GOLD DEPOSITS AND THEIR GEOLOGICAL CLASSIFICATION

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ABSTRACT

Classifications of ore deposits provide essential frameworks for designing exploration strategies, evaluating prospects, and performing resource assessments of selected areas. A rational geological classification of the commonly recognized lode gold deposits is feasible if it is based on the geological settings of the deposits, host rocks, nature of mineralization and geochemical signature. Sixteen common types of bedrock gold deposits are distinguished from one another and their main geological attributes are summarized. Many of these deposit types represent different components of larger hydrothermal systems active at the same crustal levels and are genetically related. The geochemical parameters for most of deposit types are the results of the interaction of the hydrothermal systems with particular wallrock packages. On this basis unique geochemical signatures are diagnostic of deposit types only for fluid-dominated systems but are less reliable indicators of deposit types for rock-dominated systems.

INTRODUCTION

Classification of gold deposits is much more than a textbook exercise: it provides an essential framework for resource assessment studies, for designing exploration strategies (e.g., what type of deposit to look for, where and how), and for evaluating prospects. Large amounts of new information, generated in the last 15 years in response to a renewed focus on gold mining, reinforces the fact that there is a wide diversity in gold deposit types. There is a need to summarize such information and, more importantly, to attempt to synthesize it into a coherent classification of gold deposits. The purpose of this paper therefore is to present a summary of the geological attributes of commonly recognized types of bedrock gold deposits and to present a workable geological classification, highlighting the role of geochemistry in determining each of the deposit types.

The development of a simple classification scheme for gold deposits, as presented here, has been approached with a full appreciation that there are many difficulties associated with classification of ore deposits in general. In the case of lode gold deposits, contrasting classifications and nomenclatures have been arrived at historically depending on whether they were approached from genetic, geochemical, economic or tectonic points of view (Emmons, 1937; Boyle, 1979; Cox and Singer, 1986; Bache, 1987). In addition, several classification schemes have been developed for subsets of gold deposits such as those considered to be epithermal (Heald *et al.*, 1987), intrusion-related (Sillitoe, 1991), bulk-mineable (Bonham, 1989) or epigenetic Archean (Gebre-Mariam *et al.*, 1995). These have provided additional points of view and expanded the nomenclature surrounding the problem of gold deposit classification.

Geological classification of lode gold deposits is further complicated by the following factors:

1. A significant number of large deposits are the results of superposition of two or more systems, or of superposition of distinct components of hydrothermal systems due to telescoping (Sillitoe, 1994): this can lead to apparently hybrid deposit types.
2. Different geological environments are also commonly superimposed upon one another. For example, continental arcs commonly are found superimposed on miogeoclines of mainly sedimentary origin or older accreted arcs of mainly volcanic origin, making it difficult to determine which geological features are directly related to deposits and which are coincidental.
3. Geological attributes used to discriminate among deposit types should also be as diagnostic as possible to allow adequate classification of deposits that have been deformed and metamorphosed in distinction to deposits that simply occur in deformed and metamorphosed rocks. This is a particularly acute problem for deposits in Precambrian terranes.

The above caveats notwithstanding, the classification scheme proposed here is first and foremost geological in scope. It is based mainly, but not exclusively, on the nature and mesoscopic attributes of the mineralization and on the geological settings of the deposits, in large part following the approaches of other workers. Genetic connotations are secondary and many of the different deposits types described here may have formed by similar processes operating in different settings. In addition, many deposits are appear to be hybrid in that they possess, to different degrees, characteristics of more than one deposit type. Accordingly the proposed classification scheme should not be viewed

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Table 1: ***Commonly recognized types of lode gold deposits and their main geological attributes.***

	Deposit Type	Type Example	Selected Examples World; Canadian	Geological Setting	Form of Mineralization
1	Paleoplacer	Witwatersrand (S. Africa)	Tarkwa (Ghana), Jacobina (Brazil); rare: Huronian (ON), Sakami (QC)	Mature fluviatile to deltaic facies rocks in extensive cratonic sedimentary basins	Pyrite-bearing quartz-pebble conglomerate and quartz arenite
2	Submarine gold-rich massive sulphide	Boliden (Sweden)	Mt. Lyell & Mt. Morgan (Australia), Horne, Bousquet, Agnico-Eagle (QC), Eskay Creek (BC)	Mixed volcanic, volcaniclastic and sedimentary sequences in greenstone belts	Banded and stratiform massive sulphide lenses and adjacent stockwork zones
3	Hot spring	McLaughlin (California)	Hasbrouk Mountain, Buckskin Mountain (Nevada), Cherry Hill, Champagne Pool (New Zealand); Cinola (BC)	Subaerial mafic and felsic volcanic centers and associated epiclastic rocks in volcano-plutonic belts	Disseminated sulphides in silicified and brecciated rocks; underlying quartz veins
4	Adularia-sericite epithermal	Creede (Colorado)	Hishikari (Japan), Cavnic (Romania), Round Mountain (Nevada); Lawyers, Blackdome, Cinola (BC), Skukum (YT)	Subaerial intermediate to felsic volcanic centers and associated subvolcanic intrusions in volcano-plutonic belts	Crustiform-colloform to brecciated quartz-carbonate-adularia veins
5	Alunite-kaolinite epithermal	Goldfield (Nevada)	El Indio (Chile), Pueblo Viejo (Dominican Republic), Nansatsu (Japan); Hope Brook (NF), Equity Silver (BC)	Subaerial intermediate to felsic volcanic centers and associated subvolcanic intrusions in volcano-plutonic belts	Disseminated sulphide in vuggy silica zones, veins, breccias and stockworks
6	Porphyry gold	Lepanto Far South East (Philippines), Lobo (Chile)	Refugio (Chile), Yu-Erya (China), Fort Knox (Alaska); Dublin Gulch (YT), Young-Davidson (ON), Douay, Troilus (QC)	Calc-alkalic to alkalic, subaerial intermediate volcanic centers and associated subvolcanic intrusions in volcano-plutonic belts	Intrusion-hosted (in part) quartz-pyrite stockwork zones
7	Breccia pipe	Kidston (Australia)	Montana Tunnels (Montana), Cripple Creek (Colorado); Sunbeam Kirkland (MB), Chadbourne (QC)	Mafic to felsic volcanic centers and associated subvolcanic intrusions in volcano-plutonic belts	Mineralized discordant breccia bodies
8	Skarn	Fortitude (Nevada)	Red Dome (Australia), Suan (Korea); Hedley & Tillicum (BC), Marn (YT), Akasaba (QC)	Carbonate platform sequences overprinted by volcano-plutonic arcs	Disseminated to massive sulphide lenses and veins cutting skarn
9	Carbonate replacement (manto)	Ruby Hill (Nevada)	Mammoth (Utah); Mosquito Creek-Island Mountain (BC), Ketza River (YT)	Carbonate platform sequences overprinted by volcano-plutonic arcs	Concordant to discordant massive sulphide bodies in carbonate rocks
10	Sediment-hosted micron gold (Carlin-type)	Carlin (Nevada)	Mercur (Utah), Golden Reward (South Dakota), Guizhou (China); possibly Golden Bear (BC), Brewery Creek (YT)	Carbonate and impure carbonate-argillite facies of continental shelves overprinted by volcano-plutonic arcs	Disseminated sulphides in discordant breccia bodies and strata-bound zones
11	Non-carbonate stockwork-disseminated	Porgera (Papua New Guinea)	Andacollo (Chile), Muruntau (Uzbekistan); East Malartic, Beattie (QC), Hemlo(?), Holt-McDermott (ON), QR (BC)	Siliciclastic, turbiditic and volcaniclastic facies in common association with felsic to intermediate stocks and dykes	Stockwork, sheeted vein and disseminated strata-bound to discordant zones
12	Au-Cu sulphide-rich vein	Rossland (British Columbia)	Tennant Creek (Australia); Red Mountain (BC), Mouska, Cooke, Copper Rand, Doyon #3 zone (QC)	High-level intrusions and associated dykes in volcano-plutonic arcs and greenstone belts	Quartz-sulphide veins (>20% sulphide)
13	Batholith-associated quartz vein (Korean type)	Chenoan (Korea)	Linglong (China), Charters Towers (Australia); Zeballos, Surf Inlet (BC), Venus (YT)	Tectonic uplifts containing metamorphic basement rocks and abundant granitoid batholiths	Quartz veins in brittle to brittle-ductile faults
14	Greenstone-hosted quartz-carbonate vein	Mother Lode-Grass Valley (California)	Mt. Charlotte, Norseman, Victory (Australia); Giant (NWT), Contact Lake (SK), San Antonio (MB), Dome, Kerr Addison (ON), Sigma-Lamaque (QC)	Greenstone belts; spatially associated with major fault zones	Quartz-carbonate veins associated with brittle-ductile shear zones
15	Turbidite-hosted quartz-carbonate vein (Bendigo type)	Victoria Goldfields (Australia)	Ashanti (Ghana), Otago (New Zealand); Camlaren (NWT), Little Long Lac (ON), Meguma (NS), Cape Ray (NF)	Deformed turbidite sequences	Quartz-carbonate veins in folds and brittle-ductile shear zones
16	Iron-formation-hosted vein and disseminated (Homestake type)	Homestake (S. Dakota)	Jardine (Montana), Cuiaba (Brazil), Hill 50 (Australia); Lupin (NWT), Farley (MB), Central Patricia and Cockshutt (ON)	Mixed volcanic, volcaniclastic and sedimentary sequences in greenstone belts	Banded strata-bound disseminated to massive sulphide lenses and discordant quartz veins

Table 1: ***Commonly recognized types of lode gold deposits and their main geological attributes (cont'd.)***

	Deposit Type	Associated Alteration	Metal Association	Size & Grade of Deposits	Selected References
1	Paleoplacer	Overprinting sericitization and silicification	Au> Ag; U common; Au:Ag typically 10:1	1-100 Mt of ore @ 1-10 g/t Au; some up to 1000 t Au	Minter (1991)
2	Submarine gold-rich massive sulphide	Sericitization and silicification; common aluminous acid alteration	Ag, Au, Cu, base metals; typically Ag>Au	1-10 Mt of ore @ 3-10 g/t Au and 1-5% base metals	Poulsen and Hannington (1996)
3	Hot spring	Silicification, argillic and advanced argillic alteration; adularia	Au, Ag, Hg,As, Sb, Tl, Ba; locally W; typically Ag>Au; strong vertical zoning	Typically <30 t Au; up to 20 Mt of ore @ 5 g/t Au	Nelson (1988); Bonham (1989); Berger (1985)
4	Adularia-sericite epithermal	Sericite-Illite/Sericite- adularia; silicification; outward propylitic alteration	Au, Ag, As, Sb, Hg ± Pb, Zn, Te; Au:Ag = 1:10 to 1:25; vertical zoning	<100 t Au but some >500 t Au; grades of 2-70 g/t Au	Heald et al. (1987); White and Hedenquist (1995)
5	Alunite-kaolinite epithermal	Silicification and alunite-bearing advanced argillic alteration, grading outward into argillic or propylitic	Au, Ag, As, Cu, Sb, Bi, Hg, Te, Sn Pb; Au:Ag 1:2 to 1:10; metal zoning	10-150 t Au but up to 600 t Au; grades of 1-8 g/t Au, averaging 4-5 g/t	Arribas (1995); Heald et al. (1987); White and Hedenquist (1995)
6	Porphyry gold	K- (±Na-)silicate alteration; common argillic and advanced argillic overprint; hydrothermal magnetite	Au, Cu, Ag ± Bi-Te; Au:Ag>1:1	50-100 t Au, up to 400 t; grades of 0.5-2 g/t Au and <0.8% Cu	Sillitoe (1991)
7	Breccia pipe	Sericite-carbonate alteration; variable silicification	Au, Ag, Pb, Cu, Zn; Au:Ag <1:1	6-60 Mt of ore @ 1-2 g/t Au; some up to 100 t Au	Sillitoe (1991)
8	Skarn	Al-rich prograde skarn assemblages; retrograde alteration common	Au, Ag, As, Bi, Te; Au:Ag variable	1-10 Mt of ore @ 3-10 g/t Au, <1% base metals; <100 t Au	Meinert (1989)
9	Carbonate replacement (manto)	Silicification of limestone; sericitization of clastic rocks	Au, Ag, As, Bi, Hg ± Pb, Cu, Zn; typically Au<Ag	Typically <3 Mt of ore @ 5-20 g/t Au & 1-5% base metals; up to 65 t Au	Sillitoe (1991)
10	Sediment-hosted micron gold (Carlin-type)	Decalcification and silicification of carbonate rocks	Au, Ag, As, Sb, Hg; typically Au<Ag	1-10 Mt of ore @ 1-10 g/t Au; some up to 500 t Au.	Berger and Bagby (1991)
11	Non-carbonate stockwork-disseminated	K-metasomatism (K-spar, roscoelite, biotite) or albite commonly accompanied by carbonate	Cu, As, Bi, Te ± W, F, B	1-20 Mt of ore @ 2-5 g/t Au; some greater than 500 t Au.	Sillitoe (1991)
12	Au-Cu sulphide-rich vein	Sericitization and chloritization	Au, Ag, Cu ± Pb, Zn; typically Au<Ag	Mostly <5 Mt of ore at 3-15 g/t Au; some >100 t Au	Fyles (1984)
13	Batholith-associated quartz vein (Korean type)	Sericitization and chloritization	Au, Ag ± Cu, Pb, Zn; Au:Ag variable	1-10 Mt of ore @ 1-10 g/t Au	Shelton et al. (1988)
14	Greenstone-hosted quartz-carbonate vein	Carbonatization and sericitization	Au, Ag, W, B ± As, Mo; Au:Ag = 5:1 to 10:1; no vertical zoning	1-10 Mt of ore @ 5-10 g/t Au; mostly 25-100 t Au, but many >250 t Au	Knopf (1929)
15	Turbidite-hosted quartz-carbonate vein (Bendigo type)	Minor sericitization and silicification	Au, Ag, As ± W; Au:Ag = 5:1 to 10:1	Mostly <5 Mt or ore @ 6-15 g/t Au; some >500 t Au	Boyle (1986); Cox *et al.* (1991)
16	Iron-formation-hosted vein and disseminated (Homestake type)	Sulphidation of pre-existing iron-formation facies; chlorite-carbonate alteration	Au, Ag, As Au:Ag = 5:1 to 10:1	1-10 Mt of ore @ 3-20 g/t Au; some >500 t Au	Caddy *et al.* (1991)

rigidly as a means of pigeon-holing all gold deposits. It is rather intended to illustrate the diversity of types of lode gold deposits that can be encountered in a particular geological environment and to provide a means of identifying unusual deposits that are not readily classifiable using the present scheme.

GOLD DEPOSIT TYPES

An appraisal of existing classification schemes suggests that there are at least 16 globally recognized types of lode gold deposits. Their main geological attributes are presented in Table 1. An analysis of this table shows that the combination of geological environment, nature of the mineralization, and hydrothermal alteration is unique for almost every deposit type. These geological attributes of deposits therefore represent three important discriminating criteria to be used in the development of a classification scheme.

The different deposit types are thought to have formed in a variety of geological environments over a wide range of crustal depths as illustrated in Figure 1. Most of those thought to have formed at shallow to moderately deep crustal levels are commonly considered to be components (proximal to distal) of larger intrusion-centered systems (Sillitoe, 1991). Such deposits have formed at convergent plate margins during plutonism and volcanism marking stages of magmatic continental and island arc development. Deposits formed at deeper crustal levels (Figure 1) are also generally considered to have formed at convergent plate margins, but during deformation related to accretion and collision (Kerrich and Cassidy, 1994; Hodgson, 1993). Most of the common categories of lode gold deposits have at least one known world-class example containing more than 100 tonnes of gold (Table 1) and, in some cases, giant deposits lend their names to an entire class (e.g., Carlin-type or Homestake-type), leading to alternative methods of naming many of the important deposit types.

The following pages contain brief descriptions and discussions of each deposit type based on our own observations and a review of selected literature. Because of the nomenclature problems highlighted above, each deposit type is identified by a simple descriptive term accompanied by alternate names or by the names of generally accepted type examples (Table 1). The deposits are numbered below to correspond to those used in Table 1 and in Figures 1 and 2.

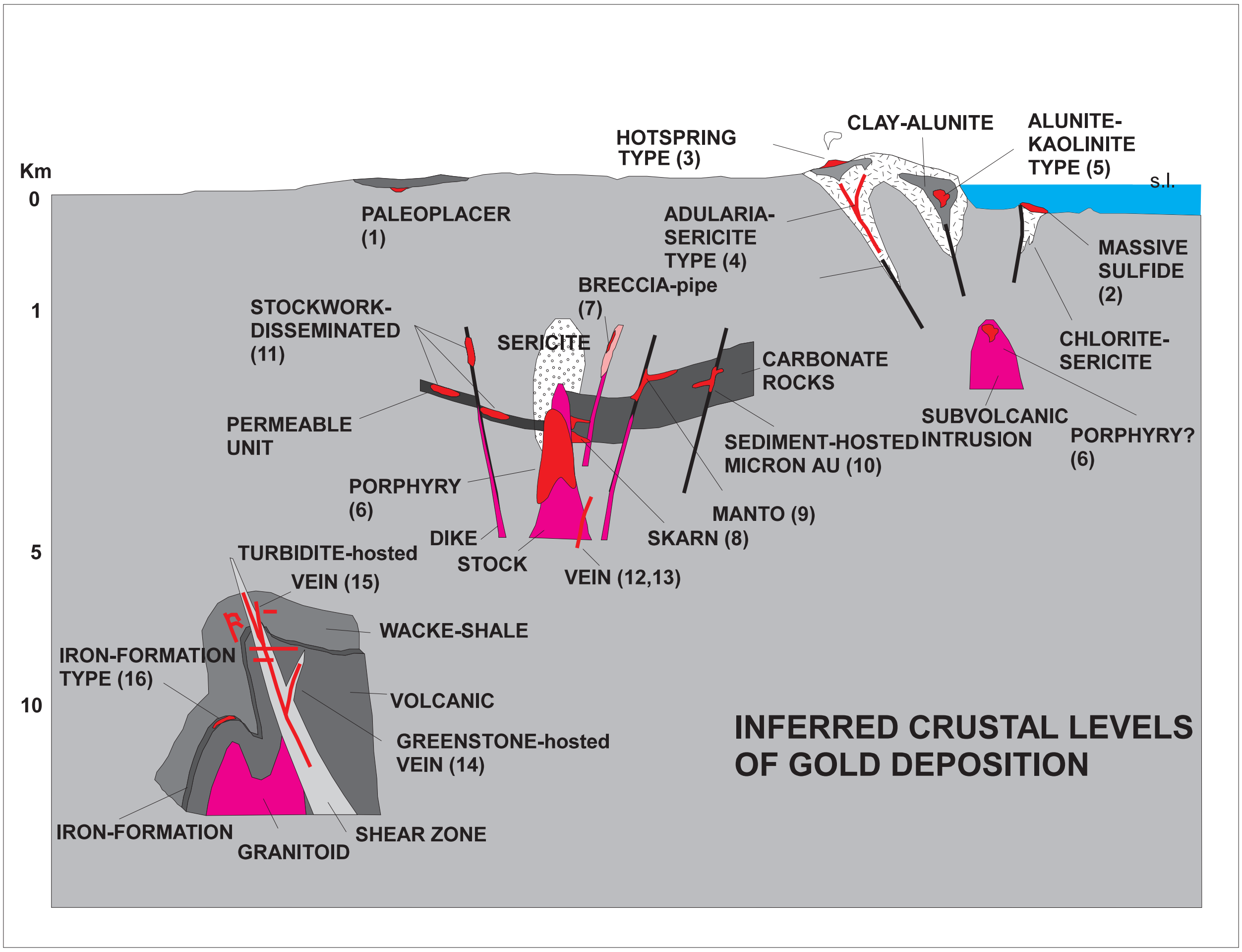

Figure 1: *Schematic representation of the crustal levels inferred for gold deposition for commonly recognized deposit types. The depth scale is approximate and logarithmic and numbers beside named deposit types coincide with those used in the text, Figure 2 and Table 1.*

Paleoplacer deposits (1)

Paleoplacer deposits such as those of the Witwatersrand consist of stratiform layers (bankets) of auriferous quartz-pebble conglomerate, pebbly quartz arenite and cross-bedded arenite, with gold locally enriched in thin carbonaceous seams. The deposits occur in mature fluviatile to deltaic facies rocks in extensive cratonic sedimentary basins. The most significant deposits of this type occur in Late Archean and Early Proterozoic sedimentary basins, perhaps reflecting an important control by an oxygen-poor atmosphere.

The ore and associated minerals consist of native gold and pyrite, in most cases of detrital origin, and of the heavy minerals magnetite, uraninite, ilmenite and locally hematite. The ores are typically gold-rich relative to silver (Au:Ag = 10:1). Hydrothermal alteration, mainly sericitization and chloritization, overprints some deposits and may have locally re-distributed gold. In addition, pyrite in some deposits is paragenetically late and may result from sulphidation of detrital oxide grains. Neverthless, the detailed distribution of gold is controlled by primary sedimentary facies variations.

Submarine gold-rich massive sulphide deposits (2)

These deposits, as exemplified by Horne and Boliden, consist of banded and stratiform massive lenses and adjacent stockwork zones but significant syntectonic sulphide veins are also present in deformed and metamorphosed deposits. The deposits occur in mixed submarine volcanic, volcaniclastic and sedimentary sequences in greenstone belts of all ages, typically metamorphosed to greenschist and lower amphibolite facies. They are distinguished from other massive sulphide deposits in that gold concentrations in parts per million (ppm) exceed the percentage of combined base metals. Mineralization is composed mainly of pyrite and base metal sulphides, but commonly contains complex high-sulphidation assemblages including minor phases such as bornite, sulphosalts, arsenopyrite and tellurides. Ore contains considerable iron, variable amounts of Cu, Pb, and Zn and has locally high concentrations of As, Sb, Hg. Silver content generally exceeds that of gold (Au:Ag = 1:2 to 1:10).

The deposits occur in districts containing subvolcanic intrusions and other massive sulphide deposits that contain proportionately less gold. They are hosted mostly by felsic volcanic tuffs and derived schist, near their interface with basalt or sedimentary strata. The host rocks are typically sericitized and chloritized, and some deposits are enveloped by zones of aluminous alteration resulting from extreme alkali depletion. The latter may be another distinguishing feature of gold-rich massive sulphides and is thought to result from boiling of ore-forming fluids (Hannington, 1994; Sillitoe *et al.*, 1996). This further suggests that shallow water sequences showing transition to subaerial conditions may be more favourable than other massive sulphide environments (Sillitoe *et al.*, 1996).

Hot spring deposits (3)

Hot spring deposits like McLaughlin contain siliceous sinter and geyserite formed at the paleosurface but also include funnel-shaped hydrothermal and tectonic breccias and quartz stockworks narrowing at depth into structurally controlled feeder zones. These deposits occur in belts of subaerial mafic and felsic volcanic centres and intervening clastic sedimentary rocks in subduction-related arc settings. They are mainly recognized in young volcanic belts but, perhaps due to their poor degree of preservation, are not known to exist widely in older, deformed terranes. Nonetheless, some Paleozoic examples have been reported (Cuneen and Sillitoe, 1989).

Mineralization is generally hosted by vent and hydrothermal breccias in volcanic, volcaniclastic or sedimentary rocks, as well as by subvolcanic porphyritic intrusions. It consists of micron-scale gold and electrum in zones of massive silicification, less commonly in sinters which are nonetheless defining features, and in crustiform banded quartz, chalcedony ± adularia and barite + carbonate veins and stockwork zones. Mineralization typically contains up to 5% pyrite ± marcasite, pyrrhotite, cinnabar, stibnite, realgar or arsenopyrite and tellurides, with elevated concentrations Hg, As, Sb, Tl, Ba and locally Mo and W. It displays a characteristic steep vertical metal zoning with near-surface enrichments in Au, Hg, Sb, Tl, and As and with increasing Ag and Ba content with depth (Au:Ag from 1:1 near surface to 1:30 at depth). Associated alteration consists of massive silicification and adularization of breccia zones, grading outward into advanced argillic and argillic alteration zones, and downward into narrower zones of adularia along vein margins and as replacements along hydrothermal conduits. These deposits are thought to represent the paleosurface expressions of deeper adularia-sericite deposits (Figure 1).

Adularia-sericite epithermal deposits (4)

These deposits, also referred to as low-sulphidation epithermal deposits, consist of subvertical banded and breccia veins of quartz and chalcedony with associated irregular stockwork and hydrothermal breccia zones and less common disseminations. They occur in volcano-plutonic continental and island arcs at convergent plate margins, in association with subaerial intermediate to felsic calc-alkalic volcanic centres and related subvolcanic porphyritic intrusions or, less commonly, with alkalic-shoshonitic igneous rocks and related sedimentary rocks. The deposits are hosted by extensional or transcurrent structures and are commonly associated with calderas as in the case of Creede. They commonly occur immediately above basement to the host volcanics but also in basement lithologies, and relatively impermeable rock types play an important role in fluid ponding in some deposits. Most significant deposits of this type are Cenozoic in age.

Veins and hydrothermal breccias consist of crustiform chalcedonic quartz, adularia and Mn-carbonate with pyrite, electrum, high-Fe sphalerite, arsenopyrite, silver-sulphides and sulphosalts. The associated metals include Au, Ag, As, Sb, Hg, Pb, Zn, and Cu, and mineralization is typically vertically zoned and grades downward over distances of hundreds of metres into precious-metal-poor, base-metal-rich (Zn, Pb, Cu) ores. Mineralization is either base-metal poor with Au:Ag = 10:1 to 1:10, or base-metal-rich with Au:Ag <1:25. Hydrothermal alteration grades outward from silicification and sericite-illite/smectite assemblages ± fine-grained adularia near the veins to a broader external zone of propylitic alteration.

Alunite-kaolinite epithermal deposits (5)

These deposits, also known as high-sulphidation or acid-sulphate types, consist of disseminated and replacement mineralization in irregular strata-bound to mushroom-shaped discordant vuggy silica replacement zones and less common hydrothermal breccias, stockworks and veins. They are associated with subaerial, calc-alkaline andesite to rhyodacite volcanic centers and related subvolcanic porphyritic intrusions and sediments in volcano-plutonic arcs at convergent plate margins of all ages. The deposits are hosted by volcanic dome-vent complexes, maar diatreme and clastic sedimentary rocks above basement, or by underlying basement lithologies, in association with regional normal and transcurrent faults or with diatreme ring faults. Most deposits such as Goldfield are Cenozoic in age, with a few Mesozoic to Precambrian examples.

Mineralization commonly consists of "high sulphidation" assemblages including phases such as pyrite, enargite-luzonite, chalcopyrite, tennantite-tetrahedrite and gold in a gangue of massive or vuggy silica or of quartz ± alunite in veins and breccias. This ore assemblage commonly occurs within, and overprints, the core of zones of massive silicification, above or grading outward into advanced argillic, argillic and/or propylitic alteration zones which are hallmarks of deposits of this type. The Au:Ag ratios of the ore range from 1:2 to 1:10, and associated metals include As, Cu, Sb and Bi and locally Hg, Pb, Te and Sn. The deposits have limited vertical extent (<500 m) and lack significant vertical zoning. They commonly occur above porphyry Cu or Cu-Au systems.

Porphyry gold deposits (6)

Porphyry Au and Au-Cu deposits are irregular to pipe-like zones of quartz-sulphide stockwork and associated sulphide disseminations confined to intrusions and their immediate wall rocks. They occur in volcano-plutonic belts (including greenstone belts) in continental or island arc settings, overlying a wide range of basement lithologies. The deposits are associated with composite stocks of calc-alkaline (diorite, granodiorite, quartz-monzonite) and alkaline (monzonite, quartz syenite) compositions, with locally preserved remnants of coeval volcanic rocks. The quartz stockworks are less well developed in deposits associated with alkalic intrusions.

Pyrite is the dominant sulphide mineral; its abundance ranges from 1–3 vol.% in the ore zone to 5–10 vol.% outside, and it is accompanied by up to 20 vol.% hydrothermal magnetite ± hematite either in the stockwork or as wallrock disseminations. Ore typically contains more silver than gold (Au:Ag <1), and associated metals include Cu, Bi, Te, ± Mo. Mineralization is coincident with K-silicate alteration, or albite and calc-silicate alteration in alkalic systems, in most cases grading outward into large zones of propylitic alteration. In some deposits, argillic or advanced argillic alteration overprints part, or most, of K-silicate alteration.

Breccia pipe deposits (7)

Such deposits, as represented by Kidston, consist of mineralized funnel-shaped, pipe-like, discordant breccia bodies and sheeted fracture zones in mafic to felsic calc-alkaline volcanic environments in volcano-plutonic arcs and greenstone belts. They are controlled by graben faults and ring complexes related to cauldron development. Ore is hosted by a variety of breccia types, including magmatic-hydrothermal, phreatomagmatic, hydraulic and collapse varieties. Breccia cement consists dominantly of quartz, carbonate (calcite, ankerite, siderite), with specularite and tourmaline at some deposits. The ore contains pyrite, chalcopyrite, sphalerite, galena, and pyrrhotite, with minor molybdenite, bismuthinite, telluro-bismuthite and tetrahedrite, which occur either in the matrix or in rock fragments. Ore is silver-rich (Au:Ag = 1:10), with associated Pb, Zn, Cu ± Mo, Mn, Bi, Te, W), and a lateral (concentric) metal zoning is present at some deposits. A sericite-quartz-carbonate-pyrite alteration assemblage and variably developed silicification is coincident with the ore zones grading outward into propylitic alteration. An early stage K-silicate alteration is present at some deposits. Breccia pipe deposits are commonly associated with intrusion-related hydrothermal systems.

Skarn gold deposits (8)

Skarn deposits, as exemplified by Hedley, consist of disseminated to massive sulphide lenses and crosscutting veins in carbonate platform sequences superimposed by volcanic and/or plutonic arcs. Mineralization is associated with Al-rich garnet-pyroxene skarn assemblages replacing limestone, calcareous siltstone and carbonatized volcanic rocks adjacent to diorite or granodiorite stocks, dykes or sills. They occur in some districts along with porphyry Cu-Mo mineralization and tend to be associated with more mafic, hotter intrusions.

Ore bodies are composed of pyrite, pyrrhotite, arsenopyrite and lesser telluride minerals. Ores contain locally high concentrations of As, Bi, and Te, and show wide variations in their gold to silver ratios (Au:Ag = 1:10 to 10:1). Retrogression of prograde skarn assemblages is common and gold mineralization is considered to be related to such retrogression.

Carbonate replacement (manto) deposits (9)

Carbonate replacement deposits like those at Ruby Hill, Nevada consist of discordant pipes or tabular concordant bodies of massive sulphides replacing limestone or dolostone beds, commonly interlayered with calcareous quartzite, quartzite and phyllite. They occur in continental platform carbonate sedimentary sequences superimposed by volcano-plutonic arcs. The deposits occur close to a "marble front" related to nearby intrusions, represented in some cases only by dioritic sills and dykes, but they are in many cases remote from intrusive rocks. Fault intersections are important in localizing discordant mineralized pipes.

Ore bodies are composed largely of pyrite, and may contain variable amounts of pyrrhotite, galena, sphalerite, chalcopyrite, magnetite and arsenopyrite. The ores are typically silver-rich (Au:Ag < 1), with elevated concentrations of As, Bi, Hg, and they may contain several percent of combined Pb, Zn and Cu. Associated hydrothermal alteration is generally restricted to the immediate vicinity of the ore bodies and consists of silicification of carbonate rocks and sericitization of adjacent clastic sedimentary rocks.

Sediment-hosted micron gold deposits (10)

These deposits, also referred to as "Carlin-type" deposits, are irregular discordant breccia bodies and concordant strata-bound disseminated zones confined to particular stratigraphic units. They occur in carbonate and impure carbonate-argillite facies of continental platforms and shelves that have been overprinted by regional thrusting, extensional faulting and felsic plutonism. The deposits are hosted mostly by impure carbonate rocks of Paleozoic age, but also by clastic sedimentary rocks, greenstones and rarely granitoid stocks. They commonly occur near hornfels, skarn or calc-silicate rocks, but typically outward from the edge of contact metamorphic aureoles. They coexist regionally with Cu and/or Mo porphyry, Cu or W-Mo skarn and Ag-Pb-Zn vein and manto deposits.

Mineralization consists of disseminated very fine-grained pyrite overgrown by arsenian pyrite rims containing sub-micron grain-size gold inclusions. Orpiment, realgar, cinnabar and stibnite are common accessory minerals at the deposit scale. The Au:Ag ratios of the ores are highly variable but typically less than one, and the ores contain locally high concentrations of As, Sb and Hg. Decalcification and silicification (jasperoid) of carbonate rocks are typically associated with ore, and may be enveloped by zones of argillic and sericitic alteration.

Non-carbonate stockwork-disseminated gold deposits (11)

This poorly defined group of deposits, which includes Porgera, Muruntau and perhaps Hemlo, consists of discordant to strata-bound stockwork and disseminated sulphide zones along faults, permeable units and lithologic contacts (including intrusive contacts) in miogeoclinal siliciclastic and volcaniclastic sequences in volcano-plutonic arcs in oceanic and continental settings. The deposits are hosted mostly by supracrustal rocks, but in cases where felsic sills, dykes and stocks are present, the ore may also occur within and along the contacts of intrusions.

Disseminated sulphides (1–20 vol.%) are mostly pyrite, with lesser amounts of chalcopyrite and arsenopyrite, accompanied by hematite, magnetite, molybdenite, tellurides and anhydrite in some deposits. Ores have variable but generally gold-rich compositions (Au:Ag > 1) and contain elevated concentrations of Cu, As, Bi, Te ± W, F, B and locally, Mo, Sb and Ba. Associated alteration involves K-metasomatism (sericite or roscoelite, biotite or K– feldspar) and / or Na metasomatism (albite), accompanied by carbonatization and, in some deposits, silicification.

Au-Cu sulphide-rich vein deposits (12)

These deposits consist of groups of sulphide-rich veins (>20 vol.% sulphides), up to several hundred metres in strike lengths, in volcano-plutonic arcs and greenstone belts of all ages. As in the case of Rossland, they occur in faults and fractures hosted by a wide variety of volcanic and intrusive rocks; individual veins commonly follow dykes of dioritic, tonalitic or lamprophyric composition. In many cases, there is a marked structural control by regional fault systems.

The veins consists of variable proportions of pyrite, pyrrhotite, chalcopyrite and magnetite, with subordinate amounts of sphalerite and galena, in a gangue of quartz and carbonate with lesser amounts of chlorite and sericite. The veins typically contain more silver than gold (Au:Ag = 1:2 to 1:5) and 0.5–3% Cu. The associated hydrothermal alteration consists of chloritization and sericitization and is generally restricted to the immediate vicinity of the veins.

Batholith-associated quartz vein deposits (13)

These deposits, including Chenoan and Linglong, consist of quartz veins in brittle ± ductile faults and adjacent crushed altered wallrocks and veinlet zones in tectonic uplifts containing metamorphic basement and abundant granitoid rocks. Ore bodies are hosted both by granitoid batholiths and adjacent medium- to high-grade schists and gneisses. Deposits are controlled by regional fault systems and form extensive districts that locally contain porphyry and epithermal styles of mineralization as well. Veins consist of small amounts of pyrite and minor base metal sulphides and stibnite in some cases, in a gangue of quartz and minor calcite. The ores contain nearly equal abundances of gold and silver (Au:Ag = 1:5 to 5:1) and locally high concentrations of Cu, Pb, Zn. Hydrothermal alteration consists of sericitization and chloritization of wallrocks, generally within a few metres from the veins.

Greenstone-hosted quartz-carbonate vein deposits (14)

Deposits of this group, typified by the Mother Lode and Grass Valley and including many important Precambrian examples, consist of quartz-carbonate veins in moderately to steeply dipping brittle-ductile shear zones and locally in related shallow-dipping extensional fractures. They are commonly distributed along major fault zones in deformed greenstone terranes of all ages. Veins have strike- and dip-lengths of 100 to 1000 m either singly or, more typically, in complex vein networks. They are hosted by a wide variety of lithologies but there are district-specific lithologic associations.

The veins are dominated by quartz and carbonate, with lesser amounts of chlorite, scheelite, tourmaline and native gold; pyrite, chalcopyrite and pyrrhotite comprise less than 10 vol.% of the veins. The ores are gold-rich (Au:Ag = 5:1 to 10:1) and have elevated concentrations of As, W, B, and Mo, with very low base metal concentrations. Despite their significant vertical extent (commonly > 1 km), the deposits lack any clear vertical mineral zoning. Wallrock alteration haloes are zoned and consist of carbonatization, sericitization and pyritization. Halo dimensions vary with the composition of the host lithologies and may envelope entire deposits in mafic and ultramafic rocks.

Turbidite-hosted quartz-carbonate vein deposits (15)

These deposits consist of veins and vein arrays in folds (saddle reefs), faults and brittle-ductile shear zones in turbidite sequences of all ages, deformed and metamorphosed to lower to upper greenschist facies. Graphitic schists in such sequences are particularly favourable hosts, and intrusive rocks are generally lacking within and immediately around the deposits. The deposits are commonly associated with anticlines and related limb-thrust faults as exemplified by Bendigo and Ballarat. Veins consist of quartz and carbonate, with lesser amounts of chlorite and sericite; arsenopyrite and pyrite typically comprise less than 10 vol.% of the veins. The ores are gold-rich (Au:Ag > 5) and contain elevated concentrations of As and W. Wallrock alteration, in the form of sericitization and some silicification, is generally restricted to the immediate vicinity of the vein.

Iron-formation-hosted vein and disseminated deposits (16)

This class of deposits consists of strata-bound, disseminated to massive sulphide lenses and discordant quartz veins in folded iron formation. Also commonly termed "Homestake-type" deposits, they occur in mixed volcanic, volcaniclastic and sedimentary sequences in greenstone belts of all ages, typically metamorphosed to greenschist to lower amphibolite facies. Host rocks are oxide, carbonate and sulphide facies iron formation, commonly at or near a volcanic-sedimentary contact. The deposits occur in regionally extensive banded iron formation at local sites of structural complexity such as fold hinges and discordant shear zones. Strata-bound sulphide lenses consist of pyrite, pyrrhotite, arsenopyrite and native gold. Gold is more abundant in the ore than silver (Au:Ag = 5:1 to 10:1) and typically correlates positively with As. Sulphidation of pre-existing iron-formation facies is most common adjacent to quartz veins, and chloritic and carbonate alteration form distal envelopes at some deposits.

PROPOSED CLASSIFICATION SCHEME

Subdivision of gold deposits into the types described above has developed historically from several sources and has not necessarily resulted from a single systematic attempt at classification. Furthermore, the listing of deposit types along with their characteristics does not really constitute a classification in itself. One might therefore ask whether there are logical steps to be followed in assessing a deposit as being of one type to the exclusion of another. There are recurring parameters that geologists have used for decades in their attempts to do this. These include geological environment, host rocks, mineralization types and hydrothermal signatures as expressed by ore and alteration mineralogy and chemistry (e.g., Boyle, 1979; Cox and Singer, 1986; Bache, 1987; Heald *et al.*, 1987). The use of these parameters to construct a classification scheme is also warranted by the observation that their various combinations are distinctive for nearly all gold deposit types, as illustrated above. These parameters have therefore been used to construct the logical decision

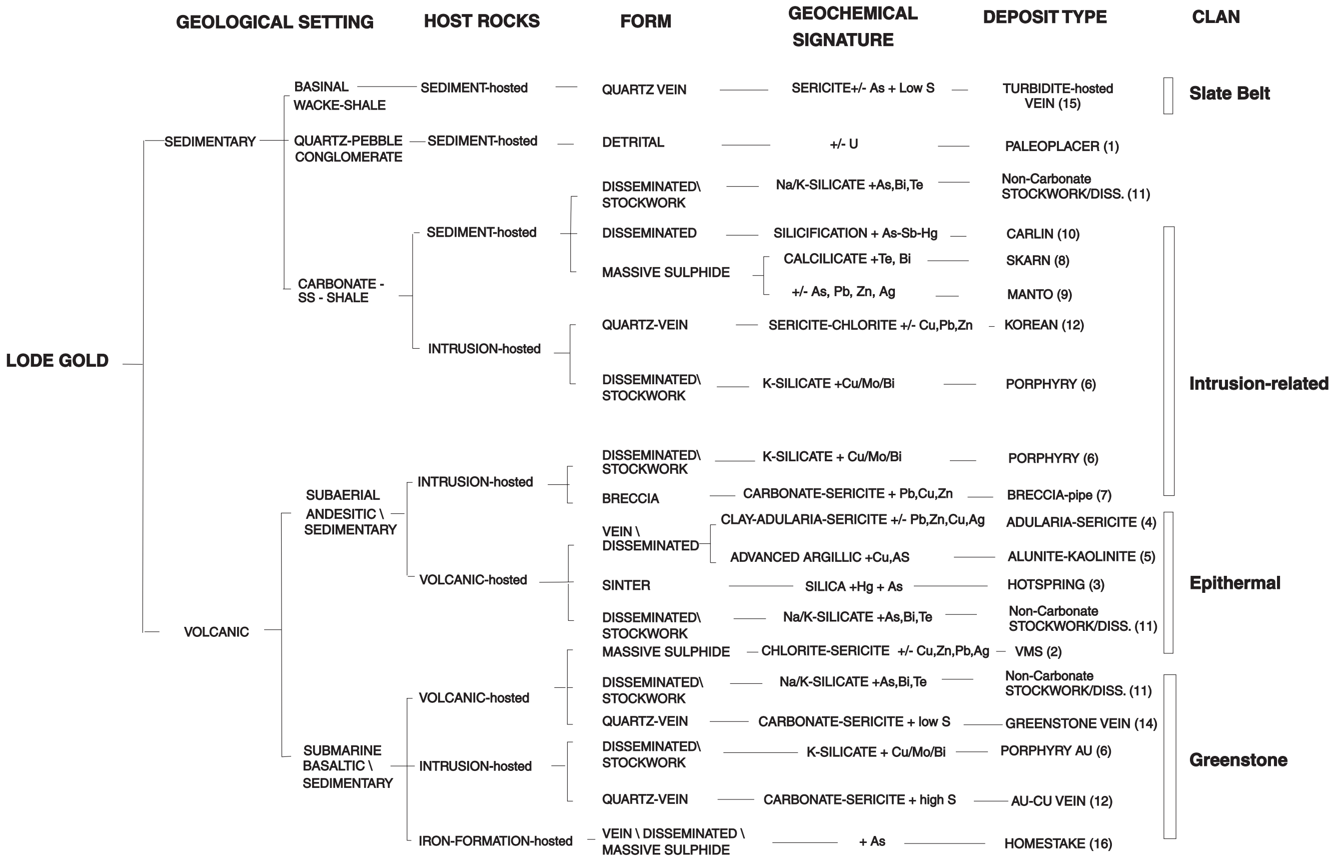

Figure 2: *Classification chart or "decision tree" illustrating how the common deposit types can be distinguished from one another by a consideration of geological setting, host rocks, form of mineralization and geochemical signature. Numbers in parentheses beside deposit types correspond to those used in the text, Figure 1 and Table 1.*

tree illustrated in Figure 2. This chart provides a coherent method of distinguishing the globally recognized deposit types from one another using practical information which is generally at hand or easily obtainable, even at early stages of prospect evaluation. It should be noted that this is only one of several ways of rationalizing the various deposit types but the chart does illustrate the point that the historical classification of gold deposits is much less a random process than it might at first appear. The decision tree illustrated in Figure 2 relies on four main parameters, each considered in detail below: geological setting, host rocks, style of mineralization and geochemical signature.

Geological setting

Supracrustal rocks in and around a deposit will mainly be volcanic or sedimentary, and normally can be assigned to a major tectonic environment. For supracrustal sequences that are dominantly sedimentary, the decision is whether the rocks are composed mainly of basinal wacke and shale, of mature arenite and quartz-pebble conglomerate, or of shallow-water carbonate, sandstone and shale. These correspond broadly, in turn, to marginal basins, intracratonic basins and continental miogeoclines. For supracrustal sequences that are dominantly volcanic, the two main possibilities are that they are subaerial, commonly andesitic to dacitic flow domes and volcaniclastic rocks and related sedimentary units or that they are mainly submarine, commonly basaltic to rhyolitic volcanic rocks and derived sediments. These two volcanic environments can be normally distinguished from one another by the volcanic and sedimentary facies that predominate. In younger terranes, these two alternatives correspond broadly to continental volcanic arcs and oceanic island arcs, respectively, whereas ancient “greenstone” terranes are thought to be mainly of the second type.

Host rocks

The question of the main host rock for ore is relatively straightforward. Intrusions in one form or another are ubiquitous features in and around gold deposits. Is the gold deposit in question hosted mainly by an intrusion or by supracrustal rocks? In most cases this is a relatively easy decision but in some cases both intrusion and country rock host mineralization and a choice must be made, either in favour of the dominant host or of two alternate paths that can be followed simultaneously to allow other parameters to assist in the decision-making process.

Form

The form of mineralization similarly is an important variable that needs careful consideration. This is one of the most accepted criteria used by economic geologists and typically involves a decision whether ore bodies are discordant, strata-bound or stratiform and whether, at the mesoscopic scale, ore can be classified as being of vein, stockwork, breccia, disseminated sulphide or massive sulphide in type. This is a decision that is relatively easy in undeformed deposits but which can be ambiguous in deposits that are strongly deformed.

Geochemical signature

The hydrothermal signature of the deposit as expressed by chemical composition and mineralogy of both ore and hydrothermal alteration products is the last major parameter to be considered. This includes both major constituents as expressed mineralogically and trace elements which may be minor but critical components of hydrothermal products. Ideally, this should be one of the most diagnostic parameters available and in some cases it is: for example, the combination of “high sulphidation” mineral assemblages involving enargite and “advanced argillic” alteration assemblages including alunite, kaolite and/or pyrophyllite directly point to alunite-kaolinite-type epithermal gold deposits. Classical treatments of gold deposits (e.g., Emmons, 1937) emphasized that variations in ore and gangue mineral species in gold deposits were a reflection of lateral and vertical zoning and hence, to some degree, of deposit type. Accordingly, minerals such as arsenopyrite and pyrrhotite distinguished “mesothermal” and “hypothermal” deposits from “epithermal” ones, and minerals such as tourmaline and scheelite were used to further distinguish the “hypothermal” deposits from the mesothermal ones. The use of such mineralogical distinctions is hampered however by the fact that ore mineral assemblages are commonly thought to not only be a reflection of fluid composition and intensive variables but also a reflection of the degree of buffering by host rocks. In this sense minerals such as arsenopyrite tend to occur in several deposit types found in sedimentary environments and minerals such as scheelite tend to indicate felsic intrusive host rocks. Similarly, most hydrothermal alteration assemblages result from a combination of original fluid composition and the degree of rock buffering: in some cases (e.g., advanced argillic) alteration is so fluid-dominated as to be diagnostic whereas in others (e.g., carbonatization) rock composition dictates alteration mineralogy and chemistry to a greater degree. Further difficulties in relying strictly on alteration as a diagnostic criterion are encountered in metamorphic terranes where hydrothermal alteration assemblages are indistinguishable from regional ones (e.g., propylitic assemblages in the greenschist facies) or are reconstituted into new assemblages (e.g., amphibolite facies).

DISCUSSION

The proposed decision tree (Figure 2) can be used beyond the simple classification of deposit types to illustrate several important aspects of gold deposits and the problems associated with their classification. It also illustrates the diverse geochemical suites that are commonly found in association with gold.

One well-known feature of gold deposits is their occurrence in spatially and genetically related groups, i.e., “clans”, in part distinguished from one another by a distinct crustal level inferred for gold deposition (Figure 1). Deposit types are likewise naturally arranged into similar “clans” on Figure 2, on the basis of the tectonic environments represented by their host rocks. Thus terms such as “intrusion-related”, “epithermal”, “greenstone gold” all retain a meaning in that they refer to a group of deposit types, possibly genetically related, that reflect a particular environment or crustal level of gold deposition. This point has been made by Cox and Singer (1986) to show the correlation of tectonic-geological environments and deposit models. This has value in resource assessment where one tries to predict the likelihood of occurrence of deposit type using a knowledge of geological environments but conversely, certain clans of deposits may be used as indicators of particular geological environments.

There is an element of transition from clan to clan and from deposit type to deposit type which is also taken into account in Figure 2. Thus the "intrusion-related" and "epithermal" clans merge from one to another in that these are groups of deposits that commonly occur in similar environments and which some workers also believe to be genetically related. Similarly, subaerial "epithermal" deposits are placed in transition to submarine gold-rich volcanogenic massive sulphide deposits (Hannington, 1994; Sillitoe *et al.*, 1996). Note also that deposits on the bottom of the chart (the "greenstone" clan) have well-known similarities to those on the top (the "slate belt" clan): in this case, it may be useful to view the chart in a cylindrical form with top and bottom edges joined.

Although there is an ideal correlation between environments and deposit types illustrated in Figure 2, there are some deposit types that can occur across environments. A good example is afforded by porphyry deposits (also skarns?) which are well known to occur in both (mainly submarine) island arc and (mainly subaerial) continental arc environments.

Note that all deposit types do not classify to the same level in the chart. For example, for most workers, "Homestake-type" deposits are distinguished simply by their iron-formation host whereas a "porphyry-type" deposit can really be identified, not only on basis of the host rock, but also on the form of mineralization and on the type of hydrothermal alteration.

There also is not always a need to use the chart (Figure 2) from left to right. As noted above, some deposits, such as the alunite-kaolinite type, are identified mainly by one parameter, hydrothermal signature, and there is less need to establish all of the other parameters. Furthermore, all parameters relating to a deposit may not be understood at a point in time, yet the chart may still be used to narrow down the number of alternatives. In particular, simple observable parameters such as host rock and form can considerably narrow the possibilities and direct an observer to search for manifestations of those parameters (either left or right in the chart) that would allow further distinctions to be made. Note however that post-ore deformation may substantially modify the form of mineralization in which case an understanding of chronological relationships between ore and deformation may be essential to correctly classify a deposit.

Finally, there is no need to force a deposit into a particular category using this chart. The decision branches illustrated in Figure 2 are but a few of many possible alternatives for each parameter. It is fully acceptable to add extra branches that will lead to potentially new deposit types or to individual atypical deposits. In addition, it is fully accepted that some deposits classify as being of more than one type in that the existence of transitional deposit types, such those found between the epithermal and porphyry environments, has been proposed by several workers (Giggenbach, 1992; Panteleyev, 1996).

The above analysis confirms the geological diversity of gold deposits. Likewise, their attendant geochemical diversity appears to be as much a function of host-rock environment as of the nature of hydrothermal fluids. Although certain elemental combinations such as Cu-Pb-Zn, As-Sb-Hg or Bi-Te-W show up with some regularity within deposits of a particular type (Table 1), it is probable that, unless they are products of fluid-dominated hydrothermal systems, they are mainly reflections of volcanic, sedimentary and intrusive environments, respectively. For this reason one might expect that deposit classifications that rely solely on particular elemental combinations could be at odds with ones that emphasize geological parameters. This leads to the ultimate question as to how "pathfinder" suites of elements are used in gold exploration.

The above analysis of gold deposit types clearly shows that no particular element, or combination of elements, is a universal pathfinder for gold. The most important implication of the present deposit classification scheme for geochemical exploration for gold deposits is therefore that elemental suites should be sought to accurately identify a specific deposit type rather than a gold deposit in general. This suggests that there is some scope for extracting several different elemental groupings from a geochemical data set, each with a particular deposit type in mind.

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