets are recovered as byproducts.*

EXAMPLES (British Columbia and *Canada/International*): Williams Creek (Au, 093H 119), Bullion (Au, 093A 025), Lightning Creek (Au, 093H 012), Otter Creek (Au, 104N 032), Spruce Creek (Au, 104N 034); *Chaudière Valley (*Au, Québec, Canada), *Livingstone Creek (*Au, Yukon, Canada), *Valdez Creek (*Au, Alaska, USA), *Ballarat (*Au, Victoria, Australia), *Bodaibo River (*Au, Lena Basin, Russia), *Gibsonville (*Sn, New South Wales, Australia), *Ringarooma (*Sn , Tasmania, Australia).

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Detrital gold, platinum group elements and other heavy minerals occurring in buried valleys (typically with at least several metres of overlying barren material, usually till, clay or volcanic rocks), mainly as channel-lag and gravel-bar deposits. See description of surficial placers (C01) for general information about alluvial placer deposits.

TECTONIC SETTINGS: Coarse-grained, paleochannel placer Au deposits occur mainly in Cenozoic and Mesozoic accretionary orogenic belts and volcanic arcs, commonly along major faults that may also control paleodrainage patterns. PGE-bearing deposits commonly associated with accreted and obducted oceanic terranes. Fine-grained paleoplacers also may occur in stable tectonic settings (shield or platformal environments) where reworking of clastic material has proceeded for long periods of time.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: Mainly incised paleochannels in mountainous areas including: high-gradient (generally >0.05, less commonly >0.1), narrow bedrock-floored valleys (paleogulches); high-level, abandoned tributary valleys with intermediate gradients (typically 0.01 to 0.1); large, buried trunk valleys (on the order of 100 m deep, a few hundred metres wide and >1 km long) with low channel gradients (generally <0.02 in mountainous reaches and <0.001 in plateau areas); channels buried in modern alluvial valleys with gradients similar to the modern streams. The first two settings are dominated by high-energy, low-sinuosity, single-channel, coarse-grained autochthonous placer deposits, whereas the latter two are characterized by autochthonous and allochthonous placers deposited in wandering gravel-bed river, braided stream and alluvial fan environments. In most paleochannels, coarse-grained placer concentrations occur mainly along channel floors or along other erosional surfaces such as at the base of cut-and-fill sequences; in meandering stream environments finer grained placers also occur along point bar margins and in other areas of slack water.

AGE OF MINERALIZATION: Tertiary and Pleistocene. Older paleoplacers (excepting the Proterozoic Witwatersrand placers) are rare, due to poor long-term preservation of deposits in high-relief, subaerial environments. Pleistocene paleoplacer deposits in British Columbia generally predate at least the last glaciation.

BURIED-CHANNEL PLACERS C02

HOST/ASSOCIATED ROCK TYPES: Coarse (pebble to boulder), rounded gravels (or conglomerate), commonly with sandy interbeds or lenses. Gravels usually imbricated, clast supported, open work or with a sandy matrix, and typically with abundant resistant rock types (quartzite, vein quartz, chert, basalt, granite) and minor, less resistant, lithologies (shale, siltstone, schist, etc.). Au placers are commonly associated with rock types hosting epithermal or mesothermal vein deposits. PGE placers occur with ultramafic hostrocks. Paleoplacers can be buried under a variety of materials, including glacial till, glaciolacustrine silts and clays, glaciofluvial sands and gravels, marine sediments and basalt flows.

DEPOSIT FORM: Highly variable and laterally discontinuous; paystreaks typically thin (<2 m), lens shaped and tapering in the direction of paleoflow; usually interbedded with barren sequences.

TEXTURE/STRUCTURE: Typically well rounded, flattened flakes or plates of low sphericity; coarse, more spherical nuggets common in high-gradient channels; fine (flour) gold common in distal stream reaches; evidence of primary crystal structure very rare.

ORE MINERALOGY (principal and *subordinate*): Au nuggets, flakes and grains and PGE minerals, (*Cu, Ag, and various industrial minerals and gemstones*).

GANGUE MINERALOGY: Quartz, pyrite and other sulphides and in many deposits subeconomic concentrations of various heavy minerals, especially magnetite and ilmenite.

ALTERATION MINERALOGY: Fe and Mn oxide precipitates common. Clay alteration of unstable clasts and matrix in some deposits.

ORE CONTROLS: Dominant controls on the geographic distribution of ore include the location of paleodrainage channels, proximity to bedrock sources, and paleorelief. Paleochannels are locally controlled by faults and less resistant rock units. Stratigraphically, placers accumulate mainly at the base of erosional successions along unconformities overlying bedrock or resistant sediments such as basal tills or glaciolacustrine clays. Overlying bedded gravel sequences generally contain less placer minerals and reflect bar sedimentation during aggradational phases. Sedimentologic factors controlling placer accumulations are discussed in Profile C01 (Surficial Placers).

GENETIC MODEL: For an explanation of formation of alluvial placers see surficial placers (C01). Placer deposits are buried when base level rises or channel abandonment occurs. Factors inducing these changes include glaciation, volcanism, stream capture and cutoff, or rising sea level.

ASSOCIATED DEPOSIT TYPES: Paleochannel placer deposits are associated with alluvial fan and fan-delta paleoplacer deposits in some areas (see comments below). Autochthonous fluvial and alluvial placers commonly derive from hydrothermal vein deposits. PGE placers are associated with Alaskan-type ultramafics.

COMMENTS: Alluvial fan and fan delta paleoplacer sequences comprise a distinct subtype of buried placer deposits. They occur in relatively unconfined depositional settings compared to paleochannel placer deposits and typically are dominated by massive or graded, poorly sorted gravels and sands, locally with interbedded diamicton. They are generally lower grade and larger volume than fluvial deposits but they contain relatively uniform placer concentrations. Paleofan deposits are mainly local in origin as indicated by high clast angularity and local derivation. Placer minerals occur in both poorly sorted debris-flow sediments and interstratified fluvial gravels and sands. Concentrations are commonly highest at sites of subsequent fluvial degradation.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Anomalous concentrations of Au, Ag, Hg, As, Cu, Fe and Mn in stream sediments. Gold fineness (relative Ag content) and trace element geochemistry (Hg, Cu) can be used as a signature to identify lode sources.

BURIED-CHANNEL PLACERS C02

GEOPHYSICAL SIGNATURE: Shallow seismic refraction and reflection techniques are useful for delineating paleochannel geometry and depth to bedrock. Electromagnetic, induced polarization, resistivity and magnetometer surveys are locally useful. Geophysical logging of drill holes with apparent conductivity, naturally occurring gamma radiation and magnetic susceptibility tools can supplement stratigraphic data.

OTHER EXPLORATION GUIDES: Exploration should focus on sites of natural overburden removal, such as along glacial meltwater channels, and areas underlain by Tertiary fluvial deposits. Buried placers are commonly preserved below glacial lake sediments, on the lee-side of bedrock highs where glacial erosion was minimal and along narrow valleys oriented transversely to the regional ice-flow direction. Airphoto interpretation and satellite imagery data can aid exploration for buried valley placers. Concentrations of magnetite, hematite, pyrite, ilmenite, chromite, garnet, zircon, rutile and other heavy minerals can be used to indicate placer potential.

ECONOMIC FACTORS

TYPICAL GRADE AND TONNAGE: Placer concentrations in fluvial deposits are highly variable both within and between individual deposits. In paleochannel gold placers, grades of 0.5 to 5 g/m^3 Au are typical, although grades as high as 75 g/m^3 Au are reported. The values, however, do not include overburden dilution factors which can reduce grades tenfold or more. Deposit sizes are also highly variable, ranging from 1000 t to 10 Mt.

ECONOMIC LIMITATIONS: The main economic limitation to locating, evaluating and mining paleochannel placer deposits is the thick overburden which results in high stripping ratios. Over-consolidation of tills and other sediments due to glaciation makes overburden stripping difficult and is a major limitation inhibiting exploitation of these buried deposits.

IMPORTANCE: Placer gold deposits account for more than two-thirds of the world's gold reserves and about 25% of known total production in British Columbia. Buried-channel placers have been under developed in British Columbia and other countries because of difficulties in locating deposits and high overburden to ore stripping ratios.

REFERENCES

Boyle, R.W. (1979): The Geochemistry of Gold and its Deposits; *Geological Survey of Canada,* Bulletin 280, 584 pages.

Johnston, W. A. and Uglow, W. L. (1926): Placer and Vein Gold Deposits of Barkerville, Cariboo District, British Columbia; *Geological Survey of Canada,* Memoir 149, 246 pages.

Kartashov, I.P. (1971): Geological Features of Alluvial Placers; *Economic Geology,* Volume 66, pages 879 - 885.

Levson, V.M. (1991): Geologic Controls on Alluvial Gold Mining in the Cariboo District, British Columbia, Canada; *in* Alluvial Mining, *Institution of Mining and Metallurgy,* London, pages 245 - 267.

Levson, V. M. (1992): The Sedimentology of Pleistocene Deposits Associated with Placer Gold Bearing Gravels in the Livingstone Creek Area, Yukon Territory; *in* Yukon Geology - Volume 3, Bremner, T., Editor, *Indian Affairs and Northern Development, Yukon Exploration and Geological Services Division,* Whitehorse, pages 99-132.

Levson, V. M. and Giles, T.R. (1993): Geology of Tertiary and Quaternary Gold-Bearing Placers in the Cariboo Region, British Columbia; *B. C. Ministry of Energy, Mines and Petroleum Resources,* Bulletin 89, 202 pages.

Levson, V.M. and Blyth, H. (1994): Applications of Quaternary Geology to the Study of Glacial Placer Deposits; A Case Study of the Otter Creek Paleoplacer, British Columbia; *Quaternary International,* Volume 20, pages 93-105.

BURIED-CHANNEL PLACERS C02

Levson, V.M. and Morison, S.R. (in press): Geology of Placer Deposits in Glaciated Environments; *in* Glacial Environments - Processes, Sediments and Landforms, Menzies, J., Editor, *Pergamon Press,* Oxford, U.K., 44 pages.

Minter, W.E.L. (1991): Ancient Placer Gold Deposits; *in* Gold Metallogeny and Exploration, Foster, R.P., Editor, *Blackie*, pages 283-308.

Morison, S.R. (1989): Placer Deposits in Canada. *in* Quaternary Geology of Canada and Greenland, R.J. Fulton, Editor, *Geological Survey of Canada,* Geology of Canada, Number 1, pages 687-694.

Reger, R.D. and Bundtzen, T.K. (1990): Multiple Glaciation and Gold-placer Formation, Valdez Creek Valley, Western Clearwater Mountains, Alaska; *Alaska Department of Natural Resources, Division of Geological and Geophysical Surveys*, Professional Report 107, 29 pages.

Smith, N.D. and Minter, W.E.L. (1980): Sedimentologic Controls of Gold and Uranium in Two Witwatersrand Paleoplacers; *Economic Geology*, Volume 75, pages 1-14.

Shilts, W.W. and Smith, S.L. (1986): Stratigraphy of Placer Gold Deposits; Overburden Drilling in Chaudière Valley, Quebec; *Geological Survey of Canada*, Paper 86-1A, pages 703-712.

MARINE PLACERS C03

by Victor M. Levson

IDENTIFICATION

SYNONYMS: Beach, coastal or shoreline placers; offshore placer deposits; coastal dune placers (rare).

COMMODITIES (*BYPRODUCTS*): Ti (ilmenite, rutile), Zr (zircon), Sn, Au, PGEs (*locally Ag, Th, REE, monazite, yttrium, magnetite, garnet, diamonds and other gems*).

EXAMPLES (British Columbia - *Canada/International*): Graham Island (PGE, Au), Queen Charlotte Sound (Au); *Country Harbour (Au, Nova Scotia, Canada), Nome (*Au, Alaska, USA), *Bermagui* (Au, Australia), *Westland and Nelson provinces (*Au, New Zealand), *Starke (*ilmenite, Florida, USA), *Atlantic beaches (* ilmenite, zircon, Brazil), *Sherbo deposit;* rutile (Sierra Leone), *Rosetta sand spit (*ilmenite, magnetite, zircon, Egypt), *Kerala and Quilon (*ilmenite, zircon, monazite, India).

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Detrital gold, ilmenite, cassiterite, platinum group elements and other heavy minerals occurring at the present or paleoseafloor surface. They usually occur in Holocene raised or submarine beach or strandline deposits along wave-dominated shorelines, but can also be found in coastal dunes, drowned fluvial channels, or as offshore relict lag concentrations.

TECTONIC SETTINGS: Placers occur mainly along cratonic margins where reworking of clastic material has proceeded for long periods of time. The margins of Cenozoic and Mesozoic accretionary orogenic belts and volcanic arcs are also important settings.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: Marine placers form in exposed, shoreline or nearshore environments in areas of active winnowing by waves and long-shore or tidal currents. They occur along present beaches and are also preserved as relict submerged deposits or raised strandlines that formed during glacially induced, low or high sea level stands. Beach placers accumulate mainly in the upper foreshore and backshore depositional environments. Geological settings include sand spits, barrier islands, coastal dunes, buried marine scarps, drowned fluvial deposits and submerged residual or lag deposits overlying bedrock or till.

AGE OF MINERALIZATION: Mainly Holocene (rarely Late Pleistocene) in glaciated areas; generally Tertiary or younger in unglaciated regions.

HOST ROCK TYPES: Well sorted, medium to coarse-grained sands overlying fine-grained shallow marine deposits; some lag gravel concentrations over till or bedrock.

DEPOSIT FORM: Paystreaks follow strandlines in shoreline environments and are thin (often <1 m), long (>100 m, often > 1 km) and narrow (<50 m); usually interbedded with barren sequences; titaniferous sands are up to 20 m thick in Queen Charlotte Sound.

TEXTURE/STRUCTURE: Au is typically very fine grained (< 0.5 mm diameter), well rounded, flattened and of high fineness; coarser Au (~1 mm diameter) occurs in relict lag gravels.

ORE MINERALOGY (principal and *subordinate*): Native Au, ilmenite, rutile, cassiterite, PGEs, zircon, magnetite (*Ag, gemstones, garnet, monazite, various industrial minerals*).

GANGUE MINERALOGY: Quartz, pyrite and other sulphides and in many deposits subeconomic concentrations of various heavy minerals.

MARINE PLACERS C03

WEATHERING: Leaching (*e.g.* Fe from ilmenite) and destruction of unstable minerals may result in residual enrichment of the deposit.

ORE CONTROLS: Heavy mineral concentrations occur along stable shorelines where long-term sorting and winnowing by wave or current action occurs; richest pay streaks usually follow strandlines marked by beach gravels or coquina accumulations; common over clay beds, till or bedrock; occurrence often controlled by the extent of onshore placer or bedrock sources.

ASSOCIATED DEPOSIT TYPES: Coastal placer concentrations commonly associated with present or former fluvial or deltaic surficial placers (CO1).

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Anomalous concentrations of Au, As, Fe, Sn, Ti, Zr, REE, Th, Y and U in shoreline or nearshore sediments.

GEOPHYSICAL SIGNATURE: Ground penetrating radar useful for delineating the geometry, structure and thickness of sandy shoreline deposits. Shallow seismic, electromagnetic, induced polarization, resistivity and magnetometer surveys are locally useful (*e.g.* IP anomalies from ilmenite).

OTHER EXPLORATION GUIDES: Panning and other methods of using gravity sorting to identify concentrations of gold, ilmenite, zircon, rutile, magnetite or other heavy minerals.

ECONOMIC FACTORS

TYPICAL GRADE AND TONNAGE: Deposits are typically high tonnage (0.1 to 100 Mt) but low grade (*e.g.* 0.05-0.25 g/t Au, 50-200 g/t Sn); higher grade deposits are small (*e.g.* Graham Island beach deposits 120 m long, 15 m wide and 15 cm thick [1000 t] contain up to 20 g/t Au and 70 g/t Pt). Surface relict gravels offshore of Nome contain 920 ppb Au. Placer concentrations are highly variable both within and between individual deposits.

ECONOMIC LIMITATIONS: The main economic limitations to mining surficial placer deposits are the typically low grades and their location near or below the water table. Offshore placers may occur as much as 100 m below present sea level. Environmental concerns have placed severe restrictions on development in many areas.

IMPORTANCE: Beach placers account for a significant part of the world's Ti production (mainly from Australia, India, Brazil and Florida) and are an important source of Au, zircon, magnetite, garnet, monazite and diamonds.

REFERENCES

Barker, J.C., Robinson, M.S. and Bundtzen, T.K. (1989): Marine Placer Development and Opportunities in Alaska; *Mining Engineering*, volume 42, pages 551-558.

Barrie, J.V. (1990): Contemporary and Relict Titaniferous Sand Facies on the Western Canadian Continental Shelf; *Continental Shelf Research*, Volume 11, pages 67-80.

Barrie, J.V. (1994). Western Canadian Marine Placer Potential. *Canadian Institute of Mining, Metallurgy and Petroleum*, Bulletin, Volume 87 (977), pages 27-30.

Barrie, J.V. Emory-Moore, M., Luternauer, J.L. and Bornhold, B.D. (1988): Origin of Modern Heavy Mineral Deposits, Northern British Columbia Continental Shelf. *Marine Geology*, Volume 84, pages 43-51.

Emory-Moore, M. (1991): Placer Gold Potential of the Northern Newfoundland Shelf; *Geological Survey of Canada*, Open File 2417, 113 pages.

Hein, F.J., Syvitski, J.P.M., Dredge, L.A. and Long, B.F. (1993): Quaternary Sedimentation and Marine Placers along the North Shore, Gulf of St. Lawrence; *Canadian Journal of Earth Sciences*, Volume 30, pages 553-574.

MARINE PLACERS C03

Laznicka, P. (1985): Empirical Metallogeny - Depositional Environments, Lithologic Associations and Metallic Ores - Volume 1: Phanerozoic Environments, Associations and Deposits, Part A; *Elsevier Science Publishers,* Developments in Economic Geology, 19, 1002 pages.

Nelson, C.H. and Hopkins, D.M. (1972): Sedimentary Processes and Distribution of Particulate Gold in the North Bering Sea; *U.S. Geological Survey*, Professional Paper 689, 27 pages.

IRON OXIDE OXIDE BRECCIAS AND VEINS P-Cu-Au-Ag-U

D07

By David V. Lefebure

IDENTIFICATION

SYNONYMS: Olympic Dam type, Kiruna type, apatite iron ore, porphyrite iron (Yangtze Valley), iron oxide rich deposits, Proterozoic iron oxide (Cu-U-Au-REE), volcanic-hosted magnetite.

COMMODITIES (*BYPRODUCTS*): Fe, P, Cu, Au, Ag, U (*potential for REE, Ba, F*).

EXAMPLES (British Columbia - *Canada/International*): Iron Range (082FSE014 - 028) - *Sue-Dianne (Northwest Territories, Canada); Wernecke breccias (Yukon, Canada), Kiruna district(Sweden), Olympic Dam (Australia), Pea Ridge and Boss-Bixby (Missouri, USA), El Romeral (Chile).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Magnetite and/or hematite breccia zones and veins which form pipes and tabular bodies hosted by continental volcanics and sediments and intrusive rocks. The deposits exhibit a wide range in their nonferrous metal contents. They vary from Kiruna type monometallic (Fe ± P) to Olympic Dam type polymetallic (Fe ± Cu ± U ± Au ± REE).

TECTONIC SETTING: Associated with stable cratons, typically associated with grabens related to rifting. Intracratonic extensional tectonics coeval with hostrock deposition. Upper crustal igneous or sedimentary rocks.

DEPOSITIONAL ENVIRONMENT/ GEOLOGICAL SETTING: Found crosscutting a wide variety of sedimentary and igneous rocks; magnetite-apatite deposits show an affinity for volcanics and associated hypabyssal rocks.

AGE OF MINERALIZATION: Proterozoic to Tertiary and believed to be virtually contemporaneous with associated suite of intrusive and/or volcanic rocks. Polymetallic Fe oxide deposits are commonly mid-Proterozoic age varying from 1.2 to 1.9 Ga.

HOST/ASSOCIATED ROCK TYPES: Veins and breccias crosscut, or are conformable with, a wide variety of continental sedimentary and volcanic rocks and intrusive stocks, including felsic volcanic breccia, tuff, clastic sedimentary rocks and granites. There may be a special association with a felsic alkalic rock suite ranging from "red" granite, and rapakivi granite to mangerite and charnockite and various volcanic equivalents. Fe oxides have been reported as common accessories in the associated igneous rocks. In some deposits the Fe oxide forms the matrix to heterolithic breccias which are composed of lithic and oxide clasts (usually hematite fragments), hematite-quartz microbreccia and fine-grained massive breccia. Some deposits have associated hematite-rich breccias, bedded Fe oxides and Fe oxide-bearing volcanic rocks which are conformable with associated volcanic rocks. Magnetite lavas and feeder dikes exist on the El Laco volcano in Chile.

DEPOSIT FORM: Discordant pod-like zones, veins (dike-like), tabular bodies and stockworks; in some deposits dikes are overlain by Fe oxide tuffs and flows. The veins and tabular zones extend horizontally and vertically for kilometres with widths of metres to hundreds of metres.

TEXTURE/STRUCTURE: Cu-U-Au mineralization is typically hosted in the Fe oxide matrix as disseminations with associated microveinlets and sometimes rare mineralized clasts. Textures indicating replacement and microcavity filling are common. Intergrowths between minerals are common. Hematite and magnetite may display well developed crystal forms, such as interlocking mosaic, tabular or bladed textures. Some of the deposits (typically hematite rich) are characterized by breccias at all scales with Fe oxide and hostrock fragments which grade from weakly fractured

IRON OXIDE OXIDE BRECCIAS AND VEINS P-Cu-Au-Ag-U D07

TEXTURE/STRUCTURE (cont.): hostrock on the outside to matrix-supported breccia (sometimes heterolithic) with zones of 100% Fe oxide in the core. Breccias may be subtle in hand sample as the same Fe oxide phase may comprise both the fragments and matrix. Breccia fragments are generally angular and have been reported to range up to more than 10 m in size, although they arefrequently measured in centimetres. Contacts with hostrocks are frequently gradational over scale of centimetres to metres. Hematite breccias may display a diffuse wavy to streaky layered texture of red and black hematite.

ORE MINERALOGY (Principal and *subordinate*): The deposits vary between magnetite-apatite deposits with actinolite or pyroxene (Kiruna type) and hematite-magnetite deposits with varying amounts of Cu sulphides, Au, Ag, uranium minerals and REE (Olympic Dam type). Hematite (variety of forms), specularite, magnetite, bornite, chalcopyrite, chalcocite, pyrite; *digenite, covellite, native copper, carrolite, cobaltite, Cu-Ni-Co arsenates, pitchblende, coffinite, brannerite, bastnaesite, monazite, xenotime, florencite, native silver and gold and silver tellurides*. At Olympic Dam, Cu is zoned from a predominantly hematite core (minor chalcocite-bornite) to chalcocite-bornite zone then bornite-chalcopyrite to chalcopyrite-pyrite in the outermost breccia. Uraninite and coffinite occur as fine-grained disseminations with sulphides; native gold forms fine grains disseminated in matrix and inclusions in sulphides. Bastnaesite and florencite are very fine grained and occur in matrix as grains, crystals and crystal aggregates.

GANGUE MINERALOGY (Principal and *subordinate*): Gangue occurs intergrown with ore minerals, as veins or as clasts in breccias. Sericite, carbonate, chlorite, quartz, fluorite, barite, and sometimes minor *rutile and epidote*. Apatite and actinolite or pyroxene with magnetite ores (Kiruna type). Hematite breccias are frequently cut by 1 to 10 cm veins with fluorite, barite, siderite, hematite and sulphides.

ALTERATION MINERALOGY (Principal and *subordinate*): A variety of alteration assemblages with differing levels of intensity are associated with these deposits, often with broad lateral extent. <u>Olympic Dam type:</u> Intense sericite and hematite alteration with increasing hematite towards the centre of the breccia bodies at higher levels. Close to the deposit the sericitized feldspars are rimmed by hematite and cut by hematite veinlets. Adjacent to hematite breccias the feldspar, rock flour and sericite are totally replaced by hematite. Chlorite or k-feldspar alteration predominates at depth. <u>Kiruna type:</u> Scapolite and albite?; there may also be actinolite-epidote alteration in mafic wallrocks. With both types of deposits quartz, fluorite, barite, carbonate, rutile, orthoclase ± epidote and garnet alteration are also reported.

WEATHERING: Supergene enrichment of Cu and U, for example, the pitchblende veins in the Great Bear magmatic zone.

ORE CONTROLS : Strong structural control with emplacement along faults or contacts, particularly narrow grabens. Mid-Proterozoic rocks particularly favourable hosts. Hydrothermal activity on faults with extensive brecciation. May be associated with felsic volcanic and alkalic igneous rocks. In some deposits calderas and maars have been identified or postulated. Deposits may form linear arrays more than 100 km long and 40 km wide with known deposits spaced 10-30 km along trend.

ASSOCIATED DEPOSIT TYPES: Volcanic-hosted U (D06)?; alkaline porphyry Cu-Au deposits (L03); supergene uranium veins.

COMMENTS: Hitzman *et al.* (1992) emphasize that these are low-Ti iron deposits, generally less than 0.5% TiO_2 and rarely above 2% TiO_2 which allows distinction from Fe oxides associated with anorthosites, gabbros and layered mafic intrusions. Fe and Cu sulphides may be more common with hematite Fe oxides.

IRON OXIDE OXIDE BRECCIAS AND VEINS P-Cu-Au-Ag-U D07

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Anomalously high values for Cu, U, Au, Ag, Ce, La, Co, ± P, ± F, and ± Ba in associated rocks and in stream sediments.

GEOPHYSICAL SIGNATURE: Large positive gravity anomalies because of Fe oxides. Regional aeromagnetic anomalies related to magnetite and/or coeval igneous rocks. Radiometric anomaly (such as airborne gamma-ray spectrometer survey) expected with polymetallic deposits containing uranium.

OTHER EXPLORATION GUIDES: Proterozoic faulting with associated Fe oxides (particularly breccias), possibly related to intracratonic rifting. Widespread hematite, sericite or chlorite alteration related to faults. Possibly form linear arrays 100 or more kilometres long and up to tens of kilometres wide.

ECONOMIC FACTORS

TYPICAL GRADE AND TONNAGE : Deposits may exceed 1000 Mt grading greater than 20 % Fe and frequently are in 100 to 500 Mt range. Olympic Dam deposit has estimated reserves of 2000 Mt grading 1.6% Cu, 0.06% U_3O_8, 3.5 g/t Ag and 0.6 g/t Au with a measured and indicated resource in a large number of different ore zones of 450 Mt grading 2.5% Cu, 0.08 % U_3O_8, 6 g/t Ag and 0.6 g/t Au with ~5,000 g/t REE. The Eastern Henry deposit in Australia contains 100 Mt at 1.6% Cu and 0.8 g/t Au. Sue-Dianne deposit in the Northwest Territories contains 8 Mt averaging 0.8% Cu and 1000 g/t U and locally significant gold. The Kiruna district contains more than 3000 Mt of Fe oxide apatite ore grading 50-60% Fe and 0.5 -5 % P. The largest orebody at Bayan Obo deposit in Inner Mongolia, China contains 20 Mt of 35 % Fe and 6.19% REE.

ECONOMIC LIMITATIONS: Larger Fe oxide deposits may be mined for Fe only; however, polymetallic deposits are more attractive.

IMPORTANCE: These deposits continue to be significant producers of Fe and represent an important deposit type for producing Cu, U and possibly REE.

REFERENCES

ACKNOWLEDGEMENTS: This deposit profile represents the results of a literature review. The only "ground truthing" is thanks to instructive conversations with Sunil Gandhi of the Geological Survey of Canada and Tom Setterfield of Westminer Canada Ltd.

Cox, D.P. (1986): Descriptive Model of Olympic Dam Cu-U-Au; *in* Mineral Deposit Models, Cox, D.P. and Singer, D.A., Editors, *U.S. Geological Survey*, Bulletin 1693, 379 pages.

Einaudi, M.T. and Oreskes, N. (1990); Progress Toward an Occurrence Model for Proterozoic Iron Oxide Deposits - A Comparison Between the Ore Provinces of South Australia and Southeast Missouri; *in* The Midcontinent of the United States - Permissive Terrane for an Olympic Dam Deposit?, Pratt, W.P. and Sims, P.K. Editors, *U. S. Geological Survey*, Bulletin 1392, pages 589-69.

Gandhi, S.S. (1994): Geological Setting and Genetic Aspects of Mineral Occurrences in the Southern Great Bear Magmatic Zone, Northwest Territories; *in* Studies of Rare-metal Deposits in the Northwest Territories, Sinclair, W.D. and Richardson, D.G, Editors, *Geological Survey of Canada*, Bulletin 475, pages 63-96.

IRON OXIDE OXIDE BRECCIAS AND VEINS P-Cu-Au-Ag-U D07

Gandhi, S.S. and Bell, R.T. (1993): Metallogenetic Concepts to Aid in Exploration for the Giant Olympic Dam Type Deposits and their Derivatives; Proceedings of the Eighth Quadrennial IAGOD Symposium, in Ottawa, Ontario, August 12-18, 1990, International Asssociation on the Genesis of Ore Deposits, Maurice, Y.T., Editor, *Schweizerbar'sche Verlagsbuchhandlung*, Stuttgart, pages 787-802.

Hauck, S.A. (1990): Petrogenesis and Tectonic Setting of Middle Proterozoic Iron Oxide-rich Ore Deposits; An Ore Deposit Model for Olympic Dam Type Mineralization; *in* The Midcontinent of the United States - Permissive Terrane for an Olympic Dam Deposit?, Pratt, W.P. and Sims, P.K. Editors, *U. S. Geological Survey,* Bulletin 1932, pages 4-39.

Hildebrand, R.S. (1986): Kiruna-type Deposits: Their Origin and Relationship to Intermediate Subvolcanic Plutons in the Great Bear Magmatic Zone, Northwest Canada; *Economic Geology,* Volume 81, pages 640-659.

Hitzman, M. W., Oreskes, N. and Einaudi, M. T. (1992): Geological Characteristics and Tectonic Setting of Proterozoic Iron Oxide (Cu-U-Au-REE) Deposits; *Precambrian Research,* Volume 58, pages 241-287.

Laznicka, P. and Gaboury, D. (1988): Wernecke Breccias and Fe, Cu, U Mineralization: Quartet Mountain-Igor Area (NTS 106E); *in* Yukon Exploration and Geology, *Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada*, pages 42-50.

Oreskes, N. and Einaudi, M.T. (1990): Origin of Rare Earth-enriched Hematite Breccias at the Olympic Dam Deposit, Roxby Downs, South Australia; *Economic Geology*, Volume 85, pages 1-28.

Parak, T. (1975). Kiruna Iron Ores are not "Intrusive-magmatic Ores of the Kiruna Type"; *Economic Geology*, Volume 68, pages 210 -221.

Reeve, J.S., Cross, K.C., Smith, R.N. and Oreskes, N. (1990): Olympic Dam Copper-Uranium-Gold-Silver Deposit; *in* Geology of the Mineral Deposits of Australia and Papua New Guinea, Hughes, F.E., Editor, *The Australasian Institute of Mining and Metallurgy*, pages 1009-1035.

Research Group of Porphyrite Iron Ore of the Middle-Lower Yangtze Valley (1977): Porphyrite Iron Ore - A Genetic Model of a Group of Iron Ore Deposits in Andesitic Volcanic Area; *Acta Geological Sinica*, Volume 51, No. 1, pages 1-18.

Roberts, D.E. and Hudson, G.R.T. (1983): The Olympic Dam Copper-Uranium-Gold Depôsit, Roxby Downs, South Australia; *Economic Geology*, Volume 78, pages 799-822.

SEDIMENTARY EXHALATIVE Zn-Pb-Ag E14

by Don MacIntyre

IDENTIFICATION

SYNONYMS: Shale-hosted Zn-Pb-Ag; sediment-hosted massive sulphide Zn-Pb-Ag; Sedex Zn-Pb.

COMMODITIES (*BYPRODUCTS*): Zn, Pb, Ag, (*minor Cu, barite*).

EXAMPLES (British Columbia - *Canada/International*): Cirque, Sullivan, Driftpile; *Faro, Grum, Dy, Vangorda, Swim, Tom and Jason (Yukon, Canada), Red Dog (Alaska, USA), McArthur River and Mt. Isa (Australia); Megen and Rammelsberg (Germany).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Beds and laminations of sphalerite, galena, pyrite, pyrrhotite and rare chalcopyrite, with or without barite, in euxinic clastic marine sedimentary strata.. Deposits are typically tabular to lensoidal in shape and range from centimetres to tens of metres thick. Multiple horizons may occur over stratigraphic intervals of 1000 m or more.

TECTONIC SETTING: Intracratonic or continental margin environments in fault-controlled basins and troughs. Troughs are typically half grabens developed by extension along continental margins or within back-arc basins.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: Restricted second and third order basins within linear, fault-controlled marine, epicratonic troughs and basins. There is often evidence of penecontemporaneous movement on faults bounding sites of sulphide deposition. The depositional environment varies from deep, starved marine to ? shallow water restricted shelf.

AGE OF MINERALIZATION: The major metallogenic events are Middle Proterozoic, Early Cambrian, Early Silurian and Middle to Late Devonian to Mississippian. The Middle Proterozoic and Devonian-Mississippian events are recognized worldwide. In the Canadian Cordillera, minor metallogenic events occur in the Middle Ordovician and Early Devonian.

HOST/ASSOCIATED ROCK TYPES: The most common hostrocks are those found in euxinic, starved basin environments, namely, carbonaceous black shale, siltstone, cherty argillite and chert. Thin interbeds of turbiditic sandstone, granule to pebble conglomerate, pelagic limestone and dolostone, although volumetrically minor, are common. Evaporites, calcareous siltstone and mudstone are common in shelf settings. Small volumes of volcanic rocks, typically tuff and submarine mafic flows, may be present within the host succession. Slump breccia, fan conglomerates and similar deposits occur near synsedimentary growth faults. Rapid facies and thickness changes are found near the margins of second and third order basins. In some basins high-level mafic sills with minor dikes are important.

DEPOSIT FORM: These deposits are stratabound, tabular to lens shaped and are typically comprised of many beds of laminae of sulphide and/or barite. Frequently the lenses are stacked and more than one horizon is economic. Ore lenses and mineralized beds often are part of a sedimentary succession up to hundreds of metres thick. Horizontal extent is usually much greater than vertical extent. Individual laminae or beds may persist over tens of kilometres within the depositional basin.

SEDIMENTARY EXHALATIVE Zn-Pb-Ag E14

TEXTURE/STRUCTURE: Sulphide and barite laminae are usually very finely crystalline where deformation is minor. In intensely folded deposits, coarser grained, recrystallized zones are common. Sulphide laminae are typically monomineralic.

ORE MINERALOGY [Principal and *subordinate*]: The principal sulphide minerals are pyrite, pyrrhotite, sphalerite and galena. Some deposits contain significant amounts of *chalcopyrite*, but most do not. Barite may or may not be a major component of the ore zone. Trace amounts of *marcasite, arsenopyrite, bismuthinite, molybdenite, enargite, millerite, freibergite, cobaltite, cassiterite, valleriite and melnikovite* have been reported from these deposits. These minerals are usually present in very minor amounts.

ALTERATION MINERALOGY: Alteration varies from well developed to nonexistent. In some deposits a stockwork and disseminated feeder zone lies beneath, or adjacent to, the stratiform mineralization. Alteration minerals, if present, include silica, tourmaline, carbonate, albite, chlorite and dolomite. They formed in a relatively low temperature environment. Celsian, Ba-muscovite and ammonium clay minerals have also been reported but are probably not common.

ORE CONTROLS: Favourable sedimentary sequences, major structural breaks, basins.

GENETIC MODEL: The deposits accumulate in restricted second and third order basins or half grabens bounded by synsedimentary growth faults. Exhalative centres occur along these faults and the exhaled brines accumulate in adjacent seafloor depressions. Biogenic reduction of seawater sulphate within an anoxic brine pool is believed to control sulphide precipitation.

ASSOCIATED DEPOSIT TYPES: Associated deposit types include carbonate-hosted sedimentary exhalative, such as the Kootenay Arc and Irish deposits (E13), bedded barite (E17) and iron formation (F10).

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: The deposits are typically zoned with Pb found closest to the vent grading outward and upward into more Zn-rich facies. Cu is usually found either within the feeder zone of close to the exhalative vent. Barite, exhalative chert and hematite-chert iron formation, if present, are usually found as a distal facies. Sediments such as pelagic limestone interbedded with the ore zone may be enriched in Mn. NH_3 anomalies have been documented at some deposits, as have Zn, Pb and Mn haloes. The host stratigraphic succession may also be enriched in Ba on a basin-wide scale.

GEOPHYSICAL SIGNATURE: Airborne and ground geophysical surveys, such as electromagnetics or magnetics should detect deposits that have massive sulphide zones, especially if these are steeply dipping. However, the presence of graphite-rich zones in the host sediments can complicate the interpretation of EM conductors. Also, if the deposits are flat lying and comprised of fine laminae distributed over a significant stratigraphic interval, the geophysical response is usually too weak to be definitive. Induced polarization can detect flat-lying deposits, especially if disseminated feeder zones are present.

OTHER EXPLORATION GUIDES: The principal exploration guidelines are appropriate sedimentary environment and stratigraphic age. Restricted marine sedimentary sequences deposited in an epicratonic extensional tectonic setting during the Middle Proterozoic, Early Cambrian, Early Silurian or Devono-Mississippian ages are the most favourable.

SEDIMENTARY EXHALATIVE Zn-Pb-Ag E14

ECONOMIC FACTORS

GRADE AND TONNAGE: The median tonnage for this type of deposit worldwide is 15 Mt, with 10 % of deposits in excess of 130 Mt (Briskey, 1986). The median grades worldwide are Zn - 5.6%, Pb - 2.8% and Ag - 30 g/t. The Sullivan deposit, one of the largest deposits of this type ever discovered, has a total size of more than 155 Mt grading 5.7% Zn, 6.6% Pb and 7 g/t Ag. Reserves at the Cirque are 32.2 Mt grading 7.9% Zn, 2.1% Pb and 48 g/t Ag.

ECONOMIC LIMITATIONS: The large, near-surface deposits are amenable to high volume, open pit mining operations. Underground mining is used for some deposits.

IMPORTANCE: Sedimentary exhalative deposits currently produce a significant proportion of the world's Zn and Pb. Their large tonnage potential and associated Ag values make them an attractive exploration target.

REFERENCES

Briskey, J.A. (1986): Descriptive Model of Sedimentary Exhalative Zn-Pb; *in* Mineral Deposit Models, Cox, D.P. and Singer, D.A., Editors, *U.S. Geological Survey*, Bulletin 1693, 379 pages.

Carne, R.C. and Cathro, R.J. (1982): Sedimentary-exhalative (Sedex) Zn-Pb-Ag Deposits, Northern Canadian Cordillera; *Canadian Institute of Mining and Metallurgy,* Bulletin, Volume 75, pages 66-78.

Gustafson, L.B. and Williams, N. (1981): Sediment-hosted Stratiform Deposits of Copper, Lead and Zinc; *in* Economic Geology Seventy-fifth Anniversary Volume, 1905-1980, Skinner, B.J., Editor, *Economic Geology Publishing Co.*, pages 139-178.

Large, D.E. (1981): Sediment-hosted Submarine Exhalative Sulphide Deposits - a Review of their Geological Characteristics and Genesis; *in* Handbook of Stratabound and Stratiform Ore Deposits, Wolfe, K.E., Editor, *Geological Association of Canada,* Volume 9, pages 459-507.

Large, D.E. (1983): Sediment-hosted Massive Sulphide Lead-Zinc Deposits; *in* Short Course in Sedimentary Stratiform Lead-Zinc Deposits, Sangster, D.F., Editor, *Mineralogical Association of Canada*, pages 1-29.

MacIntyre, D.G. (1991): Sedex - Sedimentary-exhalative Deposits, *in* Ore Deposits, Tectonics and Metallogeny in the Canadian Cordillera, McMillan, W.J., Coordinator, *B. C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1991-4, pages 25-69.

Sangster, D.F. (1986): Classifications, Distribution and Grade-Tonnage Summaries of Canadian Lead-Zinc Deposits; *Geological Survey of Canada*, Economic Geology Report 37, 68 pages.

BLACKBIRD SEDIMENT-HOSTED Cu-Co E15

by Trygve Höy

IDENTIFICATION

SYNONYM: Sediment-hosted Cu-Co deposit.

COMMODITIES (*BYPRODUCTS*): Cu, Co, (*Au, Bi, Ni, Ag; possibly Pb, Zn*).

EXAMPLES (British Columbia - *Canada/International)*: Canadian examples are not known; *Blackbird, Bonanza Copper and Tinker's Pride (Idaho, USA), possibly Sheep Creek deposits (Montana, USA).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Pyrite and minor pyrrhotite, cobaltite, chalcopyrite, arsenopyrite and magnetite occur as disseminations, small veins and tabular to pod-like lenses in sedimentary rocks. Chloritic alteration and tourmaline breccias are locally associated with mineralization

TECTONIC SETTINGS: Near continental margins or in intracratonic basins. Within the Belt-Purcell basin, which may have formed in a large inland sea, extensional tectonics are suggested by possible turbidite deposition, growth faulting, gabbroic sills and (?)tuff deposition. Alternative setting is marine, in an incipient or failed rift along a continental margin.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: These deposits are not well understood. Possible turbidite deposition in marine or inland sea, associated with basaltic pyroclastic volcanics or mafic synsedimentary gabbroic sills; alternatively, tidal flat environment.

AGE OF MINERALIZATION: Can be of any age. The Blackbird deposits at the type locality are assumed to be approximately 1460 Ma, the age of the hostrocks.

HOST/ASSOCIATED ROCK TYPES: Fine-grained metasedimentary rocks; thin-bedded siltstone, fine-grained quartzite, black argillite and calcareous siltstone; garnet schist, phyllite, quartz-mica schist. In the Blackbird district synaeresis cracks (subaqueous shrinkage cracks) occur within immediate hostrocks, sedimentary structures indicative of shallow water, and locally subaerial exposure in overlying rocks, suggest shallow water environment. Numerous biotite-rich beds within the host succession may be mafic tuff units (or diorite sills ?). Sheep Creek deposits are within correlative Newland Formation dolomitized shales and conglomerates.

DEPOSIT FORM: Irregular, tabular to pod-like deposits, from approximately 2 to 10 m thick.

TEXTURE/STRUCTURE: Fine to fairly coarse grained, massive to disseminated sulphides; pyrite locally has colloform textures. Locally sheared; vein sulphides in some deposits; quartz-tourmaline breccia pipes (?).

ORE MINERALOGY (Principal and *subordinate*) Cobaltite, chalcopyrite, pyrite, pyrrhotite, gold and silver in breccia pipes; *arsenopyrite, magnetite, cobaltian pyrite.* Sheep Creek: pyrite, marcasite, chalcopyrite, *tennantite* plus cobalt minerals; *covellite, bornite* in barite.

GANGUE MINERALOGY: quartz, biotite, barite; *tourmaline, hornblende, chlorite, muscovite, ankerite, dolomite, siderite, calcite and apatite.*

ALTERATION MINERALOGY: Silicification and intense chloritization; locally quartz-tourmaline breccias.

BLACKBIRD SEDIMENT-HOSTED Cu-Co E15

WEATHERING: Supergene enrichment with ludlamite and vivianite; erythrite (cobalt bloom); intense gossans at surface.

ORE CONTROLS: Regional controls include synsedimentary extensional fault structures, basin margin and growth faults. Local controls include association with mafic tuffs and stacked deposits at several stratigraphic intervals separated by barren rock.

GENETIC MODEL: Based on stratabound nature of deposits and similarity with unmetamorphosed Sheep Creek deposits, the Blackbird lenses are interpreted to be either syngenetic or diagenetic.

ASSOCIATED DEPOSIT TYPES: Possibly Besshi volcanogenic massive sulphide deposits (G04), Fe formations (F10), base metal veins, tourmaline breccias.

COMMENTS: Sheep Creek deposits are a relatively new exploration target in Belt rocks in Montana. They are in equivalent, lower metamorphic grade hostrocks to those of the Blackbird deposits, and have similar mineralogy and trace metal geochemistry. Lower Purcell Supergroup rocks and other structurally controlled sedimentary basins associated with variable mafic magmatism are prospective hosts in Canada.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Enriched in Fe, As, B, Co. Cu, Au, Ag and Mn; may be depleted in Ca and Na. Sheep Creek also contains high Ba.

GEOPHYSICAL SIGNATURE: Sulphide lenses usually show either an electromagnetic or induced polarization signature based on the style of mineralization and presence of conductive sulphides.

OTHER EXPLORATION GUIDES: Proximity to mafic tuffs or possibly early gabbroic sills, rapid sedimentary facies changes indicative of growth faults; regional pyrite development; may grade laterally to pyritic zones with anomalous Pb-Zn.

ECONOMIC FACTORS

GRADE AND TONNAGE: The Blackbird district deposits range from less than 100 000 t to 1.3 Mt containing 0.4 - 0.6 % Co and 1.3% Cu. Two zones of the Sheep Creek deposits contain respectively 4.5 Mt of 2.5% Cu and 0.12% Co, and 1.8 Mt with 6% Cu. Variable gold, up to 20 g/t in Blackbird lenses.

ECONOMIC LIMITATIONS: Generally lower copper grades favour open pit mining; Au and Ag are important byproducts.

IMPORTANCE: Small past producers of copper, cobalt and gold in Idaho.

REFERENCES

ACKNOWLEDGMENT: This deposit profile draws heavily from the USGS descriptive deposit model of Blackbird Co-Cu by Robert Earhart.

Anderson, A.L. (1947): Cobalt Mineralization in the Blackbird District, Lemhi County, Idaho; *Economic Geology*, Volume 42, pages 22-46.

Earhart, R.L. (1986): Descriptive Model of Blackbird Co-Cu; in Mineral Deposit Models, Cox, D.P and Singer, D.A., Editors, US Geological Survey, Bulletin 1693, page 142.

Himes, M.D. and Petersen, E.U. (1990): Geological and Mineralogical Characteristics of the Sheep Creek Copper-Cobalt Sediment-hosted Stratabound Sulfide Deposit, Meagher County, Montana; *in* Gold '90 Symposium, Salt Lake City, Utah, Chapter 52, *Society of Economic Geologists*, pages 533-546.

Hughes, G.J. (1982): Basinal Setting of the Idaho Cobalt Belt, Blackbird Mining District, Lemhi County, Idaho; *in* the Genesis of Rocky Mountain Ore Deposits; Changes with Time and Tectonics, *Denver Region Geologists Society*, pages 21-27.

SHALE-HOSTED Ni-Zn-Mo-PGE

E16

by D.V. Lefebure and R.M. Coveney, Jr.[1]

IDENTIFICATION

SYNONYMS: Sediment-hosted Ni-Mo-PGE, Stratiform Ni-Zn-PGE.

COMMODITIES (*BYPRODUCTS*): Ni, Mo, (*Zn, Pt, Pd, Au*).

EXAMPLES (British Columbia - *Canada/International*): *Nick (Yukon, Canada)*; *mining camps of Tianeshan, Xintuguo, Tuansabao and Jinzhuwoin and Zunyi Mo deposits, Dayong-Cili District (China).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Thin layers of pyrite, vaesite (NiS_2), jordisite (amorphous MoS_2) and sphalerite in black shale sub-basins with associated phosphatic chert and carbonate rocks.

TECTONIC SETTING(S): Continental platform sedimentary sequences and possibly successor basins. All known deposits associated with orogenic belts, however, strongly anomalous shales overlying the North American craton may point to as yet undiscovered deposits over the stable craton.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: Anoxic basins within clastic sedimentary (flysch) sequences containing black shales.

AGE OF MINERALIZATION: Post Archean. Known deposits are Early Cambrian and Devonian, however, there is potential for deposits of other ages.

HOST/ASSOCIATED ROCK TYPES: Black shale is the host; associated limestones, dolomitic limestones, calcareous shale, cherts, siliceous shale, siliceous dolomite, muddy siltstone and tuffs. Commonly associated with phosphate horizons. In the Yukon at base of a 10 to 20 m thick phosphatic shale bed and in China the Ni-Mo beds are in black shales associated with phosphorite.

DEPOSIT FORM: Thin beds (0 to 15 cm thick, locally up to 30 cm) covering areas up to at least 100 ha and found as clusters and zones extending for tens of kilometres.

TEXTURE/STRUCTURE: Semimassive to massive sulphides as nodules, spheroids, framboids and streaks or segregations in a fine-grained matrix of sulphides, organic matter and nodular phosphorite or phosphatic carbonaceous chert. Mineralization can be rhythmically laminated; often has thin discontinuous laminae. Brecciated clasts and spheroids of pyrite, organic matter and phosphorite. In China nodular textures (~ 1 mm diameter) grade to coatings of sulphides on tiny 1-10 μm spherules of organic matter. Fragments and local folding reflect soft sediment deformation. Abundant plant fossils in Nick mineralization and abundant fossils of microorganisms (cyanobacteria) in the Chinese ores.

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SHALE-HOSTED Ni-Zn-Mo-PGE E16

ORE MINERALOGY (Principal and *subordinate*): Pyrite, vaesite (NiS_2), amorphous molybdenum minerals (jordisite, MoS_2), bravoite, *sphalerite, wurtzite, polydimite, gersdorffite, violarite, millerite, sulvanite, pentlandite, tennanite and as traces native gold, uranitite, tiemannite, arsenopyrite, chalcopyrite and covellite*. Discrete platinum group minerals may be unusual. Some ore samples are surprisingly light because of abundant organic matter and large amount of pores.

GANGUE MINERALOGY (Principal and *subordinate*): Chert, amorphous silica, phosphatic sediments and bitumen. Can be interbedded with pellets of solid organic matter (called stone coal in China). Barite laths are reported in two of the China deposits.

ALTERATION MINERALOGY: Siliceous stockworks and bitumen veins with silicified wallrock occur in the footwall units. Carbonate concretions up to 1.5 m in diameter occur immediately below the Nick mineralized horizon in the Yukon.

WEATHERING: Mineralized horizons readily oxidize to a black colour and are recessive. Phosphatic horizons can be resistant to weathering.

ORE CONTROLS : The deposits developed in restricted basins with anoxic conditions. Known deposits are found near the basal contact of major formations. Underlying regional unconformities and major basin faults are possible controls on mineralization. Chinese deposits occur discontinuously in a 1600 km long arcuate belt, possibly controlled by basement fractures.

GENETIC MODEL: Several genetic models have been suggested reflecting the limited data available and the unusual presence of PGEs without ultramafic rocks. Syngenetic deposition from seafloor springs with deposition of metals on or just beneath the seafloor is the most favoured model. Siliceous venting tubes and chert beds in the underlying beds in the Yukon suggest a hydrothermal source for metals.

ASSOCIATED DEPOSIT TYPES: Phosphorite layers (F07?), stone coal, SEDEX Pb-Zn (E14), Sediment-hosted barite (E17), vanadian shales, sediment-hosted Ag-V, uranium deposits.

COMMENTS: Ag-V and V deposits hosted by black shales have been described from the same region in China hosted by underlying late Precambrian rocks.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Elevated values of Ni, Mo, Au, PGE, C, P, Ba, Zn, Re, Se, As, U, V and S in rocks throughout large parts of basin and derived stream sediments. In China average regional values for host shales of 350 g/t Mo, 150 g/t Ni, several wt % P_2O_5 and 5 to 22% organic matter. Organic content correlates with metal contents for Ni, Mo and Zn.

GEOPHYSICAL SIGNATURE: Electromagnetic surveys should detect pyrite horizons.

OTHER EXPLORATION GUIDES: Anoxic black shales in sub-basins within marginal basins. Chert or phosphate-rich sediments associated with a pyritiferous horizon. Barren, 5 mm to 1.5 cm thick, pyrite layers (occasionally geochemically anomalous) up to tens of metres above mineralized horizon.

SHALE-HOSTED Ni-Zn-Mo-PGE E16

ECONOMIC FACTORS

TYPICAL GRADE AND TONNAGE : The thin sedimentary horizons (not economic) represent hundreds of thousands of tonnes grading in per cent values for at least two of Ni-Mo-Zn with significant PGEs. In China, Zunyi Mo mines yield ~ 1000 t per year averaging ~4 % Mo and containing up to 4 % Ni, 2 % Zn, 0.7 g/t Au, 50 g/t Ag, 0.3 g/t Pt, 0.4 g/t Pd and 30 g/t Ir. The ore is recovered from a number of small adits using labour-intensive mining methods.

ECONOMIC LIMITATIONS: In China the Mo-bearing phase is recovered by roasting followed by caustic leaching to produce ammonium molybdate. Molybedenum-bearing phases are fine grained and dispersed, therefore all ore (cutoff grade 4.1% Mo) is direct shipped to the smelter after crushing.

IMPORTANCE: Current world production from shale-hosted Ni-Mo-PGE mines is approximately 1000 t of ore with grades of approximately 4 % Mo. Known deposits of this type are too thin to be economic at current metal prices, except in special conditions. However, these deposits contain enormous tonnages of relatively high grade Ni, Mo, Zn and PGE which may be exploited if thicker deposits can be found, or a relevant new technology is developed.

REFERENCES

ACKNOWLEDGEMENTS: Larry Hulbert of the Geological Survey of Canada introduced the senior author to this deposit type and provided many useful comments. Rob Carne of Archer, Cathro and Associates Limited reviewed a draft manuscript.

Coveney, R.M., Jr. and Nansheng, C. (1991): Ni-Mo-PGE-Au-rich Ores in Chinese Black Shales and Speculations on Possible Analogues in the United States; *Mineralium Deposita*, Volume 26, pages 83-88.

Coveney, R.M. Jr., Murowchick, J.B., Grauch, R.I., Nansheng, C. and Glascock, M.D. (1992): Field Relations, Origins and Resource Implications for Platiniferous Molybdenum-Nickel Ores in Black Shales of South China; *Canadiun Institute of Mining, Metallurgy and Petroleum*, Exploration and Mining Geology, Volume 1, No. 1, pages 21-28.

Coveney, R. M. Jr., Grauch, R. I. and Murowchick, J.B. (1993): Ore Mineralogy of Nickel-Molybdenum Sulfide Beds Hosted by Black Shales of South China; *in* The Paul E. Queneau International Symposium, Extractive Metallurgy of Copper, Nickel and Cobalt, Volume 1: Fundamental Aspects, Reddy, R.G. and Weizenbach, R.N., Editors, *The Minerals, Metals and Materials Society*, pages 369-375.

Fan Delian (1983): Poly Elements in the Lower Cambrian Black Shale Series in Southern China; *in* The Significance of Trace Metals in Solving Petrogenetic Problems and Controversies, Augustithis, S.S., Editor, *Theophrastus Publications*, Athens, Greece, pages 447-474.

Horan, M.F., Morgan, J.W., Grauch, R.I., Coveney, R.M. Jr, Murowchick, J.B. and Hulbert, L.J. (1994): Rhenium and Osmium Isotopes in Black Shales and Ni-Mo-PGE-rich Sulphide Layers, Yukon Territory, Canada, and Hunan and Guizhou Provinces, China; *Geochimica et Cosmochimica Acta*, Volume 58, pages 257-265.

Hulbert, L. J., Gregoire, C.D., Paktunc, D. and Carne, R. C. (1992): Sedimentary Nickel, Zinc and Platinum-group-element Mineralization in Devonian Black Shales at the Nick Property, Yukon, Canada: A New Deposit Type; *Canadiun Institute of Mining, Metallurgy and Petroleum*, Exploration and Mining Geology, Volume 1, No. 1, pages 39 - 62.

Murowchick, J.B., Coveney, R. M. Jr., Grauch, R.I., Eldridge, C. S. and Shelton, K.I. (1994): Cyclic Variations of Sulfur Isotopes in Cambrian Stratabound Ni-Mo-(PGE-Au) Ores of Southern China; *Geochimica et Cosmochimica Acta*, Volume 58, No. 7, pages 1813-1823.

Nansheng, C. and Coveney, R. M. Jr. (1989). Ores in Metal-rich Shale of Southern China; *U. S. Geological Survey*, Circular 1037, pages 7-8.

BESSHI MASSIVE SULPHIDE G04

by Trygve Höy

IDENTIFICATION

SYNONYMS: Besshi type, Kieslager.

COMMODITIES (*BYPRODUCTS*): Cu, Zn, Pb, Ag, (*Au, Co, Sn, Mo, Cd*).

EXAMPLES (British Columbia - *Canada/International*): Goldstream (082M141), Standard (082M090), Montgomery (082M085), True Blue (082F002), Granduc (?) (104B021), Windy Craggy (?) (114P020); *Greens Creek (Alaska, USA), Besshi (Japan).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Deposits typically comprise thin sheets of massive to well layered pyrrhotite, chalcopyrite, sphalerite, pyrite and minor galena within interlayered, terrigenous clastic rocks and calcalkaline basaltic to andesitic tuffs and flows.

TECTONIC SETTINGS: Oceanic extensional environments, such as back-arc basins, oceanic ridges close to continental margins, or rift basins in the early stages of continental separation.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: Terrigenous clastic rocks associated with marine volcanic rocks and sometimes carbonate rocks; these may overlie platformal carbonate or clastic rocks.

AGE OF MINERALIZATION: Any age. In British Columbia, most deposits are Cambrian, Late Triassic and less commonly Mississippian-Permian in age.

HOST/ASSOCIATED ROCK TYPES: Clastic sediments and marine volcanic rocks; basaltic tuffs and flows, shale and siltstone, commonly calcareous; less commonly chert and Fe formations. Possibly ultramafics and metagabbro in sequence.

DEPOSIT FORM: Typically a concordant sheet of massive sulphides up to a few metres thick and up to kilometres in strike length and down dip; can be stacked lenses.

TEXTURE/STRUCTURE: Massive to well-layered, fine to medium-grained sulphides; gneissic sulphide textures common in metamorphosed and deformed deposits; durchbewegung textures; associated stringer ore is uncommon. Crosscutting pyrite, chalcopyrite and/or sphalerite veins with chlorite, quartz and carbonate are common.

ORE MINERALOGY [Principal and *subordinate*]: Pyrite, pyrrhotite, chalcopyrite, sphalerite, *cobaltite, magnetite, galena, bornite, tetrahedrite, cubanite, stannite, molybdenite, arsenopyrite, marcasite.*

GANGUE MINERALOGY (Principal and *subordinate*): Quartz, calcite, ankerite, siderite, albite, tourmaline, *graphite, biotite.*

ALTERATION MINERALOGY: Similar to gangue mineralogy - quartz, chlorite, calcite, siderite, ankerite, pyrite, sericite, graphite.

ORE CONTROLS: Difficult to recognize; early (syndepositional) faults and mafic volcanic centres.

GENETIC MODEL: Seafloor deposition of sulphide mounds in back-arc basins, or several other tectonic settings, contemporaneous with volcanism.

ASSOCIATED DEPOSIT TYPES: Cu, Zn veins.

BESSHI MASSIVE SULPHIDE G04

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Cu, Zn, Ag, Co/Ni>1; Mn halos, Mg enrichment.

GEOPHYSICAL SIGNATURE: Sulphide lenses usually show either an electromagnetic or induced polarization signature depending on the style of mineralization and presence of conductive sulphides.

OTHER EXPLORATION GUIDES: Mafic volcanic rocks (tholeiitic, less commonly alkalic) associated with clastic rocks; Mn-rich garnets in metamorphosed exhalative horizons, possible structures, such as faults; possible association with ultramafic rocks.

ECONOMIC FACTORS

GRADE AND TONNAGE: Highly variable in size. B.C. deposits range in size from less than 1 Mt to more than 113 Mt. For example, Goldstream has a total resource (reserves and production) of 1.8 Mt containing 4.81 % Cu, 3.08 % Zn and 20.6 g/t Ag and Windy Craggy has reserves in excess of 113.0 Mt containing 1.9 % Cu, 3.9 g/t Ag and 0.08% Co. The type-locality Besshi deposits average 0.22 Mt, containing 1.5% Cu, 2-9 g/t Ag, and 0.4-2% Zn (Cox and Singer, 1986).

IMPORTANCE: Significant sources of Cu, Zn and Ag that can be found in sedimentary sequences that have not been thoroughly explored for this type of target.

REFERENCES

Cox, D.P. and Singer, D.A., Editors (1986): Mineral Deposit Models; *U.S. Geological Survey*, Bulletin 1693, 379 pages.

Höy, T. (1991): Volcanogenic Massive Sulphide Deposits in British Columbia; *in* Ore Deposits, Tectonics and Metallogeny in the Canadian Cordillera, McMillan, W.J., Coordinator, *B. C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1991-4, pages 89-123.

Franklin, J.M., Lydon, J.W. and Sangster, D.M. (1981): Volcanic-associated Massive Sulfide Deposits; *Economic Geology*, 75th Anniversary Volume, pages 485-627.

Hutchinson, R.W. (1980): Massive Base Metal Sulphide Deposits as Guides to Tectonic Evolution; *in* The Continental Crust and its Mineral Deposits, Strangway, D.W., Editor, *Geological Association of Canada*, Special Paper 20, pages 659-684.

Fox, J.S. (1984): Besshi-type Volcanogenic Sulphide Deposits - a Review; *Canadian Institute of Mining and Metallurgy*, Bulletin, Volume 77, pages 57-68.

Slack, J.F. (in press): Descriptive and Grade-Tonnage Models for Besshi-type Massive Sulphide Deposits; *Geological Association of Canada*, Special Paper.

CYPRUS MASSIVE SULPHIDE Cu (Zn) G05

by Trygve Höy

IDENTIFICATION

SYNONYMS: Cyprus massive sulphide, cuprous pyrite.

COMMODITY (*BYPRODUCTS*): Cu, (*Au, Ag, Zn, Co, Cd*).

EXAMPLES (British Columbia - *Canada/International*): Chu Chua (092F140), Lang Creek (104P008), Hidden Creek (103P021), Bonanza (103P023), Double Ed (103P025), ; *Cyprus; York Harbour and Betts Cove (Newfoundland, Canada); Turner-Albright (USA); Lokken (Norway).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Deposits typically comprise one or more lenses of massive pyrite and chalcopyrite hosted by mafic volcanic rocks and underlain by a well developed pipe-shaped stockwork zone.

TECTONIC SETTINGS: Within ophiolitic complexes formed at oceanic or back-arc spreading ridges; possibly within marginal basins above subduction zones or near volcanic islands within an intraplate environment.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: Lenses commonly are in tholeiitic or calcalkaline marine basalts, commonly pillowed, near a transition with overlying argillaceous sediments. Many lenses appear to be structurally controlled, aligned near steep normal faults.

AGE OF MINERALIZATION: Any age. Deposits in British Columbia are primarily Mississippian-Permian or Late Triassic.

HOST/ASSOCIATED ROCK TYPES: Tholeiitic or calcalkaline pillow and flow basalts, basaltic tuff, chert, argillite. Overlying "umbers" consist of ochre [Mn-poor, Fe-rich bedded mudstone containing goethite, maghemite (Fe_3O_4-Fe_2O_3 mixture) and quartz] or chert.

DEPOSIT FORM: Concordant massive sulphide lens overlying crosscutting zone of intense alteration and stockwork mineralization and hydrothermally altered wallrock, and overlain by chert.

TEXTURE/STRUCTURE: Massive, fine-grained pyrite and chalcopyrite, sometimes brecciated or banded?; massive magnetite, magnetite-talc and talc with variable sulphide content; associated chert layers, locally brecciated, contain disseminated sulphides; disseminated, vein and stockwork mineralization beneath lenses.

ORE MINERALOGY (Principal and *subordinate*): Pyrite, chalcopyrite, magnetite, sphalerite, *marcasite, galena, pyrrhotite, cubanite, stannite-besterite, hematite*. Sometimes goethite alteration of top of sulphide layer.

GANGUE MINERALOGY: Talc, chert, magnetite, chlorite.

ALTERATION MINERALOGY: Chlorite, talc, carbonate, sericite and quartz veins in the core of the stringer zone, sometimes with an envelope of weak albite with illite alteration.

ORE CONTROLS: Prominent structural control with clustering or alignment of sulphide lenses along early normal faults, near transition from mafic pillow basalts; less commonly mafic tuff; to overlying fine pelagic material.

GENETIC MODEL: Seafloor deposition of sulphide mounds contemporaneous with mafic volcanism, such as spreading ridges.

CYPRUS MASSIVE SULPHIDE Cu (Zn) G05

ASSOCIATED DEPOSIT TYPES: Vein and stockwork Cu (-Au) mineralization; Mn and Fe-rich cherts; massive magnetite (-talc) deposits.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Cu, Zn; common depletion of Ca and Na; less common, local minor Na enrichment; possible local K enrichment; prominent Fe and Mn enrichment in footwall stringer zone.

GEOPHYSICAL SIGNATURE: Sulphide lenses usually show either an electromagnetic or induced polarization signature depending on the style of mineralization and presence of conductive sulphides.

OTHER EXPLORATION GUIDES: Mafic ophiolitic volcanic rocks; transition to argillite; clustering or alignment of deposits indicative of fault control; ochre and exhalite (chert) horizons; regional pyritic horizons.

ECONOMIC FACTORS

GRADE AND TONNAGE: Published average is 1.6 Mt containing 1.7 % Cu, 0-33 g/t Ag; 0-1.9 g/t Au, 0-2.1 % Zn (Cox and Singer, 1986). B.C. examples: Chu Chua reserves - 1.043 Mt, 2.97 % Cu, 0.4 % Zn, 8.0 g/t Ag, 1.0 g/t Au; Anyox deposits - 0.2 to 23.7 Mt, approx. 1.5% Cu, 9.9 g/t Ag and 0.17 g/t Au.

IMPORTANCE: Deposits at Anyox produced 335846 t Cu, 215057 kg Ag and 3859 kg Au. Worldwide these deposits are generally significant more for their higher grades and polymetallic nature, than their size.

REFERENCES

Cox, D.P. and Singer, D.A., Editors (1986): Mineral Deposit Models; *U.S. Geological Survey*, Bulletin 1693, 379 pages.

Höy, T. (1991): Volcanogenic Massive Sulphide Deposits in British Columbia; in Ore Deposits, Tectonics and Metallogeny in the Canadian Cordillera, McMillan, W.J., Coordinator, *B. C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1991-4, pages 89-123.

Franklin, J.M., Lydon, J.W. and Sangster, D.M. (1981): Volcanic-associated Massive Sulfide Deposits; *Economic Geology*, 75th Anniversary Volume, pages 485-627.

Lydon, J.W. (1988): Volcanogenic Massive Sulphide Deposits, Part 2: Genetic Models; *Geoscience Canada*; Volume 15, pages 43-65.

Constantinou, G. and Govett, G.J.S. (1972): Genesis of Sulphide Deposits, Ochre and Umber of Cyprus; *Institution of Mining and Metallurgy*, Transactions, Volume 8, pages B36-B46.

Spooner, E.T.C. (1980): Cu-pyrite Mineralization and Seawater Convection in Oceanic Crust - The Ophiolite Ore Deposits of Cyprus; *in* The Continental Crust and its Mineral Deposits, Strangway, D.W., Editor, *Geological Association of Canada*, Special Paper 20, pages 685-704.

NORANDA/KUROKO MASSIVE SULPHIDE Cu-Pb-Zn G06

by Trygve Höy

IDENTIFICATION

SYNONYM: Polymetallic volcanogenic massive sulphide.

COMMODITIES (*BYPRODUCTS*): Cu, Pb, Zn, Ag, Au (*Cd, S, Se, Sn, barite, gypsum*).

EXAMPLES (British Columbia - *Canada/International*): Homestake (082M025), Lara (092B001), Lynx (092B129), Myra (092F072), Price (092F073), H-W (092F330), Ecstall (103h011), Tulsequah Chief (104K011), Big Bull (104K008), Kutcho Creek (104J060), Britannia (092G003); *Kidd Creek (Ontario, Canada), Buchans (Newfoundland, Canada), Bathurst-Newcastle district (New Brunswick, Canada), Horne-Quemont (Québec, Canada), Kuroko district (Japan), Mount Lyell (Australia), Rio Tinto (Spain), Shasta King (California, USA), Lockwood (Washington, USA).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: One or more lenses of massive pyrite, sphalerite, galena and chalcopyrite commonly within felsic volcanic rocks in a calcalkaline bimodal arc succession. The lenses may be zoned, with a Cu-rich base and a Pb-Zn-rich top; low-grade stockwork zones commonly underlie lenses and barite or chert layers may overlie them.

TECTONIC SETTING: Island arc; typically in a local extensional setting or rift environment within, or perhaps behind, an oceanic or continental margin arc.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: Marine volcanism; commonly during a period of more felsic volcanism in an andesite (or basalt) dominated succession; locally associated with fine-grained marine sediments; also associated with faults or prominent fractures.

AGE OF MINERALIZATION: Any age. In British Columbia typically Devonian; less commonly Permian-Mississippian, Late Triassic, Early (and Middle) Jurassic, and Cretaceous.

HOST/ASSOCIATED ROCK TYPES: Submarine volcanic arc rocks: rhyolite, dacite associated with andesite or basalt; less commonly, in mafic alkaline arc successions; associated epiclastic deposits and minor shale or sandstone; commonly in close proximity to felsic intrusive rocks. Ore horizon grades laterally and vertically into thin chert or sediment layers called informally “exhalites”.

DEPOSIT FORM: Concordant massive to banded sulphide lens which is typically metres to tens of metres thick and tens to hundreds of metres in horizontal dimension; sometimes there is a peripheral apron of "clastic" massive sulphides; underlying crosscutting “stringer” zone of intense alteration and stockwork veining.

TEXTURE/STRUCTURE: Massive to well layered sulphides, typically zoned vertically and laterally; sulphides with a quartz, chert or barite gangue (more common near top of deposit); disseminated, stockwork and vein sulphides (footwall).

ORE MINERALOGY (Principal and *subordinate*): Upper massive zone: pyrite, sphalerite, galena, chalcopyrite, *pyrrhotite, tetrahedrite-tennantite, bornite, arsenopyrite*. Lower massive zone: pyrite, chalcopyrite, *sphalerite, pyrrhotite, magnetite*.

GANGUE MINERALOGY: Barite, chert, *gypsum, anhydrite and carbonate* near top of lens, carbonate quartz, chlorite and sericite near the base.

ALTERATION MINERALOGY: Footwall alteration pipes are commonly zoned from the core with quartz, sericite or chlorite to an outer zone of clay minerals, albite and carbonate (siderite or ankerite).

NORANDA/KUROKO MASSIVE SULPHIDE Cu-Pb-Zn G06

ORE CONTROLS: More felsic component of mafic to intermediate volcanic arc succession; near centre of felsic volcanism (marked by coarse pyroclastic breccias or felsic dome); extensional faults.

ASSOCIATED DEPOSIT TYPES: Stockwork Cu deposits; vein Cu, Pb, Zn, Ag, Au.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Zn, Hg and Mg halos, K addition and Na and Ca depletion of footwall rocks; closer proximity to deposit - Cu, Ag, As, Pb; within deposit - Cu, Zn, Pb, Ba, As, Ag, Au, Se, Sn, Bi, As.

GEOPHYSICAL SIGNATURE: Sulphide lenses usually show either an electromagnetic or induced polarization signature depending on the style of mineralization and presence of conductive sulphides. In recent years borehole electromagnetic methods have proven successful.

OTHER EXPLORATION GUIDES: Explosive felsic volcanics, volcanic centres, extensional faults, exhalite (chert) horizons, pyritic horizons.

ECONOMIC FACTORS

GRADE AND TONNAGE: Average deposit size is 1.5 Mt containing 1.3% Cu, 1.9 % Pb, 2.0 % Zn, 0.16 g/t Au and 13 g/T Ag (Cox and Singer, 1986). British Columbia deposits range from less than 1 to 2 Mt to more than 10 Mt. The largest are the H-W (10.1 Mt with 2.0 % Cu, 3.5 % Zn, 0.3 % Pb, 30.4 g/t Ag and 2.1 g/t Au) and Kutcho (combined tonnage of 17 Mt, 1.6 % Cu, 2.3 % Zn, 0.06 % Pb, 29 g/t Ag and 0.3 g/t Au).

IMPORTANCE: Noranda/Kuroko massive sulphide deposits are major producers of Cu, Zn, Ag, Au and Pb in Canada. Their high grade and commonly high precious metal content continue to make them attractive exploration targets.

REFERENCES

Cox, D.P. and Singer, D.A., Editors (1986): Mineral Deposit Models; *U.S. Geological Survey*, Bulletin 1693, 379 pages.

Höy, T. (1991): Volcanogenic Massive Sulphide Deposits in British Columbia: *in* Ore Deposits, Tectonics and Metallogeny in the Canadian Cordillera, W.J. McMillan, Coordinator, *British Columbia Ministry of Energy, Mines and Petroleum Resources*, Paper 1991-4, pages 89-123.

Franklin, J.M., Lydon, J.W. and Sangster, D.M. (1981): Volcanic-associated Massive Sulphide Deposits; *Economic Geology*, 75th Anniversary Volume, pages 485-627.

Hutchinson, R.W. (1980): Massive Base Metal Sulphide Deposits as Guides to Tectonic Evolution; *in* The Continental Crust and its Mineral Deposits, D.W. Strangway, Editor, *Geological Association of Canada*, Special Paper 20, pages 659-684.

Lydon, J.W. (1984): Volcanogenic Massive Sulphide Deposits, Part 1: A Descriptive Model, *Geoscience Canada*, Volume 11, No. 4, pages 195-202.

Ohmoto, H. and Skinner, B.J., Editors (1983): The Kuroko and Related Volcanogenic Massive Sulfide Deposits; *Economic Geology*, Monograph 5, 604 pages.

Scott, S.D. (1985): Seafloor Polymetallic Sulfide Deposits: Modern and Ancient; *Marine Geology*, Volume 5, pages 191-212.

Sangster, D.F. (1972): Precambrian Volcanogenic Massive Sulphide Deposits in Canada: a Review; *Geological Survey of Canada*; Paper 72-22, 44 pages.

SUBAQUEOUS HOT SPRING Au-Ag G07

by Dani J. Alldrick

IDENTIFICATION

SYNONYMS: Epithermal massive sulphide; subaqueous-hydrothermal deposits; Eskay-type deposit; Osorezan-type deposit.

COMMODITIES (*BYPRODUCTS*): Ag, Au (*Cu, Pb, Zn, As, Sb, Hg*).

EXAMPLES (British Columbia - *Canada/International*): Eskay Creek (104B008), Lulu (104B376); *Osorezan, Vulcano Islands and Jade hydrothermal field (Japan), Mendeleev Volcano (Kurile Islands, Russia), Rabaul (Papua New Guinea), White Island (New Zealand), Bacon-Manito and Surigao del Norte (Phillippines).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Vein, replacement and synsedimentary bedded sulphides are deposited in volcanic rocks and associated sediments in areas of shallow lacustrine, fluvial or marine waters or in glacial subfloors.

TECTONIC SETTING: Active volcanic arcs (both oceanic island arcs and continental margin arcs) are likely setting.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: 1) Water-filled reservoirs in active continental volcanic areas (crater lakes, playa lakes, stream flood plains, glacier subfloors). 2) Sea-flooded, breached calderas, or unconsolidated shallow marine sediments at the foot of a volcano.

AGE OF MINERALIZATION: Presumably any age, oldest known example is Jurassic.

HOST/ASSOCIATED ROCK TYPES: Mineralization hosted by intermediate to felsic flows and tuffs and minor intercalated sedimentary rocks. Pillow lavas, coarse epiclastic debris flows, and assorted subvolcanic feeder dikes are all part of the local stratigraphic package.

DEPOSIT FORM: Highly variable. Footwall stockwork or stringer-style vein networks. Large, textureless massive sulphide pods, finely laminated stratiform sulphide layers and lenses, reworked clastic sulphide sedimentary beds, and epithermal-style breccia veins with large vugs, coarse sulphides and chalcedonic silica. All types may coexist in a single deposit.

TEXTURE/STRUCTURE: Range from fine clastic sulphides and "framboid"-like chemical precipitates to very coarse grained sulphide aggregates in breccia veins. Structural styles include: vein stockworks, major breccia veins, stratabound and stratiform sulphide lenses and layers.

ORE MINERALOGY (Principal and *subordinate*): Sphalerite, tetrahedrite, boulangerite, bournonite, native gold, native silver, amalgam, galena, chalcopyrite, enargite, pyrite, stibnite, realgar, arsenopyrite orpiment; *metallic arsenic, Hg-wurtzite, cinnabar, aktashite, unnamed Ag-Pb-As-S minerals, jordanite, wurtzite, krennerite, coloradoite, marcasite, magnetite, scorodite, jarosite, limonite, anglesite, native sulphur.*

GANGUE MINERALOGY (Principal and *subordinate*): Magnesian chlorite, muscovite (sericite), chalcedonic silica, amorphous silica, calcite, dolomite, pyrobitumen, gypsum, barite, potassium feldspar, alunite with minor *carbon, graphite, halite and cristobalite.*

SUBAQUEOUS HOT SPRING Au-Ag G07

ALTERATION MINERALOGY: Massive chlorite (clinochlore)-illite-quartz-gypsum-barite rock or quartz-muscovite-pyrite rock are associated with the near-footwall stockwork zones. Chlorite and pyrite alteration is associated with the deep-footwall stockwork zones where alteration minerals are restricted to fractures. Stratabound mineralization is accompanied by magnesian chlorite, muscovite, chalcedonic silica, calcite, dolomite and pyrobitumen. At the Osorezan hot spring deposits, pervasive silica and alunite microveinlets are the dominant alteration phases.

GENETIC MODEL: Deposits are formed by "hot spring" (i.e.: epithermal) fluids vented into a shallow water environment. Fluids are magmatic in character, rather than meteoric. This concept contrasts with some characteristics of the process model for volcanogenic massive sulphides. Lateral and vertical zoning has been recognized within a single lens. Lateral zoning shows changes from Sb, As and Hg-rich mineral suites to Zn, Pb and Cu-rich assemblages. Vertical zoning is expressed as a systematic increase in Au, Ag and base metal content up-section. Fluid conduits are fissures generated by seismic shock, aggradation of the volcano over a later expanding magma chamber, or fracturing in response to regional compressional tectonics. A near-surface subvolcanic magma body is an essential source of metals, fluids and heat.

ASSOCIATED DEPOSIT TYPES: Hot spring Hg (H02), hot spring Au-Ag (H03), epithermal veins (H04, H05), volcanogenic exhalative massive sulphides (G06).

COMMENTS: This deposit type is the shallow subaqueous analogue of hot spring Au-Ag, and both of these are subtypes of the "epithermal" class of mineral deposits. Considering the recent discoveries at Osorezan (1987) and Eskay Creek (1988), the brief discussion by Laznicka (1985, p. 907) seems especially prophetic.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Ag, Au, Cu, Pb, Zn, As, Sb, Hg.

GEOPHYSICAL SIGNATURE: The pyrite associated with stockwork mineralization and ubiquitous alteration should produce a widespread induced polarization anomaly, but the best targets may be local peaks within this broad anomalous 'plateau'. Airborne magnetometer surveys may help delineate favourable strata and fault offsets.

OTHER EXPLORATION GUIDES: The geological deposit model and its regional setting may be the best exploration tools available. Broad hydrothermal systems marked by widespread sericite-pyrite alteration; evidence of a volcanic crater or caldera setting; accumulations of felsic volcanic strata: 1) in a local subaqueous setting in a regionally subaerial environment, 2) along the near shore zone of a regional subaerial/subaqueous volcanic facies transition (e.g.: the western margin of the Hazelton trough). Focus on the sedimentary intervals within the volcanic pile.

ECONOMIC FACTORS

GRADE AND TONNAGE: These deposits are not well known. The Eskay Creek deposit is attractive because of the polymetallic signature and high precious metal contents. It contains an estimated mining reserve of 1.08 Mt grading 65.5 g/t Au, 2930 g/t Ag, 5.7 % Zn, 0.77 % Cu and 2.89% Pb with geological reserves of 4.3 Mt grading 28.8 g/t Au and 1 027 g/t Ag.

IMPORTANCE: These deposits are attractive because of their bonanza grades and polymetallic nature.

SUBAQUEOUS HOT SPRING Au-Ag G07

REFERENCES

Aoki, M. (1991): Gold and Base Metal Mineralization in an Evolving Hydrothermal System at Osorezan, Northern Honshu, Japan; *Geological Survey of Japan*, Report No. 277, pages 67-70.

Aoki, M. (1992a): Magmatic Fluid Discharging at the Surface from the Osorezan Geothermal System, Northern Honshu, Japan; *Geological Survey of Japan*, Report No. 279, 1992, pages 16-21.

Aoki, M. (1992b): Active Gold Mineralization in the Osorezan Caldera; 29th International Geological Congress Field Trip, Epithermal Gold and Kuroko Mineralizations, in Northeast Honshu, Shikazono, N., Aoki, M., Yamada, R., Singer, D.A., Kouda, R. and Imai, A., Editors, pages 69-75.

Britton, J.M., Blackwell, J.D. and Schroeter, T.G. (1990): 21 Zone Deposits, Eskay Creek, Northwestern British Columbia; *in* Exploration in British Columbia 1989, *B. C. Ministry of Energy, Mines and Petroleum Resources*, pages 197-223.

Izawa, E. and Aoki, M. (1991): Geothermal Activity and Epithermal Gold Mineralization in Japan; *Episodes*, Volume 14, No. 3, pages 269-273.

Laznicka, P. (1985): Subaqueous-hydrothermal Deposits, *in* Empirical Metallogeny, *Elsevier*, Amsterdam, 1758 pages.

Macdonald, A.J. (1992): Osorezan, *in* Japan '92 - A Technical Report, Mineral Deposit Research Unit, *University of British Columbia*, pages 29-67.

Mitchell, A.H.G. (1992): Andesitic Arcs, Epithermal Gold and Porphyry-type Mineralization in the Western Pacific and Eastern Europe, *Institution of Mining and Metallurgy*, Transactions, Volume 101, pages B125-B138.

Roth, T. (1982): Eskay Creek 21A Zone: An Update, *in* Iskut Project Annual Report, Year 2, Mineral Deposit Research Unit, *University of British Columbia* May 1992.

Cu SKARNS K01

by Gerald E. Ray

IDENTIFICATION

SYNONYMS: Pyrometasomatic and contact metasomatic copper deposits.

COMMODITIES (*BYPRODUCTS*): Cu (*Au, Ag, Mo, W, magnetite*)

EXAMPLES (British Columbia - *Canada/International*): Craigmont (092ISE 035), Phoenix (082ESE 020), Old Sport (092L 035), Queen Victoria (082FSW 082); *Mines Gaspé deposits (Québec, Canada), Ruth, Mason Valley and Copper Canyon (Nevada, USA), Carr Fork (Utah, USA), Ok Tedi (Papua New Guinea), Rosita (Nicaragua).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Cu-dominant mineralization (generally chalcopyrite) genetically associated with a skarn gangue (includes calcic and magnesian Cu skarns).

TECTONIC SETTING: They are most common where Andean-type plutons intrude older continental-margin carbonate sequences. To a lesser extent (but important in British Columbia), they are associated with oceanic island arc plutonism.

AGE OF MINERALIZATION: Mainly Mesozoic, but may be any age. In British Columbia they are mostly Early to mid-Jurassic.

HOST/ASSOCIATED ROCK TYPES: Porphyritic stocks, dikes and breccia pipes of quartz diorite, granodiorite, monzogranite and tonalite composition, intruding carbonate rocks, calcareous volcanics or tuffs. Cu skarns in oceanic island arcs tend to be associated with more mafic intrusions (quartz diorite to granodiorite), while those formed in continental margin environments are associated with more felsic material.

DEPOSIT FORM: Highly varied; includes stratiform and tabular orebodies, vertical pipes, narrow lenses, and irregular ore zones that are controlled by intrusive contacts.

TEXTURES: Igneous textures in endoskarn. Coarse to fine-grained, massive granoblastic to mineralogically layered textures in exoskarn. Some hornfelsic textures.

ORE MINERALOGY (Principal and *subordinate*): Moderate to high sulphide content. Chalcopyrite ± pyrite ± magnetite in inner garnet-pyroxene zone. Bornite ± chalcopyrite ± sphalerite ± tennantite in outer wollastonite zone. Either hematite, pyrrhotite or magnetite may predominate (depending on oxidation state). Scheelite and traces of *molybdenite, bismuthinite, galena, cosalite, arsenopyrite, enargite, tennantite, loellingite, cobaltite and tetrahedrite* may be present.

ALTERATION MINERALOGY: Exoskarn alteration: high garnet:pyroxene ratios. High Fe, low Al, Mn andradite garnet (Ad35-100), and diopsidic clinopyroxene (Hd2-50). The mineral zoning from stock out to marble is commonly: diopside + andradite (proximal); wollastonite ± tremolite ± garnet ± diopside ± vesuvianite (distal). Retrograde alteration to actinolite, chlorite and montmorillonite is common. In British Columbia, skarn alteration associated with some of the alkalic porphyry Cu-Au deposits contains late scapolite veining. Magnesian Cu skarns also contain olivine, serpentine, monticellite and brucite.
Endoskarn alteration: Potassic alteration with K-feldspar, epidote, sericite ± pyroxene ± garnet. Retrograde phyllic alteration generates actinolite, chlorite and clay minerals.

ORE CONTROLS: Irregular or tabular orebodies tend to form in carbonate rocks and/or calcareous volcanics or tuffs near igneous contacts. Pendants within igneous stocks can be important. Cu mineralization is present as stockwork veining and disseminations in both endo and exoskarn; it commonly accompanies retrograde alteration.

Cu SKARNS K01

COMMENTS: Calcic Cu skarns are more economically important than magnesian Cu skarns. Cu skarns are broadly separable into those associated with strongly altered Cu-porphyry systems, and those associated with barren, generally unaltered stocks; a continuum probably exists between these two types (Einaudi *et al.*, 1981). Copper skarn deposits related to mineralized Cu porphyry intrusions tend to be larger, lower grade, and emplaced at higher structural levels than those associated with barren stocks. Most Cu skarns contain oxidized mineral assemblages, and mineral zoning is common in the skarn envelope. Those with reduced assemblages can be enriched in W, Mo, Bi, Zn, As and Au. Over half of the 340 Cu skarn occurrences in British Columbia lie in the Wrangellia Terrane of the Insular Belt, while another third are associated with intraoceanic island arc plutonism in the Quesnellia and Stikinia terranes. Some alkalic and calcalkalic Cu and Cu-Mo porphyry systems in the province (e.g. Copper Mountain, Mount Polley) are associated with variable amounts of Cu-bearing skarn alteration.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Rock analyses may show Cu-Au-Ag-rich inner zones grading outward through Au-Ag zones with high Au:Ag ratios to an outer Pb-Zn-Ag zone. Co-As-Sb-Bi-Mo-W geochemical anomalies are present in the more reduced Cu skarn deposits.

GEOPHYSICAL SIGNATURE: Magnetic, electromagnetic and induced polarization anomalies.

ASSOCIATED DEPOSIT TYPES: Porphyry Cu deposits (L04), Au (K04), Fe (K03) and Pb-Zn (K02) skarns, and replacement Pb-Zn-Ag deposits (M01).

ECONOMIC FACTORS

GRADE AND TONNAGE: Average 1 to 2 % copper. Worldwide, they generally range from 1 to 100 Mt, although some exceptional deposits exceed 300 Mt. Craigmont, British Columbia's largest Cu skarn, contained approximately 34 Mt grading 1.3 % Cu.

IMPORTANCE: Historically, these deposits were a major source of copper, although porphyry deposits have become much more important during the last 30 years . However, major Cu skarns are still worked throughout the world, including in China and the U.S.

REFERENCES

Cox, D.P. and Singer, D.A. (1986): Mineral Deposit Models; *U.S. Geological Survey*, Bulletin 1693, 379 pages.

Dawson, K.M., Panteleyev, A. and Sutherland-Brown, A (1991): Regional Metallogeny, Chapter 19, in Geology of the Cordilleran Orogen in Canada, Editors, Gabrielse, H. and Yorath, C.J., *Geological Survey of Canada*, Geology of Canada, Number 4, page 707-768 (also, *Geological Society of America*, The Geology of North America, Volume G-2).

Eckstrand, O.R. (1984): Canadian Mineral Deposit Types: A Geological Synopsis; *Geological Survey of Canada*, Economic Geology Report 36, 86 pages.

Einaudi, M.T. (1982): General Features and Origin of Skarns Associated with Porphyry Copper Plutons, Southwestern North America; *in* Advances in Geology of the Porphyry Copper Deposits, Southwestern U.S., Titley, S.R., Editor, *Univ. Arizona Press*, pages 185-209.

Einaudi, M.T. and Burt, D.M. (1982): Introduction - Terminology, Classification and Composition of Skarn Deposits; *Economic Geology*; Volume 77, pages 745-754.

Einaudi, M.T., Meinert, L.D. and Newberry, R.J. (1981): Skarn Deposits; *in* Seventy-fifth Anniversary Volume, 1906-1980, Economic Geology, Skinner, B.J., Editor, *Economic Geology Publishing Co.*, pages 317-391.

Meinert, L.D. (1983): Variability of Skarn-deposits: Guides to Exploration; *in* Revolution in the Earth Sciences - Advances in the Past Half-century, Boardman, S.J., Editor; *Kendall/Hunt Publishing Company*, pages 301-316.

Pb-Zn SKARNS K02

by Gerald E. Ray

IDENTIFICATION

SYNONYMS: Pyrometasomatic or contact metasomatic Pb-Zn deposits.

COMMODITIES (*BYPRODUCTS*): Pb, Zn, Ag, (*Cu, Cd, W, Au*).

EXAMPLES (British Columbia - *Canada/International*): Piedmont (082FNW 129), Contact (104P 004), *Quartz Lake (Yukon, Canada), Groundhog (New Mexico, USA), Darwin (California, USA) San Antonio, Santa Eulalia and Naica (Mexico), Yeonhwa-Ulchin deposits (South Korea), Nakatatsu deposits (Japan), Shuikoushan and Tienpaoshan (China).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Galena and/or sphalerite-dominant mineralization genetically associated with a skarn gangue.

TECTONIC SETTING: Along continental margins where they are associated with late orogenic plutonism. Pb-Zn skarns occur at a wide range of depths, being associated with subvolcanic aphanitic dikes and high-level breccia pipes, as well as deep-level batholiths. In British Columbia, some Pb-Zn skarns are found in oceanic island arcs where they form distally to larger calcic Fe or Cu skarn systems.

AGE OF MINERALIZATION: Mainly Mesozoic, but may be any age. In British Columbia, the 80 Pb-Zn skarn occurrences identified have a wide age range; over 40 % are Early to mid-Jurassic, 22 % are Cretaceous, and a further 17 % are Eocene-Oligocene in age.

HOST/ASSOCIATED ROCK TYPES: Variable; from high-level skarns in thick limestones, calcareous tuffs and sediment to deeper level skarns in marbles and calcsilicate-bearing migmatites. Associated intrusive rocks are granodiorite to leucogranite, diorite to syenite (mostly quartz monzonite). Pb-Zn skarns tend to be associated with small stocks, sills and dikes and less commonly with larger plutons. The composition of the intrusions responsible for many distal Pb-Zn skarns is uncertain.

DEPOSIT FORM: Variable; commonly occurs along igneous or stratigraphic contacts. Can develop as subvertical chimneys or veins along faults and fissures and as subhorizontal blankets. Pb-Zn skarn deposits formed either at higher structural levels or distal to the intrusions tend to be larger and more Mn-rich compared to those formed at greater depths or more proximal.

TEXTURES: Igneous textures in endoskarn. Coarse to fine-grained, massive granoblastic to mineralogically layered textures in exoskarn.

ORE MINERALOGY (Principal and *subordinate*): Sphalerite ± galena ± pyrrhotite ± pyrite ± magnetite ± arsenopyrite ± chalcopyrite ± bornite. Other trace minerals reported include *scheelite, bismuthinite, stannite, cassiterite, tetrahedrite, molybdenite, fluorite, and native gold.* Proximal skarns tend to be richer in Cu and W, whereas distal skarns contain higher amounts of Pb, Ag and Mn.

ALTERATION MINERALOGY: Exoskarn alteration: Mn-rich hedenbergite (Hd30-90, Jo10-50), andraditic garnet (Ad20-100, Spess2-10) ± wollastonite ± bustamite ± rhodonite. Late-stage Mn-rich actinolite ± epidote ± ilvaite ± chlorite ± dannermorite ± rhodochrosite ± axinite. Endoskarn alteration: Highly variable in development, and in many of the distal Pb-Zn skarns the nature of the endoskarn is unknown. However, Zn-rich skarns formed near stocks are often associated with abundant endoskarn that may equal or exceed the exoskarn (Einaudi et al., 1981).

Pb-Zn SKARNS K02

ALTERATION MINERALOGY (cont.): Endoskarn mineralogy is dominated by epidote ± amphibole ± chlorite ± sericite with lesser rhodonite ± garnet ± vesuvianite ± pyroxene ± K-feldspar ± biotite and rare topaz. Marginal phases may contain greisen and/or tourmaline.

ORE CONTROLS: Carbonate rocks, particularly along structural and/or lithogical contacts (e.g. shale-limestone contacts or pre-ore dikes). Deposits may occur considerable distances (100-1000 m) from the source intrusions.

ASSOCIATED DEPOSIT TYPES: Pb-Zn-Ag veins (I05), Cu skarns (K01) and Cu porphyries (L03, L04). In B.C., small Pb-Zn skarns occur distally to some Fe (K03) and W (K04) skarns.

COMMENTS: Pb-Zn skarn occurrences are preferentially developed in: (1) continental margin sedimentary rocks of the Cassiar and Ancestral North America terranes, (2) oceanic island arc rocks of the Quesnellia and Stikinia terranes, and (3) arc rocks of the Wrangellia Terrane. Their widespread terrane distribution partly reflects their formation as small distal mineralized occurrences related to other skarns (notably Cu, Fe and W skarns), as well as some porphyry systems. British Columbia is endowed with some large and significant Pb-Zn reserves classified as manto deposits (Nelson, 1991; Dawson et al., 1991). These deposits lack skarn gangue, but are sometimes grouped with the Pb-Zn skarns.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Pb, Zn, Ag, Cu, Mn, As, Bi, W, F, Sn, Mo, Co, Sb, Cd and Au geochemical anomalies.

GEOPHYSICAL SIGNATURE: Generally good induced polarization response. Galena-rich orebodies may be marked by gravity anomalies whereas pyrrhotite-rich mineralization may be detected by magnetic surveys. CS-AMT may also be a useful exploration system.

OTHER EXPLORATION GUIDES: Thick limestones distal to small granitoid stocks; structural traps and lithological contacts; exoskarns with low garnet/pyroxene ratios.

ECONOMIC FACTORS

GRADE AND TONNAGE: Pb-Zn skarns tend to be small (<3 Mt) but can reach 45 Mt, grading up to 15 % Zn, 10 % Pb and > 150 g/t Ag with substantial Cd. Cu grades are generally < 0.2 %. Some deposits (e.g. Naica (Mexico) and Falun (Sweden)) contain Au. The 80 British Columbia Pb-Zn skarn occurrences are generally small and have had no major metal production.

IMPORTANCE: Important past and current producers exist in Mexico, China, U.S.A (New Mexico and California), and Argentina. No large productive Pb-Zn skarns have been discovered in B.C.

REFERENCES

Dawson, K.M. and Dick, L.A. (1978): Regional Metallogeny in the Northern Cordillera: Tungsten and Base Metal-bearing Skarns in Southeastern Yukon and Southwestern Mackenzie; *in* Current Research, Part A, *Geological Survey of Canada*, Paper 1978-1A, pages 287-292.

Dawson, K.M., Panteleyev, A. and Sutherland Brown, A. (1991): Regional Metallogeny, Chapter 19, *in* Geology of the Cordilleran Orogen in Canada, Gabrielse, H. and Yorath, C.J., Editors, *Geological Survey of Canada*, Geology of Canada, Number 4, page 707-768 (also, *Geological Society of America*, The Geology of North America, Volume G-2).

Eckstrand, O.R. (1984): Canadian Mineral Deposit Types: A Geological Synopsis; *Geological Survey of Canada*, Economic Geology Report 36, 86 pages.

Einaudi, M.T. and Burt, D.M. (1982): Introduction - Terminology, Classification and Composition of Skarn Deposits; *Economic Geology*; Volume 77, pages 745-754.

Einaudi, M.T., Meinert, L.D. and Newberry, R.J. (1981): Skarn Deposits; in Seventy-fifth Anniversary Volume, 1906-1980, Skinner, B.J., Editor, *Economic Geology Publishing Co.*, pages 317-391.

Fe SKARNS K03

by Gerald E. Ray

IDENTIFICATION

SYNONYMS: Pyrometasomatic or contact metasomatic iron deposits.

COMMODITIES (*BYPRODUCTS*): Magnetite (*Cu, Ag, Au, Co, phlogopite, borate minerals*).

EXAMPLES (British Columbia - *Canada/International*): Tasu (103C003), Jessie (103B026), Merry Widow (092L044), Iron Crown (092L034), Iron Hill (092F075), Yellow Kid (092F258), Prescott (092F106), Paxton (092F107), Lake (092F259); *Shinyama (Japan), Cornwall Iron Springs (Utah, USA) Eagle Mountain (California, USA), Perschansk, Dashkesan, Sheregesh and Teya (Russia), Daiquiri (Cuba), San Leone (Italy).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Magnetite-dominant mineralization genetically associated with a skarn gangue (includes calcic and magnesian Fe skarns).

TECTONIC SETTING: Calcic Fe skarns: Intra and non-intraoceanic island arcs; rifted continental margins. Magnesian Fe skarns: Cordilleran-type, synorogenic continental margins.

AGE OF MINERALIZATION: Can be of any age, mainly Mesozoic to Cenozoic. Typically Early to mid-Jurassic in British Columbia.

HOST/ASSOCIATED ROCK TYPES: Calcic Fe skarns: Fe-rich, Si-poor intrusions derived from primitive oceanic crust. Large to small stocks and dikes of gabbro to syenite (mostly gabbro-diorite) intruding limestone, calcareous clastic sedimentary rocks, tuffs or mafic volcanics at a high to intermediate structural level. Magnesian Fe skarns: Small stocks, dikes and sills of granodiorite to granite intruding dolomite and dolomitic sedimentary rocks.

DEPOSIT FORM: Variable and includes stratiform orebodies, vertical pipes, fault-controlled sheets, massive lenses or veins, and irregular ore zones along intrusive margins.

TEXTURES: Igneous textures in endoskarn. Coarse to fine-grained, massive granoblastic to mineralogically layered textures in exoskarn. Some hornfelsic textures. Magnetite varies from massive to disseminated to veins.

ORE MINERALOGY(Principal and *Subordinate*): Calcic Fe skarns: Magnetite ± chalcopyrite ± pyrite ± cobaltite ± pyrrhotite ± arsenopyrite ± sphalerite ± galena ± molybdenite ± bornite ± hematite ± martite ± gold. Rarely, can contain *tellurobismuthite ± fluorite ± scheelite.* Magnesian Fe skarns: Magnetite ± chalcopyrite ± bornite ± pyrite ± pyrhhotite ± sphalerite ± molybdenite.

EXOSKARN ALTERATION (both calcic and magnesian): High Fe, low Mn, diopside-hedenbergite clinopyroxene (Hd20-80) and grossular-andradite garnet (Ad20-95), ± epidote ± apatite. Late stage amphibole ± chlorite ± ilvaite ± epidote ± scapolite ± albite ± K-feldspar. Magnesian Fe skarns can contain olivine, spinel, phlogopite, xanthophyllite, brucite, serpentine, and rare borate minerals such as ludwigite, szaibelyite, fluorborite and kotoite.

ENDOSKARN ALTERATION: Calcic Fe skarns: Extensive endoskarn with Na-silicates ± garnet ± pyroxene ± epidote ± scapolite. Magnesian skarns: Minor pyroxene ± garnet endoskarn, and propyllitic alteration.

ORE CONTROLS: Stratigraphic and structural controls. Close proximity to contacts between intrusions and carbonate sequences, volcanics or calcareous tuffs and sediments. Fracture zones near igneous contacts can also be important.

Fe SKARNS K03

ASSOCIATED DEPOSIT TYPES: Cu porphyries (L03, L04); Cu (K01) and Pb-Zn (K02) skarns; small Pb-Zn veins (I05).

COMMENTS: In both calcic and magnesian Fe skarns, early magnetite is locally intergrown with, or cut by, garnet and magnesian silicates (Korzhinski, 1964, 1965;. Sangster, 1969; Burt, 1977). Some calcic Fe skarns contain relatively small pockets of pyrrhotite-pyrite mineralization that postdate the magnetite; this mineralization can be Au-rich. Byproduct magnetite is also derived from some Sn, Cu and calcic Pb-Zn skarns. Over 90% of the 146 Fe skarn occurrences in British Columbia lie within the Wrangellia Terrane of the Insular Belt. The majority of these form where Early to mid-Jurassic dioritic plutons intrude Late Triassic limestones.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Calcic Fe skarn: enriched in Fe, Cu, Co, Au, Ni, As, Cr. Overall Cu and Au grades are low (<0.2% Cu and 0.5 g/t Au). Magnesian Fe skarn: enriched in Fe, Cu, Zn, Bo.

GEOPHYSICAL SIGNATURE: Strong positive magnetic, electromagnetic and induced polarization anomalies. Possible gravity anomalies.

OTHER EXPLORATION GUIDES: Magnetite-rich float. In the Wrangellia Terrane of British Columbia, the upper and lower contacts of the Late Triassic Quatsino limestone (or equivalent units) are favorable horizons for Fe skarn development.

ECONOMIC FACTORS

GRADE AND TONNAGE: Grades are typically 40 to 50 % Fe. Worldwide, calcic Fe skarns range from 3 to 150 Mt whereas magnesian Fe skarns can be larger (exceeding 250 Mt). In British Columbia, they reach 20 Mt and average approximately 4 Mt mined ore.

IMPORTANCE: Worldwide, these deposits were once an important source of iron, but in the last 40 years the market has been increasingly dominated by iron formation deposits. Nearly 90 % of British Columbia's historic iron production was from skarns.

REFERENCES

Burt, D.M. (1977): Mineralogy and Petrology of Skarn Deposits; Rendiconti, *Societa Italiana di Mineralogia e Petrologia*, Volume 33 (2), pages 859-873.

Cox, D.P. and Singer, D.A. (1986): Mineral Deposit Models; *U.S. Geological Survey*, Bulletin 1693, 379 pages.

Eckstrand, O.R. (1984): Canadian Mineral Deposit Types: A Geological Synopsis; *Geological Survey of Canada*, Economic Geology Report 36, 86 pages.

Einaudi, M.T. (1982): General Features and Origin of Skarns Associated with Porphyry Copper Plutons, Southwestern North America*; in* Advances in Geology of the Porphyry Copper Deposits, Southwestern U.S., Titley, S.R., Editor, *Univ. Arizona Press,* pages 185-209.

Einaudi, M.T., Meinert, L.D. and Newberry, R.J. (1981): Skarn Deposits*; in* Seventy-fifth Anniversary Volume, 1906-1980, Economic Geology, Skinner, B.J., Editor, *Economic Geology Publishing Co.*, pages 317-391.

Korzhinski, D.S. (1964): An Outline of Metasomatic Processes (trans. M.E. Bergunker); *International Geol. Review*, Volume 6, pages 1713-1734,

Korzhinski, D.S. (1965): The Theory of Systems with Perfectly Mobile Components and Processes of Mineral Formation; *American Journal of Science*, Volume 263, pages 193-205.

Meinert, L.D. (1984): Mineralogy and Petrology of Iron Skarns in Western British Columbia, Canada; *Economic Geology*, Volume 79, Number 5, pages 869-882.

Fe SKARNS K03

Meinert, L.D. (1992): Skarns and Skarn Deposits; *Geoscience Canada*, Volume 19, No. 4, pages 145-162.

Podlessky, K.V., Vlasova, D.K. and Kudrja, P.F. (1991): Magnetite-bearing Skarns of Mongolia; *in* Skarns - Their Genesis and Metallogeny, *Theophrastus Publications*, Athens, Greece, pages 265-298.

Ray, G.E. and Webster, I.C.L. (1991a): Geology and Mineral Occurrences of the Merry Widow Skarn Camp, Northern Vancouver Island, 92L/6; *B. C. Ministry of Energy, Mines and Petroleum Resources*, Open File Map 1991-8.

Ray, G.E., and Webster, I.C.L. (1991b): An Overview of Skarn Deposits; *in* Ore Deposits, Tectonics and Metallogeny in the Canadian Cordillera; McMillan, W.J., compiler, *B. C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1991-4, pages 213-252.

Sangster, D.F. (1969): The Contact Metasomatic Magnetite Deposits of British Columbia; *Geological Survey of Canada*, Bulletin 172, 85 pages.

Au SKARNS K04

by Gerald E. Ray

IDENTIFICATION

SYNONYMS: Pyrometasomatic, tactite, or contact metasomatic Au deposits.

COMMODITIES (*BYPRODUCTS*): Au (*Cu, Ag*).

EXAMPLES (British Columbia - Canada/*International*): Nickel Plate (092HSE 038), French (092HSE 059), Canty (092HSE 064), Good Hope (092HSE 060); *Fortitude, McCoy and Tomboy-Minnie (Nevada, USA), Buckhorn Mountain (Washington, USA), Butte Highlands (Montana, USA), Thanksgiving (Phillippines), Browns Creek (New South Wales, Australia), Mount Biggenden (Queensland, Australia), Nambija (Ecuador).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Gold-dominant mineralization genetically associated with a skarn gangue consisting of Ca - Fe - Mg silicates. It includes calcic and magnesian Au skarns.

TECTONIC SETTINGS: Most Au skarns form in orogenic belts at convergent plate margins. They tend to be associated with syn to late intraoceanic island arc intrusions emplaced into calcareous sequences in arc or back-arc environments. However, the Butte Highlands Au skarn in Montana, U.S. (Ettlinger *et al.*, in prep) is hosted by platformal carbonates and is probably associated with melts derived from continent crust.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: Most deposits are related to plutonism associated with the development of oceanic island arcs or back arcs, such as the Late Triassic to Early Jurassic Nicola Group in British Columbia.

AGE OF MINERALIZATION: Phanerozoic (mostly Cenozoic and Mesozoic); in British Columbia they are mainly of Early to mid-Jurassic age. The unusual magnesian Au skarns of Western Australia are Archean.

HOST/ASSOCIATED ROCK TYPES: High to intermediate level stocks, sills and dikes of gabbro, quartz diorite or granodiorite intruding carbonate, calcareous clastic or volcaniclastic rocks. The island arc related, I-type intrusions are commonly porphyritic and Fe-rich, and have low Fe_2O_3/FeO ratios.

DEPOSIT FORM: Variable from irregular lenses and veins to tabular or stratiform orebodies with lengths and widths ranging up to many hundreds of metres.

TEXTURE/STRUCTURE: Igneous textures in endoskarn. Coarse to fine-grained, massive granoblastic to layered textures in exoskarn. Some hornfelsic textures. Faults and fractures can be an important loci for mineralization.

ORE MINERALOGY(Principal and *subordinate*):

Calcic Au skarns: Native gold ± chalcopyrite ± pyrrhotite ± arsenopyrite ± *tellurides* (e.g. *hedleyite, tetradymite, altaite* and *hessite*) ± *bismuthinite* ± *cobaltite* ± *native bismuth* ± *pyrite* ± *sphalerite* ± *maldonite*. Generally high sulphide content and pyrrhotite:pyrite ratios, and low Cu:Au (<2000), Cu:Ag (<1000), Zn:Au (<100) and Ag/Au (<1) ratios. Gold is commonly present as micron-sized inclusions in sulphides, or at sulphide grain boundaries associated with tellurides. Therefore, to the naked eye, Au skarn ore is often indistinguishable from waste rock.

Magnesian Au skarns: Native gold ± pyrrhotite ± chalcopyrite ± pyrite ± *magnetite* ± *galena* ± *tetrahedrite*.

Au SKARNS K04

EXOSKARN MINERALOGY (GANGUE):

Calcic Au skarns: extensive exoskarn, generally with high pyroxene:garnet ratios, although at the Fortitude deposit in Nevada, some higher gold values are concentrated in thin, structurally controlled garnet-rich zones. Prograde minerals include K-feldspar, Fe-rich biotite, low Mn grandite garnet (Ad 10-100), wollastonite, diopside-hedenbergite clinopyroxene (Hd 20-100) and vesuvianite. Other less common minerals include rutile, axinite and sphene. Mineral and metal zoning common in skarn envelope with proximal coarse-grained, garnet-rich skarn containing high Cu:Au ratios, and distal finer grained pyroxene-rich skarn containing low Cu:Au ratios and gold-sulphide orebodies. Late or retrograde minerals include epidote, chlorite, clinozoisite, vesuvianite, scapolite, tremolite-actinolite, sericite and prehnite.

Magnesian Au skarns: olivine, clinopyroxene (Hd2-50), garnet (Ad7-30) and chondrodite. Retrograde minerals include serpentine, epidote, vesuvianite, tremolite-actinolite, phlogopite, talc, K-feldspar and chlorite.

ENDOSKARN MINERALOGY (GANGUE):

Calcic Au skarns: moderate endoskarn with K-feldspar, biotite, Mg-pyroxene (Hd 5-30) and garnet.

Magnesian Au skarns: details on endoskarn are poorly documented. Argillic and propyllitic alteration with some garnet, clinopyroxene and epidote occurs in the endoskarn at the Butte Highlands Au skarn.

WEATHERING: In temperate climates, skarns often form topographic features with positive relief.

ORE CONTROLS: Stratigraphic and structural controls. Sulphide-rich ore commonly develops in distal, pyroxene-dominant portion of the skarn envelope. Some orebodies form along sill-dike intersections, sill-fault or bedding-fault intersections as well as along fold axes. In some districts, specific suites of reduced, Fe-rich intrusions are spatially related to mineralization

GENETIC MODEL: Mineral assemblages and low Fe_2O_3/FeO ratios indicate that most calcic Au skarns are highly reduced systems. However, the McCoy Au skarn in Nevada represents a more oxidized system (Brookes *et al.*, 1990). There is a worldwide spatial and temporal association between porphyry Cu provinces and Au skarns.

ASSOCIATED DEPOSIT TYPES:

Calcic Au skarns: Au placers (C01,C02), calcic Fe and Cu skarns (K03, K01), porphyry Cu deposits (L04) and Au-bearing quartz and/or sulphide veins (I01, I02).

Magnesian Au skarns: Au placers (Co1,C02), Cu skarns (K01), porphyry Cu and Mo deposits (104, L05), Au-bearing quartz and/or sulphide veins (I01, I02); possibly W skarns (K05).

COMMENTS: Most Au skarns throughout the world are calcic and are associated with island arc plutonism. However, unusual and distinct magnesian Au skarns are reported in the Archean greenstones of Western Australia and in Cambrian platformal dolomites at Butte Highlands in Montana, U.S.A.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Au, As, Bi, Te, Co, Cu anomalies, as well as some geochemical zoning patterns throughout the skarn envelope (notably in Cu/Au ratios). Calcic Au skarns tend to have lower Zn/Au, Cu/Au and Ag/Au ratios than any other skarn class. Their genetically related intrusions may be relatively enriched in the compatible elements Cr, Sc and V, and depleted in lithophile incompatible elements (Rb, Zr, Ce, Nb and La), compared to intrusions associated with most other skarn classes.

GEOPHYSICAL SIGNATURE: Airborne magnetic or gravity surveys to locate plutons. Induced polarization and ground magnetic follow-up surveys can outline some deposits (magnesian skarns tend to be magnetite-bearing).

Au SKARNS K04

OTHER EXPLORATION GUIDES: Ancient placer workings.

Calcic Au skarns: Pyroxene and pyrrhotite-dominant exoskarn envelopes associated with reduced, Fe-rich intrusions in island arc environments.

Magnesian Au skarns: granodiorite intrusions in dolomitic sedimentary rocks.

ECONOMIC IMPORTANCE

TYPICAL GRADE AND TONNAGE: These deposits range from 0.4 to 10 Mt and from 2 to 15 g/t gold. Theodore et al. (1991) report median grades and tonnage of 8.6 g/t , 5.0 g/t Ag and 213,000 t. Nickel Plate has produced over 8 Mt grading 7.4 g/t Au. Average grade worldwide is approximately 4.5 g/t gold.

IMPORTANCE: Recently, there have been some significant Au skarn deposits discovered around the world. Nevertheless, total historic production of gold from skarn (approximately 1000 t of metal) is minute compared to production from other deposit types. The Nickel Plate deposit (Hedley, British Columbia) was probably one of the earliest major gold skarns in the world to be mined. Skarns have accounted for about 16 % of British Columbia's gold production, although nearly half of this was derived as a byproduct from Cu and Fe skarns

REFERENCES

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Brookes, J.W., Meinert, L.D., Kuyper, B.A. and Lane, M.L. (1990): Petrology and Geochemistry of the McCoy Gold Skarn, Lander County, Nevada; *in* Geology and Ore Deposits of the Great Basin, Symposium Proceedings, *Geological Society of Nevada*, April 1990.

Ettlinger, A.D. and Ray, G.E. (1989a): Precious Metal Enriched Skarns in British Columbia: An Overview and Geological Study; *B. C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1989-3, 128 pages.

Ettlinger, A.D. and Ray, G.E. (1989b): Tectonic Control on Distribution of Skarn Hosted Precious Metal Deposits in British Columbia, Canada; *Geological Society of America*, 42nd Annual Meeting, May 8-11, Spokane, Program with Abstracts, Volume 21, page 76.

Ettlinger, A.D., Albers, D., Fredericks, R. and Urbisinov, S. (1995, in prep.): The Butte Highlands Project, Silver Bow County, Montana; An Olivine-rich Magnesian Gold Skarn; *in* Symposium Proceedings of Geology and Ore Deposits of American Cordilleran, *Geological Society of Nevada, U.S. Geological Survey* and *Geological Society of Chile*, April 10-13, 1995, Reno, Nevada.

Meinert, L.D. (1988): Gold in Skarn Deposits - A Preliminary Overview; Proceedings of the Seventh Quadrennial IAGOD Symposium; *E. Schweizerbartische Verlagsbuchhandlung,* Stuttgart.

Meinert, L.D. (1989): Gold Skarn Deposits - Geology and Exploration Criteria; *in* The Geology of Gold Deposits; The Perspective in 1988; *Economic Geology*; Monograph 6, pages 537-552.

Meinert, L.D. (1992): Skarns and Skarn Deposits; *Geoscience Canada*, Volume 19, No. 4, pages 145-162.

Mueller, A.G. (1991): The Savage Lode Magnesian Skarn in the Marvel Loch Gold-Silver Mine, Southern Cross Greenstone Belt, Western Australia; Part I. Structural Setting, Petrography and Geochemistry; *Canadian Journal of Earth Sciences*, Volume 28, No. 5, p. 659-685.

Orris, G.J., Bliss, J.D., Hammarstrom, J.M. and Theodore, T.G. (1987): Description and Grades and Tonnages of Gold-bearing Skarns; *U. S. Geological Survey*, Open File Report 87-273, 50 pages.

Au SKARNS K04

Ray, G.E. and Dawson, G..L. (1994): The Geology and Mineral Deposits of the Hedley Gold Skarn District, Southern British Columbia. *B.C. Ministry of Energy, Mines and Petroleum Resources*, Bulletin 87, 156 pages.

Ray, G.E., and Webster, I.C.L. (1991): Geology and Mineral Occurrences of the Merry Widow Skarn Camp, Northern Vancouver Island, 92L/6; *B. C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1991-8.

Ray, G.E., Ettlinger, A.D. and Meinert, L.D. (1990): Gold Skarns: Their Distribution, Characteristics and Problems in Classification; *in* Geological Fieldwork 1989, *B.C. Ministry of Energy, Mines and Petroleum Resources,* Paper 1990-1, pages 237-246.

Theodore, T.G., Orris, G.J., Hammarstrom, J.M. and Bliss, J.D. (1991): Gold Bearing Skarns; *U. S. Geological Survey*; Bulletin 1930, 61 pages.

W SKARNS K05

by Gerald E. Ray

IDENTIFICATION

SYNONYMS: Pyrometasomatic or contact metasomatic tungsten deposits.

COMMODITIES (*BYPRODUCTS*): W (*Mo, Cu, Sn, Zn*).

EXAMPLES (British Columbia - *Canada/International*): Emerald Tungsten (082FSW010), Dodger (082FSW011), Feeney (082FSW247), Invincible (082FSW218), Dimac (082M123); *Fostung (Ontario, Canada), MacTung (Yukon, Canada), Cantung (Northwest Territories, Canada), Pine Creek and Strawberry(California, USA), Osgood Range (Nevada, USA), King Island (Tasmania, Australia), Sang Dong (South Korea).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Scheelite-dominant mineralization genetically associated with a skarn gangue.

TECTONIC SETTING: Continental margin, synorogenic plutonism intruding deeply buried sequences of eugeoclinal carbonate-shale sedimentary rocks. Can develop in tectonically thickened packages in back-arc thrust settings.

AGE OF MINERALIZATION: Mainly Mesozoic, but may be any age. Over 70% of the W skarns in British Columbia are related to Cretaceous intrusions.

HOST/ASSOCIATED ROCK TYPES: Pure and impure limestones, calcareous to carbonaceous pelites. Associated with tonalite, granodiorite, quartz monzonite and granite of both I and S-types. W skarn-related granitoids, compared to Cu skarn-related plutonic rocks, tend to be more differentiated, more contaminated with sedimentary material, and have crystallized at a deeper structural level.

DEPOSIT FORM: Stratiform, tabular and lens-like orebodies. Deposits can be continous for hundreds of metres and follow intrusive contacts.

TEXTURES: Igneous textures in endoskarn. Coarse to fine-grained, massive granoblastic to mineralogically layered textures in exoskarn. Biotite hornfelsic textures common.

ORE MINERALOGY (Principal and *subordinate*): Scheelite ± molybdenite ± chalcopyrite ± pyrrhotite ± sphalerite ± arsenopyrite ± pyrite ± powellite. May contain *trace wolframite, fluorite, cassiterite, galena, marcasite and bornite*. Reduced types are characterized by pyrrhotite, magnetite, bismuthinite, native bismuth and high pyrrhotite:pyrite ratios. Variable amounts of quartz-vein stockwork (with local molybdenite) can cut both the exo and endoskarn. The Emerald Tungsten skarns in British Columbia include pyrrhotite-arsenopyrite veins and pods that carry up to 4 g/t Au.

ALTERATION MINERALOGY: <u>Exoskarn alteration</u>: Inner zone of diopside-hedenbergite (Hd60-90, Jo5-20) ± grossular-andradite (Ad 10-50, Spess5-50) ± biotite ± vesuvianite, with outer barren wollastonite-bearing zone. An innermost zone of massive quartz may be present. Late-stage spessartine ± almandine ± biotite ± amphibole ± plagioclase ± phlogopite ± epidote ± fluorite ± sphene. Reduced types are characterized by hedenbergitic pyroxene, Fe-rich biotite, fluorite, vesuvianite, scapolite and low garnet:pyroxene ratios, whereas oxidized types are characterized by salitic pyroxene, epidote and andraditic garnet and high garnet:pyroxene ratios. Exoskarn envelope can be associated with extensive areas of biotite hornfels. Endoskarn alteration: Pyroxene ± garnet ± biotite ± epidote ± amphibole ± muscovite ± plagioclase ± pyrite ± pyrrhotite ± trace tourmaline and scapolite; local greisen developed.

W SKARNS K05

ORE CONTROLS: Carbonate rocks in extensive thermal aureoles of intrusions; gently inclined bedding and intrusive contacts; structural and/or stratigraphic traps in sedimentary rocks, and irregular parts of the pluton/country rock contacts.

ASSOCIATED DEPOSIT TYPES: Sn (K06), Mo (K07) and Pb-Zn (K02) skarns. Wollastonite-rich industrial mineral skarns (K09).

COMMENTS: W skarns are separable into two types (Newberry, 1982): reduced skarns (e.g. Cantung, Mactung), formed in carbonaceous rocks and/or at greater depths, and oxidized skarns (e.g. King Island), formed in hematitic or non-carbonaceous rocks, and/or at shallower depths. Late retrograde alteration is an important factor in many W skarns because, during retrogression, the early low-grade mineralization is often scavenged and redeposited into economic high-grade ore zones (e.g. Bateman, 1945; Dick, 1976, 1980). Dolomitic rocks tend to inhibit the development of W skarns; consequently magnesian W skarns are uncommon. In British Columbia they are preferentially associated with Cretaceous intrusions and hosted by calcareous, Cambrian age cratonic, pericratonic and displaced continental margin rocks in the Cassiar, Kootenay-Barkerville, Dorsay and Ancestral North American terranes.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: W, Cu, Mo, As, Bi and B. Less commonly Zn, Pb, Sn, Be and F geochemical anomalies.

ECONOMIC FACTORS

GRADE AND TONNAGE: Grades range between 0.4 and 2 % WO_3 (typically 0.7 %). Deposits vary from 0.1 to >30 Mt.

IMPORTANCE: Skarn deposits have accounted for nearly 60 % of the western world's production, and over 80 % of British Columbia's production.

REFERENCES

Bateman, P.C. (1945): Pine Creek and Adamson Tungsten Mines, Inyo County, California; *California Journal Mines Geology*, Volume 41, pages 231-249.

Dawson, K.M., Panteleyev, A. and Sutherland Brown, A. (1991): Regional Metallogeny, Chapter 19, *in* Geology of the Cordilleran Orogen in Canada, Gabrielse, H. and Yorath, C.J., Editors, *Geological Survey of Canada*, Geology of Canada, Number 4, pages 707-768 (also, *Geological Society of America*, The Geology of North America, volume G-2).

Dick, L.A. (1976): Metamorphism and Metasomatism at the MacMillan Pass Tungsten Deposit, Yukon and District of MacKenzie, Canada; unpublished M.Sc. thesis, *Queens University*, 226 pages.

Dick, L.A. (1980): A Comparative Study of the Geology, Mineralogy and Conditions of Formation of Contact Metasomatic Mineral Deposits in the Northeastern Canadian Cordillera; Unpublished Ph.D. Thesis, *Queen's University*, 471 pages.

Eckstrand, O.R. (1984): Canadian Mineral Deposit Types: A Geological Synopsis; *Geological Survey of Canada*, Economic Geology Report 36, 86 pages.

Einaudi, M.T. and Burt, D.M. (1982): Introduction - Terminology, Classification and Composition of Skarn Deposits; *Economic Geology*; Volume 77, pages 745-754.

Einaudi, M.T., Meinert, L.D. and Newberry, R.J. (1981): Skarn Deposits; *in* Seventy-fifth Anniversary Volume, 1906-1980, Economic Geology, Skinner, B.J., Editor, *Economic Geology Publishing Co.*, pages 317-391.

W SKARNS K05

Kwak, T.A.P. (1987): W-Sn Skarn Deposits and Related Metamorphic Skarns and Granitoids; *in* Developments in Economic Geology, Volume 24, *Elsevier Publishing Co.,* 445 pages..

Kwak, T.A.P. and White, A.J.R. (1982): Contrasting W-Mo-Cu and W-Sn-F Skarn Types and Related Granitoids. *Mining Geology*. Volume 32(4), pages 339-351.

Lowell, G.R. (1991): Tungsten-bearing Scapolite-Vesuvianite Skarns from the Upper Salcha River Area, East-central Alaska; *in* Skarns - Their Genesis and Metallogeny, *Theophrastus Publications,* Athens, Greece, pages 385-418.

Newberry, R.J. (1979): Systematics in the W-Mo-Cu Skarn Formation in the Sierra Nevada: An Overview; *Geological Society of America*, Abstracts with Programs; Volume 11, page 486.

Newberry, R.J. (1982): Tungsten-bearing Skarns of the Sierra Nevada. I. The Pine Creek Mine, California; *Economic Geology*, Volume 77, pages 823-844.

Newberry, R.J., and Swanson, S.E. (1986): Scheelite Skarn Granitoids: An Evaluation of the Roles of Magmatic Source and Process; *Ore Geology Review,* Number 1, pages 57-81.

Sn SKARNS K06

by Gerald E. Ray

IDENTIFICATION

SYNONYMS: Pyrometasomatic or contact metasomatic tin deposits.

COMMODITIES (*BYPRODUCTS*): Sn (*W, Zn, magnetite*).

EXAMPLES (British Columbia - *Canada/International*): Only three in British Columbia - Silver Diamond, Atlin Magnetite, and Daybreak (104N069, 126 and 134 respectively); *JC (Yukon, Canada), Moina, Mount Lindsay, Hole 16 and Mt. Garnet (Tasmania, Australia), Lost River (Alaska, USA).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Cassiterite-dominant mineralization genetically associated with a skarn gangue (includes calcic and magnesian Sn skarns).

TECTONIC SETTINGS: Late to post orogenic granites emplaced into thick and deeply buried continental margin sedimentary sequences, or sequences in rifted or stable cratonic environments.

AGE OF MINERALIZATION: Most economic deposits are Mesozoic or Paleozoic, but occurrences may be any age (the occurrences in British Columbia are Late Cretaceous).

HOST/ASSOCIATED ROCK TYPES: Carbonates and calcareous sedimentary sequences. Associated with differentiated (low Ca, high Si and K) ilmenite-series granite, adamellite and quartz monzonitic stocks and batholiths (of both I and S-type) intruding carbonate and calcareous clastic rocks. Sn skarns tend to develop in reduced and deep-level environments and may be associated with greisen alteration.

DEPOSIT FORM: Variable; can occur as either stratiform, stockwork, pipe-like or irregular vein-like orebodies.

TEXTURES: Igneous textures in endoskarn. Coarse to fine-grained, massive granoblastic to mineralogically layered textures in exoskarn; wrigglite skarns contain thin rhythmic and alternating layers rich in either magnetite, fluorite, vesuvianite or tourmaline. Some hornfelsic textures.

ORE MINERALOGY: Cassiterite ± scheelite ± arsenopyrite ± pyrrhotite ± chalcopyrite ± stannite ± magnetite ± bismuthinite ± sphalerite ± pyrite ± ilmenite.

ALTERATION MINERALOGY: Exoskarn alteration: Grandite garnet (Ad15-75, Pyralsp 5-30) (sometimes Sn, F, and Be enriched), hedenbergitic pyroxene (Hd40-95) ± vesuvianite (sometimes Sn and F-enriched) ± malayaite ± Fe and/or F-rich biotite ± stanniferous sphene ± gahnite ± rutile ± Sn-rich ilvaite ± wollastonite ± adularia. Late minerals include muscovite, Fe-rich biotite, chlorite, tourmaline, fluorite, sellaite, stilpnomelane, epidote and amphibole (latter two minerals can be Sn rich). Associated greisens include quartz and muscovite ± tourmaline ± topaz ± fluorite ± cassiterite ± sulphides. Magnesian Sn skarns can also contain olivine, serpentine, spinel, ludwigite, talc and brucite.

ORE CONTROLS: Differentiated plutons intruding carbonate rocks; fractures, lithological or structural contacts. Deposits may develop some distance (up to 500 m) from the source intrusions.

Sn SKARNS .K06

ASSOCIATED DEPOSIT TYPES: W skarns (K05), Sn ± Be greisens (I13), Sn-bearing quartz-sulphide veins and mantos (J02). In British Columbia, some of the Sn and W skarn-related intrusions (e.g. Cassiar batholith, Mount Haskin stock) are associated with small Pb-Zn skarn occurrences (K02).

COMMENTS: Sn skarns generally form at deep structural levels and in reduced oxidation states. However, wrigglite Sn skarns tend to develop in relatively near-surface conditions, such as over the cupolas of high-level granites. The three Sn skarn occurrences in British Columbia are all associated with an S-type, fluorine-rich accretionary granite, the Surprise Lake batholith. However, they are unusual in being hosted in allochthonous oceanic rocks of the Cache Creek Terrane.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Sn, W, F, Be, Bi, Mo, As, Zn, Cu, Rb, Li, Cs and Re geochemical anomalies. Borate-bearing magnesian Sn skarns may exhibit B enrichment.

GEOPHYSICAL SIGNATURE: Magnetic, induced polarization and possible radiometric anomalies.

ECONOMIC FACTORS

GRADE AND TONNAGE: Deposits can grade up to 1 % Sn, but much of the metal occurring in malayaite, garnet, amphibole and epidote is not economically recoverable. Worldwide, deposits reach 30 Mt, but most range between 0.1 and 3 Mt.

IMPORTANCE: Worldwide, Sn skarns represent a major reserve of tin. However, current production from skarn is relatively minor compared to that from placer Sn deposits and Sn-rich greissens and mantos. British Columbia has had no Sn production from skarns.

REFERENCES

Burt, D.M. (1978): Tin Silicate-Borate-Oxide Equilibria in Skarns and Greisens - The System $CaO-SnO_2-SiO_2-H_2O-B_2O_3-CO_2-F_2O_{-1}$; *Economic Geology*, Volume 73, pages 269-282.

Cox, D.P. and Singer, D.A. (1986): Mineral Deposit Models; *U.S. Geological Survey*, Bulletin 1693, 379 pages.

Einaudi, M.T., Meinert, L.D. and Newberry, R.J. (1981): Skarn Deposits; *in* Seventy-fifth Anniversary Volume, 1906-1980, Economic Geology, Skinner, B.J., Editor, *Economic Geology Publishing Co.*, pages 317-391.

Kwak, T.A.P. (1987): W-Sn Skarn Deposits and Related Metamorphic Skarns and Granitoids; *in* Developments in Economic Geology, Volume 24, *Elsevier Publishing Co.* 445 pages.

Kwak, T.A.P. and Askins, P.W. (1981): Geology and Genesis of the F-Sn-W (-Be-Zn) Skarn (Wrigglite) at Moina, Tasmania, Australia; *Economic Geology*, Volume 76, pages 439-467.

Mitrofanov, N.P. and Stolyarov, I.S. (1982): Comparative Description of Tin-bearing Skarns of the Ladoga Region and Central Asia; *International Geology Revue*, Volume 24, No. 11, pages 1299-1305.

Mo SKARNS K07

by Gerald E. Ray

IDENTIFICATION

SYNONYMS: Pyrometasomatic or contact metasomatic Mo deposits.

COMMODITIES (*BYPRODUCTS*): Mo (*W, Cu, Pb, Zn, Sn, Bi, U, Au*).

EXAMPLES (British Columbia - *Canada/International*): Coxey (082FSW110), Novelty (082FSW107); *Mount Tennyson (New South Wales, Australia), Little Boulder Creek (Idaho, USA), Cannivan Gulch (Montana, USA), Azegour (Morocco), Yangchiachangtze (China).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Molybdenite-dominant mineralization genetically associated with a skarn gangue (includes calcic and magnesian Mo skarns). Mo skarns are broadly separable into polymetallic and "molybdenite-only" types (see comments below).

TECTONIC SETTING: Late orogenic plutonism (derived from transitional crust) intruding continental margin carbonate sequences. Also, some are associated with Mo-bearing porphyry systems developed within intra-oceanic island arcs.

AGE OF MINERALIZATION: Mainly Mesozoic and Paleozoic, but may be any age. In British Columbia, they are mainly of Early to mid-Jurassic in age.

HOST/ASSOCIATED ROCK TYPES: Stocks and dikes of evolved, commonly leucocratic quartz monzonite to granite (some containing primary biotite and muscovite) intruding calcareous clastic rocks. Deposits tend to develop close to intrusive contacts. Some of the Mo skarns in British Columbia are associated with high-level intrusions that have explosive breccia textures.

DEPOSIT FORM: Irregular orebodies along, and controlled by, the intrusive contacts.

TEXTURES: Igneous textures in endoskarn; local explosive breccia textures. Coarse to fine-grained, massive granoblastic to mineralogically layered textures in exoskarn. Some hornfelsic textures.

ORE MINERALOGY (Principal and *subordinate*): Molybdenite ± scheelite ± pyrrhotite ± powellite ± chalcopyrite ± arsenopyrite ± pyrite ± pyrrhotite ± bismuthinite ± sphalerite ± fluorite. In rare instances also *galena* ± *magnetite* ± *uraninite* ± *pitchblende* ± *cassiterite* ± *cobalite* ± *stannite* ± *gold.*

EXOSKARN ALTERATION: Calcic Mo skarns: Hedenbergite pyroxene (Hd50-80, Jo1-3) ± low Mn grossular-andradite garnet (Ad40-95) ± wollastonite ± biotite ± vesuvianite. Magnesian Mo skarns: olivine (Fo96). Retrograde minerals: Calcic skarns: amphibole ± epidote ± chlorite and muscovite. Magnesian skarns: serpentine ± tremolite ± chlorite.

ENDOSKARN ALTERATION: Clinopyroxene, K-feldspar, hornblende, epidote, quartz veining, sericite, molybdenite.

ORE CONTROLS: Carbonate or calcareous rocks in thermal aureoles adjacent to intrusive margins.

Mo SKARNS K07

ASSOCIATED DEPOSIT TYPES: Mo porphyries of quartz monzonite type (L05), Mo-sulphide veins, and Zn-sulphide veins (I05). Some Mo skarns in China are associated with distal, sphalerite-rich mineralization.

COMMENTS: Mo skarns are broadly separable into two types: polymetallic (containing molybdenite with other W, Zn, Pb, Bi, Sn, Co or U-rich minerals), and "molybedenite-only" (containing mainly molybdenite with no or few other sulphides). Over 85% of the 21 Mo skarns recorded in British Columbia occur in the Omineca Belt. More than 60% are hosted in cratonic, pericratonic and displaced continental margin rocks of the Kootenay, Cassiar and Ancestral North America terranes, and a further 19% are found in the Quesnellia Terrane.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Enriched in Mo, Zn, Cu, Sn, Bi, As, F, Pb, U, Sb, Co (Au).

GEOPHYSICAL SIGNATURE: Positive magnetic and induced polarization anomalies.

ECONOMIC FACTORS

GRADE AND TONNAGE: Worldwide, grades range from 0.1 to 2 % MoS_2, and tonnages between 0.1 and 2 Mt. In British Columbia, the Coxey deposit produced 1 Mt of ore grading approximately 0.17 % MoS_2. The Novelty and Giant are polymetallic Mo skarns near Rossland, British Columbia with unusually high grades of up to 47 g/t Au, 1.4 % Ni, 30.5 % As and 4.84 % Co.

IMPORTANCE: Mo skarns tend to be smaller tonnage and less economically important than porphyry Mo deposits.

REFERENCES

Einaudi, M.T., Meinert, L.D. and Newberry, R.J. (1981): Skarn Deposits; *in* Seventy-fifth Anniversary Volume, 1906-1980, Economic Geology, Skinner, B.J., Editor, *Economic Geology Publishing Co.*, pages 317-391.

Theodore, T.G. and Menzie, W.D. (1984): Fluorine-deficient Porphyry Molybdenum Deposits in the Western North American Cordillera; Proceedings of the 6th Quadrennial IAGOD Symposium, Stuttgart, Germany, pages 463-470.

SUBVOLCANIC Cu-Au-Ag (As-Sb) L01

by Andre Panteleyev

IDENTIFICATION

SYNONYMS: Transitional, intrusion-related (polymetallic) stockwork and vein.

COMMODITIES (*BYPRODUCTS*): Cu, Au, Ag (*As, Sb*).

EXAMPLES (British Columbia - *Canada/International*): Equity Silver (93L001); Thorn prospect (104K031,116); Limonite Creek (93L075); *Rochester District (Nevada, USA), Kori Kollo (Bolivia), the 'epithermal gold' zones at Lepanto (Philippines), parts of Recsk (Hungary) and Bor (Serbia).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Pyritic stockworks and veins in subvolcanic intrusive bodies with stratabound to discordant massive pyritic replacements, veins, stockworks, disseminations and related hydrothermal breccias in country rocks. These deposits are located near or above porphyry Cu hydrothermal systems and commonly contain auriferous polymetallic mineralization with Ag sulphosalt and other As and Sb-bearing minerals.

TECTONIC SETTINGS: Volcano-plutonic belts in island arcs and continental margins; continental volcanic arcs. Subvolcanic intrusions are abundant. Extensional tectonic regimes allow high-level emplacement of the intrusions, but compressive regimes are also permissive.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: Uppermost levels of intrusive systems and their adjoining fractured and permeable country rocks, commonly in volcanic terrains with eroded stratovolcanoes. Subvolcanic domes and flow-dome complexes are common; their uppermost parts are exposed without much erosion.

AGE OF MINERALIZATION: Mainly Tertiary, a number of older deposits have been identified.

HOST/ASSOCIATED ROCK TYPES: Subvolcanic (hypabyssal) stocks, rhyodacite and dacite flow-dome complexes with fine to coarse-grained quartz-phyric intrusions are common. Dike swarms and other small subvolcanic intrusions are likely to be present. Country rocks range widely in character and age. Where coeval volcanic rocks are present, they range from andesite to rhyolite in composition and occur as flows, breccias and pyroclastic rocks with related erosion products (epiclastic rocks).

DEPOSIT FORM: Stockworks and sets of sulphide-bearing veins in zones within intrusions and stratabound or bedding plane replacements along permeable units and horizons in hostrocks. Veins and stockworks form in transgressive hydrothermal fluid conduits that can pass into pipe-like and planar breccias. Breccia bodies are commonly tens of metres and, rarely, a few hundred metres in size. Massive sulphide zones can pass outward into auriferous pyrite-quartz-sericite veins and replacements.

SUBVOLCANIC Cu-Ag-Au (As-Sb) L01

TEXTURE/STRUCTURE: Sulphide and sulphide-quartz veins and stockworks. Open space filling and replacement of matrix in breccia units. Bedding and lithic clast replacements by massive sulphide, disseminations and veins. Multiple generations of veins and hydrothermal breccias are common.

ORE MINERALOGY [Principal and *subordinate*]: Pyrite commonly as auriferous pyrite, chalcopyrite, terahedrite/tennantite; *enargite/luzonite, covellite, chalcocite, bornite, sphalerite, galena, arsenopyrite, argentite, sulphosalts, gold, stibnite, molybdenite, wolframite or scheelite, pyrrhotite, marcasite, realgar,hematite, tin and bismuth minerals.* Depth zoning is commonly evident with pyrite-rich deposits containing enargite near surface, passing downwards into tetrahedrite/tennantite + chalcopyrite and then chalcopyrite nearer porphyry intrusions at depth.

GANGUE MINERALOGY [Principal and *subordinate*]: Pyrite, sericite, quartz; *kaolinite, tourmaline, alunite, jarosite.*

ALTERATION MINERALOGY [Principal and *subordinate*]: Pyrite, sericite, quartz; kaolinite, dickite, pyrophyllite, andalusite, diaspore, corundum, tourmaline, alunite, anhydrite, barite, chalcedony, dumortierite, lazulite (variety scorzalite), rutile and chlorite. Tourmaline as schorlite (a black Fe-rich variety) can be present locally; it is commonly present in breccias with quartz and variable amounts of clay minerals. Late quartz-alunite veins may occur.

WEATHERING: Weathering of pyritic zones can produce limonitic blankets containing abundant jarosite and goethite.

GENETIC MODEL: These deposits represent a transition from porphyry copper to epithermal conditions with a blending and blurring of porphyry and epithermal characteristics. Mineralization is related to robust, evolving hydrothermal systems derived from porphyritic, subvolcanic intrusions. Vertical zoning and superimposition of different types of ores is typical due, in large part, to overlapping stages of mineralizations. Ore fluids with varying amounts of magmatic-source fluids have temperatures generally greater than those of epithermal systems, commonly in the order of 300° C and higher. Fluid salinities are also relatively high, commonly more than 10 weight per cent NaCl-equivalent and rarely in the order of 50 %, and greater.

ORE CONTROLS: Strongly fractured to crackled zones in cupolas and flow-dome complexes or along faulted margins of high-level intrusive bodies. Permeable lithologies, both primary and secondary in origin, in the country rocks. Primary controls are porous volcanic units, bedding plane contacts and unconformities. Secondary controls are structural features such as faults, open fractures, crackled zones and breccias. Breccia pipes provide channelways for hydrothermal fluids originating from porphyry Cu systems and commonly carry elevated values of Au and Ag. The vein and replacement style deposits can be separated from the deeper porphyry Cu mineralization by 200 to 700 m.

ASSOCIATED DEPOSIT TYPES: Porphyry Cu-Au±Mo (L04); epithermal Au-Ag commonly both high-sulphidation (H04) and low-sulphidation (H05) pyrite-sericite-bearing types; auriferous quartz-pyrite veins, enargite massive sulphide also known as enargite gold.

SUBVOLCANIC Cu-Ag-Au (As-Sb) L01

COMMENTS: This deposit type is poorly defined and overall, uncommon. It is in large part a stockwork or vein system with local massive to disseminated replacement sulphide zones. It forms as a high-temperature, pyrite-rich, commonly tetrahderite or enargite-bearing, polymetallic affiliate of epithermal Au-Ag mineralization. Both low and high-sulphidation epithermal styles of mineralization can be present. As and Sb enrichments in ores are characteristic. If abundant gas and gas condensates evolve from the hydrothermal fluids there can be extensive acid leaching and widespread, high-level advanced argillic alteration. This type of alteration is rarely mineralized.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Elevated values of Au, Cu, Ag, As, Sb, Zn, Cd, Pb, Fe and F; at deeper levels Mo, Bi, W and locally Sn. In some deposits there is local strong enrichment in B, Co, Ba, K and depletion of Na. Both depth zoning and lateral zoning are evident.

GEOPHYSICAL SIGNATURE: Induced polarization to delineate pyrite zones. Magnetic surveys are useful in some cases to outline lithologic units and delineate contacts. Electromagnetic surveys can be used effectively where massive sulphide bodies are present.

OTHER EXPLORATION GUIDES: Association with widespread sericite-pyrite, quartz-sericite-pyrite and advanced argillic (acid sulphate) alteration that might be high-level leakage from buried porphyry Cu ± Au ± Mo deposits. Extensive overprinting of sericite/illite by kaolinite. In some deposits, high-temperature aluminous alteration minerals pyrophyllite and andalusite are present but are generally overprinted by abundant sericite and lesser kaolinite. There is commonly marked vertical mineralogical and geochemical depth-zoning.

ECONOMIC FACTORS

GRADE AND TONNAGE: The deposits have orebodies of various types; vertical stacking and pronounced metal zoning are prevalent. Small, high-grade replacement orebodies containing enargite or tetrahedrite can form within larger zones of pyritization. Ores of this type at the Lepanto, Mankayan district, the Philippines, range from 2 to 27 Mt with typically ~2% Cu, 1 to ~3 g/t Au and 10 to 20 g/t Ag. The massive sulphide replacement ores have associated smaller peripheral, structurally controlled zones of sericitic alteration that constitute pyritic orebodies grading ~ 4 g/t gold. Similar tetrahedrite-bearing ores with bulk mineable reserves at Equity Silver were in the order of 30 Mt with 0.25% Cu and ~86 g/t Ag and 1 g/t Au. At the Recsk deposit, Hungary, shallow breccia-hosted Cu-Au ores overlie a porphyry deposit containing ~1000 Mt with 0.8 % Cu. The closely spaced pyritic vein systems at Kollo, La Joya district, Bolivia contained 10 Mt oxide ore with 1.62 g/t Au and 23.6 g/t Ag and had sulphide ore reserves of 64 Mt at 2.26 g/t Au and 13.8 g/t Ag.

REFERENCES

Baksa, C., Cseh-Nemeth, J., Csillag, J., Foldessy, J. and Zelenka, T. (1980): The Recsk Porphyry and Skarn Deposit, Hungary; *in* European Copper Deposits, Jankovic, S. and Sillitoe, R.H., Editors, *Society for Geology Applied to Mineral Deposits (SGA)*, Special Publication No. 1, pages 73-76.

Columba, M. and Cunningham, C.G. (1993): Geologic Model for the Mineral Deposits of the La Joya District, Oruro, Bolivia; *Economic Geology*, Volume 88, pages 701-708.

SUBVOLCANIC Cu-Ag-Au (As-Sb) L01

Cyr, J.B., Pease, R.B. and Schroeter, T.G. (1984): Geology and Mineralization at Equity Silver Mine; *Economic Geology*, Volume 79, pages 947-968.

Garcia, J.S., Jr. (1991): Geology and Mineralization Characteristics of the Mankayan Mineral District, Benguet, Philippines; *Geological Survey of Japan*, Report No. 277, pages 21-30.

Jankovic, S., Terzic. M., Aleksic, D., Karamata, S., Spasov, T., Jovanovic, M., Milicic, M., Grubiv, A. and Antonijevic, I. (1980): Metallogenic Features of Copper Deposits in the Volcano-Intrusive Complexes of the Bor District, Yugoslavia; *in* European Copper Deposits, Jankovic, S. and Sillitoe, R.H., Editors, *Society for Geology Applied to Mineral Deposits (SGA)*, Special Publication No. 1, pages 42-49.

Learned, R., Allen, M.S., Andre'-Ramos, O. and Enriquez, R (1992): A Geochemical Study of the La Joya District; *U. S. Geological Survey*, Bulletin 1975, pages 25-46.

Long, K., Ludington, S, du Bray, E., Andre'-Ramos, O. and McKee, E.H. (1992): Geology and Mineral Deposits of the La Joya District, Bolivia, SEG Newsletter, *Society of Economic Geologists*, Volume 10, Number 1, pages 13-16.

Sillitoe, R.H. (1983): Enargite-bearing Massive Sulfide Deposits High in Porphyry Copper Systems; *Economic Geology*, Volume 78, pages 348-352.

Vikre, P.G. (1981): Silver Mineralization in the Rochester District, Pershing County, Nevada; *Economic Geology*, Volume 76, pages 580-609.

PORPHYRY Cu-Au: ALKALIC L03

by Andre Panteleyev

IDENTIFICATION

SYNONYMS: Porphyry copper, porphyry Cu-Au, diorite porphyry copper.

COMMODITIES (*BYPRODUCTS*): Cu, Au (*Ag*).

EXAMPLES (British Columbian - *Canada/International*): Iron Mask batholith deposits - Afton (092INE023), Ajax (092INE012, 013), Mt. Polley (Cariboo Bell, 093A008), Mt. Milligan (093N196, 194), Copper Mt./Ingerbelle (092HSE001, 004), Galore Creek(104G090), Lorraine? (093N002); *Ok Tedi (Papua New Guinea); Tai Parit and Marian? (Philippines).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Stockworks, veinlets and disseminations of pyrite, chalcopyrite, bornite and magnetite occur in large zones of economically bulk-mineable mineralization in or adjoining porphyritic intrusions of diorite to syenite composition. The mineralization is spatially, temporally and genetically associated with hydrothermal alteration of the intrusive bodies and hostrocks.

TECTONIC SETTING(S): In orogenic belts at convergent plate boundaries, commonly oceanic volcanic island arcs overlying oceanic crust. Chemically distinct magmatism with alkalic intrusions varying in composition from gabbro, diorite and monzonite to nepheline syenite intrusions and coeval shoshonitic volcanic rocks, takes place at certain times in segments of some island arcs. The magmas are introduced along the axis of the arc or in cross-arc structures that coincide with deep-seated faults. The alkalic magmas appear to form where there is slow subduction in steeply dipping, tectonically thickened lithospheric slabs, possibly when polarity reversals (or `flips') take place in the subduction zones. In British Columbia all known deposits are found in Quesnellia and Stikinia terranes.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: High level (epizonal) stock emplacement levels in magmatic arcs, commonly oceanic volcanic island arcs with alkalic (shoshonitic) basic flows to intermediate and felsic pyroclastic rocks. Commonly the high-level stocks and related dikes intrude their coeval and cogenetic volcanic piles.

AGE OF MINERALIZATION: Deposits in the Canadian Cordillera are restricted to the Late Triassic/Early Jurassic (215-180 Ma) with seemingly two clusters around 205-200 and ~ 185 Ma. In southwest Pacific island arcs, deposits are Tertiary to Quaternary in age.

HOST/ASSOCIATED ROCK TYPES: Intrusions range from fine through coarse-grained, equigranular to coarsely porphyritic and, locally, pegmatitic high-level stocks and dike complexes. Commonly there is multiple emplacement of successive intrusive phases and a wide variety of breccias. Compositions range from (alkalic) gabbro to syenite. The syenitic rocks vary from silica-undersaturated to saturated compositions. The most undersaturated nepheline normative rocks contain modal nepheline and, more commonly, pseudoleucite.

PORPHYRY Cu-Au: ALKALIC L03

HOST/ASSOCIATED ROCK TYPES (cont.): The silica-undersaturated suites are referred to as nepheline alkalic whereas rocks with silica near-saturation, or slight silica over saturation, are termed quartz alkalic (Lang *et al.*, 1993). Coeval volcanic rocks are basic to intermediate alkalic varieties of the high-K basalt and shoshonite series and rarely phonolites.

DEPOSIT FORM: Stockworks and veinlets, minor disseminations and replacements throughout large areas of hydrothermally altered rock, commonly coincident wholly or in part with hydrothermal or intrusion breccias. Deposit boundaries are determined by economic factors that outline ore zones within larger areas of low-grade, laterally zoned mineralization.

TEXTURE/STRUCTURE: Veinlets and stockworks; breccia, sulphide and magnetite grains in fractures and along fracture selvages; disseminated sulphides as interstitial or grain and lithic clast replacements. Hydrothermally altered rocks can contain coarse-grained assemblages including feldspathic and calcsilicate replacements ('porphyroid' textures) and open space filling with fine to coarse, granular and rarely pegmatitic textures.

ORE MINERALOGY [Principal and *subordinate*]: Chalcopyrite, pyrite and magnetite; bornite, chalcocite and *rare galena, sphalerite, tellurides, tetrahderite, gold and silver*. Pyrite is less abundant than chalcopyrite in ore zones.

GANGUE MINERALOGY: Biotite, K-feldspar and sericite; garnet, clinopyroxene (diopsidic) and anhydrite. Quartz veins are absent but hydrothermal magnetite veinlets are abundant.

ALTERATION MINERALOGY: Biotite, K-feldspar, sericite, anhydrite/gypsum, magnetite, hematite, actinolite, chlorite, epidote and carbonate. Some alkalic systems contain abundant garnet including the Ti-rich andradite variety - melanite, diopside, plagioclase, scapolite, prehnite, pseudoleucite and apatite; rare barite, fluorite, sodalite, rutile and late-stage quartz. Central and early formed potassic zones, with K-feldspar and generally abundant secondary biotite and anhydrite, commonly coincide with ore. These rocks can contain zones with relatively high-temperature calcsilicate minerals diopside and garnet. Outward there can be flanking zones in basic volcanic rocks with abundant biotite that grades into extensive, marginal propylitic zones. The older alteration assemblages can be overprinted by phyllic sericite-pyrite and, less commonly, sericite-clay-carbonate-pyrite alteration. In some deposits, generally at depth in silica-saturated types, there can be either extensive or local central zones of sodic alteration containing characteristic albite with epidote, pyrite, diopside, actinolite and rarer scapolite and prehnite.

ORE CONTROLS: Igneous contacts, both internal between intrusive phases and external with wallrocks; cupolas and the uppermost, bifurcating parts of stocks, dike swarms and volcanic vents. Breccias, mainly early formed intrusive and hydrothermal types. Zones of most intensely developed fracturing give rise to ore-grade vein stockworks.

ASSOCIATED DEPOSIT TYPES: Skarn copper (K01); Au-Ag and base metal bearing mantos (M01, M04), replacements and breccias in carbonate and non-carbonate rocks; magnetite-apatite breccias (D07); epithermal Au-Ag : both high and low sulphidation types (H04, H05) and alkalic, Te and F-rich epithermal deposits (H08); auriferous and polymetallic base metal quartz and quartz-carbonate veins (I01, I05); placer Au (C01, C02).

PORPHYRY Cu-Au: ALKALIC L03

COMMENTS: Subdivision of porphyry deposits is made on the basis of metal content, mainly ratios between Cu, Au and Mo. This is a purely arbitrary, economically based criterion; there are few differences in the style of mineralization between the deposits. Differences in composition between the hostrock alkalic and calcalkalic intrusions and subtle, but significant, differences in alteration mineralogy and zoning patterns provide fundamental geologically based contrasts between deposit model types. Porphyry copper deposits associated with calcalkaline hostrocks are described in mineral deposit profile L04.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Alkalic cupriferous systems do not contain economically recoverable Mo (< 100 ppm) but do contain elevated Au (> 0.3 g/t) and Ag (>2 g/t). Cu grades vary widely but commonly exceed 0.5 % and rarely 1 %. Many contain elevated Ti, V, P, F, Ba, Sr, Rb, Nb, Te, Pb, Zn, PGE and have high CO_2 content. Leaching and supergene enrichment effects are generally slight and surface outcroppings normally have little of the copper remobilized. Where present, secondary minerals are malachite, azurite, lesser copper oxide and rare sulphate minerals; in some deposits native copper is economically significant (e.g. Afton, Kemess).

GEOPHYSICAL SIGNATURE: Ore zones, particularly those with high Au content, are frequently found in association with magnetite-rich rocks and can be located by magnetic surveys. Pyritic haloes surrounding cupriferous rocks respond well to induced polarization surveys. The more intensely hydrothermally altered rocks produce resistivity lows.

OTHER EXPLORATION GUIDES: Porphyry deposits are marked by large-scale, markedly zoned metal and alteration assemblages. Central parts of mineralized zones appear to haver higher Au/Cu ratios than the margins. The alkalic porphyry Cu deposits are found exclusively in Later Triassic and Early Jurassic volcanic arc terranes in which emergent subaerial rocks are present. The presence of hydrothermally altered clasts in coarse pyroclastic deposits can be used to locate mineralized intrusive centres.

ECONOMIC FACTORS

GRADE AND TONNAGE:

- Worldwide according to Cox and Singer (U.S. Geological Survey Open File Report 88-46, 1988) 20 typical porphyry Cu-Au deposits, including both calcalkaline and some alkalic types, contain on average:
  160 Mt with 0.55 % Cu, 0.003 % Mo, 0.38 g/t Au and 1.7 g/t Ag.
- British Columbia alkalic porphyry deposits range from <10 to >300 Mt and contain from 0.2 to 1.5 % Cu, 0.2 to 0.6 g/t Au and >2 g/t Ag; Mo contents are negligible. Median values for 22 British Columbia deposits with reported reserves (with a heavy weighting from a number of small deposits in the Iron Mask batholith) are: 15.5 Mt with 0.58 % Cu, 0.3 g/t Au and >2 g/t Ag.

END USES: Production of chalcopyrite or chalcopyrite-bornite concentrates with significant Au credits..

IMPORTANCE: Porphyry deposits contain the largest reserves of Cu and close to 50 % of Au reserves in British Columbia; alkalic porphyry systems contain elevated Au values.

PORPHYRY Cu-Au: ALKALIC L03

REFERENCES

Barr, D.A., Fox, P.E., Northcote, K.E. and Preto, V.A. (1976): The Alkaline Suite Porphyry Deposits - A Summary; *in* Porphyry Deposits of the Canadian Cordillera, Sutherland Brown, A. Editor, *Canadian Institute of Mining and Metallurgy,* Special Volume 15, pages 359-367.

Lang, J.R., Stanley, C.R. and Thompson, H.F.H. (1993): A Subdivision of Alkalic Porphyry Cu-Au Deposits into Silica-saturated and Silica-undersaturated Subtypes; *in* Porphyry Copper-Gold Systems of British Columbia, *Mineral Deposit Research Unit*, University of British Columbia, Annual Technical Report - Year 2, pages 3.2-3.14.

McMillan, W.J. (1991): Porphyry Deposits in the Canadian Cordillera; *in* Ore Deposits, Tectonics and Metallogeny in the Canadian Cordillera, *B. C. Ministry of Energy, Mines and Petroleum Resources,* Paper 1991-4, pages 253-276.

McMillan, W.J. and Panteleyev, A. (1988): Porphyry Copper Deposits; *in* Ore Deposit Models, Roberts, R.G. and Sheahan, P.A, Editors, *Geoscience Canada*, Reprint Series 3, pages 45-58.

Mutschler, F.E. and Mooney, T.C. (1995): Precious Metal Deposits Related to Alkaline Igneous Rocks - Provisional Classification, Grade-Tonnage Data, and Exploration Frontiers; IUGS/UNESCO Conference on Deposit Modeling, Ottawa, 1990, Proceedings Volume, *Geological Association of Canada, Special Paper 40.*

Sutherland Brown, A., Editor, (1976): Porphyry Deposits of the Canadian Cordillera; *Canadian Institute of Mining and Metallurgy,* Special Volume 15, 510 pages.

PORPHYRY Cu ± Mo ± Au — L04

by Andre Panteleyev

IDENTIFICATION

SYNONYM: Calcalkaline porphyry Cu, Cu-Mo, Cu-Au.

COMMODITIES (*BYPRODUCTS*): Cu. Mo and Au are generally present but quantities range from insufficient for economic recovery to major ore constituents. *Minor Ag in most deposits; rare recovery of Re from Island Copper mine.*

EXAMPLES (British Columbia - *Canada/International*):

- Volcanic type deposits (Cu + Au ± Mo) - Fish Lake (092O041), Kemess (094E021,094), Hushamu (EXPO, 092L240), Red Dog (092L200), Poison Mountain (092O046), Bell (093M001), Morrison (093M007), Island Copper (092L158); *Dos Pobres (USA); Far Southeast (Lepanto/Mankayan), Dizon, Guianaong, Taysan and Santo Thomas II (Philippines), Frieda River and Panguna (Papua New Guinea).*
- Classic deposits (Cu + Mo ± Au) - Brenda (092HNE047), Berg (093E046), Huckleberrry (093E037), Schaft Creek (104G015); *Casino (Yukon, Canada), Inspiration, Morenci, Ray, Sierrita-Experanza, Twin Buttes, Kalamazoo and Santa Rita (Arizona, USA), Bingham (Utah, USA),El Salvador, (Chile), Bajo de la Alumbrera (Argentina).*
- Plutonic deposits (Cu ± Mo) - Highland Valley Copper (092ISE001,011,012,045), Gibraltar (093B012,007), Catface (092F120); *Chuquicamata, La Escondida and Quebrada Blanca (Chile).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Stockworks of quartz veinlets, quartz veins, closely spaced fractures and breccias containing pyrite and chalcopyrite with lesser molybdenite, bornite and magnetite occur in large zones of economically bulk-mineable mineralization in or adjoining porphyritic intrusions and related breccia bodies. Disseminated sulphide minerals are present, generally in subordinate amounts. The mineralization is spatially, temporally and genetically associated with hydrothermal alteration of the hostrock intrusions and wallrocks.

TECTONIC SETTINGS: In orogenic belts at convergent plate boundaries, commonly linked to subduction-related magmatism. Also in association with emplacement of high-level stocks during extensional tectonism related to strike-slip faulting and back-arc spreading following continent margin accretion.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: High-level (epizonal) stock emplacement levels in volcano-plutonic arcs, commonly oceanic volcanic island and continent-margin arcs. Virtually any type of country rock can be mineralized, but commonly the high-level stocks and related dikes intrude their coeval and cogenetic volcanic piles.

AGE OF MINERALIZATION: Two main periods in the Canadian Cordillera: the Triassic/Jurassic (210-180 Ma) and Cretaceous/Tertiary (85-45 Ma). Elsewhere deposits are mainly Tertiary, but range from Archean to Quaternary..

PORPHYRY Cu ± Mo ± Au L04

HOST/ASSOCIATED ROCK TYPES: Intrusions range from coarse-grained phaneritic to porphyritic stocks, batholiths and dike swarms; rarely pegmatitic. Compositions range from calcalkaline quartz diorite to granodiorite and quartz monzonite. Commonly there is multiple emplacement of successive intrusive phases and a wide variety of breccias. Alkalic porphyry Cu-Au deposits are associated with syenitic and other alkalic rocks and are considered to be a a distinct deposit type (see model L03).

DEPOSIT FORM: Large zones of hydrothermally altered rock contain quartz veins and stockworks, sulphide-bearing veinlets; fractures and lesser disseminations in areas up to 10 km^2 in size, commonly coincident wholly or in part with hydrothermal or intrusion breccias and dike swarms. Deposit boundaries are determined by economic factors that outline ore zones within larger areas of low-grade, concentrically zoned mineralization. Cordilleran deposits are commonly subdivided according to their morphology into three classes - classic, volcanic and plutonic (see Sutherland Brown, 1976; McMillan and Panteleyev, 1988):

- Volcanic type deposits (e.g. Island Copper) are associated with multiple intrusions in subvolcanic settings of small stocks, sills, dikes and diverse types of intrusive breccias. Reconstruction of volcanic landforms, structures, vent-proximal extrusive deposits and subvolcanic intrusive centres is possible in many cases, or can be inferred. Mineralization at depths of 1 km, or less, is mainly associated with breccia development or as lithologically controlled preferential replacement in hostrocks with high primary permeability. Propylitic alteration is widespread and generally flanks early, centrally located potassic alteration; the latter is commonly well mineralized. Younger mineralized phyllic alteration commonly overprints the early mineralization. Barren advanced argillic alteration is rarely present as a late, high-level hydrothermal carapace.
- Classic deposits (e.g., Berg) are stock related with multiple emplacements at shallow depth (1 to 2 km) of generally equant, cylindrical porphyritic intrusions. Numerous dikes and breccias of pre, intra, and post-mineralization age modify the stock geometry. Orebodies occur along margins and adjacent to intrusions as annular ore shells. Lateral outward zoning of alteration and sulphide minerals from a weakly mineralized potassic/propylitic core is usual. Surrounding ore zones with potassic (commonly biotite-rich) or phyllic alteration contain molybdenite ± chalcopyrite, then chalcopyrite and a generally widespread propylitic, barren pyritic aureole or 'halo'.
- Plutonic deposits (e.g., the Highland Valley deposits) are found in large plutonic to batholithic intrusions immobilized at relatively deep levels, say 2 to 4 km. Related dikes and intrusive breccia bodies can be emplaced at shallower levels. Hostrocks are phaneritic coarse grained to porphyritic. The intrusions can display internal compositional differences as a result of differentiation with gradational to sharp boundaries between the different phases of magma emplacement. Local swarms of dikes, many with associated breccias, and fault zones are sites of mineralization. Orebodies around silicified alteration zones tend to occur as diffuse vein stockworks carrying chalcopyrite, bornite and minor pyrite in intensely fractured rocks but, overall, sulphide minerals are sparse. Much of the early potassic and phyllic alteration in central parts of orebodies is restricted to the margins of mineralized fractures as selvages. Later phyllic-argillic alteration forms envelopes on the veins and fractures and is more pervasive and widespread. Propylitic alteration is widespread but unobtrusive and is indicated by the presence of rare pyrite with chloritized mafic minerals, saussuritized plagioclase and small amounts of epidote.

TEXTURE/STRUCTURE: Quartz, quartz-sulphide and sulphide veinlets and stockworks; sulphide grains in fractures and fracture selvages. Minor disseminated sulphides commonly replacing primary mafic minerals. Quartz phenocrysts can be partially resorbed and overgrown by silica.

PORPHYRY Cu ± Mo ± Au   L04

ORE MINERALOGY (Principal and *subordinate*): Pyrite is the predominant sulphide mineral; in some deposits the Fe oxide minerals magnetite, and rarely hematite, are abundant. Ore minerals are chalcopyrite; molybdenite, lesser bornite and rare (primary) chalcocite. Subordinate minerals are *tetrahedrite/tennantite, enargite and minor gold, electrum and arsenopyrite.* In many deposits late veins commonly contain galena and sphalerite in a gangue of quartz, calcite and barite.

GANGUE MINERALOGY (Principal and *subordinate*): Gangue minerals in mineralized veins are mainly quartz with lesser *biotite, sericite, K-feldspar, magnetite, chlorite, calcite, epidote, anhydrite and tourmaline.* Many of these minerals are also pervasive alteration products of primary igneous mineral grains.

ALTERATION MINERALOGY: Quartz, sericite, biotite, K-feldspar, albite, anhydrite/gypsum, magnetite, actinolite, chlorite, epidote, calcite, clay minerals, tourmaline. Early formed alteration can be overprinted by younger assemblages. Central and early formed potassic zones (K-feldspar and biotite) commonly coincide with ore. This alteration can be flanked in volcanic hostrocks by biotite-rich rocks that grade outward into propylitic rocks. The biotite is a fine-grained, 'shreddy' looking secondary mineral that is commonly referred to as an early developed biotite (EDB) or a 'biotite hornfels'. These older alteration assemblages in cupriferous zones can be partially to completely overprinted by later biotite and K-feldspar and then phyllic (quartz-sericite-pyrite) alteration, less commonly argillic, and rarely, in the uppermost parts of some ore deposits, advanced argillic alteration (kaolinite-pyrophyllite).

WEATHERING: Secondary (supergene) zones carry chalcocite, covellite and other $Cu_{\sim 2}S$ minerals (digenite, djurleite, etc.), chrysocolla, native copper and copper oxide, carbonate and sulphate minerals. Oxidized and leached zones at surface are marked by ferruginous 'cappings' with supergene clay minerals, limonite (goethite, hematite and jarosite) and residual quartz.

ORE CONTROLS: Igneous contacts, both internal between intrusive phases and external with wallrocks; cupolas and the uppermost, bifurcating parts of stocks, dike swarms. Breccias, mainly early formed intrusive and hydrothermal types. Zones of most intensely developed fracturing give rise to ore-grade vein stockworks, notably where there are coincident or intersecting multiple mineralized fracture sets.

ASSOCIATED DEPOSIT TYPES: Skarn Cu (K01), porphyry Au (K02), epithermal Au-Ag in low sulphidation type (H05) or epithermal Cu-Au-Ag as high-sulphidation type enargite-bearing veins (L01), replacements and stockworks; auriferous and polymetallic base metal quartz and quartz-carbonate veins (I01, I05), Au-Ag and base metal sulphide mantos and replacements in carbonate and non-carbonate rocks (M01, M04), placer Au (C01, C02).

COMMENTS: Subdivision of porphyry copper deposits can be made on the basis of metal content, mainly ratios between Cu, Mo and Au. This is a purely arbitrary, economically based criterion, an artifact of mainly metal prices and metallurgy. There are few differences in the style of mineralization between deposits although the morphology of calcalkaline deposits does provide a basis for subdivision into three distinct subtypes - the 'volcanic, classic, and plutonic' types. A fundamental contrast can be made on the compositional differences between calcalkaline quartz-bearing porphyry copper deposits and the alkalic (silica undersaturated) class. The alkalic porphyry copper deposits are described in a separate model - L03.

PORPHYRY Cu ± Mo ± Au L04

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Calcalkalic systems can be zoned with a cupriferous (± Mo) ore zone having a 'barren', low-grade pyritic core and surrounded by a pyritic halo with peripheral base and precious metal-bearing veins. Central zones with Cu commonly have coincident Mo, Au and Ag with possibly Bi, W, B and Sr. Peripheral enrichment in Pb, Zn, Mn, V, Sb, As, Se, Te, Co, Ba, Rb and possibly Hg is documented. Overall the deposits are large-scale repositories of sulphur, mainly in the form of metal sulphides, chiefly pyrite.

GEOPHYSICAL SIGNATURE: Ore zones, particularly those with higher Au content, can be associated with magnetite-rich rocks and are indicated by magnetic surveys. Alternatively the more intensely hydrothermally altered rocks, particularly those with quartz-pyrite-sericite (phyllic) alteration produce magnetic and resistivity lows. Pyritic haloes surrounding cupriferous rocks respond well to induced polarization (I.P.) surveys but in sulphide-poor systems the ore itself provides the only significant IP response.

OTHER EXPLORATION GUIDES: Porphyry deposits are marked by large-scale, zoned metal and alteration assemblages. Ore zones can form within certain intrusive phases and breccias or are present as vertical 'shells' or mineralized cupolas around particular intrusive bodies. Weathering can produce a pronounced vertical zonation with an oxidized, limonitic leached zone at surface (leached capping), an underlying zone with copper enrichment (supergene zone with secondary copper minerals) and at depth a zone of primary mineralization (the hypogene zone).

ECONOMIC FACTORS

TYPICAL GRADE AND TONNAGE:

- Worldwide according Cox and Singer (1988) based on their subdivision of 55 deposits into subtypes according to metal ratios, typical porphyry Cu deposits contain (median values):

Porphyry Cu-Au:	160 Mt with 0.55 % Cu, 0.003 % Mo, 0.38 g/t Au and 1.7 g/t Ag.
Porphyry Cu-Au-Mo:	390 Mt with 0.48 % Cu, 0.015 % Mo, 0.15 g/t Au and 1.6 g/t Ag.
Porphyry Cu-Mo:	500 Mt with 0.41 % Cu, 0.016 % Mo, 0.012 g/t Au and 1.22 g/t Ag.

A similar subdivision by Cox (1986) using a larger data base results in:

Porphyry Cu:	140 Mt with 0.54 %Cu, <0.002 % Mo, <0.02g/t Au and <1 g/t Ag.
Porphyry Cu-Au:	100 Mt with 0.5 %Cu, <0.002 % Mo, 0.38g/t Au and 1g/t Ag. (This includes deposits from the British Columbia alkalic porphyry class, B.C. model L03.)
Porphyry Cu-Mo:	500 Mt with 0.42 % Cu, 0.016 % Mo, 0.012 g/t Au and 1.2 g/t Ag.

- British Columbia porphyry Cu ± Mo ± Au deposits range from <50 to >900 Mt with commonly 0.2 to 0.5 % Cu, <0.1 to 0.6 g/t Au, and 1 to 3 g/t Ag. Mo contents are variable from negligible to 0.04 % Mo. Median values for 40 B.C. deposits with reported reserves are: 115 Mt with 0.37 % Cu, ~0.01 % Mo, 0.3g /t Au and 1.3 g/t Ag.

ECONOMIC LIMITATIONS: Mine production in British Columbia is from primary (hypogene) ores. Rare exceptions are Afton mine where native copper was recovered from an oxide zone, and Gibraltar and Bell mines where incipient supergene enrichment has provided some economic benefits.

END USES: Porphyry copper deposits produce Cu and Mo concentrates, mainly for international export.

PORPHYRY Cu ± Mo ± Au L04

IMPORTANCE: Porphyry deposits contain the largest reserves of Cu, significant Mo resources and close to 50 % of Au reserves in British Columbia.

REFERENCES

Beane, R.E. and Titley, S.R. (1981): Porphyry Copper Deposits Part II. Hydrothermal Alteration and Mineralization; *in* 75th Anniversary Volume, *Economic Geology*, pages 235-269.

Cox, D.P. (1986): Descriptive Model of Porphyry Cu, *also* Porphyry Cu-Au and Porphyry Cu-Mo; *in* Mineral Deposit Models; *United States Geological Survey*, Bulletin 1693, pages 76-81, *also* pages 110-114 and 115-119.

Cox, D.P. and Singer, D.A. (1988): Distribution of Gold in Porphyry Copper Deposits; *U.S. Geological Survey*, Open File Report 88-46, 23 pages.

Gustafson, L.B. and Hunt, J.P. (1975): The Porphyry Copper Deposit at El Salvador, Chile; *Economic Geology*, Volume 70, pages 857-912.

Lowell, J.D. and Guilbert, J.M. (1970): Lateral and Vertical Alteration-Mineralization Zoning in Porphyry Ore Deposits; *Economic Geology*, Volume 65, pages 373-408.

McMillan, W.J. (1991): Porphyry Deposits in the Canadian Cordillera; *in* Ore Deposits, Tectonics and Metallogeny in the Canadian Cordillera, *B. C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1991-4, pages 253-276.

McMillan, W.J. and Panteleyev, A. (1988): Porphyry Copper Deposits; *in* Ore Deposit Models, Roberts, R.G. and Sheahan, P.A., Editors, Geoscience Canada Reprint Series 3, *Geological Association of Canada*, pages 45-58; also *in* Geoscience Canada, Volume 7, Number 2, pages 52-63.

Schroeter, T. G., Editor (1995): Porphyry Copper Deposits of the Northwestern Cordillera of North America; *Canadian Institute of Mining, Metallurgy and Petroleum,* Special Volume 46, in preparation.

Sutherland Brown, A., Editor, (1976): Porphyry Deposits of the Canadian Cordillera; *Canadian Institute of Mining and Metallurgy,* Special Volume 15, 510 pages.

Titley, S.R. (1982): Advances in Geology of the Porphyry Copper Deposits, Southwestern North America; *The University of Arizona Press,* Tucson, 560 pages.

Titley, S.R. and Beane, R.E. (1981): Porphyry Copper Deposits Part I. Geologic Settings, Petrology, and Tectogenesis, *in* 75th Anniversary Volume, *Economic Geology*, pages 214-234.

PORPHYRY Mo (LOW-F-TYPE)[1] L05

by: W. David Sinclair[2]

IDENTIFICATION

SYNONYMS: Calcalkaline Mo stockwork; Granite-related Mo; Quartz-monzonite Mo.

COMMODITIES (*BYPRODUCTS*): Mo (*Cu, W*)

EXAMPLES (British Columbia - *Canada/International*): Endako (093K006), Boss Mountain (093A001), Kitsault (103P120), Adanac (104N052), Carmi (082ESW029), Bell Moly (103P234), Red Bird (093E026), Storie Moly (104P069), Trout Lake (082KNW087); *Red Mountain (Yukon, Canada), Quartz Hill (Alaska, USA), Cannivan (Montana, USA), Thompson Creek (Idaho, USA), Compaccha (Peru), East Kounrad (Russia), Jinduicheng (China).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Stockwork of molybdenite-bearing quartz veinlets and fractures in intermediate to felsic intrusive rocks and associated country rocks. Deposits are low grade but large and amenable to bulk mining methods.

TECTONIC SETTING(S): Subduction zones related to arc-continent or continent-continent collision.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: High-level to subvolcanic felsic intrusive centres; multiple stages of intrusion are common.

AGE OF MINERALIZATION: Archean (e.g. Setting Net Lake, Ontario) to Tertiary; Mesozoic and Tertiary examples are more common.

HOST/ASSOCIATED ROCK TYPES: All kinds of rocks may be hostrocks. Tuffs or other extrusive volcanic rocks may be associated with deposits related to subvolcanic intrusive rocks. Genetically related intrusive rocks range from granodiorite to granite and their fine-grained equivalents, with quartz monzonite most common: they are commonly porphyritic. The intrusive rocks are characterized by low F contents (generally <0.1 % F) compared to intrusive rocks associated with Climax-type porphyry Mo deposits.

DEPOSIT FORM: Deposits vary in shape from an inverted cup, to roughly cylindrical, to highly irregular. They are typically hundreds of metres across and range from tens to hundreds of metres in vertical extent.

TEXTURE/STRUCTURE: Ore is predominantly structurally controlled; mainly stockworks of crosscutting fractures and quartz veinlets, also veins, vein sets and breccias.

ORE MINERALOGY (Principal and *subordinate*): Molybdenite is the principal ore mineral; *chalcopyrite, scheelite, and galena are generally subordinate.*

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[1] Geological Survey of Canada contribution number 61494

[2] Geological Survey of Canada, Ottawa

PORPHYRY Mo (LOW-F-TYPE) L05

GANGUE MINERALOGY: Quartz, pyrite, K-feldspar, biotite, sericite, clays, calcite and anhydrite.

ALTERATION MINERALOGY: Alteration mineralogy is similar to that of porphyry Cu deposits. A core zone of potassic and silicic alteration is characterized by hydrothermal K-feldspar, biotite, quartz and, in some cases, anhydrite. K-feldspar and biotite commonly occur as alteration selvages on mineralized quartz veinlets and fractures but may be pervasive in areas of intense fracturing and mineralization. Phyllic alteration typically surrounds and may be superimposed to various degrees on the potassic-silicic core; it consists mainly of quartz, sericite and carbonate. Phyllic alteration is commonly pervasive and may be extensive. Propylitic alteration consisting mainly of chlorite and epidote may extend for hundreds of metres beyond the zones of potassic-silicic and phyllic alteration. Zones of argillic alteration, where present, are characterized by clay minerals such as kaolinite and are typically overprinted on the other types of alteration; distribution of argillic alteration is typically irregular.

WEATHERING: Oxidation of pyrite produces limonitic gossans; oxidation of molybdenite produces yellow ferrimolybdite.

ORE CONTROLS: Quartz veinlet and fracture stockwork zones superimposed on intermediate to felsic intrusive rocks and surrounding country rocks; multiple stages of mineralization commonly present.

GENETIC MODEL: Magmatic-hydrothermal. Large volumes of magmatic, highly saline aqueous fluids under pressure strip Mo and other ore metals from temporally and genetically related magma. Multiple stages of brecciation related to explosive fluid pressure release from the upper parts of small intrusions result in deposition of ore and gangue minerals in crosscutting fractures, veinlets and breccias in the outer carapace of the intrusions and in associated country rocks. Incursion of meteoric water during waning stages of the magmatic-hydrothermal system may result in late alteration of the hostrocks, but does not play a significant role in the ore-forming process.

ASSOCIATED DEPOSIT TYPES: Ag-Pb-Zn veins (I05), Mo-bearing skarns (K07) may be present.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Mo, Cu, W and F may be anomalously high in hostrocks close to and overlying mineralized zones; anomalously high levels of Pb, Zn and Ag occur in peripheral zones as much as several kilometres distant. Mo, W, F, Cu, Pb, Zn and Ag may be anomalously high in stream sediments. Mo, W and Pb may be present in heavy mineral concentrates.

GEOPHYSICAL SIGNATURE: Magnetic anomalies may reflect presence of pyrrhotite or magnetite in hornfels zones. Radiometric surveys may be used to outline anomalous K in altered and mineralized zones. Induced polarization and resistivity surveys may be used to outline high-pyrite alteration zones.

OTHER EXPLORATION GUIDES: Limonitic alteration of pyrite can result in widespread gossan zones. Yellow ferrimolybdite may be present in oxidized zones. Ag-Pb-Zn veins may be present in peripheral zones.

PORPHYRY Mo (LOW-F-TYPE) L05

ECONOMIC FACTORS

GRADE AND TONNAGE: Typical size is 100 Mt at 0.1 to 0.2 % Mo. The following figures are for production plus reserves.

Endako (B.C.): 336 Mt at 0.087 % Mo; Boss Mountain (B.C.): 63 Mt. at 0.074 % Mo;
Kitsault (B.C.): 108 Mt at 0.115 % Mo; Lucky Ship (B.C.): 14 Mt at 0.090 % Mo;
Adanac (B.C.): 94 Mt at 0.094 % Mo; Carmi (B.C.): 34 Mt at 0.091 % Mo;
Mount Haskin (B.C.): 12 Mt at 0.090 % Mo; Bell Moly (B.C.): 32 Mt at 0.066 % Mo;
Red Bird (B.C.): 34 Mt at 0.108 % Mo; Storie Moly (B.C.): 101 Mt at 0.078 % Mo;
Trout Lake (B.C.): 50 Mt at 0.138 % Mo; Glacier Gulch (B.C.): 125 Mt at 0.151 % Mo;
Red Mountain (Yukon): 187 Mt at 0.100 % Mo; Quartz Hill (Alaska): 793 Mt at 0.091 % Mo;
Thompson Creek (Idaho): 181 Mt at 0.110 % Mo; Compaccha (Peru): 100 Mt at 0.072 % Mo;
East Kounrad (Russia): 30 Mt at 0.150 % Mo.

IMPORTANCE: Porphyry Mo deposits associated with low-F felsic intrusive rocks have been an important source of world molybdenum production. Virtually all of Canada's Mo production comes from these deposits and from porphyry Cu-Mo deposits.

REFERENCES

Boyle, H.C. and Leitch, C.H.B., (1983): Geology of the Trout Lake Molybdenum Deposit, B.C.; *Canadian Institute of Mining and Metallurgy*, Bulletin, Volume 76, No. 849, pages 115-124.

Brown, P. and Kahlert, B., (1986): Geology and Mineralization of the Red Mountain Porphyry Molybdenum Deposit, South-central Yukon; *in* Mineral Deposits of Northern Cordillera, Morin, J.A., Editor, *Canadian Institute of Mining and Metallurgy*, Special Volume 37, pages 288-297.

Carten, R.B., White, W.H. and Stein, H.J., (in press): High-grade Granite-related Mo Systems; Classification and Origin; *in* Mineral Deposit Modeling, Kirkham, R.V., Sinclair, W.D., Thorpe, R.I. and Duke, J.M., Editors, *Geological Association of Canada*, Special Paper 40, pages 521-554.

Kirkham, R.V. and Sinclair, W.D., (1984), Porphyry Copper, Molybdenum, Tungsten; *in* Canadian Mineral Deposit Types; A Geological Synopsis; *Geological Survey of Canada*, Economic Geology Report 36, pages 51-52.

Kirkham, R.V., McCann, C., Prasad, N., Soregaroli, A.E. Vokes, F.M. and Wine, G., (1982): Molybdenum in Canada, Part 2: MOLYFILE -- An index-level computer file of molybdenum deposits and occurrences in Canada; *Geological Survey of Canada*, Economic Geology Report 33, pages 208.

Mutschler, F.E., Wright, E.G., Ludington, S. and Abbott, J., (1981): Granite Molybdenite Systems; *Economic Geology*, v. 76, pages 874-897.

Pilcher, S.H. and McDougall, J.J., (1976): Characteristics of some Canadian Cordilleran Porphyry Prospects, *in* Porphyry Deposits of the Canadian Cordillera, Sutherland Brown, A. , Editor, *Canadian Institute of Mining and Metallurgy*, Special Volume 15, pages 79-82.

Sutulov, A., (1978): International Molybdenum Encyclopaedia 1778-1978, Volume 1, *Intermet Publications*, Santiago, Chile, page 402.

Theodore, T.G., (1986): Descriptive Model of Porphyry Mo, Low-F; *in* Mineral Deposit Models, Cox, D.P. and Singer, D.A., Editors, *U.S. Geological Survey*, Bulletin 1693, page 120.

Theodore, T.G. and Menzie, W.D., (984), Fluorine-deficient Porphyry Molybdenum Deposits in the Western North American Cordillera; Proceedings of the Six Quadrennial IAGOD Symposium, *E. Schweitzerbart'sche Verlagsbuchhandlung (Nägele u. Obermiller)*, Stuttgart, Germany, pages 463-470.

Westra, G. and Keith S.B., (1981), Classification and Genesis of Stockwork Molybdenum Deposits; *Economic Geology*, Volume 76, pages 844-873.

Woodcock, J.R. and Carter, N.C., (1976): Geology and Geochemistry of the Alice Arm Molybdenum Deposits; *in* Porphyry Deposits of the Canadian Cordillera, Sutherland Brown, A., Editor, *Canadian Institute of Mining and Metallurgy*, Special Volume 15, pages 462-475.

PORPHYRY Sn[3] L06

by W. David Sinclair[4]

IDENTIFICATION

SYNONYM: Subvolcanic Sn

COMMODITIES (*BYPRODUCTS*): Sn (*Ag, W*)

EXAMPLES (British Columbia - *Canada/International*): *Mount Pleasant (New Brunswick, Canada), East Kemptville (Nova Scotia, Canada), Catavi, Chorolque and Cerro Rico stock (Bolivia), Ardlethan and Taronga (Australia), Kingan (Russia), Yinyan (China), Altenberg (Germany).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Fine-grained cassiterite in veinlet and fracture stockwork zones, breccia zones, and disseminated in porphyritic felsic intrusive rocks and associated country rocks.

TECTONIC SETTING: Zones of weak to moderate extension in cratons, particularly post orogenic zones underlain by thick crust, possibly cut by shallow-dipping subduction zones.

GEOLOGICAL SETTING: High-level to subvolcanic felsic intrusive centres in cratons; multiple stages of intrusion may be present.

AGE OF MINERALIZATION: Paleozoic to Tertiary.

HOST/ASSOCIATED ROCK TYPES: Predominantly genetically related intrusive rocks and associated breccias, but may also include related or unrelated sedimentary, volcanic, igneous and metamorphic rocks. Genetically related felsic intrusive rocks are F and/or B enriched and are commonly porphyritic. Tuffs or other extrusive volcanic rocks may be associated with deposits related to subvolcanic intrusions.

DEPOSIT FORM: Deposits vary in shape from inverted cone, to roughly cylindrical, to highly irregular. They are typically large, generally hundreds of metres across and ranging from tens to hundreds of metres in vertical extent.

TEXTURE/STRUCTURE: Ore is predominantly structurally controlled in stockworks of crosscutting fractures and quartz veinlets, or disseminated in hydrothermal breccia zones. Veins, vein sets, replacement zones may also be present.

ORE MINERALOGY (Principal and subordinate): Cassiterite; *stannite, chalcopyrite, sphalerite and galena. Complex tin- and silver-bearing sulphosalts occur in late veins and replacement zones.*

GANGUE MINERALOGY: Pyrite, arsenopyrite, löllingite, topaz, fluorite, tourmaline, muscovite, zinnwaldite and lepidolite.

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[3] Geological Survey of Canada contribution number 61594
[4] Geological Survey of Canada, Ottawa

PORPHYRY Sn L06

ALTERATION MINERALOGY: In the Bolivian porphyry Sn deposits, sericite + pyrite ± tourmaline alteration is pervasive; in some deposits it surrounds a central zone of quartz + tourmaline. Sericitic alteration is typically bordered by weak propylitic alteration. In other deposits (e.g., Ardlethan, Yinyan), central zones are characterized by greisen alteration consisting of quartz + topaz + sericite; these zones grade outward to quartz + sericite + chlorite alteration.

WEATHERING: Oxidation of pyrite produces limonitic gossans. Deep weathering and erosion can result in residual concentrations of cassiterite in situ or in placer deposits downslope or downstream.

ORE CONTROLS: Ore minerals occur in fracture stockworks, hydrothermal breccias and replacement zones centred on 1-2 km^2, genetically related felsic intrusions.

GENETIC MODEL: Magmatic-hydrothermal. Large volumes of magmatic, highly saline aqueous fluids under pressure strip Sn and other ore metals from temporally and genetically related magma. Multiple stages of brecciation related to explosive fluid pressure release from the upper parts of small intrusions result in deposition of ore and gangue minerals in crosscutting fractures, veinlets and breccias in the outer carapace of the intrusions and associated country rocks. Mixing of magmatic with meteoric water during waning stages of the magmatic-hydrothermal system may result in deposition of some Sn and other metals, particularly in late-stage veins.

ASSOCIATED DEPOSIT TYPES: Sn veins (I13), Sn-polymetallic veins (H07).

COMMENTS: Some of the deposits listed (e.g., Taronga, East Kemptville) are not "subvolcanic" but they are similar to some porphyry Cu deposits with regard to their large size, low grade, relationship to felsic intrusive rocks and dominant structural control (ie., mineralized veins, fractures and breccias).

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Sn, Ag, W, Cu, Zn, As, Pb, Rb, Li, F, B may be anomalously high in hostrocks close to mineralized zones and in secondary dispersion halos in overburden. Anomalously high contents of Sn, W, F, Cu, Pb and Zn may occur in stream sediments and Sn, W, F (topaz) and B (tourmaline) may be present in heavy mineral concentrates.

GEOPHYSICAL SIGNATURE: Genetically related intrusions may be magnetic lows (ilmenite- rather than magnetite-dominant); contact aureole may be magnetic high if pyrrhotite or magnetite are present in associated skarn or hornfels zones. Radiometric surveys may be used to outline anomalous U, Th or K in genetically related intrusive rocks or in associated altered and mineralized zones.

OTHER EXPLORATION GUIDES: Sn (-Ag) deposits may be zoned relative to base metals at both regional (district) and local (deposit) scales.

PORPHYRY Sn L06

ECONOMIC FACTORS

GRADE AND TONNAGE: Tens of millions of tonnes at grades of 0.2 to 0.5% Sn.
Mount Pleasant (New Brunswick): 5.1 Mt @ 0.79% Sn; East Kemptville (Nova Scotia): 56 Mt @ 0.165% Sn; Catavi (Bolivia): 80 Mt @ 0.3% Sn; Cerro Rico stock, Bolivia: averages 0.3% Sn; Ardlethan (Australia): 9 Mt @ 0.5% Sn; Taronga (Australia): 46.8 Mt @ 0.145% Sn; Altenberg, (Germany): 60 Mt @ 0.3% Sn; Yinyan (China): "large" (50 - 100 Mt?) @ 0.46% Sn

ECONOMIC LIMITATIONS: Low grades require high volumes of production which may not be justified by demand.

IMPORTANCE: A minor source of tin on a world scale; when it was in production, East Kemptville was the major producer of tin in North America.

REFERENCES

Grant, J.N., Halls, C., Avila, W. and Avila, G., (1977): Igneous Systems and Evolution of Hydrothermal Systems in some Sub-volcanic Tin Deposits of Bolivia; *in* Volcanic Process in Orogenesis; *Geological Society of London*, Special Paper Publication 7, pages 117-126.

Grant, J.N., Halls, C., Sheppard, S.M.F. and Avila, W., (1980): Evolution of the Porphyry Tin Deposits of Bolivia; *in* Granitic Magmatism and Related Mineralization, Ishihara, S. and Takenouchi, S., Editors; *The Society of Mining Geologists of Japan*, Mining Geology Special Issue, No. 8, pages 151-173.

Guan, X., Shou, Y., Xiao, J., Liang, S. and Li, J., (1988): A New Type of Tin Deposit - Yinyan Porphyry Tin Deposit; *in* Geology of Tin Deposits in Asia and the Pacific, Hutchison, C.S., Editor, *Springer-Verlag*, Berlin, pages 487-494.

Lin, G., (1988): Geological Characteristics of the Ignimbrite-related Xiling Tin Deposit in Guangdong Province; *in* Geology of Tin Deposits in Asia and the Pacific, Hutchison, C.S., Editor, *Springer-Verlag*, Berlin, pages 494-506.

Reed, B.L., (1986): Descriptive Model of Porphyry Sn; *in* Mineral Deposit Models, Cox, D.P. and Singer, D.A. Editors; *U.S. Geological Survey*, Bulletin 1693, pages 108.

Sillitoe, R.H., Halls, C. and Grant, J.N., (1975): Porphyry Tin Deposits in Bolivia; *Economic Geology*, Volume 70, pages 913-927.

Taylor, R.G. and Pollard, P.J., (1986): Recent Advances in Exploration Modelling for Tin Deposits and their application to the Southeastern Asian Environment; GEOSEA V Proceedings, Volume 1, *Geological Society of Malaysia*, Bulletin 19, pages 327-347.

PORPHYRY W[5] L07

by W. David Sinclair[6]

IDENTIFICATION

SYNONYM: Stockwork W-Mo

COMMODITIES (*BYPRODUCTS*): W (*Mo, Sn, Ag*).

EXAMPLES (British Columbia - *Canada/International*): Boya; *Mount Pleasant (New Brunswick, Canada), Logtung (Yukon, Canada), Xingluokeng, Lianhuashan and Yanchuling (China).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Stockwork of W-bearing quartz veinlets and fractures in felsic intrusive rocks and associated country rocks. Deposits are low grade but large and amenable to bulk mining methods.

TECTONIC SETTING: Zones of weak to moderate extension in cratons, particularly post-collisional zones in areas of tectonically thickened crust.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: High-level to subvolcanic felsic intrusive centres; multiple stages of intrusion are common.

AGE OF MINERALIZATION: Paleozoic to Tertiary, but Mesozoic and Tertiary examples are more common.

HOST/ASSOCIATED ROCK TYPES: Highly variable; mineralized rocks may be predominantly genetically related intrusive rocks, but may also be related or unrelated sedimentary, volcanic, igneous and metamorphic rocks. Genetically related felsic intrusive rocks are commonly F-rich (fluorite and/or topaz bearing) and porphyritic; unidirectional solidification features, particularly comb quartz layers, may also be present. Tuffs or other extrusive volcanic rocks may be associated with deposits related to subvolcanic intrusions.

DEPOSIT FORM: Deposits vary in shape from inverted cup-shaped, to roughly cylindrical, to highly irregular. They are typically large, generally hundreds of metres across and ranging from tens to hundreds of metres in vertical extent.

TEXTURE/STRUCTURE: Ore minerals is structurally controlled; mainly stockworks of crosscutting fractures and quartz veinlets, also veins, vein sets, breccias, disseminations and replacements.

ORE MINERALOGY (Principal and *subordinate*): Main ore mineral is generally either scheelite or wolframite, although in some deposits both are present. *Subordinate ore minerals include molybdenite, bismuth, bismuthinite and cassiterite.*

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[5] Geological Survey of Canada contribution number 61694
[6] Geological Survey of Canada, Ottawa

PORPHYRY W L07

GANGUE MINERALOGY: Pyrite, pyrrhotite, magnetite, arsenopyrite, löllingite, quartz, K-feldspar, biotite, muscovite, fluorite, topaz.

ALTERATION MINERALOGY: Hydrothermal alteration is pervasive to fracture controlled and, at deposit scale, is concentrically zoned. It is commonly characterized by the presence of greisen alteration minerals, including topaz, fluorite and Li- and F-rich micas. At Mount Pleasant, for example, pervasive greisen alteration consisting of quartz + topaz ± sericite ± chlorite associated with high-grade W zones and grades laterally into fracture-controlled quartz-biotite-chlorite-topaz alteration associated with lower grade W zones. Propylitic alteration, mainly chlorite and sericite, extends as far as 1500 m beyond the mineralized zones. Potassic alteration, dominated by K-feldspar, occurs locally within the central areas of pervasive greisen alteration. Other deposits such as Xingluokeng (China) are characterized more by central zones of silicic and potassic alteration (K-feldspar and biotite); zones of weak greisen alteration consisting of muscovite and fluorite may be present. Sericitic alteration forms a broad aureole around the central potassic zone; irregular zones of argillic alteration may be superimposed on both the potassic and sericitic zones. In detail, alteration patterns may be complex; at Logtung, for example, different stages of mineralized veins and fractures are characterized by different assemblages of ore and alteration minerals.

WEATHERING: Oxidation of pyrite produces limonitic gossans; oxidation of molybdenite, if present, may produce yellow ferrimolybdenite.

ORE CONTROLS: Quartz veinlet and fracture stockwork zones surround or are draped over and are superimposed to varying degrees on small stocks (<1 km^2); multiple stages of mineralization commonly present; felsic intrusions associated with the deposits are typically F-rich.

GENETIC MODEL: Magmatic-hydrothermal. Large volumes of magmatic, highly saline aqueous fluids under pressure strip W, Mo and other ore metals from temporally and genetically related magma. Multiple stages of brecciation related to explosive fluid pressure release from the upper parts of small intrusions result in deposition of ore and gangue minerals in crosscutting fractures, veinlets and breccias in the outer carapace of the intrusions and associated country rocks. Incursion of meteoric water during waning stages of the magmatic-hydrothermal system may result in late alteration of the hostrocks, but does not play a significant role in the ore forming process.

ASSOCIATED DEPOSIT TYPES: Porphyry W deposits may be part of a spectrum of deposits that include Climax-type Mo deposits (L08) as one end-member and porphyry Sn deposits as the other (L06). Vein/replacement W, Sn, Ag deposits may be associated (I05, H07), e.g. Logjam Ag-Pb-Zn veins peripheral to the Logtung W-Mo deposit. Skarn (contact metamorphic) zones associated with genetically related felsic intrusions may be mineralized, but are not typical skarn W (i.e. contact metasomatic) deposits.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: W, Mo and Sn are anomalous in hostrocks close to mineralized zones; anomalously high contents of F, Zn, Pb and Cu occur in wallrocks up to several kilometres from mineralized zones. W, Sn, Mo, F, Cu, Pb and Zn may be anomalously high in stream sediments and W, Sn and F (topaz) may be present in heavy mineral concentrates.

PORPHYRY W L07

GEOPHYSICAL SIGNATURE: Genetically related intrusions may be magnetic lows (ilmenite rather than magnetite dominant); contact aureole may be magnetic high if pyrrhotite or magnetite are present in associated skarn or hornfels zones. Radiometric surveys may be used to outline anomalous U, Th or K in genetically related intrusive rocks or in associated altered and mineralized zones.

OTHER EXPLORATION GUIDES: The presence of scheelite can be detected with an ultraviolet lamp.

ECONOMIC FACTORS

GRADE AND TONNAGE: Tens to more than 100 Mt at grades of 0.2 to 0.3 % W (Lianhushan is exceptional at 0.8 % W). Boya (British Columbia): limited size due to thrust fault truncation, no published resource data. Mount Pleasant (New Brunswick): Fire Tower zone: 22.5 Mt @ 0.21 % W, 0.10 % Mo, 0.08 % Bi, (includes 9.4 Mt @ 0.31 % W, and 0.12 % Mo), North zone: 11 Mt @ 0.2 % W, 0.1 % Mo. Logtung (Yukon): 162 Mt @ 0.10 % W, 0.03 % Mo. Xingluokeng (China): 78 Mt @ 0.18 % W. Lianhuashan (China): ~40 Mt @ 0.8 % W.

ECONOMIC LIMITATIONS: Low grades require high production volumes which may not be justified by current demand for tungsten.

IMPORTANCE: Not currently an important source of world W production; some W may be recovered from deposits in China (e.g. Lianhuashan), but none is recovered at present (1994) from deposits outside China. Mount Pleasant Tungsten in New Brunswick produced slightly more than 2000 t of concentrate grading 70 % WO_3 from 1 Mt of ore mined from 1983 to 1985.

REFERENCES

Kirkham, R.V. and Sinclair, W.D. (1984): Porphyry Copper, Molybdenum, Tungsten; *in* Canadian Mineral Deposit Types: A Geological Synopsis; *Geological Survey of Canada*, Economic Geology Report 36, pages 51-52.

Kirkham, R.V. and Sinclair, W.D. (1988): Comb Quartz Layers in Felsic Intrusions and their Relationship to Porphyry Deposits; *in* Recent Advances in the Geology of Granite-related Mineral Deposits, *Canadian Institute of Mining and Metallurgy*, Special Volume 39, pages 50-71.

Kooiman, G.J.A., McLeod, M.J. and Sinclair, W.D. (1986): Porphyry Tungsten-Molybdenum Orebodies, Polymetallic Veins and Replacement Bodies, and Tin-bearing Greisen Zones in the Fire Tower Zone, Mount Pleasent, New Brunswick; *Economic Geology*, Volume 81, pages 1356-1373.

Liu, W. (1980): Geological Features of Mineralization of the Xingluokeng Tungsten (Molybdenum) Deposit, Fujian Province; *in* Tungsten Geology, China, Hepworth, J.V. and Lu, H.Z., Editors, *ESCAP/RMRDC*, Bandung, Indonesia, pages 338-348.

Noble, S.R., Spooner, E.T.C. and Harris, F.R. (1986): Logtung: A Porphyry W-Mo Deposit in the Southern Yukon; *in* Mineral Deposits of Northern Cordillera, Morin, J.A., Editor, *Canadian Institute of Mining and Metallurgy*, Special Volume 37, pages 274-287.

Sinclair, W.D. (1986): Molybdenum, Tungsten and Tin Deposits and associated Granitoid Intrusions in the Northern Canadian Cordillera and adjacent parts of Alaska; *in* Mineral Deposits of Northern Cordillera, Morin, J.A., Editor, Canadian Institute of Mining and Metallurgy, Special Volume 37, pages 216-233.

PORPHYRY W L07

Yan, M-Z., Wu, Y-L. and Li, C.-Y. (1980): Metallogenetic Systems of Tungsten in Southeast China and their Mineralization Characteristics; *in* Granitic Magmatism and Related Mineralization, Ishihara, S. and Takenouchi, S., Editors, *The Society of Mining Geologists of Japan*, Mining Geology Special Issue, No. 8, pages 215-221.

PORPHYRY Mo (Climax-type)[7] L08

by W. David Sinclair[8]

IDENTIFICATION

SYNONYMS: Granite molybdenite; Climax Mo; granite-related Mo.

COMMODITIES (*BYPRODUCTS*): Mo (*W, Sn; pyrite and monazite have also been recovered from the Climax deposit*)

EXAMPLES (British Columbia - *Canada/International*): No unequivocal Climax-type porphyry Mo deposits occur in British Columbia or *other parts of Canada*; *Climax, Henderson, Mount Emmons and Silver Creek (Colorado, USA), Pine Grove (Utah, USA), Questa (New Mexico), Malmbjerg (Greenland), Nordli (Norway).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Stockworks of molybdenite-bearing quartz veinlets and fractures in highly evolved felsic intrusive rocks and associated country rocks. Deposits are low grade but large and amenable to bulk mining methods.

TECTONIC SETTING: Rift zones in areas of thick cratonic crust.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: High-level to subvolcanic felsic intrusive centres; multiple stages of intrusion are common.

AGE OF MINERALIZATION: Paleozoic to Tertiary, but mainly Tertiary.

HOST/ASSOCIATED ROCK TYPES: Genetically related felsic intrusive rocks are high-silica (>75% SiO_2), F-rich (>0.1% F) granite/rhyolite; they are commonly porphyritic and contain unidirectional solidification textures (USTs), particularly comb quartz layers. Contents of Rb, Y and Nb are high; Ba, Sr and Zr are low. Mineralized country rocks may include sedimentary, metamorphic, volcanic, and older intrusive rocks. Tuffs or other extrusive volcanic rocks may be associated with deposits related to subvolcanic intrusions.

DEPOSIT FORM: Deposits typically form an inverted cup or hemispherical shell; shapes may be modified by regional or local structures. They are typically large, generally hundreds of metres across and ranging from tens to hundreds of metres in vertical extent.

TEXTURE/STRUCTURE: Ore is structurally controlled; mainly stockworks of crosscutting fractures and quartz veinlets, also veins, vein sets and breccias; disseminations and replacements are less common.

ORE MINERALOGY (Principal and *subordinate)*: Molybdenite; *wolframite, cassiterite, sphalerite, galena, monazite.*

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[7] Geological Survey of Canada contribution number 61794
[8] Geological Survey of Canada, Ottawa

PORPHYRY Mo (Climax-type) L08

GANGUE MINERALOGY: Quartz, pyrite, topaz, fluorite and rhodochrosite.

ALTERATION MINERALOGY: Potassic alteration (K-feldspar ± biotite) is directly associated with high-grade Mo (>0.2% Mo); pervasive silicic alteration (quartz ± magnetite) may occur locally in the lower parts of high-grade Mo zones. Quartz-sericite-pyrite alteration may extend hundreds of metres vertically above orebodies; argillic alteration may extend hundreds of metres beyond quartz-sericite-pyrite alteration, both vertically and laterally. Spessartine garnet occurs locally within quartz-sericite-pyrite and argillic alteration zones. Greisen alteration consisting of quartz-muscovite-topaz occurs as alteration envelopes around quartz-molybdenite veins below high-grade Mo zones. Propylitic alteration is widespread and may extend for several km.

WEATHERING: Oxidation of pyrite produces limonitic gossans; oxidation of molybdenite produces yellow ferrimolybdite.

ORE CONTROLS: Quartz veinlet and fracture stockwork zones surround or are draped over, and are superimposed to varying degrees on small, genetically related stocks (area <1 km^2); multiple stages of mineralization are commonly present; abundant comb quartz layers and other USTs characterize productive intrusions.

GENETIC MODEL: Magmatic-hydrothermal. Large volumes of magmatic, highly saline aqueous fluids under pressure strip Mo and other ore metals from temporally and genetically related magma. Multiple stages of brecciation related to explosive fluid pressure release from the upper parts of small intrusions result in deposition of ore and gangue minerals in crosscutting fractures, veinlets and breccias in the outer carapace of the intrusions and associated country rocks. Incursion of meteoric water during waning stages of the magmatic-hydrothermal system may result in late alteration of the hostrocks, but does not play a significant role in the ore-forming process.

ASSOCIATED DEPOSIT TYPES: Ag-base metal veins (I05), fluorspar deposits. Some porphyry W-Mo deposits (e.g. Mount Pleasant) may be W-rich Climax-type deposits. Mo may also be present in adjacent skarn deposits (K07). Climax-type porphyry Mo deposits may be related to rhyolite-hosted Sn deposits (H07, USGS model 25h).

COMMENTS: This model is based mainly on descriptions of Climax and Climax-type deposits in Colorado. These deposits tend to have more complex igneous-hydrothermal systems and higher average Mo grades than low-F-type porphyry Mo deposits.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Mo, Sn, W, Rb, Mn and F may be anomalously high in hostrocks close to and overlying mineralized zones; Pb, Zn, F and U may be anomalous in wallrocks as much as several kilometres distant. Mo, Sn, W, F, Cu, Pb, Zn may be anomalous in stream sediments and Mo, Sn, W, and F (topaz) may be present in heavy mineral concentrates.

GEOPHYSICAL SIGNATURE: Genetically related intrusions may be magnetic lows (ilmenite rather than magnetite dominant). Radiometric surveys may be used to outline anomalous U, Th or K in genetically related intrusive rocks or in associated altered and mineralized zones.

PORPHYRY Mo (Climax-type) L08

OTHER EXPLORATION GUIDES: Deposits occur in extensional tectonic settings in areas of thick continental crust. Genetically related felsic intrusive rocks generally have high contents of Nb (>75 ppm). Ag-Pb-Zn veins, topaz, fluorite and Mn-garnet may be present in peripheral zones. Yellow ferrimolybdite may be present in oxidized zones.

ECONOMIC FACTORS

GRADE AND TONNAGE: Deposits typically contain hundreds of millions of tonnes at 0.1 to 0.3 % Mo. Following figures are production plus reserves (from Carten et al., 1993): Climax, Colorado: 769 Mt @ 0.216% Mo (mineable), Henderson, Colorado: 727 Mt @ 0.171% Mo (geological), Mount Emmons, Colorado: 141 Mt @ 0.264% Mo (mineable), Silver Creek, Colorado: 40 Mt @ 0.310% Mo (geological), Pine Grove, Utah: 125 Mt @ 0.170% Mo (geological), Questa, New Mexico: 277 Mt @ 0.144% Mo (mineable), Malmbjerg, Greenland: 136 Mt @ 0.138% Mo (geological), Nordli, Norway: 181 Mt @ 0.084% Mo (geological)

ECONOMIC LIMITATIONS: Economic viability of these deposits is affected by Mo production from other types of deposits such as porphyry Cu-Mo deposits, which produce Mo as a coproduct or byproduct.

IMPORTANCE: Porphyry Mo deposits of the Climax type have been a major source of world Mo production and contain substantial reserves.

REFERENCES

Carten, R.B., White, W.H. and Stein, H.J. (1993): High-grade Granite-related Mo Systems: Classification and Origin: *in* Mineral Deposit Modeling, Kirkham, R.V., Sinclair, W.D., Thorpe, R.I. and Dute, J.M. Editors,: *Geological Association of Canada*, Special Paper 40, pages 521-554.

Kirkham, R.V. and Sinclair, W.D. (1984): Porphyry Copper, Molybdenum, Tungsten; *in* Canadian Mineral Deposit Types: A Geological Synopsis; *Geological Survey of Canada,* Economic Geology Report 36, pages 51-52.

Kirkham, R.V. and Sinclair, W.D. (1988): Comb Quartz Layers in Felsic Intrusions and their Relationship to Porphyry Deposits; *in* Recent Advances in the Geology of Granite-related Mineral Deposits, *Canadian Institute of Mining and Metallurgy,* Special Volume 39, pages 50-71.

Keith, J.D. and Christiansen, E.H. (1992): The Genesis of Giant Molybdenum Deposits; *in* Giant Ore Deposits, Whiting, B.H., Masong, R. and Hodgson, C.J., Editors, Proceedings of the Giant Deposits Workshop, *Queen's University*, Kingston, 11-13 May, 1992.

Ludington, S.D. (1986): Descriptive Model of Climax Mo Deposits; *in* Mineral Deposit Models, Cox, D.P. and Singer, D.A., Editors, *U.S. Geological Survey*, Bulletin 1693, page 73.

Mutschler, F.E., Wright, E.G., Ludington, S. and Abbot, J. (1981): Granite Molybdenite Systems; *Geology*, Volume 13, pages 469-474.

Wallace, S.R., Muncaster, N.K., Jonson, D.D., MacKenzie, W.B., Bookstrom, A.A. and Surface, V.E. (1968): Multiple Intrusion and Mineralization at Climax, Colorado; *in* Ore Deposits of the United States, 1933-1967 (The Graton-Sales Volume), Ridge, J.D., Editor, *American Institute of Mining, Metallurgy and Petroleum Engineers*, New York, pages 605-640.

Westra, G. and Keith, S.B. (1981): Classification and Genesis of Stockwork Molybdenum Deposits; *Economic Geology*, Volume 76, pages 844-873.

PORPHYRY Mo (Climax-type) L08

White, W.H., Bookstrom, A.A., Kamilli, R.J., Ganster, M.W., Smith, R.P., Ranta, D.E. and Steininger, R.C. (1981): Character and Origin of Climax-type Molybdenum Deposits; *Economic Geology*, 75th Anniversary Volume, pages 270-316.

APPENDIX I

GUIDELINES FOR AUTHORS

FOR MINERAL DEPOSIT PROFILES

MINERAL DEPOSIT
B.C.
PROFILES

INTRODUCTION

The objective of the British Columbia mineral deposit profiles is to define and characterize coal and mineral deposits which exist, or could exist within the province. These descriptions are one of the tools to be used in determining the mineral potential of British Columbia using a modified United States Geological Survey (USGS) three step method (Kilby, 1995). Specifically, the deposit profiles will be used to classify existing deposits and occurrences, to identify possible undiscovered mineral deposits in tracts of land and to separate deposits into groups to allow compilation of representative grade and tonnage data. They are also valuable reference documents for geologists and prospectors exploring for new mineral deposits in the Cordillera.

INSTRUCTIONS TO AUTHORS

In addition to these notes, authors should refer to the six page introduction to USGS Bulletin 1693 (Cox and Singer, 1986) and review several of their deposit descriptions. Another useful reference is Economic Geology Report 36 of the Geological Survey of Canada (Eckstrand, 1984) on "Canadian Mineral Deposit Types: A Geological Synopsis".

In keeping with the original USGS descriptions, the deposit profiles provide a concise overview for a deposit type that is as up-to-date as posible. The models should be based on information from all relevant deposits from around the world with special emphasis on those from British Columbia. **The profile should be sufficient to describe the deposit anywhere in the world**, however, we will be adding more information specific to British Columbia under the following headings - examples, tectonic setting, age of mineralization, comments, typical grade and tonnage, economic limitations, importance and references.

The deposit profiles are organized with a standard format (see Tables 1 and 2). This will assist the reader in finding the relevant information. Please note that some headings are optional or may need to be modified to fit the deposit type. Delete any headings not used. The text for the profiles should be written using complete sentences where appropriate. Avoid using abbreviations, such as I.P. and B.C. In commodity lists and model names, use the element abbreviation (Cu, Au) rather than the complete word. For deposit types which produce minerals use the word (barite, gypsum) rather than the molecular formula.

Table 1. Deposit Profile Outline

NAME

IDENTIFICATION

SYNONYMS:
COMMODITIES (*BYPRODUCTS*):
EXAMPLES (British Columbia - *Canada/international*):

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION:
TECTONIC SETTING:
DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING:
AGE OF MINERALIZATION:
HOST/ASSOCIATED ROCK TYPES:
DEPOSIT FORM:
TEXTURE/STRUCTURE:
ORE MINERALOGY (Principal and *subordinate*)
GANGUE MINERALOGY (Principal and *subordinate*):
ALTERATION MINERALOGY:
WEATHERING:
ORE CONTROLS:
GENETIC MODEL:
ASSOCIATED DEPOSIT TYPES:
COMMENTS:

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE:
GEOPHYSICAL SIGNATURE:
OTHER EXPLORATION GUIDES:

ECONOMIC FACTORS

GRADE AND TONNAGE:
ECONOMIC LIMITATIONS:
END USES:
IMPORTANCE:

REFERENCES

ACKNOWLEDGMENTS:

FIGURES

CROSS-SECTION AND/OR PLAN (not included in Open File volumes)

Table 4. Example Deposit Profile

SHALE-HOSTED Ni-Zn-Mo-PGE E16

by D.V. Lefebure and R.M. Coveney, Jr.[1]

IDENTIFICATION

SYNONYMS: Sediment-hosted Ni-Mo-PGE, Stratiform Ni-Zn-PGE.

COMMODITIES (*BYPRODUCTS*): Ni, Mo, (*Zn, Pt, Pd, Au*).

EXAMPLES (British Columbia - *Canada/International*): *Nick (Yukon, Canada)*; *mining camps of Tianeshan, Xintuguo, Tuansabao and Jinzhuwoin and Zunyi Mo deposits, Dayong-Cili District (China).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Thin layers of pyrite, vaesite (NiS_2), jordisite (amorphous MoS_2) and sphalerite in black shale sub-basins with associated phosphatic chert and carbonate rocks.

TECTONIC SETTING(S): Continental platform sedimentary sequences and possibly successor basins. All known deposits associated with orogenic belts, however, strongly anomalous shales overlying the North American craton may point to as yet undiscovered deposits over the stable craton.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: Anoxic basins within clastic sedimentary (flysch) sequences containing black shales.

AGE OF MINERALIZATION: Post Archean. Known deposits are Early Cambrian and Devonian, however, there is potential for deposits of other ages.

HOST/ASSOCIATED ROCK TYPES: Black shale is the host; associated limestones, dolomitic limestones, calcareous shale, cherts, siliceous shale, siliceous dolomite, muddy siltstone and tuffs. Commonly associated with phosphate horizons. In the Yukon at base of a 10 to 20 m thick phosphatic shale bed and in China the Ni-Mo beds are in black shales associated with phosphorite.

DEPOSIT FORM: Thin beds (0 to 15 cm thick, locally up to 30 cm) covering areas up to at least 100 ha and found as clusters and zones extending for tens of kilometres.

TEXTURE/STRUCTURE: Semimassive to massive sulphides as nodules, spheroids, framboids and streaks or segregations in a fine-grained matrix of sulphides, organic matter and nodular phosphorite or phosphatic carbonaceous chert. Mineralization can be rhythmically laminated; often has thin discontinuous laminae. Brecciated clasts and spheroids of pyrite, organic matter and phosphorite. In China nodular textures (~ 1 mm diameter) grade to coatings of sulphides on tiny 1-10 μm spherules of organic matter. Fragments and local folding reflect soft sediment deformation. Abundant plant fossils in Nick mineralization and abundant fossils of microorganisms (cyanobacteria) in the Chinese ores.

[1] University of Missouri - Kansas City, Kansas City, Missouri, 64110-2499, U.S.A.

Table 4. Example Deposit Profile (cont.)

SHALE-HOSTED Ni-Zn-Mo-PGE E16

ORE MINERALOGY [Principal and *subordinate*]: Pyrite, vaesite (NiS_2), amorphous molybdenum minerals (jordisite, MoS_2), bravoite, *sphalerite, wurtzite, polydimite, gersdorffite, violarite, millerite, sulvanite, pentlandite, tennanite and as traces native gold, uranitite, tiemannite, arsenopyrite, chalcopyrite and covellite*. Discrete platinum group minerals may be unusual. Some ore samples are surprisingly light because of abundant organic matter and large amount of pores.

GANGUE MINERALOGY [Principal and *subordinate]* Chert, amorphous silica, phosphatic sediments and bitumen. Can be interbedded with pellets of solid organic matter (called stone coal in China). Barite laths are reported in two of the China deposits.

ALTERATION MINERALOGY: Siliceous stockworks and bitumen veins with silicified wallrock occur in the footwall units. Carbonate concretions up to 1.5 m in diameter occur immediately below the Nick mineralized horizon in the Yukon.

WEATHERING: Mineralized horizons readily oxidize to a black colour and are recessive. Phosphatic horizons can be resistant to weathering.

ORE CONTROLS : The deposits developed in restricted basins with anoxic conditions. Known deposits are found near the basal contact of major formations. Underlying regional unconformities and major basin faults are possible controls on mineralization. Chinese deposits occur discontinuously in a 1600 km long arcuate belt, possibly controlled by basement fractures.

GENETIC MODEL: Several genetic models have been suggested reflecting the limited data available and the unusual presence of PGEs without ultramafic rocks. Syngenetic deposition from seafloor springs with deposition of metals on or just beneath the seafloor is the most favoured model. Siliceous venting tubes and chert beds in the underlying beds in the Yukon suggest a hydrothermal source for metals.

ASSOCIATED DEPOSIT TYPES: Phosphorite layers (F07?), stone coal, SEDEX Pb-Zn (E14), Sediment-hosted barite (E17), vanadian shales, sediment-hosted Ag-V, uranium deposits.

COMMENTS: Ag-V and V deposits hosted by black shales have been described from the same region in China hosted by underlying late Precambrian rocks.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Elevated values of Ni, Mo, Au, PGE, C, P, Ba, Zn, Re, Se, As, U, V and S in rocks throughout large parts of basin and derived stream sediments. In China average regional values for host shales of 350 g/t Mo, 150 g/t Ni, several wt % P_2O_5 and 5 to 22% organic matter. Organic content correlates with metal contents for Ni, Mo and Zn.

GEOPHYSICAL SIGNATURE: Electromagnetic surveys should detect pyrite horizons.

OTHER EXPLORATION GUIDES: Anoxic black shales in sub-basins within marginal basins. Chert or phosphate-rich sediments associated with a pyritiferous horizon. Barren, 5 mm to 1.5 cm thick, pyrite layers (occasionally geochemically anomalous) up to tens of metres above mineralized horizon.

Table 4. Example Deposit Profile (cont.)

SHALE-HOSTED Ni-Zn-Mo-PGE E16

ECONOMIC FACTORS

TYPICAL GRADE AND TONNAGE : The thin sedimentary horizons (not economic) represent hundreds of thousands of tonnes grading in per cent values for at least two of Ni-Mo-Zn with significant PGEs. In China, Zunyi Mo mines yield ~ 1000 t per year averaging ~4 % Mo and containing up to 4 % Ni, 2 % Zn, 0.7 g/t Au, 50 g/t Ag, 0.3 g/t Pt, 0.4 g/t Pd and 30 g/t Ir. The ore is recovered from a number of small adits using labour-intensive mining methods.

ECONOMIC LIMITATIONS: In China the Mo-bearing phase is recovered by roasting followed by caustic leaching to produce ammonium molybdate. Molybedenum-bearing phases are fine grained and dispersed, therefore all ore (cutoff grade 4.1% Mo) is direct shipped to the smelter after crushing.

IMPORTANCE: Current world production from shale-hosted Ni-Mo-PGE mines is approximately 1000 t of ore with grades of approximately 4 % Mo. Known deposits of this type are too thin to be economic at current metal prices, except in special conditions. However, these deposits contain enormous tonnages of relatively high grade Ni, Mo, Zn and PGE which may be exploited if thicker deposits can be found, or a relevant new technology is developed.

REFERENCES

ACKNOWLEDGEMENTS: Larry Hulbert of the Geological Survey of Canada introduced the senior author to this deposit type and provided many useful comments. Rob Carne of Archer, Cathro and Associates Limited reviewed a draft manuscript.

Coveney, R.M., Jr. and Nansheng, C. (1991): Ni-Mo-PGE-Au-rich Ores in Chinese Black Shales and Speculations on Possible Analogues in the United States; *Mineralium Deposita*, Volume 26, pages 83-88.

Coveney, R.M. Jr., Murowchick, J.B., Grauch, R.I., Nansheng, C. and Glascock, M.D. (1992): Field Relations, Origins and Resource Implications for Platiniferous Molybdenum-Nickel Ores in Black Shales of South China; *Canadiun Institute of Mining, Metallurgy and Petroleum*, Exploration and Mining Geology, Volume 1, No. 1, pages 21-28.

Coveney, R. M. Jr., Grauch, R. I. and Murowchick, J.B. (1993): Ore Mineralogy of Nickel-Molybdenum Sulfide Beds Hosted by Black Shales of South China; *in* The Paul E. Queneau International Symposium, Extractive Metallurgy of Copper, Nickel and Cobalt, Volume 1: Fundamental Aspects, Reddy, R.G. and Weizenbach, R.N., Editors, *The Minerals, Metals and Materials Society*, pages 369-375.

Fan Delian (1983): Poly Elements in the Lower Cambrian Black Shale Series in Southern China; *in* The Significance of Trace Metals in Solving Petrogenetic Problems and Controversies, Augustithis, S.S., Editor, *Theophrastus Publications*, Athens, Greece, pages 447-474.

Note that not all references listed in this Table, see page 45.

EXPLANATION OF HEADINGS

Please refer to the following guidelines for more information on the format for each heading. These are modified from an outline from Eckstrand (1984, p. 3).

NAME:

Descriptive names with the principal commodities are preferred and individual deposit names should be avoided, unless they provide for easy recognition by geologists. The commodities are the element or mineral names linked by hyphens (*e.g.* Cu-Pb-Zn-barite).

SYNONYM(S):

Other geological names commonly used for this deposit type, for example Mississippi Valley type and Carbonate-hosted Pb-Zn. Remember if there are no synonyms, delete this heading. If there is only one synonym, delete the (s) in the heading.

COMMODITIES (*BYPRODUCTS*):

The commodities listed first constitute the principal recovered products at one or more of the deposits. However, all commodities so listed are not necessarily recovered from all deposits of that type. Byproducts and byproduct commodities are listed in italics. For example the commodities for a sedex deposit would be listed Zn, Pb, Ag, barite (*Cd, Cu, Sn*).

EXAMPLES (British Columbia - *Canada/International*):

Examples of the deposit type are an important part of the profile. Please use a specific deposit name in preference to the name of the district or region. As many as five examples from British Columbia should be included with their associated MINFILE number (*e.g.* Lawyers 094E 066). The editors will provide MINFILE numbers for all authors who do not work for the B.C. Geological Survey. Up to ten Canadian or foreign examples should be included and they will be typed in italics. The latter should be followed by the name of the country in brackets. For Canada and the United States, please insert the name of the province or state before the country name. For example, Nick (Yukon, Canada) or Carlin (Nevada, USA). **Please note that we would appreciate resource data for any deposits of the type described in the profile to assist us in generating grade and tonnage probability curves.**

CAPSULE DESCRIPTION:

A short description introducing the reader to the deposit type. Capsule descriptions usually emphasize the important mineralogy, deposit form and associated geological features.

TECTONIC SETTING(S):

In USGS descriptions this heading has several meanings including regional structural setting or regional structural control. Typically this heading will be used to describe the generalized plate tectonic setting which can include reference to specific terranes in B.C. (*e.g.* oceanic terranes - Cache Creek) . Note the following heading can be used to describe the regional and structural settings.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING:

Descriptions of the depositional environment will typically include the associated geological events (*e.g.* marine turbidite deposition with basaltic pyroclastic activity, *e.g.* subaerial rhyolitic volcanic centres .....). The geological setting describes the broad scale setting of the deposit without explaining the tectonic setting.

AGE OF MINERALIZATION:

The age of ore emplacement is given in the form of either absolute dates or geological eons, eras or periods. For some deposit types it may be necessary to express the age in terms relative to hostrocks or a structural control. If British Columbia has a more restricted age range for the deposit type this should be stated.

HOST/ASSOCIATED ROCK TYPES:

A lithological description of the rocks which host, or are associated, with the ore.

DEPOSIT FORM:

The typical geometrical shape of orebodies and their physical and structural relationship to wallrocks and associated rocks. Average dimensions in metric units should be included if possible.

TEXTURE/STRUCTURE:

A description of the common textural features within the ore and any related structures.

ORE MINERALOGY (principal and *subordinate*):

The principal ore minerals are listed first. Less abundant ore minerals follow in italics. Ore minerals present in small or trace amounts or that occur only in one or two deposits should be printed in italics and identified by adding a qualifier. For the convenience of the reader include all metallic minerals, such as pyrite and pyrrhotite, even though they can be considered gangue by strict definition. (*e.g.* chalcopyrite, sphalerite, pyrite, *galena, tetrahedrite, minor pyrrhotite noted at deposits X and Y*).

GANGUE MINERALOGY (principal and *subordinate*):

The principal gangue minerals are listed first. Less abundant gangue minerals follow in italics. Gangue minerals present in small or trace amounts or that occur only in one or two deposits should be printed in italics and identified by adding a qualifier. (*e.g.* chlorite, quartz, sericite, *carbonate*, *garnet at deposits X and Y*).

ALTERATION MINERALOGY (principal and *subordinate*):

List the alteration minerals in relative order of importance. Minerals present in subordinate amounts or only at one or two deposits should be identified by adding a qualifier and printed in italics. The dimensions, zoning (if any) and relationship of the alteration to the ore deposit should be described.

WEATHERING:

An optional section to be used to describe weathering characteristics important to ore formation or as exploration guides.

ORE CONTROLS:

Review the pertinent features of ore genesis or controls on ore emplacement or deposition.

GENETIC MODEL:

This is an optional section which can be used by the author to describe the current genetic models for the deposit type. As space is limited, the descriptions should be to the point.

ASSOCIATED DEPOSIT TYPES:

A listing of deposit types that are genetically related to the deposit type being described. Spatial association in one or two districts is not usually enough to consider the deposit types being associated.

COMMENTS:

This is the section for including any pertinent information, such as deposit subtypes or features of particular relevance to British Columbia, which are not covered by one of the other headings. Preferably less than five and no more than eight sentences.

GEOCHEMICAL SIGNATURE:

Geochemical elements and related methods which may be useful for the discovery of the deposits.

GEOPHYSICAL SIGNATURE:

Geophysical methods which may be useful for the discovery of the deposits.

OTHER EXPLORATION GUIDES:

An optional section to allow for any other exploration aids, such as geological vectors, metallotects, etc.

GRADE AND TONNAGE:

Indicate the typical size and grade of the deposit type using metric figures. The USGS Bulletin 1693 is a good source of data for some deposit types.

ECONOMIC LIMITATIONS:

This is an optional section of particular relevance to industrial mineral deposits. The text should consider physical and chemical properties affecting end use, compositional and mechanical processing restrictions and distance limitations relating to transportation, processing and end use.

END USES:

This is an optional section which is particularly suitable for industrial mineral deposits. List individual uses separated by commas; uses of minor importance should be in italics.

IMPORTANCE:

The importance of the deposit type to British Columbia and in a global context as expressed in terms of consumption, production, reserves or potential. **Please note that this is not the importance of the commodity itself.**

REFERENCES :

Citations should be restricted to major papers or texts, with a special emphasis on overview articles. Please use the format required for the British Columbia Geological Survey's publication titled "Geological Fieldwork". See example below.

Webster, I.C.L. and Ray, G.E. (1991): Skarns in the Iskut River - Scud River Region, Northwest British Columbia (104B); *in* Geological Fieldwork 1990, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1991-4, pages 245-253.

FIGURES:

A schematic cross-section and/or plan view of a typical deposit showing the orebody and associated lithologies, structures, alteration, etc. would be a useful addition to the profile for the final comprehensive publication. These can be complimented by, or in some cases replaced by, a cross-section and plan of a specific deposit. **For all deposits a figure depicting a generalized model might be the most helpful figure.** The final publication will be able to accommodate up to four half-page figures.

APPENDIX II

LISTING OF DEPOSIT PROFILES BY DEPOSIT GROUP AND LITHOLOGICAL AFFINITIES

Note that tables 3 and 4 are available in wall-sized poster format (Open File 1995-8).

British Columbia Mineral Deposit Profiles
Listing by Deposit Group
(Version 2)

BC PROFILE #	DEPOSIT TYPE	SYNONYMS
A - ORGANIC		
A01	Peat	
A02	Lignitic coal	"Brown coal"
A03	Sub-bituminous coal	Thermal coal, Black lignite
A04	Bituminous coal	Coking coal, Thermal coal
A05	Anthracitic coal	Stone coal
B - RESIDUAL/SURFICIAL		
B01*	Laterite Fe	Gossan Fe
B02*	Laterite Ni	
B03*	Laterite-Saprolite Au	Eluvial placers
B04*	Bauxite Al	Lateritic bauxite
B05	Residual kaolin	Primary kaolin
B07*	Bog Fe, Mn, U, Cu, Au	
B08	Surficial U	"Calcrete U"
B09*	Karst-hosted Fe, Al, Pb-Zn	
B10	"Terra Rossa" Au-Ag	Residual Au; Precious metal gossans
B11*	Marl	
B12*	Sand and Gravel	
C - PLACER		
C01	Surficial placers	Placer Au-PGE-Sn-diamond-mag-gar-gems
C02	Buried-channel placers	
C03*	Marine placers	Off-shore heavy mineral sediments
C04*	Paleoplacer U-Au-PGE-Sn-Ti-diam-mag-gar-zir	Quartz pebble conglomerate Au-U
D- CONTINENTAL SEDIMENTS AND VOLCANICS		
D01	Open-system zeolites	
D02	Closed basin zeolites	
D03	Volcanic redbed copper	Basaltic Cu
D04	Basal U	
D05*	Sandstone U	Roll front U, Tabular U
D06	Volcanic-hosted U	"Epithermal" U, Volcanogenic U
D07	Iron oxide Cu-Au-U breccias and veins	Olympic Dam type, Kiruna type

Table 3. British Columbia Mineral Deposit Profiles Listing by Deposit Group

(Version 2)

GLOBAL EXAMPLES Deposit (Province, State or Country)	B.C. EXAMPLES
Ireland, Ontario, New Brunswick	Fraser Delta, North Coast
Estevan (Saskatchewan)	Skonun Point (Graham Island)
Highvale (Alberta), Powder River Basin (Wyoming)	Hat Creek, Princeton
Gregg River (Alberta), Sydney Coalfield (Nova Scotia)	Quintette, Bullmoose, Greenhills, Fording
Pennsylvannia Coalfields, Canmore (Alberta)	Mt Klappan
Glenravel (Ireland), Araxa (Brazil)	
Riddle (Oregon)	
Boddington, Mt. Gibson (Australia), Akaiwang (Guyana)	
Queensland, Pocos de Caldas (Brazil), Salem Hills (Oregon)	Florence (Sooke)
Germany, North Carolina, Idaho	Lang Bay, Sumas Mountain
Trois Riviéres (Québec)	Whipsaw Creek, Limonite Creek
Flodelle Creek (Washington)	Prairie Flats
Transvaal (Pb-Zn, South Africa), Sardinia (Pb-Zn), Jamaica (Al)	Villalta (Fe)
Rio Tinto (Spain)	Villalta
	Cheam Lake (Chiliwack)
North Saskatchewan River (Saskatchewan), Nome (Alaska)	Fraser River, Quesnel River, Graham Island
Livingstone Creek (Yukon), Valdez Creek (Alaska)	Williams Creek, Otter Creek, Bullion mine
New South Wales & Queensland (Australia)	Middlebank (off north end of Vancouver Island)
Elliot Lake & Blind River (Ontario), Witwatersrand (South Africa)	Mulvehill
Ash Meadows (California), John Day Formation (Oregon)	Princeton Basin, Cache Creek area
Bowie (Arizona), Lake Magadi (Kenya)	
Keewenaw (Michigan), Coppermine (Northwest Territories)	Sustut
Sherwood (Washington)	Blizzard, Tyee
Colorado Plateau, Grants (New Mexico)	
Marysvale (Utah), Aurora (Oregon)	Rexspar, Bullion (Birch Island)
El Romeral (Chile), Sue-Dianne (Northwest Territories)	Iron Range

Table 3. British Columbia Mineral Deposit Profiles Listing by Deposit Group

(Version 2)

BC PROFILE #	DEPOSIT TYPE	SYNONYMS
E - SEDIMENT-HOSTED		
E01*	Almaden Hg	
E02*	Kipushi Cu-Pb-Zn	Carbonate-hosted Cu-Pb-Zn
E03	Carlin-type sediment-hosted Au-Ag	Carbonate-hosted Au-Ag
E04*	Sediment-hosted Cu	Sandstone Cu, Sediment-hosted stratiform Cu
E05	Sandstone Pb	
E06	Bentonite	Volcanic clay, Soap clay
E07*	Sedimentary kaolin	"Secondary" kaolin
E08	Carbonate-hosted talc	Dolomite-hosted talc
E09	Sparry magnesite	Veitsch-type, carbonate-hosted magnesite
E10	Mississippi Valley type barite	
E11	Mississippi Valley type fluorite	
E12	Mississippi Valley type Pb-Zn	Carbonate-hosted Pb-Zn, Appalachian Zn
E13	Kootenay Arc type Pb-Zn	
E14	Sedex Zn-Pb-Ag	Sediment-hosted massive sulphide
E15	Blackbird massive sulphide Cu-Co	Sediment-hosted Cu-Co massive sulphide
E16	Sediment-hosted Ni	
E17	Sediment-hosted barite	Bedded barite
F - CHEMICAL SEDIMENT		
F01	Sedimentary Mn	
F02	Bedded gypsum / anhydrite	Marine evaporite gypsum
F03	Gypsum-hosted sulphur	Frasch sulphur
F04*	Bedded celestite	
F05*	Palygorskite	Attapulgite
F06	Lacustrine diatomite	Diatomaceous earth, Kieselguhr
F07	Phosphate, upwelling type	
F08	Phosphate, warm-current type	
F09*	Playas	Hydromagnesite, Na carbonate lake brines
F10*	Superior type iron formation	
G - MARINE VOLCANIC ASSOCIATION		
G01*	Algoma Fe	
G02	Volcanogenic Mn	
G03*	Volcanogenic anhydrite / gypsum	
G04	Besshi massive sulphide Zn-Cu-Pb	Kieslager
G05	Cyprus massive sulphide Cu	
G06	Noranda / Kuroko massive sulphide Cu-Pb-Zn	
G07	Subaqueous hot spring Ag-Au	

Table 3. British Columbia Mineral Deposit Profiles Listing by Deposit Group

(Version 2)

GLOBAL EXAMPLES Deposit (Province, State or Country)	B.C. EXAMPLES
Almaden (Spain), Santa Barbara (Peru)	
Tsumeb (Namibia), Kipushi (Zaire), Ruby Creek (Alaska)	
Carlin, Getchell & Cortez (Nevada)	
Kupferschiefer (Germany & Poland), White Pine (Michigan)	Sage Creek
Laisvall (Sweden), George Lake (Saskatchewan)	
Black Hills (Wyoming), Rodalquilar (Spain)	Princeton, Quilchena
Cordova District (Alabama), Ozark Region (Missouri), Felipe (Brazil)	Sumas Mountain, Quinsam
Treasure Mtn (Montana), Trimouns (France), Henderson (Ontario)	Red Mountain, Silver Dollar
Eugui (Spain), Veitsch (Austria)	Mt. Brussilof, Driftwood Creek
Illinois - Kentucky, Italian Alps	Muncho Lake
Illinois - Kentucky, Italian Alps	Liard Fluorite
Viburnum Trend (Missouri), Pine Point (Northwest Territories)	Robb Lake, Monarch
Navin & Tynagh (Ireland)	Reeves MacDonald, H.B., Aspen, Duncan
Mount Isa (Australia), Faro & Grum (Yukon)	Sullivan, Cirque, Driftpile
Blackbird & Sheep Creek (Montana), Boleo (Mexico)	
Nick (Yukon), Tianeshan & Zunyi (China)	
Tea (Yukon), Magcobar (Ireland)	Kwadacha
Molongo (Mexico), Atasu (Kazakhstan), Kalahari (South Arica)	
Paris Basin (France), Appalachian Basins (New York, Pennsylvania)	Lussier River, Windermere
Texas, Louisiana, Poland, Coronation (Alberta)	Trutch area
Lake Enon (Nova Scotia), Mexico, Germany	Kitsault Lake
Metalline Falls (Washington)	
Juntura and Trout Ck Formations (Oregon), Lake Myvatn (Iceland)	Crownite Formation (Quesnel)
Phosphoria Formation (Idaho), Meskala (Morocco)	Fernie synclinorium
Athabaska Basin (Saskatchewan), Florida	
	Milk River
Mesabi Ranges (Minnesota), Minas Gervas (Brazil)	Falcon
Vermillion iron formation (Minnesota), Helen mine (Ontario)	
Olympic Mountains (Washington), Nicoya (Costa Rica)	
	Britannia, Falkland
Besshi (Japan), Greens Creek (Alaska)	Goldstream, Windy Craggy
Cyprus, Oman	Anyox, Chu Chua
Horne & Millenbach (Québec), Kuroko District (Japan)	Britannia, Kutcho Creek, Myra Falls
Osorezan (Japan)	Eskay Creek

Table 3. British Columbia Mineral Deposit Profiles
Listing by Deposit Group
(Version 2)

BC PROFILE #	DEPOSIT TYPE	SYNONYMS
H - EPITHERMAL		
H01*	Travertine	Tufa
H02	Hot spring Hg	
H03	Hot spring Au-Ag	
H04	Epithermal Au-Ag; high sulphidation	Acid-sulphate epithermal, Nansatsu-type
H05	Epithermal Au-Ag; low sulphidation	Adularia-sericite epithermal
H06*	Epithermal Mn	
H07	Polymetallic Sn veins	
H08*	Au-Ag-Te veins	
H09*	Hydrothermal alteration clays-Al-Si	Kaolin, Alunite, Siliceous cap, Pyrophyllite
I - VEIN, BRECCIA AND STOCKWORK		
I01	Gold-quartz veins	Mesothermal, Motherlode, saddle reefs
I02	Subvolcanic shear-hosted gold	
I03*	Turbidite-hosted gold veins	Meguma type
I04*	Iron formation-hosted gold	
I05	Polymetallic veins Ag-Pb-Zn	
I06*	Cu-Ag quartz veins	
I07*	Silica veins	
I08	Silica-Hg carbonate	
I09	Stibnite veins and disseminations	Simple and disseminated Sb deposits
I10	Vein barite	
I11	Barite-fluorite veins	
I12*	W veins	Quartz-wolframite veins
I13*	Sn veins and greisens	
I14*	U-Th-REE veins	
I15*	Felsic plutonic U	
I16*	Unconformity U-Au-Ni	Vein-like type U
I17	Magnesite veins and stockworks	Bone magnesite, Kraubath-type magnesite
J - REPLACEMENT		
J01	Polymetallic mantos Ag-Pb-Zn	Polymetallic replacement deposits
J02	Sn mantos and stockworks	"Replacement Sn"
J03*	Mn veins and replacements	"Replacement Mn"
J04	Sulphide manto Au	Au-Ag sulphide mantos
K - SKARN		
K01	Cu skarn	
K02	Zn-Pb skarn	
K03	Fe skarn	
K04	Au skarn	
K05	W skarn	
K06	Sn skarn	
K07	Mo skarn	
K08	Garnet skarn	
K09	Wollastonite skarn	

Table 3. British Columbia Mineral Deposit Profiles Listing by Deposit Group

(Version 2)

GLOBAL EXAMPLES Deposit (Province, State or Country)	B.C. EXAMPLES
	Clinton, Slocan
Sulphur Bank (California), Steamboat Springs (Nevada)	Ucluelet
McLaughlin (California), Round Mountain (Nevada)	Cinola
El Indio (Chile), Nansatsu (Japan)	Taseko property, Expo
Comstock (Nevada), Sado (Japan)	Lawyers, Blackdome, Silbak Premier
Talamantes (Mexico), Gloryana (New Mexico)	
Black Range (New Mexico), Potosi (Bolivia), Ashio (Japan)	D Zone (Cassiar)
Emperor (Fiji), Cripple Creek (Colorado)	
Cornwall (England)	Monteith Bay, Pemberton Hills

Alaska-Juneau (Alaska), Red Lake (Ontario)	Bralorne, Erickson
	Scottie, Snip, Johnny Mountain, Iron Colt
Ballarat (Australia), Meguma (Nova Scotia)	Frasergold
Homestake (South Dakota)	
Keno Hill (Yukon)	Silver Queen, Beaverdell
Nikolai & Kathleen-Margaret (Alaska)	Davis-Keays, Churchill Copper
	Granby Point
Red Devil? (Alaska)	Pinchi, Bralorne Takla
Jerritt Canyon (Nevada), Bolivia	Minto, Congress, Snowbird
Del Rio district (Tennessee), Jebel Ighoud (Morocco)	Parson. Brisco
Mongolian fluorite belt	Rock Candy, Eaglet
Pasto Bueno (Peru), Carrock Fell (England)	
Cornwall (England), Lost River (Alaska)	Duncan Lake
Uranium City (Sakatchewan), Schwartzwalder (Colorado)	Little Gem
Roy Creek & Bokan Mountain (Alaska), Massif Central (France)	Coryell intrusions, Surprise Lake
Key Lake (Saskatchewan), Jabiluka (Australia)	

East Tintic (Utah), Naica (Mexico), Sa Dena Hess (Yukon)	Bluebell, Midway
Renison Bell & Cleveland (Australia), Dachang district (China)	
Lake Valley (New Mexico), Phillipsburg (Montana)	
Ketza River (Yukon)	Mosquito Creek , Island Mountain

Mines Gaspé (Québec), Carr Fork (Yukon)	Craigmont, Phoenix
San Antonio (Mexico), Ban Ban (Australia)	Piedmont, Contact
Shinyama (Japan), Cornwall (Pennsylvannia)	Tasu, Jessie, Merry Widow, HPH
Fortitude & McCoy (Nevada), Buckhorn Mountain (Washington)	Nickel Plate
Cantung & Mactung (Yukon), Pine Creek (California)	Emerald Tungsten, Dimac
Lost River (Alaska), JC (Yukon)	Daybreak
Little Boulder Creek (Idaho), Mt. Tennyson (Australia)	Coxey, Novelty
	Crystal Peak
Fox Knoll & Lewis (New York)	Mineral Hill, Rossland

Table 3. British Columbia Mineral Deposit Profiles
Listing by Deposit Group

(Version 2)

BC PROFILE #	DEPOSIT TYPE	SYNONYMS
L - PORPHYRY		
L01	Subvolcanic Cu-Ag-Au (As-Sb)	Enargite Au, Transitional Au-Ag
L02	Porphyry-related Au	Granitoid Au, Porphyry Au
L03	Alkalic porphyry Cu-Au	
L04	Porphyry Cu ± Mo ± Au	
L05	Porphyry Mo	
L06	Porphyry Sn	"Subvolcanic tin"
L07	Porphyry W	
L08	Climax-type Porphyry Mo	
M - ULTRAMAFIC / MAFIC ASSOCIATION		
M01*	Basaltic subvolcanic Cu-Ni-PGE	
M02	Gabbroid Ni-Cu-PGE	
M03	Podiform chromite	
M04*	Anorthosite Ti-V	
M05	Alaskan-type PGE	Zoned ultramafic Fe-Ti-V / PGE / Cr / Cu-Ni
M06	Asbestos	Serpentinite-hosted asbestos
M07	Serpentinite-hosted magnesite-talc	
M08	Vermiculite	
N - ALKALIC ASSOCIATION (includes kimberlites and lamproites)		
N01	Carbonatite-hosted deposits	
N02*	Kimberlite-hosted diamonds	Diamond pipes
N03*	Lamproite-hosted diamonds	
O - PEGMATITE		
O01	Rare element pegmatite - LCT family	Zoned pegmatite (Lithium-Cesium-Tantalum)
O02	Rare element pegmatite - NYF family	Niobium-Yttrium-Fluorine pegmatite
O03	Muscovite pegmatite	Mica-bearing pegmatite
O04*	Feldspar-quartz pegmatite	Barren pegmatite
P - METAMORPHIC HOSTED		
P01	Andalusite hornfels	
P02	Kyanite family	
P03	Microcrystalline graphite	"Amorphous" graphite
P04	Crystalline flake graphite	
P05	Vein graphite	"Lump and chip" graphite
P06	Corundum in aluminous metasediments	

Table 3. British Columbia Mineral Deposit Profiles
Listing by Deposit Group
(Version 2)

GLOBAL EXAMPLES Deposit (Province, State or Country)	B.C. EXAMPLES
Lepanto (Philippines), Resck (Hungary), Kori Kollo (Bolivia)	Equity Silver, Thorn
Marte & Lobo (Chile), Lihir (Papua New Guinea)	Snowfields
Tai Parit (Philippines)	Afton, Copper Mountain, Galore Creek
Chuquicamata & La Escondida (Chile)	Highland Valley, Gibraltar
Quartz Hill (Alaska)	Endako, Kitsault, Glacier Gulch
Llallagua (Bolivia), Potato Hills (Yukon)	
Logtung (Yukon), Xingluokeng (China)	Boya
Climax & Henderson (Colorado)	
Noril'sk (Russia), Duluth (Minnesota)	
Lynn Lake (Manitoba), Kluane (Yukon), Noril'sk-Talnakh (Russia)	Giant Mascot, Nickel Mountain
Josephine ophiolite (Oregon), Coto (Philippines), Elazig (Turkey)	
Roseland (Virginia), Pluma Hidalgo (Mexico)	
Duke Island (Alaska)	Tulameen
Thetford (Québec)	Cassiar, Kutcho
Thetford & Magog (Québec), Deloro (Ontario)	
Enoree (USA)	Fort Fraser arèa
Palabora (South Africa), Oka (Québec), Mountain Pass (California)	Aley, Mount Grace tuff
Kimberley & Premier (South Africa)	Cross
Argyle (Australia)	
Bikita Field (Zimbabwe), Blackhills (South Dakota)	
South Platte district (Colorado), Bancroft (Ontario)	
Rajahstan (India), Appalachian Province (USA)	
Buckingham (Québec)	
Bushveld (South Africa), Brittany (France)	Leech River
Willis Mountain (Virginia), NARCO (Québec)	
Keiserberg (Austria)	
Lac Knife (Québec)	AA
Calumet & Clot (Québec), Bogala (Sri Lanka)	
Gallatin & Madison Counties (Montana)	

Table 3. British Columbia Mineral Deposit Profiles
Listing by Deposit Group
(Version 2)

BC PROFILE #	DEPOSIT TYPE	SYNONYMS
Q - GEMS AND SEMI-PRECIOUS STONES (diamonds under N)		
Q01	Jade	
Q02	Rhodonite	
Q03*	Agate	
Q04*	Amethyst	
Q05*	Jasper	
Q06	Columbia-type emerald	
Q07	Schist-hosted emerald	Exometamorphic emerald deposit
Q08	Australian-type opal	Sediment-hosted opal
Q09	Gem corundum in contact zones	
Q10	Gem corundum hosted by alkalic rocks	
Q11	Volcanic-hosted opal	
R - INDUSTRIAL ROCKS		
R01	Cement shale	
R02	Expanding shale	
R03	Dimension stone - granite	
R04	Dimension stone - marble	
R05	Dimension stone - andesite	
R06*	Dimension stone - sandstone	
R07	Silica sandstone	High-silica quartzite
R08*	Flagstone	
R09	Limestone	
R10*	Dolomite	
R11*	Volcanic ash - pumice	
R12*	Volcanic glass - perlite	
R13*	Nepheline syenite	
R14*	Alaskite	
R15*	Crushed rock	Road metal, Riprap, Railroad ballast

Table 3. British Columbia Mineral Deposit Profiles Listing by Deposit Group

(Version 2)

GLOBAL EXAMPLES Deposit (Province, State or Country)	B.C. EXAMPLES
	Cry Lake, Ogden Mountain
	Hill 60, Arthur Point, Cassiar
Thunder Bay (Ontario), Artigas (Uruguay), Maraba (Brazil)	
Chivor and Muzo districts (Columbia)	
Habachtal (Austria), Leysdorp (South Africa), Socoto (Brazil)	
Coober Pedy (Australia)	
Umba (Tanzania), Kinyki Hill (Kenya)	
Yogo Gulch (Montana)	

GLOBAL EXAMPLES Deposit (Province, State or Country)	B.C. EXAMPLES
	Dunsmuir shale, Sumas Mountain
Wabamun shales (Alberta)	Nanaimo shale, Saturna Island
Riviére á Pierre (Québec), Black Hills (South Dakota)	Nelson Island
Vermont, Alabama, Georgia	Marblehead, Anderson Bay (Texada Island)
	Haddington Island
	Saturna Island, Newcastle Island
	Moberley, Nicholson
Southowram (England)	Salmo, Revelstoke
	Texada Island, Quatsino Belt
	Crawford Bay, Rock Creek
	Meagher Mountain, Buse Lake
	Frenier, Francois Lake
Blue Mountain (Ontario)	Trident Mountain
Spruce Pine alaskite (North Carolina)	
	McAbbee, Gissome

Table 4. British Columbia Mineral Deposit Profiles
Listing by Lithological Affinities (Version 2)

DEPOSIT TYPE	SYNONYMS	GLOBAL EXAMPLES Deposit (Province, State or Country)	B.C. EXAMPLES	BC PROFILE #	U.S.G.S. MODEL #
UNCONSOLIDATED DEPOSITS					
Peat		Ireland, Ontario, New Brunswick	Fraser Delta, North Coast	A01	--
Bog Fe, Mn, U, Cu, Au		Trois Rivières (Québec)	Whipsaw Creek, Limonite Creek	B07*	--
Surficial U	"Calcrete U"	Flodelle Creek (Washington)	Prairie Flats	B08	--
Residual					
Laterite Fe	Gossan Fe	Glenravel (Ireland), Araxa (Brazil)		B01*	--
Laterite Ni		Riddle (Oregon)		B02*	38a
Laterite-Saprolite Au	Eluvial placers	Boddington (Australia), Akaiwang (Guyana)		B03*	38g
Bauxite Al	Lateritic bauxite	Pocos de Caldas (Brazil), Salem Hills (Oregon)	Florence (Sooke)	B04*	38b
Residual kaolin	Primary kaolin	Germany, North Carolina, Idaho	Lang Bay, Sumas Mountain	B05	38h*
Karst-hosted Fe, Al, Pb-Zn		South Africa (Pb-Zn), Jamaica (Al)	Villhalta (Fe)	B09*	--
"Terra Rossa" Au-Ag	Residual Au; Precious metal gossans	Rio Tinto (Spain)	Villalta	B10	--
Alluvium					
Sand and Gravel				B12*	
Surficial placers	Placer Au-PGE-Sn-U- diam-mag-gar-gems	North Saskatchewan River (Saskatchewan), Nome (Alaska)	Fraser River, Quesnel River	C01	39a
Buried-channel placers		Livingstone Creek (Yukon), Valdez Creek (Alaska)	Williams Creek, Otter Creek	C02	39a
Marine					
Marine placers	Off-shore heavy mineral sediments	Australia (New South Wales, Queensland)	Middlebank (north of Vancouver Island)	C03*	39f*?
SEDIMENTARY ROCKS					
CHEMICAL SEDIMENTARY ROCKS					
(Sediment-hosted Ni)		Nick (Yukon), Tianeshan & Zunyi (China)		E16	--
Sedimentary Mn		Molongo (Mexico), Atasu (Kazakhstan)		F01	34b
Palygorskite	Attapulgite	Metalline Falls (Washington)		F05*	34e*
Phosphate, upwelling type		Phosphoria Formation (Idaho)	Fernie synclinorium	F07	34c
Phosphate, warm-current type		Athabaska Basin (Saskatchewan), Florida		F08	34d
Superior Type iron formation		Mesabi Ranges (Minnesota), Minas Gervas (Brazil)	Falcon	F10*	34a
Playa Evaporites					
Playas	Hydromagnesite, Na carbonate lake brines		Milk River	F09*	35ba
Lacustrine					
Marl			Cheam Lake (Chiliwack)	B11*	
Marine Evaporites					
Bedded gypsum / anhydrite	Marine evaporite gypsum	Paris Basin (France), Appalachian Basins (USA)	Lussier River, Windermere	F02	35ae
Gypsum-hosted sulphur	Frasch sulphur	Texas, Louisiana, Poland, Coronation (Alberta)	Trutch area	F03	--
Bedded celestite		Lake Enon (Nova Scotia), Mexico, Germany	Kitsault Lake	F04*	35aa*
CARBONATE ROCKS					
No Associated Igneous Rocks					
Kipushi Cu-Pb-Zn	Carbonate-hosted Cu-Pb-Zn	Kipushi (Zaire), Tsumeb (Namibia), Ruby Creek (Alaska)		E02*	32c
Carbonate-hosted talc	Dolomite-hosted talc		Red Mountain, Silver Dollar	E08	18?i*
Sparry magnesite	Veitsch-type, carbonate-hosted magnesite	Eugui (Spain), Veitsch (Austria)	Mt. Brussilof, Driftwood Creek	E09	18i*
Mississippi Valley type barite		Illinois - Kentucky, Italian Alps	Muncho Lake	E10	--
Mississippi Valley type fluorite		Illinois - Kentucky, Italian Alps	Liard Fluorite	E11	32d*
Mississippi Valley type Pb-Zn	Carbonate-hosted Pb-Zn, Appalachian Zn	Viburnum Trend (Missouri), Pine Point (Northwest Terr.)	Robb Lake, Monarch	E12	32a/32b
Kootenay Arc type Pb-Zn		Navin & Tynagh (Ireland)	Reeves MacDonald, H.B., Aspen	E13	--
Travertine	Tufa		Clinton, Slocan	H01*	35d*
(Vein barite)			Muncho Lake	I10	IM27e
(Polymetallic mantos Ag-Pb-Zn)	Polymetallic replacement deposits		Bluebell	J01	19a
(Sn mantos and stockworks)	"Replacement Sn"			J02	14c
(Mn veins and replacements)	"Replacement Mn"			J03*	19b
Sulphide manto Au	Au-Ag sulphide mantos	Ketza River (Yukon)	Mosquito Creek , Island Mountain	J04	--

Table 4. British Columbia Mineral Deposit Profiles
Listing by Lithological Affinities (Version 2)

DEPOSIT TYPE	SYNONYMS	GLOBAL EXAMPLES Deposit (Province, State or Country)	B.C. EXAMPLES	BC PROFILE #	U.S.G.S. MODEL #
Limestone			Texada Island, Quatsino Belt	R09	- -
Dolomite			Crawford Bay, Rock Creek	R10*	- -
Associated Igneous Rocks					
Carlin-type sediment-hosted Au-Ag	Carbonate-hosted Au-Ag	Carlin (Nevada)		E03	26a,19c
Polymetallic mantos Ag-Pb-Zn	Polymetallic replacement deposits	East Tintic (Utah), Naico (Mexico), Sa Dena Hess (Yukon)	Midway	J01	19a
Sn mantos and stockworks	"Replacement Sn"	Renison Bell (Australia), Dachang district (China)		J02	14c
Mn veins and replacements	"Replacement Mn"	Lake Valley (New Mexico), Phillipsburg (Montana)		J03*	19b
(Cu skarn)		Mines Gaspé (Québec), Carr Fork (Yukon)	Craigmont, Phoenix	K01	18a,b
Zn-Pb skarn		Yeonhwa-Ulchin District (S. Korea), Darwin (California)	Piedmont, Contact	K02	18c
(Fe skarn)		Shinyama (Japan)	Tasu, Jessie, Merry Widow	K03	18d
(Au skarn)		Fortitude & McCoy (Nevada), Buckhorn Mtn (Washington)	Nickel Plate	K04	- -
(W skarn)		Cantung & Mactung (Yukon), Pine Creek (California)	Emerald Tungsten, Dimac	K05	14a
(Sn skarn)		Lost River (Alaska), JC (Yukon)	Daybreak	K06	14b
(Garnet skarn)			Crystal Peak	K08	- -
(Wollastonite skarn)		Fox Knoll, Lewis (New York)	Mineral Hill	K09	18g
CLASTIC SEDIMENTARY ROCKS					
Biogenic					
(Phosphate, upwelling type)		Phosphoria Formation (Idaho), Meskala (Morocco)	Fernie synclinorium	F07	34c
(Phosphate, warm-current type)		Athabaska Basin (Saskatchewan), Florida		F08	34d
Clays					
(Bentonite)	Volcanic clay, Soap clay	Black Hills (Wyoming), Pembina District (Manitoba)	Princeton, Quilchena	E06	28e7*
Sedimentary kaolin	"Secondary" kaolin	Cordova District (Alabama), Ozark Region (Missouri)	Sumas Mountain, Quinsam	E07*	31k*
Shale-Siltstone					
Lignitic coal	"Brown coal"	Estevan (Saskatchewan)	Skonun Point (Graham Island)	A02	- -
Sub-bituminous coal	Thermal coal, Black lignite	Highvale (Alberta), Powder River Basin (Wyoming)	Hat Creek, Princeton	A03	- -
Bituminous coal	Coking coal, Thermal coal	Sydney Coalfield (Nova Scotia)	Quintette, Bullmoose, Greenhills, Fording	A04	- -
Anthracitic coal	Stone coal	Pennsylvannia Coalfields, Canmore (Alberta)	Mt Klappan	A05	- -
(Carlin-type sediment-hosted Au-Ag)	Carbonate-hosted Au-Ag	Carlin (Nevada), Cortez (Nevada)		E03	26a,19c
Sediment-hosted Cu	Sandstone Cu, Sediment-hosted stratiform Cu	Kupferschiefer (Germany & Poland), White Pine (Michigan)		E04*	30b
Sedex Zn-Pb-Ag-S	Sediment-hosted massive sulphides	Mount Isa (Australia), Faro, Grum (Yukon)	Sullivan, Cirque, Driftpile	E14	31a
Blackbird massive sulphide Cu-Co	Sediment-hosted Cu-Co massive sulphide	Blackbird & Sheep Creek (Montana)		E15	24d
Sediment-hosted Ni		Nick (Yukon), Tianeshan & Zunyi (China)		E16	- -
Sediment-hosted barite	Bedded barite	Tea (Yukon), Magcobar (Ireland)	Kwadacha	E17	31b
Besshi massive sulphide Zn-Cu-Pb	Kieslager	Greens Creek (Alaska)	Goldstream, Windy Craggy	G04	24b
Polymetallic veins Ag-Pb-Zn		Keno Hill (Yukon)	Highland Bell, Lucky Jim	I05	22c, 25b
Cu-Ag quartz veins		Nikolai mine & Kathleen-Margaret (Alaska)	Davis-Keays, Churchill Copper	I06*	?
Vein barite		Nevada	Parson, Brisco	I10	IM27e
(Barite-fluorite veins)		Pforzheim-Naaburg (Germany)	Stone Mountain Park (Alaska Hwy)	I11	26c*
Columbia-type emerald deposits		Chivor and Muzo districts (Columbia)		Q06	31c
Cement shale			Dunsmuir shale, Sumas Mountain	R01	- -
Expanding shale		Wabamun shales (Alberta)	Nanaimo shale, Saturna Island	R02	- -
Flagstone				R08*	- -
Sandstone					
(Sub-bituminous coal)	Thermal coal, Black lignite			A03	- -
(Bituminous coal)	Coking coal, Thermal coal	Gregg River (Alberta)	Quintette, Bullmoose	A04	- -
(Anthracitic coal)	Stone coal		Mt Klappan	A05	- -
(Volcanic redbed copper)	Basaltic Cu	Keewenaw (Michigan), Coppermine (Northwest Territories)	Sustut	D03	23
Basal U		Sherwood (Washington)	Blizzard, Tyee	D04	- -
Sandstone U	Roll front U, Tabular U	Colorado Plateau, Grants (New Mexico)		D05*	30c
(Iron oxide Cu-Au-U breccias and veins)	Olympic Dam-type Fe (Cu-U-Au)		Iron Range	D07	29b,25l
(Sediment-hosted Cu)	Sandstone Cu	Dorchester (New Brunswick), Nacimento (New Mexico)	Sage Creek	E04*	30b
Sandstone Pb		Laisvall (Sweden), Largentiere (France)		E05	30a
(Sedex Zn-Pb-Ag-S)	Sediment-hosted massive sulphide			E14	31a
(Blackbird massive sulphide Cu-Co)	Sediment-hosted Cu-Co massive sulphide	Blackbird (Montana)		E15	24d
Agate				Q03*	- -
Australian-type opal	Sediment-hosted opal	Coober Pedy (Australia)		Q08	- -
Dimension stone - sandstone			Saturna Island, Newcastle Island	R06*	30d*
Silica sandstone	High-silica quartzite	Selkirk Silica (Manitoba)	Moberley	R07	30e*
Flagstone		Southowram (England)	Salmo	R08*	- -
Conglomerate and Sedimentary Breccia					
Paleoplacer U-Au-PGE-Sn-Ti-diam-mag-gar-zir	Quartz pebble conglomerate Au-U	Elliot Lake (Ontario), Witwatersrand (South Africa)		C04*	39c,d,e
(Sandstone U)	Roll front U, Tabular U			D05*	30c

Table 4. British Columbia Mineral Deposit Profiles
Listing by Lithological Affinities (Version 2)

DEPOSIT TYPE	SYNONYMS	GLOBAL EXAMPLES Deposit (Province, State or Country)	B.C. EXAMPLES	BC PROFILE #	U.S.G.S. MODEL #
REGIONALLY METAMORPHOSED ROCKS					
Carbonate-hosted talc	Dolomite-hosted talc	Treasure Mountain (Montana), Henderson (Ontario)		E08	18i*
Gold-quartz veins	Mesothermal, saddle reefs	Alaska-Juneau (Alaska)		I01	36a
Turbidite-hosted gold veins	Meguma type	Ballarat (Australia), Meguma (Nova Scotia)	Frasergold	I03*	36a
Iron formation-hosted gold		Homestake (South Dakota)		I04*	36b
U veins		Uranium City (Sask.), Schwartzwalder (Colorado)	Little Gem	I14*	- -
Unconformity U-Au-Ni	Vein-like type U	Key Lake (Saskatchewan), Jabiluka (Australia)		I16*	37a
(Asbestos)	Serpentinite-hosted asbestos	Thetford (Québec)	Cassiar	M06	8d
Rare element pegmatite - LCT family	Zoned pegmatite (Lithium-Cesium-Tantalum)	Bikita Field (Zimbabwe), Blackhills (South Dakota)		O01	13a*,b*
Rare element pegmatite - NYF family	Niobium-Yttrium-Fluorine pegmatite	South Platte district (Colorado), Bancroft (Ontario)		O02	- -
Muscovite pegmatite	Mica-bearing pegmatite	Rajahstan (India), Appalachian Province (USA)		O03	13f*
Feldspar-quartz pegmatite	Barren pegmatite	Buckingham (Quebec)		O04*	- -
Kyanite family		Willis Mountain (Virginia), NARCO (Québec)		P02	- -
Microcrystalline graphite	"Amorphous" graphite	Kieserberg (Austria)		P03	- -
Crystalline flake graphite		Lac Knife (Québec)	AA	P04	- -
Vein graphite	"Lump and chip graphite"	Calumet & Clot (Québec), Bogala (Sri Lanka)		P05	- -
Corundum in aluminous metasediments		Gallatin & Madison Counties (Montana)		P06	- -
(Schist-hosted emerald deposits)		Santana Dos Ferros & Itabira (Brazil)		Q07	- -
(Dimension stone - granite)	metamorphic gneiss and migmatite			R03	- -
Dimension stone - marble		Vermont, Alabama, Georgia	Marblehead, Anderson Bay (Texada Is.)	R04	- -
Silica sandstone	High-silica quartzite		Moberley, Nicholson	R07	30e*
Flagstone			Revelstoke	R08*	- -

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DEPOSIT TYPE	SYNONYMS	GLOBAL EXAMPLES Deposit (Province, State or Country)	B.C. EXAMPLES	BC PROFILE #	U.S.G.S. MODEL #
VOLCANIC ROCKS					
SUBAERIAL VOLCANIC ROCKS - Felsic-Mafic					
Mainly Volcanic Host					
(Open-system zeolites)		John Day Formation (Oregon)		D01	25oa
Volcanic redbed copper	Basaltic Cu	Keewenaw (Michigan), Coppermine (Northwest Territories)	Sustut	D03	23
Volcanic-hosted U	"Epithermal" U, Volcanogenic U	Marysvale (Utah), Aurora (Oregon)	Rexspar, Bullion (Birch Island)	D06	25f
Iron oxide Cu-Au-U breccias and veins	Olympic Dam type Fe (Cu-U-Au), Kiruna type	El Romeral (Chile), Sue-Dianne (Northwest Territories)		D07	29b,25i
Hot spring Au-Ag		McLaughlin (California), Round Mountain (Nevada)	Cinola	H03	25a
Epithermal Au-Ag; high sulphidation	Acid-sulphate epithermal, Nansatsu-type	El Indio (Chile), Nansatsu (Japan)	Taseko property, Expo	H04	25d
Epithermal Au-Ag; low sulphidation	Adularia-sericite epithermal	Comstock (Nevada), Sado (Japan)	Lawyers, Blackdome	H05	25c
Epithermal Mn		Talamantes (Mexico), Gloryana (New Mexico)		H06*	25g
Polymetallic Sn veins		Black Range (New Mexico), Potosi (Bolivia)		H07	25h, 20b
Hydrothermal alteration clays-Al-Si	Kaolin, Alunite, Siliceous cap, Pyrophyllite		Monteith Bay, Pemberton Hills	H09*	25lb*
(Subvolcanic shear-hosted gold)			Scottie	I02	- -
(Cu-Ag quartz veins)		Nikolai mine & Kathleen-Margaret (Alaska)		I06*	?
Silica veins			Granby Point	I07*	- -
Barite-fluorite veins		Spor Mountain & Indian Peak District (Utah)	Rock Candy	I11	26c*
Volcanic-hosted opal		Querétaro State (Mexico)		Q11	*- -
Dimension stone - andesite			Haddington Island	R05	- -
Volcanic ash - pumice			Meagher Mountain	R11*	- -
Perlite			Frenier, Francois Lake	R12*	- -
Interbedded or Underlying Sedimentary Rocks					
Almaden Hg		Almaden (Spain), Santa Barbara (Peru)		E01*	27b
Hot spring Hg		Sulphur Bank (California), Steamboat Springs (Nevada)	Ucluelet?	H02	27a
(Subvolcanic shear-hosted gold)			Snip	I02	- -
Silica-Hg carbonate		Red Devil? (Alaska)	Pinchi, Bralorne Takla	I08	27c
Stibnite veins and disseminations	Simple and disseminated Sb deposits	Jerritt Canyon (Nevada), Bolivia	Minto, Congress, Snowbird	I09	27d,27e
(Barite-fluorite veins)			Rock Canyon Creek	I11	26c*
SUBAQUEOUS VOLCANIC ROCKS - Felsic-Mafic					
Mainly Volcanic Host					
Open-system zeolites		Death Valley (California), John Day Formation (Oregon)	Princeton Basin, Cache Creek area	D01	25oa
Closed basin zeolites		Bowie (Arizona), Lake Magadi (Kenya)		D02	25ob
(Volcanic-hosted U)	"Epithermal" U, Volcanogenic U		Rexspar, Bullion (Birch Island)	D06	25f
Bentonite	Volcanic clay, Soap clay	Wyoming, Alberta, Rodalquilar (Spain)	, Hat Creek	E06	28e?*
Lacustrine diatomite	Diatomaceous earth, Kieselguhr	Juntura Formation (Oregon), Lake Myvatn (Iceland)	Crownite Formation (Quesnel)	F06	31s
Algoma Fe		Vermillion Iron formation (Minn.), Helen mine (Ontario)		G01*	28b
(Volcanogenic Mn)		North Island (New Zealand), Rio Tinto (Spain)		G02	24c
Volcanogenic anhydrite / gypsum			Britannia, Falkland	G03*	- -
Noranda / Kuroko massive sulphide Cu-Pb-Zn		Horne & Millenbach (Québec), Kuroko District (Japan)	Britannia, Kutcho Creek, Myra Falls	G06	28a
Subaqueous hot spring Ag-Au		Osorezan (Japan)	Eskay Creek	G07	- -
Subvolcanic shear-hosted gold			Johnny Mountain	I02	- -
Rhodonite			Hill 60, Arthur Point, Cassiar	Q02	- -
Jasper			Cowichan Lake district	Q05*	- -
MARINE - Mafic (including ophiolites)					
(Blackbird massive sulphide Cu-Co)	Sediment-hosted Cu-Co massive sulphide	Boleo (Mexico)		E15	24d
Volcanogenic Mn		Olympic Mountains (Washington), Nicoya (Costa Rica)		G02	24c
(Besshi massive sulphide Zn-Cu-Pb)	Kieslager	Besshi (Japan)	Windy Craggy	G04	24b
Cyprus massive sulphide Cu		Cyprus, Oman	Anyox, Chu Chua	G05	24a
VOLCANIC ROCKS - Alkalic					
(Carbonatite-hosted deposits)			Mount Grace tuff	N01	10
Gem corundum hosted by alkalic rocks				Q10	- -

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INTRUSIVE ROCKS					
GRANITOID INTRUSIONS					
(Iron oxide Cu-Au-U breccias and veins)	Olympic Dam-type Fe (Cu-U-Au), Kiruna-type	Olympic Dam (Australia)		D07	29b,25l
(Polymetallic Sn veins)			D Zone (Cassiar)	H07	25h, 20b
(Hydrothermal alteration clays-Al-Si)	Kaolin, Alunite, Siliceous cap, Pyrophyllite	Cornwall (England)		H09*	25lb*
Felsic plutonic U		Roy Creek (Alaska), Massif Central (France)	Coryell intrusions, Surprise Lake	I15*	
(Alkalic porphyry Cu-Au)		Tai Parit (Philippines)	Afton, Copper Mountain, Galore Creek	L03	- -
Porphyry Cu ± Mo ± Au		Chuquicamata & La Escondida (Chile)	Highland Valley, Gibraltar	L04	17,20,21a1
Porphyry Mo		Quartz Hill (Alaska)	Endako, Kitsault, Glacier Gulch	L05	21b
Porphyry Sn	"Subvolcanic tin"	Llallagua (Bolivia), Potato Hills (Yukon)		L06	20a
Porphyry W		Logtung (Yukon), Xingluokeng (China)	Boya	L07	21c*
Climax-type Porphyry Mo		Climax & Henderson (Colorado)		L08	16
(Rare element pegmatite - LCT family)	Zoned pegmatite			O01	13a*,b*
(Rare element pegmatite - NYF family)	Niobium-Yttrium-Fluorine pegmatite			O02	- -
(Muscovite pegmatite)	Mica-bearing pegmatite			O03	13f*
(Feldspar-quartz pegmatite)	Barren pegmatite			O04*	
Amethyst		Thunder Bay (Ontario)		Q04*	- -
Dimension stone - granite		Rivière à Pierre (Québec), Black Hills (South Dakota)	Nelson Island	R03	- -
Alaskite		Spruce Pine alaskite (North Carolina)		R14*	
Coeval Volcanic Wallrocks					
(Epithermal Mn)		Talamantes (Mexico), Gloryana (New Mexico)		H06*	25g
(Polymetallic veins Ag-Pb-Zn)			Silver Queen, Beaverdell	I05	22c, 25b
Subvolcanic Cu-Ag-Au (As-Sb)	Enargite Au, Transitional Au-Ag	Lepanto (Philippines), Resck (Hungary), Kori Kollo (Bolivia)	Equity Silver, Thom	L01	22a/25e
Alkalic porphyry Cu-Au			Copper Mountain, Galore Creek	L03	- -
(Porphyry Cu ± Mo ± Au)		Bajo de la Alumbrera (Argentina)	Island Copper, Fish Lake	L04	17,20,21a1
(Porphyry Sn)	"Subvolcanic tin"			L06	20a
Calcareous Wallrocks					
(Carbonate-hosted talc)	Dolomite-hosted talc			E08	18?i*
Cu skarn		Mines Gaspé (Québec), Carr Fork (Yukon)	Craigmont, Phoenix	K01	18a,b
(Zn-Pb skarn)		Yeonhwa-Ulchin District (S. Korea), Darwin (California)	Piedmont, Contact	K02	18c
(Fe skarn)				K03	18d
(Au skarn)				K04	- -
W skarn		Cantung (Yukon), Pine Creek (California), Salau (France)	Emerald Tungsten, Dimac	K05	14a
Sn skarn		Lost River (Alaska)	Daybreak	K06	14b
Mo skarn		Little Boulder Creek (Idaho), Mt. Tennyson (Australia)	Coxey, Novelty	K07	- -
Garnet skarn			Crystal Peak	K08	- -
(Wollastonite skarn)			Mineral Hill	K09	18g
Other Wallrocks					
(Polymetallic Sn veins)				H07	25h, 20b
(Gold-quartz veins)	Mesothermal, saddle reefs	Alaska-Juneau (Alaska), Red Lake (Ontario)		I01	36a
(Polymetallic veins Ag-Pb-Zn)		Riverside (Alaska)	Porter-Idaho	I05	22c, 25b
W veins	Quartz-wolframite veins	Pasto Bueno (Peru), Carrock Fell (England)		I12*	15a
Sn veins and griesens		Cornwall (England), Lost River (Alaska)	Duncan Lake	I13*	15b, 15c
Porphyry-related Au	Granitoid Au, Porphyry Au	Marte & Lobo (Chile)	Snowfields?	L02	20d
(Climax-type Porphyry Mo)		Climax & Henderson (Colorado)		L08	16
Andalusite hornfels		Bushveld (South Africa), Brittany (France)	Leech River	P01	- -
(Kyanite family)			Coast plutonic complex	P02	- -
(Microcrystalline graphite)	"Amorphous" graphite	South Korea		P03	- -
Gem corundum in contact zones		Umba (Tanzania), Kinyiki Hill (Kenya)		Q09	S4
ANORTHOSITE INTRUSIONS					
Anorthosite Ti-V		Roseland (Virginia), Pluma Hidalgo (Mexico)		M04*	7b
Calcareous Wallrocks					
Wollastonite skarn		Fox Knoll, Lewis (New York)		K09	18g
MAFIC AND ULTRAMAFIC INTRUSIONS					
(Laterite Ni)		Riddle (Oregon)		B02*	38a
(Surficial placers)	Placer U-Au-PGE-Sn-diam-mag-garnet, gems		Atlin, Cassiar	C01	39a
(Buried-channel placers)			Otter Creek	C02	39a

Table 4. British Columbia Mineral Deposit Profiles
Listing by Lithological Affinities (Version 2)

DEPOSIT TYPE	SYNONYMS	GLOBAL EXAMPLES Deposit (Province, State or Country)	B.C. EXAMPLES	BC PROFILE #	U.S.G.S. MODEL #
(Gold-quartz veins)	Mesothermal, Motherlode	Motherlode (California)	Bralorne, Erickson	I01	36a
(Silica-Hg carbonate)		Red Devil? (Alaska)	Pinchi, Bralorne Takla	I08	27c
Magnesite veins and stockworks	Bone magnesite, Kraubath-type magnesite	- -		I17	- -
Podiform chromite		Josephine ophiolite (Oregon), Coto (Philippines)	Stuart Lake region	M03	8a/8b
Zoned ultramafic Fe-Ti-V / PGE / Cr / Cu-Ni	Alaskan type Fe-Ti-V / PGE / Cr / Cu-Ni	Duke Island (Alaska)	Tulameen	M05	9
Asbestos	Serpentinite-hosted asbestos	Thetford (Québec)	Cassiar	M06	8d
Serpentinite-hosted magnesite-talc		Thetford & Magog (Québec), Deloro (Ontario)		M07	8f*
Vermiculite		Libby (Montana)	Fraser Lake	M08	- -
Schist-hosted emerald deposits		Habachtal (Austria), Leysdorp (South Africa), Socoto (Brazil)		Q07	- -
Jade			Cry Lake, Ogden Mountain	Q01	- -
Calcareous Wallrocks					
(Cu skarn)				K01	18a,b
Fe skarn		Shinyama (Japan)	Tasu, Jessie, Merry Widow, Texada Fe	K03	18d
Au skarn		Fortitude (Nevada), Buckhorn Mountain (Washington)	Nickel Plate	K04	- -
Coeval Volcanic Rocks					
Basaltic subvolcanic Cu-Ni-PGE		Noril'sk (Russia), Duluth (Minnesota)		M01*	5a/5b
Gabbroid Ni-Cu-PGE		Lynn Lake (Manitoba), Noril'sk (Russia)	Giant Mascot, Nickel Mountain	M02	7a
ALKALINE INTRUSIONS					
Au-Ag-Te veins		Emperor (Fiji), Zortman (Montana), Cripple Ck (Colorado)		H08*	22b
Kimberlite-hosted diamonds	Diamond pipes	Kimberley & Premier (South Africa)	Cross	N02*	12
Lamproite-hosted diamonds		Argyle (Australia)		N03*	12
Gem corundum in alkalic rocks		Yogo (Montana)		Q10	- -
Nepheline syenite		Blue Mountain (Ontario)	Trident Mountain	R13*	- -
Carbonatites					
(Vermiculite)		Palabora (South Africa)	Perry River	M08	- -
Carbonatite-hosted deposits		Palabora (South Africa), Oka (Québec)	Aley	N01	10

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