A REVIEW OF SEDIMENT-HOSTED GOLD DEPOSITS OF THE WORLD WITH SPECIAL EMPHASIS ON RECENT DISCOVERIES OUTSIDE THE U.S.A.

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ABSTRACT

Most of the Great Basin sediment-hosted gold deposits are located along well defined, northwest-striking trends. Trends coincide with faults, intrusive rocks and magnetic anomalies. Sedimentary host rocks are siltstone, sandstone, conglomerate, argillic, interbedded chert and shales. Silty bedded silty dolomites, limestone and carbonaceous shales are the most favourable hosts. High, and locally, low-angle faults are very important structural features related to the formation of the ore bodies. High-angle faults are conduits of hydrothermal fluids which react, shatter and prepare the favourable host rock. Decalcification, silicification, and argillization are the most common hydrothermal alteration types. Jasperoid (intense silica replacement) is a significant characteristic; not all of these deposits are gold-bearing. Most deposits contain both oxidized and unoxidized ore. Fine grained disseminated pyrite, arsenian pyrite, and carbonaceous material are the most common hosts for gold in many deposits. These deposits are also characterized by high Au/Ag ratios, notable absence of base metal and geochemical associations of Au, As, Sb, Hg, Ba and Tl.

Recently numerous sediment-hosted gold deposits have been recognized in different regions of the world. They vary in their size, grades, texture, host rock lithology, degrees of structural control and chemical characteristics. However, they have many common features which are very similar to the general characteristics of sediment-hosted gold deposits in the Great Basin, U.S.A. Besides these similarities, several unusual features are recorded in some newly discovered deposits elsewhere, such as predominant fault controlled paleokarst related mineralization and the lack of two very common trace elements (Hg, Tl) in Lobongan/Alason, Indonesia; and Early Proterozoic age metamorphosed host rocks and lack of Sb in Maoling, China.

The discovery of the deep ores in the Post-Betze and Rabbit Canyon, Nevada, proposed sediment-hosted Au emplacement at deeper level (4 ± 2 km; Kuehn & Rose, 1995) combined with a lack of field evidence for paleowater table and paleosurface features has ruled out a shallow epithermal origin. Recent discoveries in other parts of the world throw important new light on the ongoing genetic problems. Intrusive rocks are present in nearly all sediment-hosted gold deposits. Numerous intrusion-centred districts worldwide are characterized by two or more different mineralization types and consequently by metal zoning. Sediment-hosted gold deposits are proposed as a distal part of intrusion-centred magmatic hydrothermal systems (Sillitoe & Bonham, 1990).

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A. INTRODUCTION

Since the discovery of the Carlin deposits in 1962, deposits with similar mineralogy, host rocks and trace elements to Carlin have become known as Carlin-type deposits. In this dissertation, the more descriptive term "sediment-hosted gold deposits" is used in preference. Sediment-hosted gold deposits predominantly occur throughout the western U.S.A. Thirty separate centres of gold mineralization exist, containing gold resources exceeding 2500 tonnes. Quite a number of newly discovered deposits outside of the U.S.A. in places such as China, Indonesia, Peru, Chile, and Macedonia have shifted the new exploration programs to these countries and other potential targets.

This dissertation presents the general characteristics of sediment-hosted gold deposits in the Great Basin, although this type of deposits is largely concentrated and also best understood in Nevada. Thirty five selected individual deposits from the Great Basin and their lithological, structural and mineralogical characteristics are tabulated to provide an understanding of the similarities and differences in these deposits (Tables 1 and 2). Bagby & Berger (1985), Berger & Bagby (1991), Skead (1994) and many other individual papers, reports and books are used as a basis for this review section. Fourteen newly discovered sediment-hosted gold deposits from other parts of the world have also been studied and tabulated according to their general characteristics (Tables 3, 4, 5 and 6). The comparative part of this work tries to point out the common geological and geochemical features between the deposits in the Great Basin, U.S.A. and others elsewhere.

New geological and geochemical observation from the new discoveries has permitted the development of a new model regarding the genesis. Genetic interpretations combined with the descriptive data are helpful in determining the potential targets all over the world and in indicating the new prospecting possibilities, within already known areas.

B. OVERVIEW OF SEDIMENT-HOSTED GOLD DEPOSITS IN THE GREAT BASIN, NEVADA, U.S.A.

1. REGIONAL, GEOLOGICAL AND TECTONIC SETTING

The North American sediment-hosted disseminated gold deposits occur throughout the Great Basin, but, predominantly occur within the Basin and Range physiographic province in Nevada (Fig. 1). The Great Basin region is one of the best well exposed and stratigraphically complete geological provinces in the world.

The North American continent developed as a result of rifting and separation from late Proterozoic supercontinent (Armin & Mayer, 1983). Rifting apart from the supercontinent formed an ocean basin which became a site for accumulation after the passive edge of North America subsided. This is named the Great Basin, where thick shallow-water carbonate sediments and deeper-water sediments accumulated during the Cambrian through to Devonian (Cook & Taylor, 1991). The resulting sedimentary sequences thicken westward. The Paleozoic stratigraphic section is divided into three zones which are: (1) thousands of feet thick of eugeoclinal, fine grained, siliceous sediments deposited to the west; (2) thin, miogeoclinal carbonates comprising limestone, dolomite and silty limestone deposited on the thin continental shelf to the east; (3) a thin, transitional zone of mixed siliceous clastics and carbonates deposited between the two distinct lithological assemblages. Fig. 2 (Stewart, 1980) and Fig.3 (Rota, 1991)

The remarkably stable depositional environment from the Cambrian to the late Devonian changed by subduction and possible island arc accretion during the Antler Orogeny. During the Antler Orogeny, which occurred in Late Devonian to Mississippian, eugeoclinal siliciclastic sediments were thrust eastward, transported (~145 km.) and overrode both transitional carbonates-clastics and miogeoclinal carbonates along imbricated thrust faults (Robert Mountain Thrust Fault). Carbonates and transitional

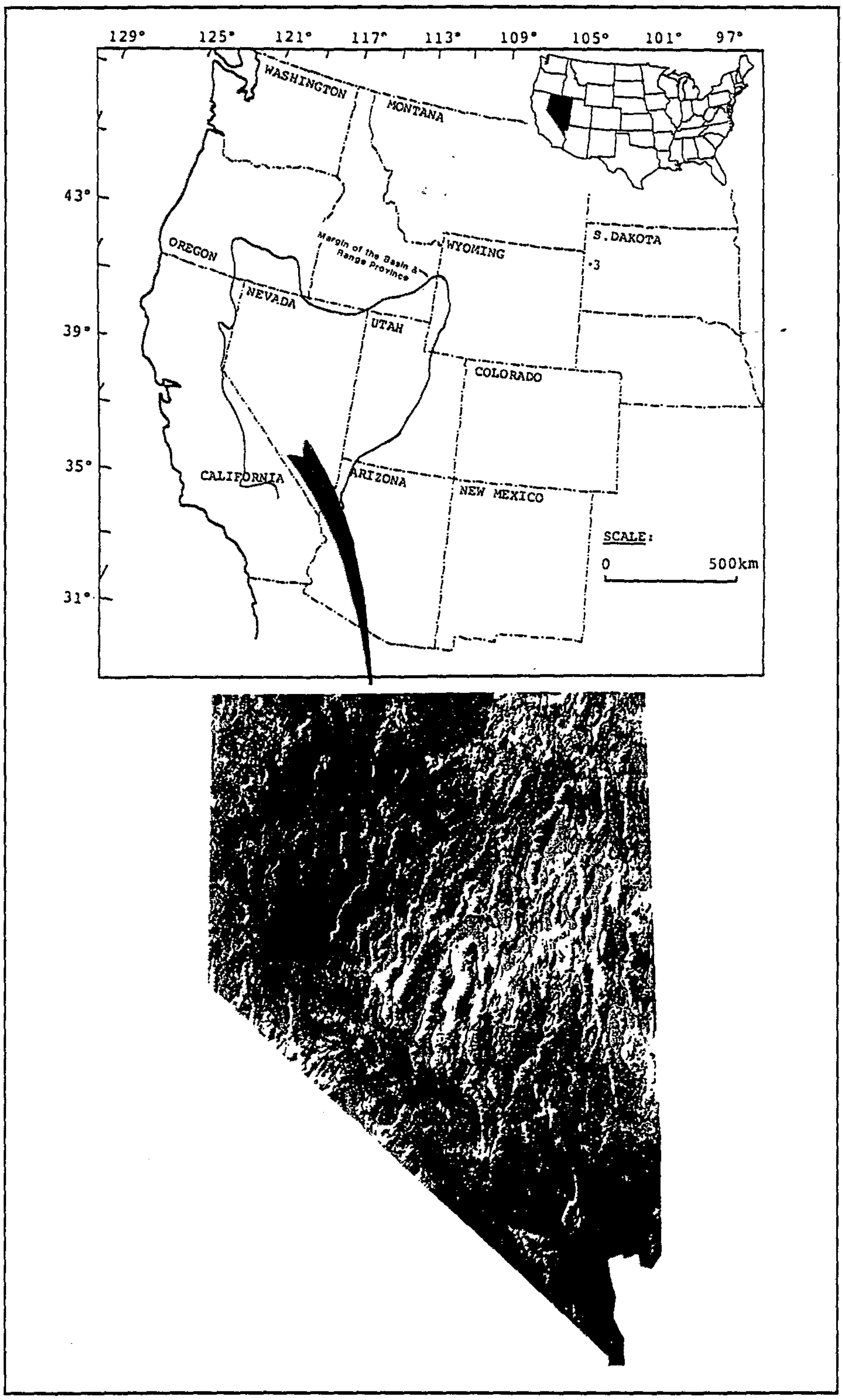


FIGURE 1. Location map of the Basin and Range Province and topography of the state of Nevada (modified from Wright, 1993).

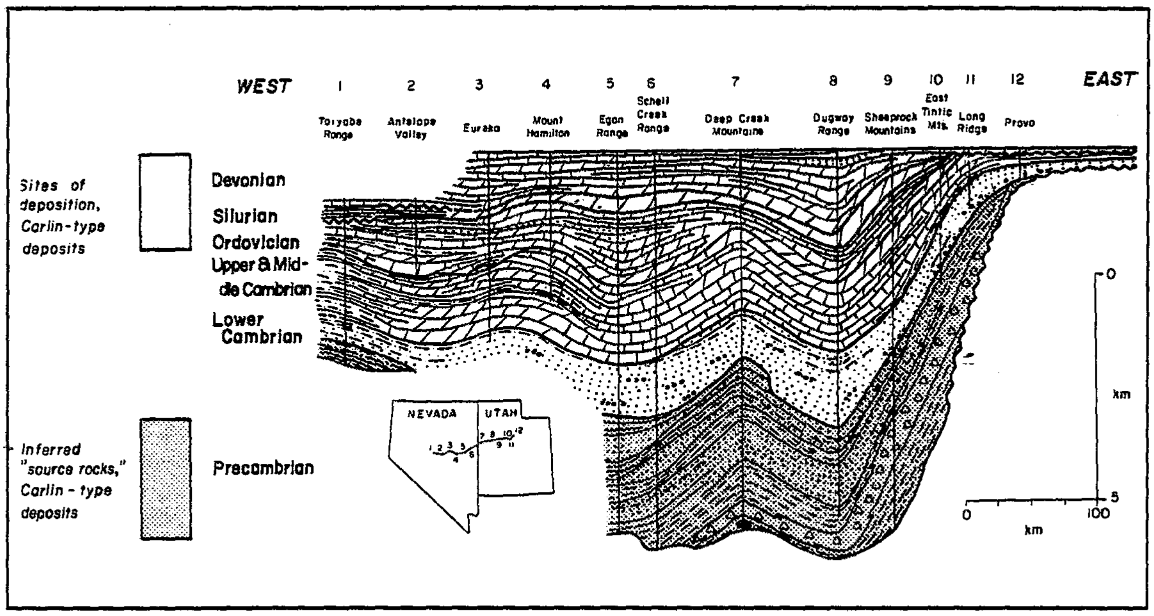


FIGURE 2. Stratigraphic cross section of Devonian and older rocks across the Central Great Basin, showing occurrences of upper Proterozoic clastic rocks (from Seedorff, 1991).

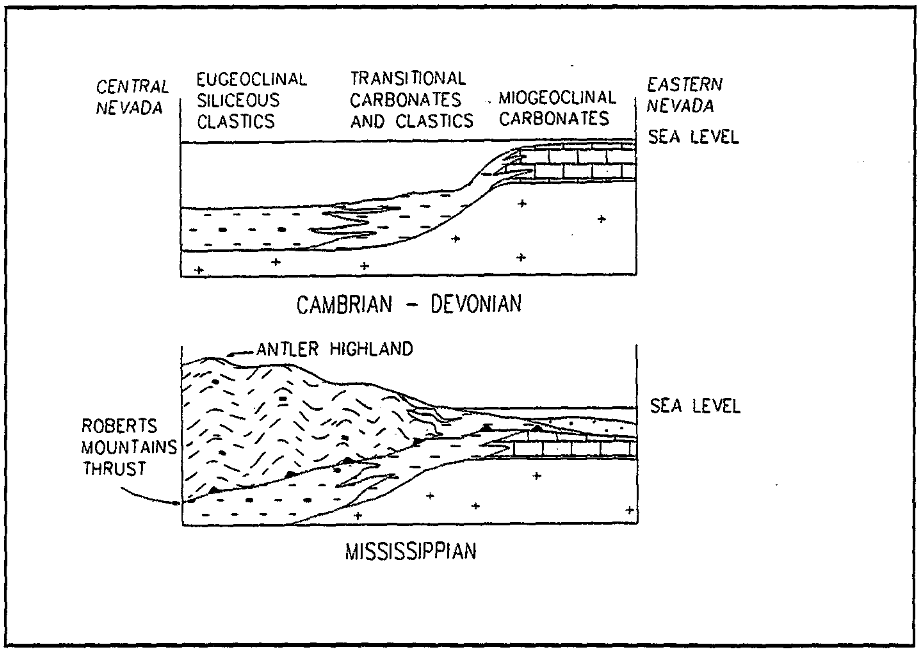


FIGURE 3. Palaeozoic depositional environments in Nevada (from Rota & Hausen).

carbonates-clastics are separated from western siliceous rocks by stratigraphically, smaller thrust faults and high angle faults. Recently Schull (1991) suggested that the transition from the carbonates to overlying western facies siliceous rocks can be part of a regressive succession (Rota, 1991; Berger & Bagby, 1991). No magmatism or metamorphism can be related to this orogenic activity.

The Antler Orogeny was followed by the Golcanda Allochthon which is a complex assemblage of allochthonous Upper Paleozoic rocks (e.g. argillite, basal limestone, calcarenites and sandstones) (Jones and Jones, 1991). The Permian Sonoma Orogeny is the result of an arc-continent collision, which may reflect the final stages of the tectonic period which began with the Antler Orogeny. Post-Antler siliciclastic and carbonate rocks were thrust eastward over the Roberts Mountain Allochthon (Snyder et al., 1991; Berger & Bagby, 1991).

From Late Jurassic to Early Tertiary time, results of two major compressional events and orogenies (Late Jurassic Elko and Early Cretaceous to Tertiary Sevier) led to the regional metamorphism of miogeosynclinal rocks, the formation of large-scale southeast - and east - directed structures, some extensional structures, plutonism and regional uplift.

The last tectonic event was extensional and ranges in age from Late Eocene to the present time. This event, which includes the classical horst and graben development of the Basin and Range province, can be divided into two phases. From Oligocene to Early Miocene there was a low-angle detachment faulting phase and from Late Miocene to Holocene there was a dominantly high-angle faulting phase which defined the Basin and Range physiography. Widespread ashflow tuffs, coeval lacustrines and fluvials were deposited on Paleozoic to Triassic strata while the metamorphism and plutonism were occurring at depth during Cenozoic time (Thorman et al., 1991).

The first major magmatic and metamorphic events took place during Mesozoic

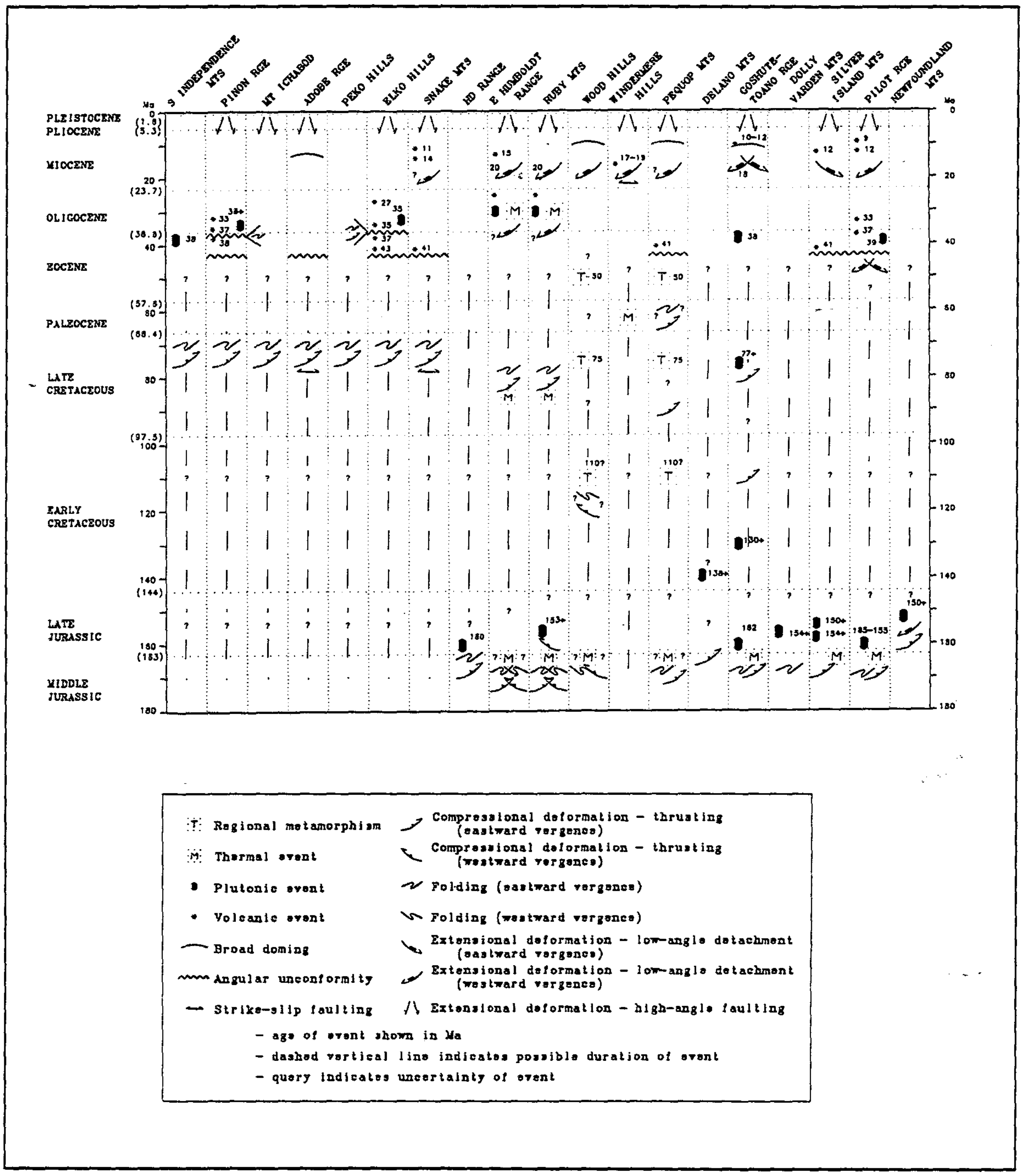


FIGURE 4. Summary of tectonic and igneous events during Mesozoic-Cenozoic in Nevada (Thorman et al., 1991).

Orogenies, unlike the Palaeozoic Orogenies in the region (Fig. 4). Plutonism extended throughout the Tertiary and has been related to many sediment-hosted gold deposits by some authors. In particular, many Early Jurassic - Late Cretaceous intrusives are spatially related to gold deposits (Stewart, 1980; Berger & Bagby, 1991).

2. DISTRIBUTION OF DEPOSITS

Numerous gold deposits are aligned along geologically and geophysically recognized regional trends in Nevada (Fig. 5). The Carlin and Cortez trends were postulated a long time ago by alignment of the mineralized windows of eastern facies carbonates (Roberts, 1966). Recent works indicate that the trends of ore deposits coincide with faults, intrusive rocks and/or geophysical discontinuities (Fig. 6) (Shawe, 1991).

The **Carlin trend** includes the series of significant gold deposits such as Rain (southeastern end of trend), Gold Quarry, Carlin, Gold Strike and Dee (northwestern end). Gold mineralization along the Northwest striking (80 km. long) Carlin trend is mostly hosted by autochthonous silty carbonates and massive fossiliferous limestones,

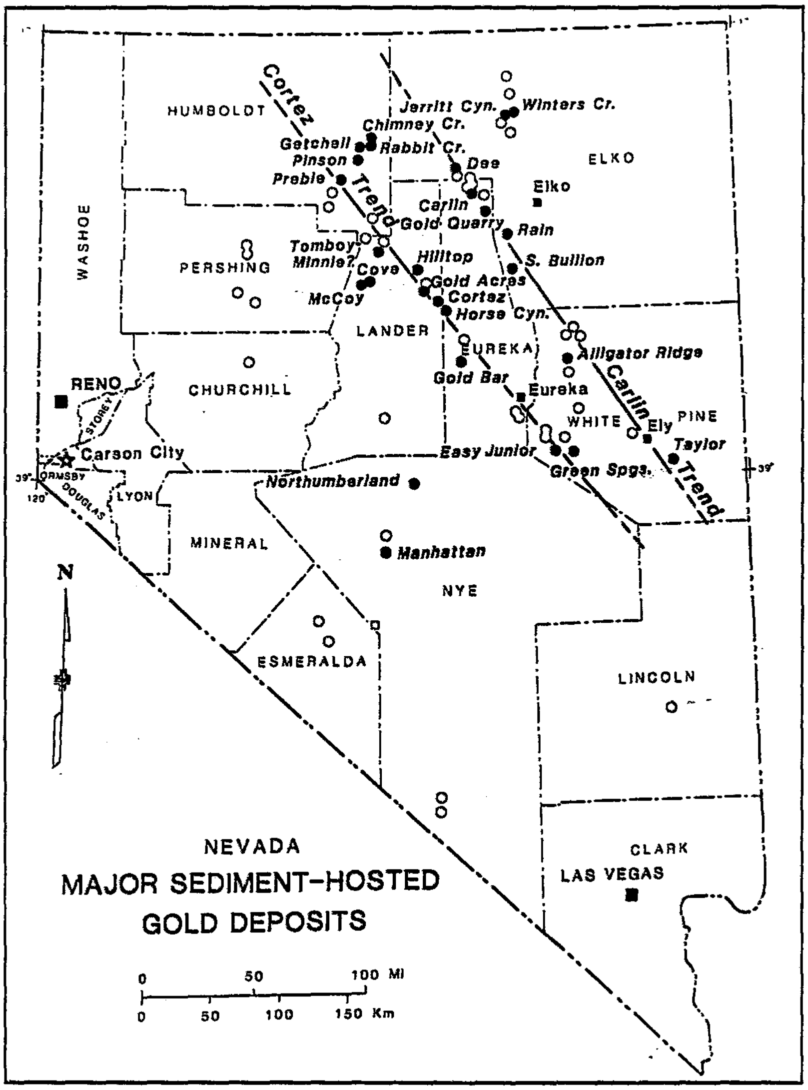


FIGURE 5. Location and trends for sediment-hosted gold deposits in Nevada (adams & Putnam, 1992).

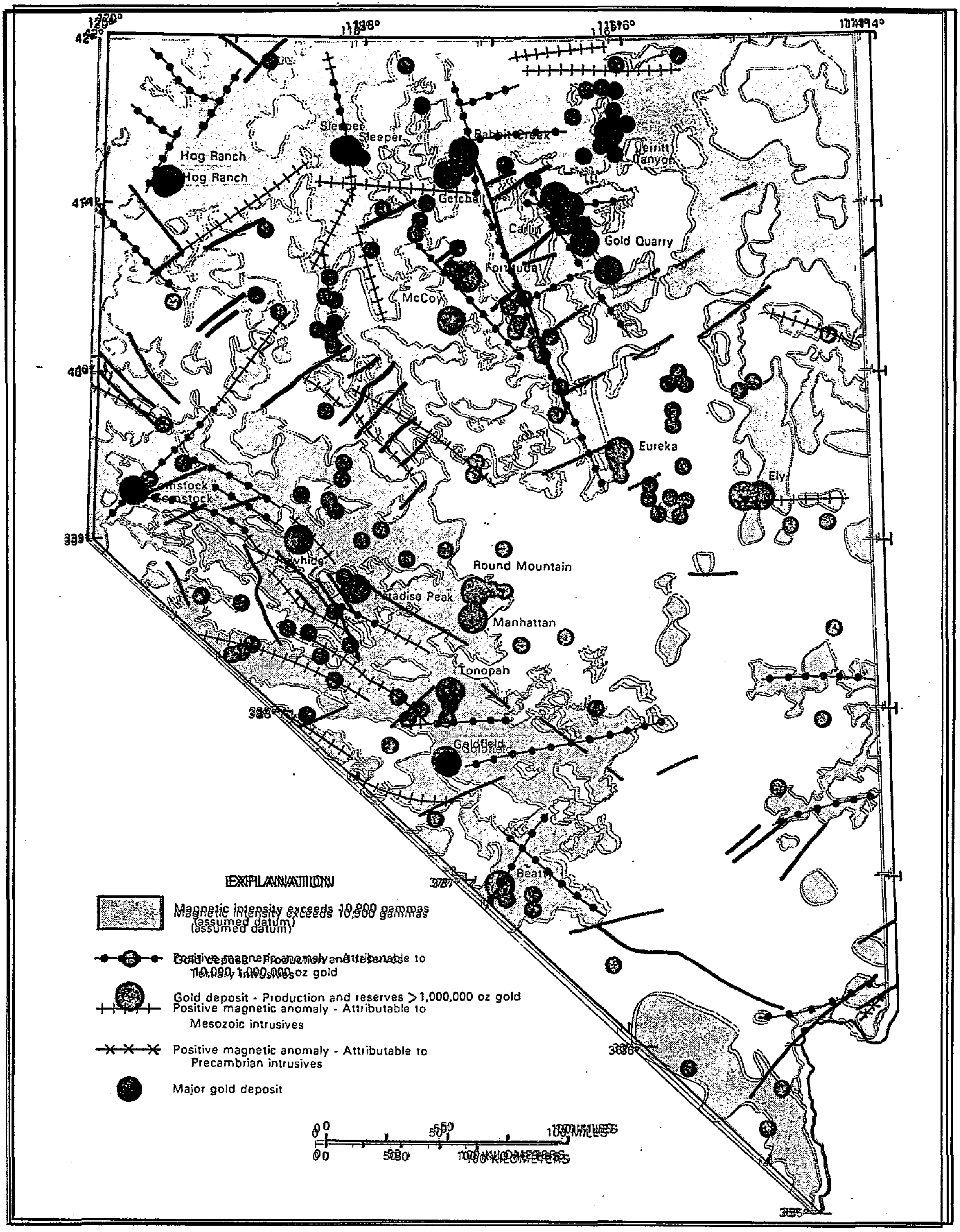


FIGURE 6.a. Significant traverse geologic breaks in Nevada as relates to magnetic intensity (Shawe, 1991).

FIGURE 6.b. Magnetic intensity and alignment of intrusives (Shawe, 1991).

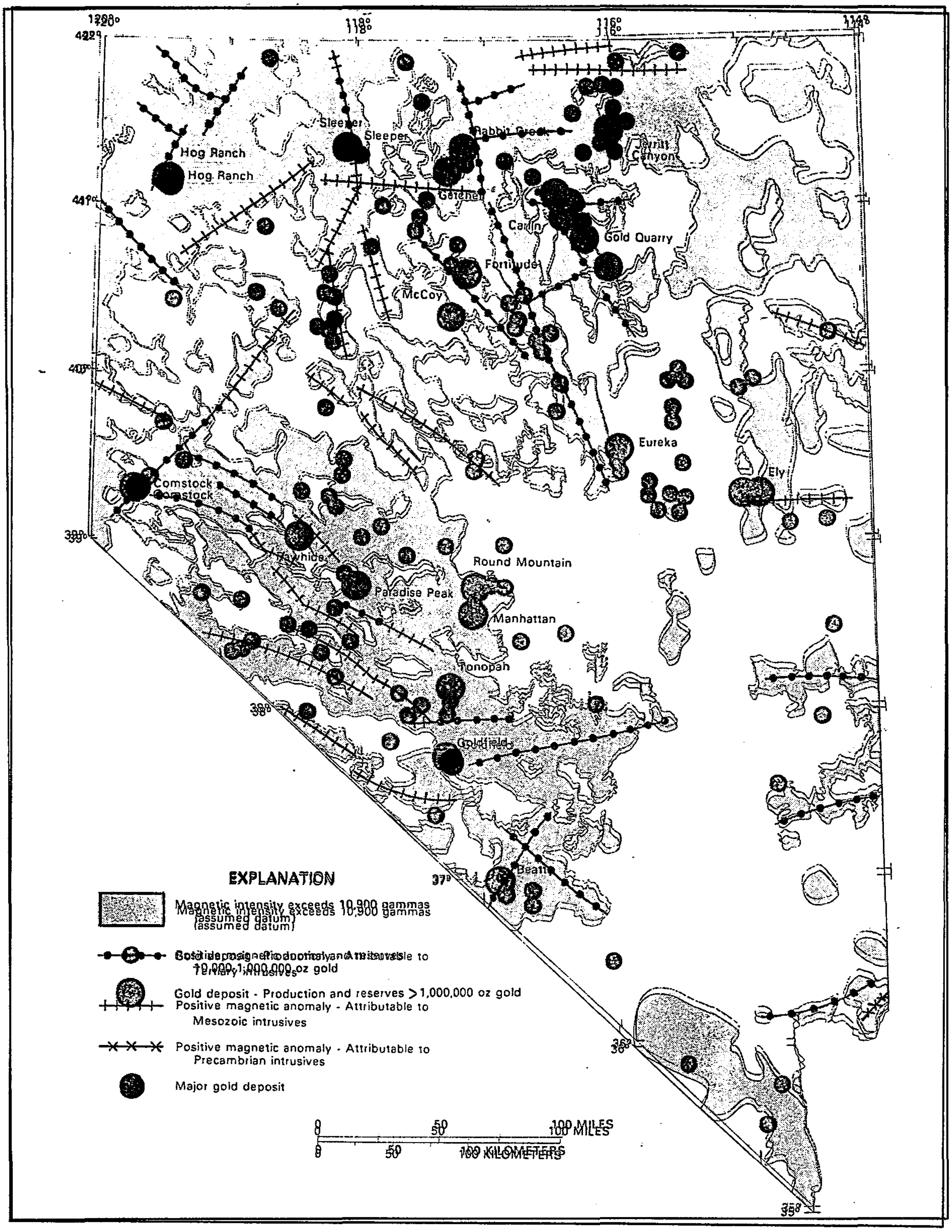


FIGURE 6.b. Locations of significant gold deposits and areas of magnetic intensity (Shawe, 1991).

Magnetic intensity and alignment of intrusives (Shawe, 1991).

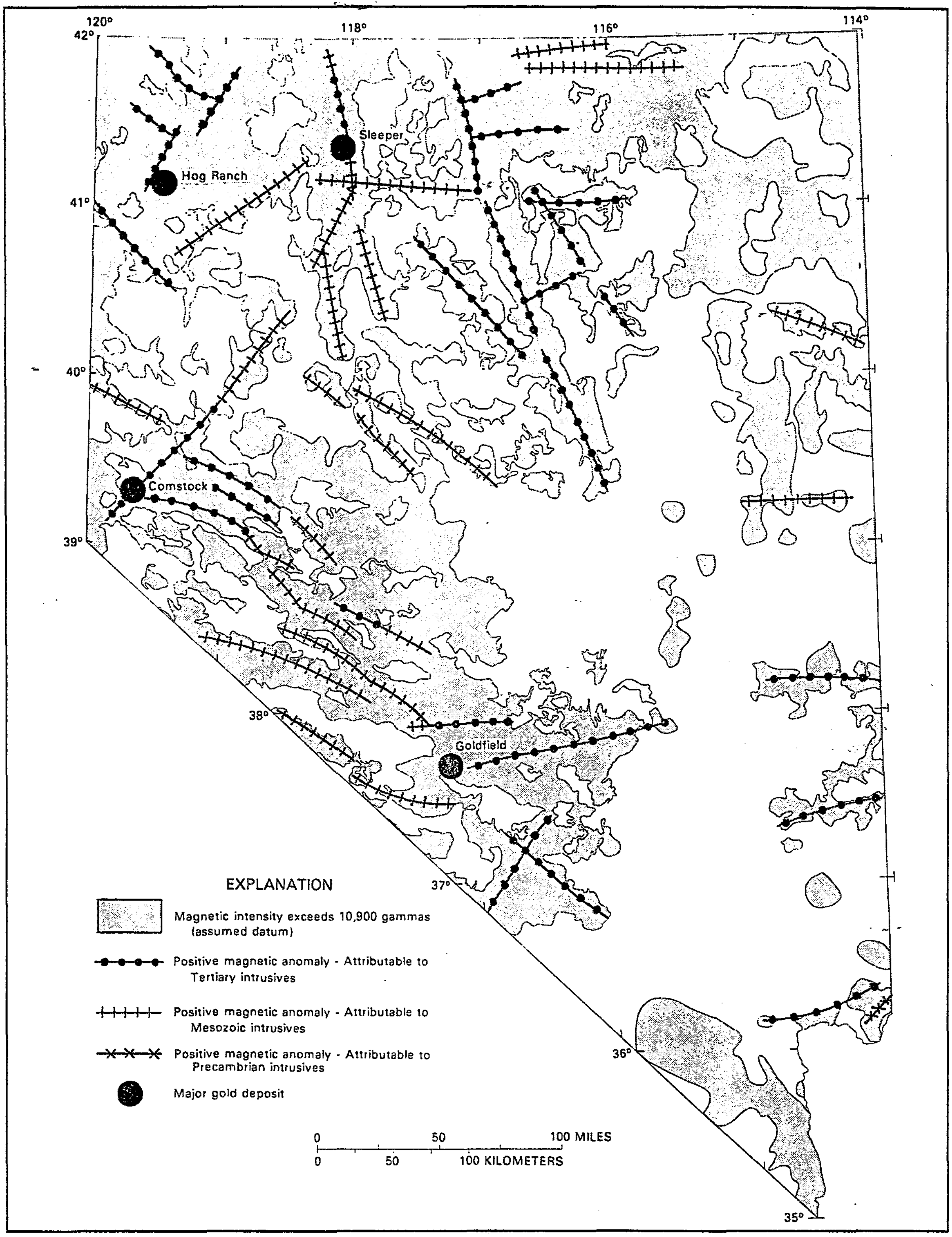


FIGURE 6.c. Magnetic intensity and alignment of intrusives (Shawe, 1991).

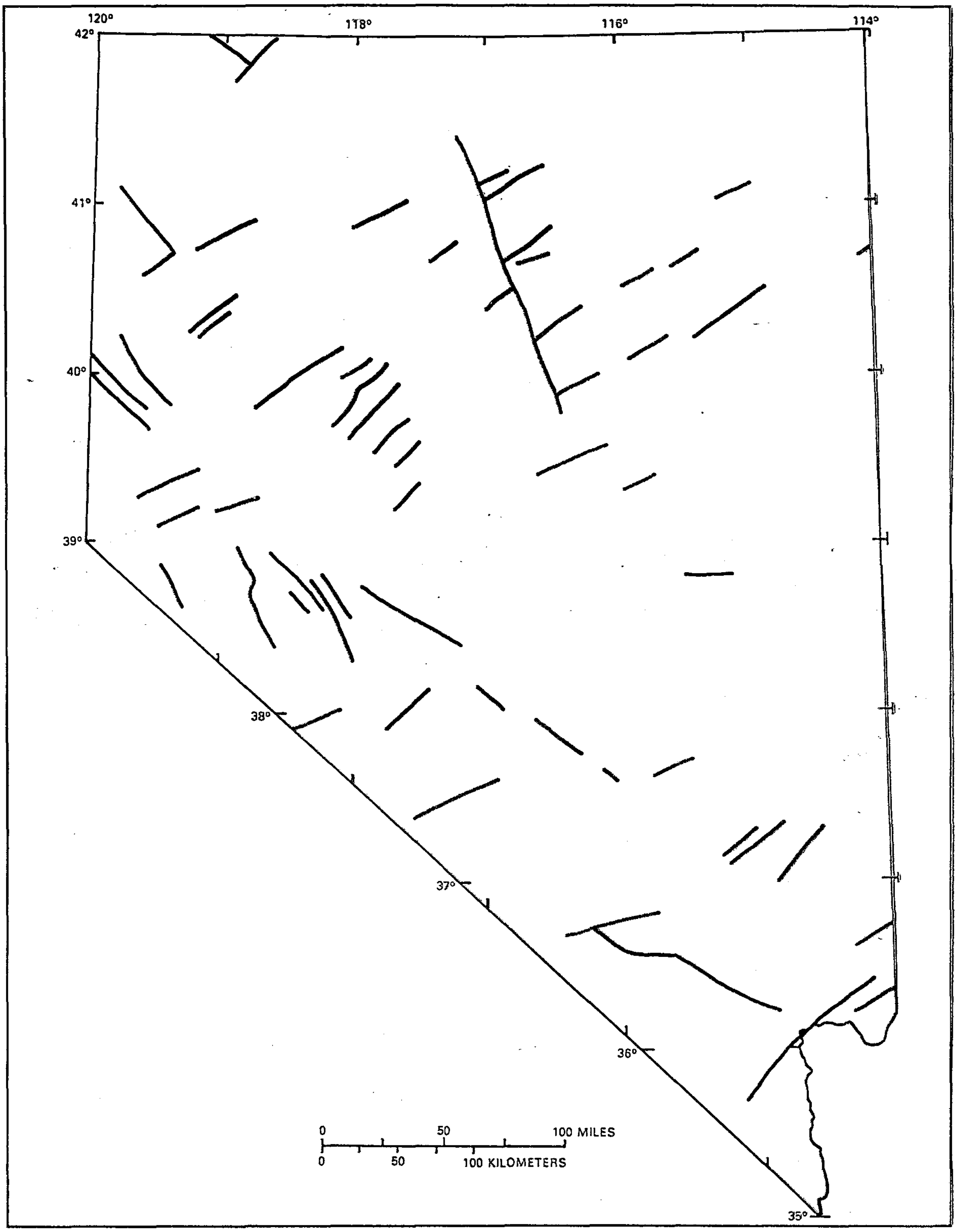


FIGURE 6.a. Significant traverse geologic breaks in Nevada (Shawe, 1991).

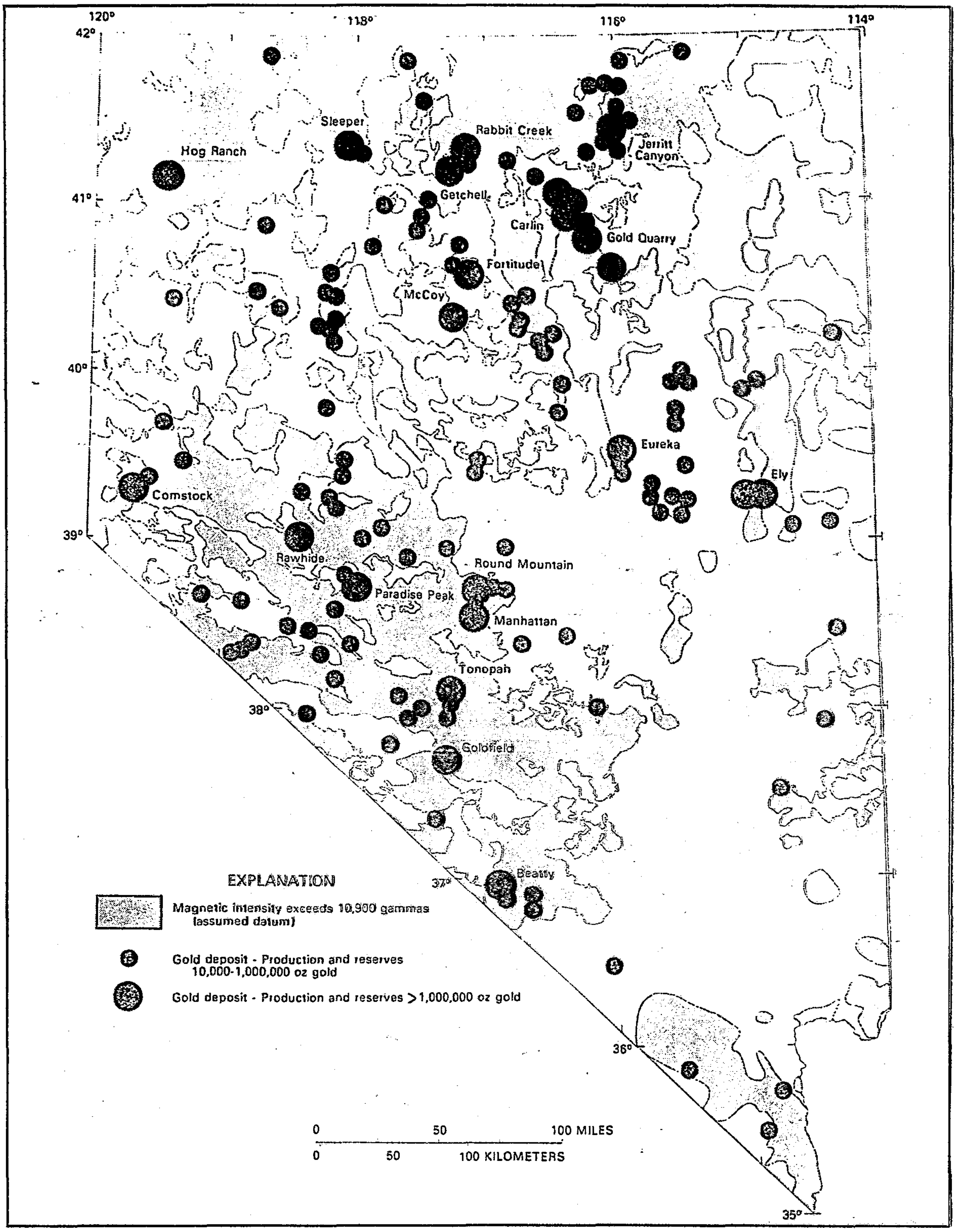


FIGURE 6.b. Locations of significant gold deposits and areas of magnetic intensity (Shawe, 1991).

allochthonous chert, shales and clastic units derived from debris shed (Percival et al., 1988).

The 200 km. long **Cortez trend** which includes the Hilltop, Gold Acres, Cortez, Eureka Horse Canyon, Tonkin Spring, Gold Bar, Easy Junior, Green-Spring, Merigold and Lone Tree deposits was defined by alignment of structural windows and Mesozoic and Tertiary intrusive rocks. Apart from these geological features, aeromagnetics and Landsat imagery define the distinct linear feature of the Cortez trend which is oblique to the Central Nevada Rift (Percival et al., 1988; Skead, 1994). Gold mineralization, occurs within both lower and upper plate sedimentary rocks along the Cortez trend that consists of several components such as skarn gold deposits associated with hypabyssal stocks, vein and stockwork deposits, and disseminated types (Shawe, 1991).

The **Getchell trend** is the alignment of the Preble, Pinson, Getchell and Chimney Creek deposits along the northeastern margin of the Osgood Mountains. The Rabbit Creek gold deposit which lies along strike of Chimney deposits (N-S) may be included in the Getchell by widening the trend, Seedorff (1991) and Bloomstein et al. (1991); Bloomstein et al. (1993) suggested that the Getchell trend is degenerated, biased and controversial. Several formations (e.g. phyllitic shale, massive limestone, cherts, clastics and volcanoclastics) occur along the trend and host gold, tungsten and barite mineralization (Bagby and Berger, 1985).

The **Humboldt trend** is not a well defined linear feature as are the other trends discussed previously. It is rather a cluster of four deposits. They are: Florida Canyon, Standard, Willard and Relief Canyon. Along the trend, thrusting without windows and numerous dominantly north-trending high-angle faults occurred (Percival et al., 1988).

Apart from the aligned sediment-hosted gold deposits, some deposits seem to be isolated occurrences.

3. GEOLOGICAL CHARACTERISTICS OF THE DEPOSITS

3.1. *HOST ROCKS*

Gold mineralization is hosted in a number of different lithologies of varying age from Cambrian to Triassic. Most of the host sedimentary rocks are of Paleozoic age (Cambrian to Mississippian) (Table 1). Thinly bedded silty dolomites, limestones and carbonaceous shales are the most favourable hosts, which provide the porosity and permeability for penetrating hydrothermal fluids. Other sedimentary rocks of autochthonous miogeosynclinal, allochthonous eugeosynclinal and Antler overlap sequences also serve as host rocks (e.g. siltstone, sandstone, conglomerate, argillite, interbedded clay and shales).

Massive, thick-bedded, recrystallized limestones, dolomites and low carbonate-bearing shales, siltstones, phyllites are not favourable host rocks for disseminated ores because of their less reactive and lower permeability characteristics. They require open spaces and permeabilities that can be created by tectonic process and disruption such as thrusts, high-angle faulting, cleavage sets and breccias. Radtke (1985) suggested that 20 to 60 percent of the calcite or dolomite content of sedimentary rocks can be dissolved by primary fluids thereby increasing permeability to prepare the rocks for penetration of fluids and deposition of silica and gold.

The Carlin trend gold deposits are predominantly hosted by both the rocks of the Roberts Mountain allochthon (Paleozoic siliceous assemblage; interbedded cherts, shales and siltstones) and autochthonous rocks (Lower Paleozoic carbonate assemblage; silty limestone and dolomites, shales and siltstones) (Bagby & Berger, 1985). Aragonite involved coarse carbonate debris flows which are reactive to mineralizing hydrothermal fluids and have high permeabilities, occurred in contact between the Roberts Mountains and Popovich Formations. The debris flows are important in control of mineralization at the Betze/Post, Meikle, Genesis/Blue Star and

TABLE 1. PRINCIPAL GEOLOGICAL CHARACTERISTICS OF SELECTED SEDIMENT-HOSTED GOLD DEPOSITS, GREAT BASIN.

DEPOSIT	HOST ROCK	HOST ROCK AGE	FOLD	FAULTS	ALTERATION	MINERALIZATION	IGNEOUSROCKS
ALLIGATOR RIDGE	Carbonaceous, calcareous siltstone and marlstone/ Limestone and dolomite	L. Missip. & U.Devonian	NNE-trending anticline	NNE, NNW, & ENE- trending	Decarbonization, remobilized carbon, silicification	NNE trend; Eocene	Tertiary tuffs & lavas
BETZE/POST	Siliceous mudstone, siltstone & fine sandstone / Calcareous, carbonaceous siltstone, silty limestone & debris flows / Dolomitic siltstone & limestone	Devonian / Silurian to Devonian	NW-trending anticline,	RMT, intrusive thrusting, NW, N to NNW, NE high-angle faults	Pre-skarn, decalcification, silicification, argillization, oxidation (supergene & hypogene?)	Intersection of high-angle NNW-ENE mineralized fault system	Biotite feldspar 39 Ma. (dykes, plugs & sills) Quartz monozite porphyry 110 Ma sills & dykes.
BOOTSTROP CAPSTONE	Calcareous siltstone, limestone / Calcareous, laminated silty limestone	Devonian	n.d.	N-S dominant, NW, NE, E-W	Silicification, argillization	Along N striking high-angle dykes along interface limestone-siliceous sedimentary	Highly altered dykes, granodiorite-tonalite
CARLIN	Siltstone, argillaceous siltstone, dolomitic limestone	L. Silurian to L. Devonian	NW-trending anticline; NW ore trend	ENE, NNE, NE & NNW- trending; RMT	Decalcification, silicification, pyritization, illitization, oxidation of upper 10m of RMT	Ore & alteration most common on NNW-trending faults; estimated depth of ore formation 3 km	131-121 Ma NW-trending dykes
CHIMNEY CREEK	Sandy dolomite / Basalt	Pennsylvanian to Permian/ Missip.	NNW ore trend	RMT & Golconda Thrusts	Silicification	Associated with high-angle faults & favourable lithology	n.d.
CORTEZ	Silty, argillaceous, carbonaceous, pyritic limestone & dolomite finely-laminated siltstone	L. Silurian to L. Devonian	NW-trending anticline; NW ore trend	NNW, N, & ENE-trending; low-angle thrusts?; RMT	Decalcification, silicification, dolomitization	Trend NW associated with faults, dykes & breccias; 34 Ma	34 Ma pre-ore felsic dykes
DEE	Massive limestone Cherts	Devonian Ordovician?	NW-trending anticline; NW ore trend	NNE, NW, NE, & ENE-trending; inter-leaved thrust slabs; RMT	Silicification, argillization	Along faults & thrust-related breccia & shears	Altered dykes
EASY JUNIOR	Mudstone / Limestone	Missip./ L. Missip.	NW-trending anticline; NW ore trend	NE-trending	Argillization, silicification	Along NE-trending faults; Eocene	n.d.
GENESIS BLUE STAR	Siltstone, carbonaceous mudstones & argillites / carbonaceous, slightly calcareoussiltstone, mudstone, argillites & minor calcarenites / Siliciclastic siltstone & chert	Devonian / Ordivician	NW-trending Tuscora antiform,	RMT with numerous imbricate thrusts / Intrusive thrusting / N-S, NW, NE high-angle faults	Pre-mineral skarn, Decalcification, argillization, silicification, oxidation (supergene, hypogene?)	Mineralization along the intersections of high-angle & low-angle thrust faults, & around the crest of Tuscora anticline	Altered Biotite Feldspar dykes, Lamprophyre dykes

CONTINUED

DEPOSIT	HOST ROCK	HOST ROCK AGE	FOLD	FAULTS	ALTERATION	MINERALIZATION	IGNEOUS ROCKS
GETCHELL	Phyllitic shales & interbedded limestone	Cambrian to Ordovician	NE-trending anticline; NE ore trend	N-trending fault zone	Pre-ore skarn; decalcification, silicification, argillization (92-87 Ma)	Sheet-like zone along faults; 90 Ma	Cretaceous granodiorite pluton & porphyry dykes
GOLD ACRES	Silty limestone / Thin bedded chert Quartzite, sand-stone, chert, shale, siltstone, green-stone, limestone	L. Silurian to L. Devonian / Ordovician	NNW-trending anticline; NW ore trend	NNW, N, & NE-trending; imbricate thrust zone	Pre-ore skarn; silicification. argillization, carbonization	In imbricate thrust zone; base metals & pyrite; 32 Ma	Altered sills & dykes
GOLD BAR	Argillaceous limestone	Devonian	NNE-trending antiform; NNW ore trend	E, NW-trending & bedding faults	Stratabound (earlier) & fault-related silicification; decalcification	Associated with NW-trending & bedding faults; Eocene	Felsic dykes
GOLD QUARRY	Siltstone, silty limestone, shale, sandstone & chert	Ordovician?	NNW-trending anticline; NNW ore trend	NNW & ENE-trending hydrothermal? breccia; interleaved thrusts in upper plate of RMT	Decalcification, silicification, argillization, baritization, alunitization	Associated with NNW-trending faults;	NW-trending dyke
GREEN SPRINGS	Silty limestone	Missippian	NW ore trend	NNE & NNW	Silicification, argillization	N-NE ore trend associated with jasperoid & lithology	n.d.
HILLTOP	Chert, calcareous argillite, minor greenstone	Ordovician	NW ore trend	NW-trending; low-angle thrusts; breccia	Silicification	Skarn; ore between two thrusts	Dykes, breccia dykes, stock (38 Ma)
HORSE CANYON	Siltstone & chert / Silty limestone	Ordovician / Devonian	NW-trending anticline; NW ore trend	NNW, ENE, & NE-trending; erosion window in thrust	Decalcification, silicification, carbonization	In NNE fractures with silicification, & carbonaceous veins	Altered dykes & sills
JERRITT CANYON	Carbonaceous limestone & calcareous siltstone	M. Ordovician to L.Silurian / L. Silurian to L.Devonian	E-trending anticline	ENE, N, & NE-trending; erosion window in thrust	Decalcification, silicification, carbonization	Fault & lithology control	Plugs & dykes
LONE TREE	Chert, basal, shale, calcareous sandstone, sandy sandstone, conglomerates, siltstone, quartzites, argillites	Pennsylvanian to Permian / Pennsylvanian / Ordivician	N-S east verging folds	RMT Dominant N-S high angle, minor NE & NW high-angle faults	Pre-Au skarn, silicification, potassic, argillic	Ore bodies along high-angle faults & in fault intersections	Tertiary feldspar dykes

CONTINUED

DEPOSIT	HOST ROCK	HOST ROCK AGE	FOLD	FAULTS	ALTERATION	MINERALIZATION	IGNEOUS ROCKS
MANHATTAN (WHITE CAPS)	Arenaceous phyllite, marble	Cambrian	NW-plunging antiform	NW-trending	Silicification, pyritization	Associated with NW-trending faults; Au coarse grained; 16 Ma	n.d.
MEIKLE	Noncalcareous siltstone, silty limestones, debris flows, dolomitic siltstone & limestone	Devonian	n.d.	RMT, NW & NE high-angle faults	Decalcification, silicification, argillization	Ore bodies in high-angle faults & thrust fault intersections. Debris flow & breccias are host for ore body	Monozite dykes, monozite porphyry, latite dykes & sills
MERCUR	Limestone & silty limestone	Missippian	NW-trending anticline	NNW-trending faults intersect ENE-trending graben	Decalcification,silicification, illitization (193-122 Ma); hypogene oxidation at base of ore interval	Au with pyrite, realgar orpiment, marcasite; post-ore barite; ore is post regional stratabound jasperoid & is fault-related	Rhyolite & quartz monzonite (37 Ma)
NIGHTHAWK RIDGE	Carbonaceous shale, siltstone, shale & cherts	Carboniferous / L. Devonian to E. Carboniferous	N15E open folds	Thrust N15E, NE, WNW-ESE high-angle faults	Decalcification, silicification, argillization, carbonization	Ore body hosted by NNE striking folds & reverse faults	n.d.
NORTHUMBERLAND	Silty limestone, shale & siltstone	L. Silurian to L. Devonian	NW-trending antiform; doming near Mesozoic stock	NE, N, & NW-trending; erosion window through thrust	Silicification, argillization	Tabular zone along sill-sediment contact & breccia zone; strataform bodies (85 Ma)	Altered Jurassic tonalite & granodiorite dykes; unaltered Tertiary ?rhyolite dykes
PINSON	Silty limestone & calcerous shale	U. Cambrian to L. Ordovician	NW-trending antiform; NS ore trend	N-trending faults	Silicification	Ore-restricted to N-trending fracture zone by pre-ore skarn; 90 Ma	Cretaceous pluton
PREBLE	Phyllitic shale & turbidite limestone	M. Cambrian	NE-trending anticline	N-trending fault system	Silicification, minor decalcification & dolomitization	Replacement & fracture-controlled	Altered dykes (40Ma)
RABBIT CREEK	Carbonaceous calcareous shales, siltstone, cherts & basaltic tuff	U. Cambrian to L.Ordovician	NW-trending overturned anticline; NS ore trend	N-trending fault zone	Decalcification, silicification, dolomitization, minor sericitization	N-trending belt, 5.6 km. long, 300-400m wide	Ordovician basaltic & ultramafic sills & flows
RAIN	Siltstone, marlstone, shale	L. Missip.	NNW-trending antiform; NW ore trend	NW & NE-trending faults	Silicification, argillization, baritization	Related to NW-trending faults	Quartz monzonite
RATTO CANYON	Claystone interbedded with limestone / Massive dolomite, minor lenses of limestone	Cambrian	N-S trending fold	E-W tear faults, N to NW, E-W, NE high-angle faults	Sanding/decalcification, silicification, argillization	Structurally controlled free gold bearing quartz veinlets	n.d.

CONTINUED

Deposit	Host Rock	Host Rock Age	Fold	Faults	Alteration	Mineralization	Igneous Rocks
Ren	Calcareous siltstone	Devonian	n.d.	RMT & imbrication, NNW-ENE high-angle fault	Decalcification, weak silicification (jasperoid), rarely argillization	Structurally controlled (associated with dyke), Manto-like along limestone siltstone contact	Gradodioritic porphyry dyke, melanocrotic dyke
South Bullion	Carbonaceous silt-stone, siliceous & calcareous mudstone	L. Missip.	N-trending anticline; NW ore trend	NW-trending with horizontal & oblique movement; breccia & karst zone at unconformity	Silicification, decalcification, argillization	Stratabound with silicification	Fault-controlled rhyolite stocks & dykes
Taylor	Limestone, shaley limestone	M. to U. Devonian	S-plunging antiform; NW ore trend	N, NW & NE-trending; stratabound breccia zone	Silicification, argillization	Fault & sedimentary breccia control	Post-ore rhyolite dykes (35Ma)
Tonkin Springs	Massive limestone, chert, shale, silty limestones	Devonian / Ordivician	n.d.	RMT & numerous smaller thrusts, N to NW, N-S, NE, E-W high angle faults	Decalcification, silicification, carbonization	Structurally & lithologically controlled ore body (intersection of high-angle, low-angle & permeable lithologies)	Altered porphyritic dykes & sills, late Mesozoic early Tertiary
Tusc	Mudstone, chert & siltstone / Silty limestone & limestone	Devonian / Silurian to Devonian	NW-trending anticline	RMT with numerous imbricate thrusts	Decalcification, argillization, slicification, oxidation (supergene)	Synformal character pluges NW joints and fractures are primary controls	n.d.
Vantage	Laminated calcareous siltstone / Dolostone limestone	Devonian to Missip. Devonian	Anticline parallels N to NE striking fault	N to NE and NE striking high-angle faults	Decalcification, silicification, oxidation (hypogene + supergen)	Four ore bodies parallel to each others Hemispherical shape, adjacent to normal fault at the limestone-shale contact	n.d.
Winters Creek	Carbonaceous, dolomitic & calcareous siltstone	L. Silurian to L. Devonian	ENE-trending doubly plunging anticline	ENE & NW-trending; bedding thrusts (saval thrust)	Silicification, oxidation, argillization carbonization	N-NW-trending zone related to faults	n.d.

Missip: Missippian; U: Upper; M: Middle; L: Late; RMT: Roberts Mountain Thrust; n.d.: no data

Source: Field Trip Reports for Minorco Services BV: A Symposium organised by the Geological Society of Nevada, Reno, Nevada, April 1995; Albino (1994); Skead (1994); Adams & Putnam (1992); Ekburg et al. (1991);

Gold Quarry Deposits along the Carlin trend (Williams, 1994; Skead, 1994).

The Cortez trend host formations comprise predominantly, laminated siltstone, limestone, cherts and shales. Minor volcanics and igneous rocks also occur as host rocks in the Cortez trend unlike the Carlin trend (Bagby & Berger, 1985). Getchell trend gold deposits are hosted by predominantly eugeosynclinal shales, cherts, sandstones and basalt, as well as Cretaceous granodiorite intrusions.

3.2. *STRUCTURE*

During the Sevier orogeny (Cretaceous to early Tertiary) the region was subjected to tectonic thickening, folding and thrust faulting. Thrusting ended in the early Eocene. Extensional tectonics (late Eocene) began with large-scale cluster extensions along low-angle faults which formed great thicknesses of mylonite, then extensional faulting continued while continental and volcanic deposits accumulated in these smaller basins, especially in Central and Northeastern Nevada (Thorman et al., 1991; Seedorff, 1991). In early to Middle Miocene, areas in the Great Basin were subjected to extreme and widespread extension. In general, extension produces both lateral and vertical

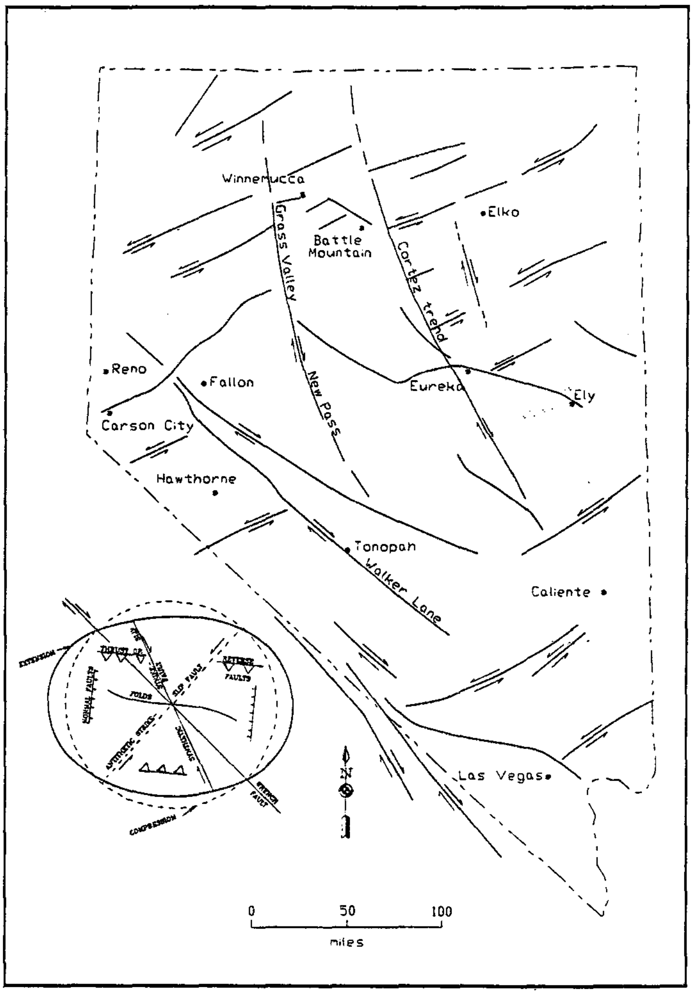


FIGURE 7. Transverse lineament with idealized strain ellipse. Walker Lane parallel principal stress (Putnam & Henriques, 1991).

displacements and individual fault blocks are rotated about horizontal axes (Seedorff, 1991). Putnam and Henriques (1991) also suggested that early Cenezoic-age, extension-related, northwest-oriented wrench-faulting events have affected localization of high-angle oblique and strike-slip faults as well as the grabens. They believed that the Carlin and Cortez trends are synthetic, right-lateral R_1 shears, related to the San Andreas and Walker Lane fault system (Fig. 7). These first order structures (NW-trending R_1 shears) exert their own localized stress field with N to NNW and NE-trending second order synthetic and antithetic R_1 and R_2 shears respectively (Fig. 8). Thus, paragenesis of high-angle faults can be explained as; NW (1st order R_1 shear) → N to NNW (2nd order R_1 shear) + NE (2nd order R_2 shears) (Skead, 1994). High-angle, mineralization-controlling, structures are very common in sediment-hosted gold deposits of the Great Basin. Structural brecciated intersections between high-angle faults and high-angle or low-angle faults localized high-grade gold deposition which decreases in grade with increasing distance from the intersections.

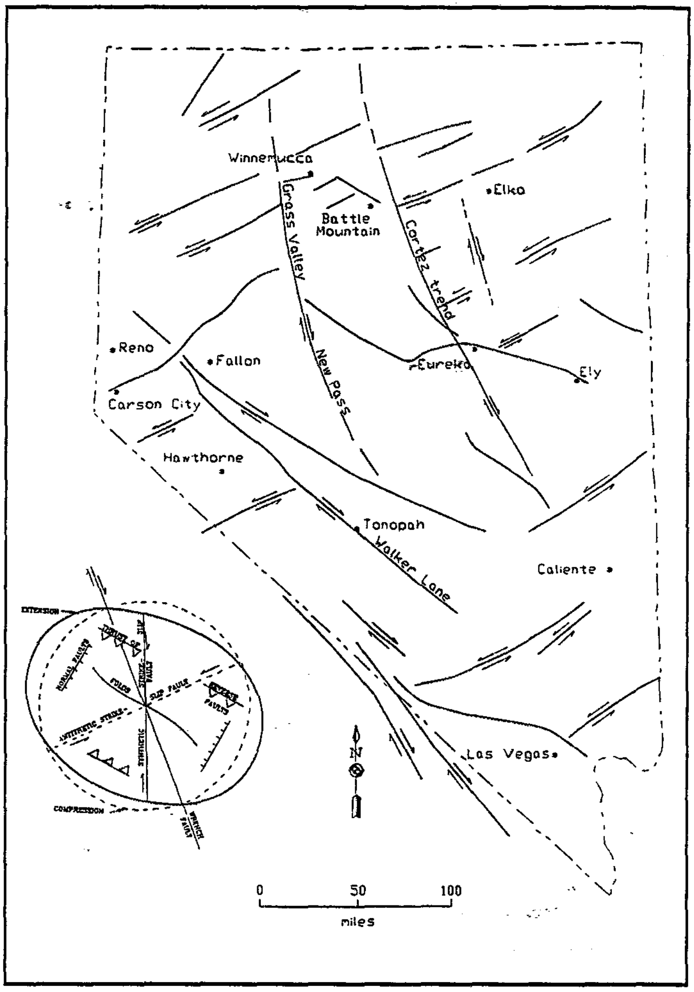


FIGURE 8. Transverse lineaments with idealized strain ellipse. Cortez trend parallel principal stress (Putnam & Henriques, 1991).

Early discoveries of sediment-hosted gold deposits along the Carlin and Cortez trend have been achieved by using "windows" and proximity of the Roberts Mountains thrust as particular exploration criteria. Shortly after, eugeosynclinal sediments were thrust eastward over coeval miogeosynclinal carbonates, as a result of folding and normal faulting, subsequent erosion of allochthonous sediments exposed miogeosynclinal carbonate rocks as "windows"; These are well known hosts for gold deposition in the region. The Robert Mountains thrust belt and a number of related discrete thrust planes and imbricated thrust zones are spatially associated with many sediment-hosted disseminated gold deposits (e.g. Gold Acres, Gold Quarry, Carlin, Dee). Thrust faults and low-angle normal fault zones help to increase permeability and reactivity of unfavourable sedimentary rocks and much of the mineralization is localized along these zones. Seedorff (1991) proposed that most of the deposits are associated with normal faults (Tertiary extension origin), although the other older structures display a guiding role for fluid flow.

High-angle faults are a very important element in sediment-hosted gold deposits both on a regional basis and in individual deposits. In all of the known deposits, high-angle faults (NE and NW predominant) are closely related with formation of the ore bodies (Percival et al., 1988). Along the Carlin trend, mineralization-associated high-angle faults are at a high-angle to the trend (Rota, 1991; Skead, 1994). This type of faulting displays a different role for ore control. Basically, such faults are channels of hydrothermal fluids that react, shatter and prepare the host rocks for subsequent mineralization. Moreover, in some deposits (e.g. Pinson and Santa Fe), faults themselves are a favourable depositional locality for gold mineralization (high-angle siliceous and brecciated gold ore body).

Breccia bodies are significant characteristics of hydrothermal systems. As Skead (1994) mentioned, they are grouped into four types in the Carlin trend. Carbonate debris flow breccias have higher initial permeability than the surrounding rock and display high reactivity properties by involving aragonite. Carbonate debris flow breccias are individual and conformable flows that have coarser fragments at the base and are trapped by siliciclastic facies. Collapse breccias are characterized simply by having variable forms (pipe to funnel shape), very angular (non-transported) monolithic host rock fragments and matrix (including an insoluble residue of clay, silt and hydrothermal products) support. They are formed by carbonate dissolution and subsequent volume loss.

Other types of breccias that occur in the Great Basin are classic, typical breccias of hydrothermal systems, such as fault and crackle breccias.

Thorman et al. (1991) and Putman & Henriques (1991) noted that during the Mesozoic to Tertiary, as a result of wrench fault tectonics, north-northwest-trending regional antiforms and several anticlinal folds developed. These structures provide favourable traps where hydrothermal fluids can react pervasively with sedimentary rocks. Fold hinges, axial plane cleavages, near-limb culminations (Carlin deposits, Tuscarora anticline) and other fold-related structures which can increase permeability or reactivity for hydrothermal fluids are suitable sites for subsequent gold mineralization (Percival et al., 1988).

3.3. *IGNEOUS ROCK ASSOCIATION*

After intrusion of late Jurassic plutons into the folded, faulted and regionally metamorphosed Upper Precambrian and Paleozoic rocks, Early Cretaceous to Early Tertiary plutonic activity occurred during the Sevier Orogeny (Figs 4 and 6c) (Thorman et al., 1991). Jurassic plutons are distributed along east-west alignments in north-eastern Nevada. These rocks and related mineral deposits are consistent with a magmatic arc environment which has numerous copper skarn, polymetallic vein and replacement type deposits hosted by carbonates (Cox et al., 1991; Dilles & Wright, 1988). Cretaceous plutons are not abundant in Central and Eastern Nevada relative to Western Nevada. The most productive Cretaceous plutons in Nevada lie along the Robinson, White Pine, Eureka belt. These plutons are all older than 100 Ma and are very similar to the Jurassic plutons in their mineralogy, texture and associated ore deposits (Cox et al., 1991).

The voluminous volcanic and coeval plutonic events started in the early Tertiary through the influence of extensional tectonics and continued throughout the Tertiary.

Dykes and sills are quite common igneous rock forms which are spatially associated with sediment-hosted gold deposits. Most of the mineralization associated with dykes and sills is emplaced along high and low-angle faults and structurally disrupted zones (Percival et al., 1990). Their compositions vary from felsic to intermediate.

There is an ongoing debate about genetic relationships between intrusives and sediment-hosted ores and the timing of intrusive events. Because of intense hydrothermal alteration and supergene oxidation overprint of intrusive rocks, suitable minerals and reliable data are not available. However, sediment-hosted gold deposits are remarkably abundant during the Tertiary. Some authors (Radtke et al., 1980; Birak, 1986; Hofstra et al., 1988; Ilchik, 1990) suggest that sediment-hosted gold deposits are the product of extensional environments and are related to Tertiary intrusives only. In contrast, other workers (Silberman et al., 1974; Bonham, 1984,1985; Arehart et al., 1993a) argue for a genetic connection between Cretaceous intrusions, ore fluids and subsequent ore deposition.

3.4. *ALTERATION*

Sediment-hosted gold deposits are characterized by primary structural controls (e.g. faults, folds) and rock permeability, dissolution of carbonate minerals and precipitation of silica. As Kuehn & Rose (1992) generalized of Carlin, major episodes of element mobilization can be distinguished by processes related to (1) hydrocarbon maturation (pre-gold ore), (2) Au ore deposition (syn-gold ore) and (3) subsequent oxidation (post-gold ore). The most common hypogene and supergene alteration types are decalcification, silicification, argillization, hypogene oxidation and supergene oxidation which occur during the second and third episodes. Mineral assemblages and intensity of alteration varies from deposit to deposit.

Decalcification is characterized by (1) removal of calcite and to a lesser extent dolomite from carbonate host rocks by early low-temperature acidic hydrothermal fluids in the pyrite stability field; (2) having significant reduction of bulk density and volume loss (50-60 % at Carlin; 30-40 % at Betze/Post) of host rocks indicated by collapse breccia, and thickness changes of altered beds, (3) abundant calcite veining or calcite zone on the peripheries of the hydrothermal system, (4) resulting increase in porosity and permeability of the host rocks to make them favourable for mineralization (Bakken & Einaudi, 1986; Kuehn & Rose, 1992; Radtke, 1985; Skead, 1994).

Near hydrothermal influx channels, which are mostly high-angle faults, permeable interbeds and bioclastic horizons, rocks have highest decalcification intensity and are composed of quartz, illite-sericite, pyrite, organic carbon and minor dickite-kaolinite. Intensity of decalcification decreases with distance away from fluid channels (Kuehn & Rose, 1992).

Silicification and silica deposition occur in different stages and in different forms as the result of multiple episodes of hydrothermal activity and different physical and chemical conditions. Although silicification starts at a very early pre-ore stage, it continues throughout the main and late hydrothermal stages. Common forms of silica are fine grained disseminated, euhedral quartz, zones of intense or complete silicification (jasperoid), veins and veinlets which can be accompanied by stibnite, realgar and cinnabar mineralization, late stage drusy, chalcedonic and amorphous silica (Percival et al., 1988; Radtke, 1985). During the main hydrothermal stage, silica-supersaturated high-temperature fluids create quartz veins in unreactive or previously silicified rocks along weakness zones. Zones of siliceous alteration or silica veins commonly contain sulphides and they occur within or close to gold ore bodies.

Jasperoids are very characteristic, easily recognisable, silica forms in sediment-hosted gold deposit environments. They consist typically of fine grained, crypto-crystalline, chalcedonic or phenocrystalline silica which has formed by replacement of mostly limestone or dolomite (Lovering, 1972; Theodore & Jones, 1992). Madrid & Bagby (1988), Fournier (1973), Romberger (1986) and Rota & Hausen (1991) observed that many jasperoids are localized around structural planes of weakness (such as; faults, breccia zones, bedding planes) and that jasperoid deposition is controlled by host rock reactivity, porosity, permeability and impermeable lithologic barriers. Rota & Hausen (1991) and Skead (1994) describe how jasperoids develop at the contact between carbonate and siliciclastic units and argue that jasperoid acts as an impermeable cap, ponding ascending hydrothermal fluids at the Gold Quarry deposits. Another unusual gold-bearing jasperoid has formed along the hinge of an anticline at the South Billion deposits (Putnam & Henriques, 1991).

High level gold-bearing jasperoids are usually associated with anomalous As, Sb, the Hg trace elements suite and some of the following hypogene minerals: pyrite, barite, calcite, fluorite and minor sulphides.

Intensity of silicification decreases away from fluid paths and gold values increase with growing silicification (Bakken & Einaudi, 1986). In contrast, Kuehn & Rose (1992) observed that the highest Au content is "adjacent" to intensely silicified zones, but not within it. However, some high Au values occurred in "some" jasperoids. As Bakken & Einaudi (1986) pointed out, in some hydrothermal systems, it is possible to see two different types of jasperoids (gold-bearing and gold-barren).

Therefore jasperoids are characteristic of sediment-hosted gold deposits and, as such, provide a useful exploration guideline (Tables 1 and 2).

Argillic alteration and formation of an argillic alteration suite (illite, kaolinite, montmorillonite) is due to an increase in SiO_2 which reflects the formation of fine-grained quartz and K_2O, Al_2O_3, $H_2O^{(+)}$ during the main hydrothermal stage (Radtke, 1985). In this stage, fine-grained quartz, sericite and minor kaolinite formed in the matrix of the carbonate rocks of the Carlin deposit.The most suitable host rocks for better development of argillic alteration are shale and igneous intrusives in sediment-hosted gold depositional environments. The intensity of alteration and mineral assemblages is highly variable. Intense argillic alteration (mostly kaolinite and illite) occurs along shears, fractures or near main feeders as pervasive alteration (Ekburg et al., 1991; Kuehn & Rose, 1992; Carden, 1991). However, at Tusc Gold Deposit, most of the host rock is weakly to moderately argillized which is the dominant alteration type (Hays & Foo, 1991; Ekburg et al., 1991). At Gold Quarry Mine, argillic alteration followed both silicification and alunitization. The core of the alteration zonation (silicified rock) is surrounded by quartz-alunite and argillic alteration (Ekburg et al., 1991; Rota & Hausen, 1991). Recently, Kuehn & Rose noted that dickite is the most common argillic alteration in dykes of the Carlin deposit.

Carbonization has been recorded from some sediment-hosted gold deposits in Nevada. In general, carbonization is mature hydrocarbon concentration which is anomalous within deposits, in relation to the surrounding rocks (Edison & Hallager, 1987). Black, sooty, mature hydrocarbons occur along fractures, bedding planes and carbon-bearing veins. This type of alteration generally includes a high amount of disseminated pyrite. In the Gold Acres deposit, carbonization is the dominant alteration type and contains three percent (by weight) organic carbon (Hays & Foo, 1991). Kuehn & Rose (1992) have studied Carlin hydrocarbon maturation and interpreted the occurrence as hydrocarbons being introduced into the Tuscora anticline, enriched during intrusive events and subsequently redistributed by hydrothermal activity. The relationship between thermal hydrocarbon maturation and gold mineralization is not yet agreed upon. Nelson (1991) and Cunningham (1988) believe that there is a positive correlation between gold and organic material.

TABLE 2. SIZE AND DISCOVERY HISTORY OF SELECTED SEDIMENT-HOSTED GOLD DEPOSITS, GREAT BASIN.

YEAR OF DISCOVERY	DEPOSIT	TONNAGE/GRADE	DISCOVERY METHOD
1883	Mercur (Utah)	n.d.	Sediment-hosted fine gold in silver district
1905	Manhattan	20.3 Mt @ 0.7 g/t	Extension of known deposit
1935	Northumberland	10.9 Mt @ 2.1 g/t	Jasperoid outcrop geochemistry
1936	Getchell	8.43 Mt @ 5.82 g/t	Extension of known deposit
1962	Carlin	12.7 Mt @ 9.2 g/t* 8.27 Mt @ 0.96 g/t**	Outcrop geochemistry, trenching
1967	Cortez	3.3 Mt @ 9.81 g/t	Outcrop geochemistry
1971	Pinson	n.d.	Drilling on mineralized jasperoid at inactive prospect
1972	Preble	n.d.	Calcareous siltstone
1973	Gold Acres	1.99 Mt @ 3.67 g/t	Extension of known deposit
1973	Jerritt Canyon	19.6 Mt @ 4.9 g/t	Drilling on geochemical anomaly similar to Carlin
1976	Alligator Ridge	0.9 Mt @ 2.2 g/t	Lithologic similarity to Carlin; jasperoid geochemistry
1976	Dee	4.1 Mt @ 2.0 g/t	Outcrop geochemistry
1976	Tomboy-Minnie	n.d.	Blind drilling on calcareous conglomerate
1979	Gold Quarry	300 Mt @ 1.5 g/t	Drilling on jasperoid at mineralized prospect
1979	McCoy-Cove	n.d.	Stream, soil and outcrop geochemistry, drilling
1980	Rain	35.1 Mt @ 1.5 g/t	Jasperoid outcrop geochemistry
1982	Horse Canyon	2.99 Mt @ 4.91 g/t	Jasperoid outcrop geochemistry

CONTINUED

YEAR OF DISCOVERY	DEPOSIT	TONNAGE/GRADE	DISCOVERY METHOD
1982	Betze-Post	136 Mt @ 5.96 g/t	Extensive drilling
1983	Hilltop	5.23 Mt @ 2.7 g/t	Drilling at prospect
1983	Gold Bar	3.15 Mt @ 3.2 g/t	Stream sediment geochemistry, drilling
1984	Genesis-Blue Star	54.08 Mt @ 1.3 g/t	Extension of known BlueStar Mine Sampling by rock chip; drilling
1985	Chimney Creek	53 Mt @ 1.8 g/t	Outcrop geochemistry
1986	Green Springs	1.1 Mt @ 2.1 g/t	Jasperoid outcrop geochemistry
1986	Easy Junior	5.2 Mt @ 1.1 g/t	Soil and jasperoid outcrop geochemistry
1986	Rabbit Creek	53 Mt @ 2.4 g/t	On trend, structural intersection drilling
1987	Cove	n.d.	Stream, soil and outcrop geochemistry; drilling
1987	South Bullion	18.1 Mt @ 0.89 g/t	Drilling on jasperoid outcrop geochemistry
1987	Winters Creek	1.2 Mt @ 5.2 g/t	Drilling on structural and mineralized trends
1990	Ruby Hill-Archimedes	22.05 Mt @ 2.6 g/t	Extension of known Ruby Hill deposit; rock chip; drilling
1990	South Pipeline	88.9 Mt @ 1.4 g/t	During investigation drilling of construction site

* Mined out reserves   ** Current reserves   n.d.: no data

Source: Field Trip Reports of Minorco Services BV: A Symposium Organised by the Geological Society of Nevada, Reno, Nevada, April 1995; Adams & Putnam (1992).

Oxidation is not a very common alteration type in sediment-hosted gold deposits. Oxidation zones are usually buff-tan coloured which are converted from grey-black to a lighter colour by remobilization of carbon and addition of iron oxide by either hypogene or supergene processes (Carden, 1991). The boundaries, mineral assemblages and origin (hypogene / supergene) of oxidation zones are variable and controversial. The oxidation zone occurs from the surface to the base of the ore body in the Tusc gold deposit (Ekburg et al., 1991). It is characterized by a coloured, bleached zone of limonite/clay - hematite/clay alteration. The Vantage Gold deposits have two periods of oxidation that produced earlier alunite ± barite veins and a later jarosite overprint (Ilchick, 1991). Radtke (1985) deduced that there are two periods of oxidation in the Carlin deposit. Hypogene oxidation is limited to near-surface exposures; however, supergene oxidation continues downwards.

Alunite, alunite-barite assemblage and alunite-gold genetic relationships cause ongoing debate in the Gold Quarry, Post and Vantage Gold deposits (Ilchick, 1990; Rota & Hausen, 1991; Kuehn & Rose, 1992).

A detailed wall rock alteration study has been performed at the Carlin gold deposits by Kuehn and Rose (1992). Alteration events and zonations are generalized in the following sequence: (1) unaltered: quartz + K-Feldspar + illite + calcite + dolomite, (2) decalcified: quartz + illite + dolomite (± calcite), (3) decarbonated: quartz + sericite - illite (± dolomite), (4) siliceous-argillic: quartz + dickite - kaolinite + sericite - illite, and (5) jasperoid: quartz + dickite - kaolinite. All these zonings are controlled by permeability and structure (tiny fractures to permeable beds).

4. MINERALOGY AND GEOCHEMISTRY

4.1. *MINERALOGY AND OCCURRENCE OF GOLD*

Sediment-hosted gold ores can be classified as oxidized and unoxidized ores. Oxidized ores were more economically desirable than most types of unoxidized ores, because of their physical and metallurgical features. However, during the 1980's, with development of technology in treating low grade refractory ores, exploration programs also shifted to unoxidized ores. Carbonaceous, pyritic, arsenical, siliceous unoxidized and jasperoid ores are the subdivisions of unoxidized ores which are based upon chemical and mineralogical characteristics (Radtke, 1985).

Carbonaceous ores mostly contain organic materials and disseminated grains. In the Vantage Gold deposit, carbonaceous ore had the highest and most consistent gold grades of all types of ore (Ilchik, 1991).

Pyrite is the most common ore-stage sulphide and quite a common host for gold in many deposits (Berger & Bagby, 1991). Pyritic ore is characterized by its 3 to 10 weight percent pyrite at the Carlin Deposit by Radtke (1985). In fact, most of the normal unoxidized ore contains fine-grained, disseminated pyrite (0.5 to 3 weight percent) which hosts gold. Determination of the pyrite grains according to their origin (diagenetic or hydrothermal) is a common problem in the interpretation of pyritic ores (Percival et al., 1988).

Arsenical ore that contains arsenic in the form of realgar, orpiment and arsenic-bearing sulphosalts is a common ore type in some deposits. Gold is also present in arsenian pyrite and in arsenian overgrowth rims around pyrite grains (Wells & Mullens, 1973; Arehart et al., 1993a).

Unoxidized intensely silicified ores are an easily recognizable and common ore type, especially in jasperoid forms. Ores contain mostly silica and certain amounts of clay, carbonate minerals, sulphides and sulphosalts. In contrast, normal unoxidized ore is hardly recognizable and is similar to normal unaltered rocks. As a result of decalcification and silicification of the host rock, disseminated pyrite and anomalous Au with some trace elements occur in normal unoxidized ore (Percival et al., 1988).

Light coloured, iron-oxide-rich, variably argillized and silicified oxidized ore has different forms and sites of gold such as: encapsulated in silica; associated with goethite and jarosite; and associated with quartz veinlets.

4.2. GEOCHEMISTRY

During the main hydrothermal stage, the fluids introduced significant amounts of SiO_2, $Fe_{(total)}$, K_2O, Al_2O_3 and removed CaO, MgO and CO_2 (Radtke, 1985; Percival, 1988). These chemical interactions altered the sedimentary host-rocks and high amounts of Si were precipitated with characteristic geochemical associations of Au, As, Sb, Hg, Ba and occasionally Tl. Sediment-hosted gold deposits are also characterized by high Au/Ag ratios and a notable absence of base metal sulphides (Cu, Pb, Zn, Mo) (Arehart et al., 1993a). Ag, F and W are also considered as a part of the anomalous Au associated suite of elements in some deposits. Occurrence of minor amounts of base metals and (Au-As-Sb-W), (Au-As-Hg-W) trace element suites can be explained by the presence of different types of mineralization (e.g. skarn) in the same depositional environment (e.g. Getchell, Maggie Creek, Pinson).

Realgar, orpiment, arsenian pyrite, rarely arsenopyrite and native arsenic (reported at very few deposits by Rytuba, 1986) are the known occurrences of arsenic in sediment-hosted gold deposits (Dickson et al., 1979). Stibnite, cinnabar, Hg and Sb coatings on the surface of pyrite grains (in unoxidized ore) are common forms of antimony and mercury. Barium and fluorine usually occur with their well known forms as barite and fluorite respectively. Thallium usually occurs as complex sulphosalts (Percival et al., 1988).

4.3. *PARAGENETIC SEQUENCES*

Several individual sediment-hosted gold deposits and their sulphide ores have been used by Arehart et al., (1993a) to generalize a paragenetic sequence (Fig. 9).

The pre-ore stage consists of the oldest depositional or diagenetic stage pyrites, later-stage hydrocarbon concentrations, quartz, calcite, earliest barite and minor base metals.

The hydrothermal episode (syn-gold) has two stages: main ore stage and late ore stage. Arsenopyrite is the earliest hydrothermal mineral to precipitate, followed by rare native arsenic. The rarely noted occurrence of native arsenic can be explained by practical difficulties in recognising very fine grained disseminations of it in highly carbonaceous ore (Rytuba, 1986). Pyrite is the most abundant main ore stage sulphide. Marcasite is also common in this stage. Most of the ore-stage pyrite is arsenic-rich and is a host for gold. Realgar and orpiment are typical post-main-stage sulphides and represent the waning stages of the hydrothermal system. Stibnite usually occurs late in the paragenetic sequence. Rarely, some base metal sulphides occur in the hydrothermal stage, but they are not associated with Au. Cinnabar and some other sulphides appear in the main ore stage in minor amounts. Arsenopyrite (deepest in the core) - arsenian pyrite - realgar and orpiment- stibnite paragenetic sequence reflects expected sulphide zonation, except the appearence of stibnite as open-space fillings in the late paragenetic sequence (Arehart et al., 1993a).

Some arsenian pyrite and some stibnite have been deposited during the late-hydrothermal quartz, barite and calcite veining stages. Barite is commonly present in considerable amounts in this stage. Fluorite is ubiquitous in sediment-hosted gold ores

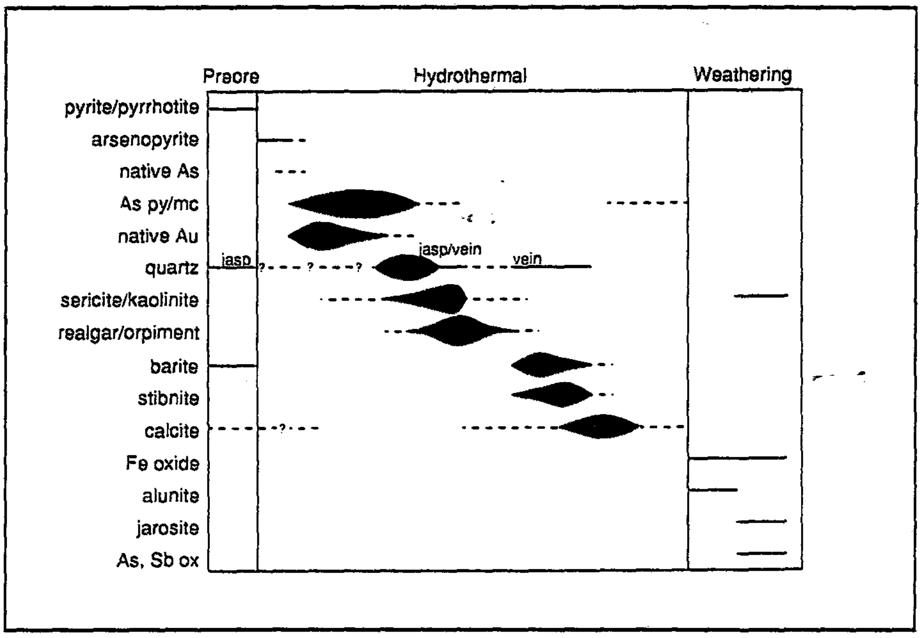


FIGURE 9. Generalized paragenetic sequence for sediment-hosted disseminated gold deposits. Mineral abbreviations: As py/mc= Arsenian pyrite/marcasite; As, SbOx= Arsenic and antimony oxides; Jasp= Jasperoidal quartz (Arehart et al., 1993a).

found in post-main stage veinings (Berger & Bagby, 1991). The hydrothermal stage is followed by controversial oxide and sulphate production in veins. The origin (supergene/hypogene) of alunite in particular deposits is not commonly agreed yet (Arehart et al., 1993a).

5. ORE ZONES

5.1. *ORE BODIES*

Three different shapes of ore bodies are defined in sediment-hosted, disseminated gold deposits (Fig. 10). They are:

(1) tabular-shaped ore bodies which are limited to a high-angle fault zone. The ore body formed within fault zones, where the wall rocks are unreceptive and unfavourable for fluids.

(2) irregularly shaped ore zones in a stratigraphic section of receptive sedimentary rocks. They usually occur in siliceous clastic rocks along or close to high- and low-

angle faults and related breccia zones.

(3) tabular and irregular shaped, stratabound ore zones that are confined to receptive sedimentary rocks within a stratigraphic section of non-receptive rocks (Percival et al., 1988).

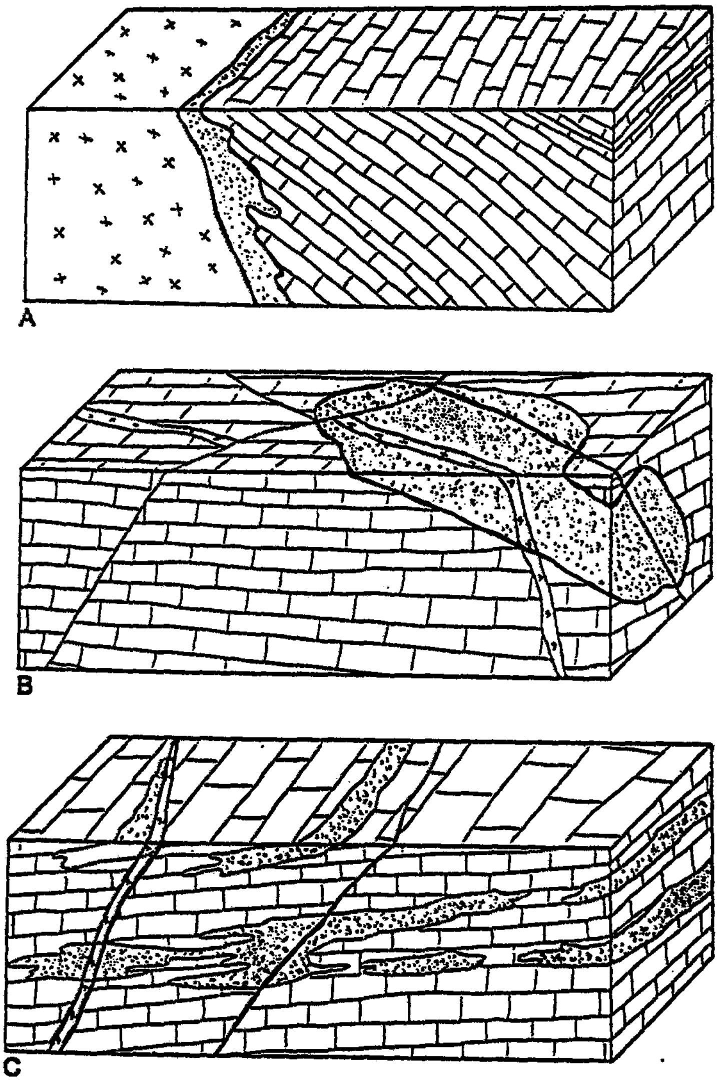


FIGURE 10. Typical shapes of ore bodies in sediment-hosted gold deposits in the Great Basin. The box pattern represents silty carbonate rocks and "X" pattern represents igneous rocks. Faults are shown as solid lines (Percival et al., 1988).

The positions, shapes and sizes of ore bodies are intimately controlled by the position of high-angle faults, structural preparation (shattering, intersections, brecciations) of the rocks, nature of the host lithologies, folds and unconformities. The position of the fluid conduit (high-angle fault) relative to the host rock is also important.

Most of the ore-controlling factors which are given above except unconformities were discussed in previous parts of the report. Several sediment-hosted gold ores are in sediments above, below or straddling major or regional unconformities. Large volumes of gold-bearing fluids travelled along high-angle faults and mixed with meteoric water along regional unconformity horizons, leading to gold precipitation in some deposits (Adams & Putnam, 1992; Skead, 1994). Also, the presence of impermeable rock above the unconformity can block ascending fluids in a "trap"-like zone which provides chemical interactions with underlying permeable rocks (Skead, 1994).

5.2. GEOCHRONOLOGY

The age of the sediment-hosted gold deposits is one of the most difficult questions to answer. The answer is a key factor in understanding the genesis of the deposits which is quite a controversial issue. Most of the rocks and ore bodies are unsuitable for dating because of the natural illite and chlorite content of the host rocks, extremely fine grained altered hydrothermal minerals and very common supergene effects resulting in oxidized exposed ore bodies.

Many authors (Silberman & McKee, 1971; Silberman et al., 1974; Berger & Taylor, 1980, Bonham, 1985; Osterberg, 1989) suggest a **Cretaceous** age for gold mineralization based on K/Ar dates on alteration minerals. In contrast, Joralemon (1951), Wells et al. (1969), Radtke (1985) and Rota & Hausen (1991) concluded that extension, abundant igneous and hydrothermal activities throughout **Tertiary** time resulted in widespread gold mineralization in the Great Basin. Seedorff (1991) dated many jasperoid-hosted gold deposits as mid-Tertiary. He also developed a hydrothermal model based on regional crustal thinning and heating in **Early Eocene-Oligocene** extension times. Pre-late Tertiary age structural evidence related to gold deposition is suggested by Bakken & Einaudi (1986). Miocene or younger ages are suggested by Radtke (1985) from igneous activity and related hydrothermal events in Carlin, by Birak (1986) for Jerritt Canyon and by Ilchick (1990) for Alligator Ridge.

Arehart et al., (1993b) pointed out that most resolutions of the ages have been determined by indirect methods based on cross-cutting relationships. He used K/Ar, $^{40}Ar/^{39}Ar$ and fission track ages of several igneous and sedimentary rocks, and suggested that sediment-hosted disseminated gold deposits are not necessarily products of extensional environments. Thus, Arehart et al., (1993b) believed that most of the deposits are associated with **Cretaceous** compressional events.

5.3. *SIZE AND GRADES OF DEPOSITS*

Sediment-hosted gold deposits vary widely in size and grade which are shown in Table 2. Grade and tonnage values of 33 deposits in Great Basin were presented on cumulative frequency graphs by Berger & Bagby (1991) (Fig.11); the data show that the median value of gold grade for 33 deposits is 2.9 g/t and median tonnage is 6.2 Mt. The cumulative frequency curve for grades shows that 90 % of the deposits have an average gold grade of less than 7.8 g/t and an average tonnage of less than 38 Mt. In some of the higher grade gold deposits, recent exploration has discovered deep ores that are greatly enlarging actual and potential tonnages (e.g. Lower Post which has 137t. Au; Chimney Creek, and Rabbit Creek).

6. GENETIC MODELS

Genetic models and evaluation of the tectonic setting of the sediment-hosted gold deposits are still unresolved problems because of the lack of consensus regarding the age and origin of these deposits. Different workers and their different interpretations will be discussed later with regard to newly discovered sediment-hosted gold deposits in other parts of the world; will be given briefly in Part B.

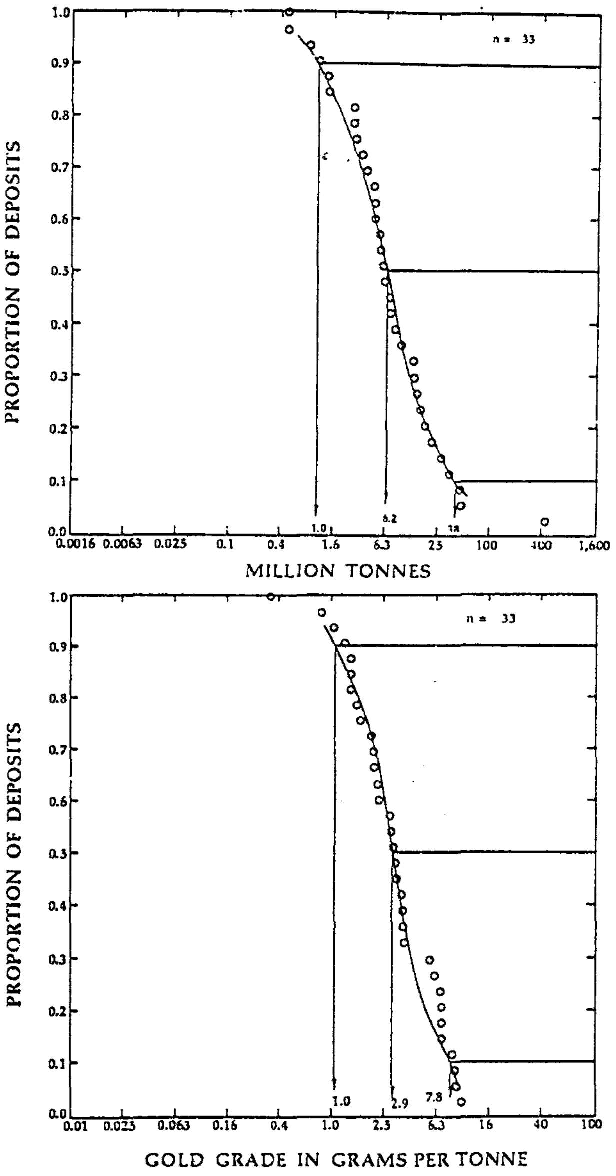


FIGURE 11. Grade-tonnage distribution for sediment-hosted gold deposits in the Great Basin (Berger & Bagby, 1991).

C. RECENTLY DISCOVERED SEDIMENT-HOSTED GOLD DEPOSITS OUTSIDE OF THE U.S.A.

The major portion of the production from sediment-hosted disseminated gold deposits comes from the Great Basin, Nevada. Recently, similar deposit types have been discovered all over the world, outside the U.S.A. (Fig. 12). Examples include China, Indonesia, Peru, Chile, Macedonia and Iran. Twelve sedimentary-rock-hosted disseminated gold deposits and occurrences have been recognized in the People's Republic of China (Ashley et al., 1991). The Pacific Rim, especially Indonesia, has at least five similar gold deposits (Sillitoe, 1994). Two South American deposits (El Hueso - Chile and Purisimo Concepcion - Peru) and a few Eastern European deposits (Alsar-Macedonia) have also been studied and interpreted as sediment-hosted gold deposits (Alvarez & Noble, 1988; Percival et al., 1990; Sillitoe, 1991). They vary in their size, grades of ores, textures and degrees of structural controls, but they share several common features which are also characteristic of sediment-hosted gold deposits in the Great Basin, Nevada (Figs 13 and 14).

Thirteen selected deposits and their geological and mineralogical key characteristics are summarized in Tables 3, 4, 5 and 6. The current chapter examines these characteristics with emphasis on similarities to Great Basin examples.

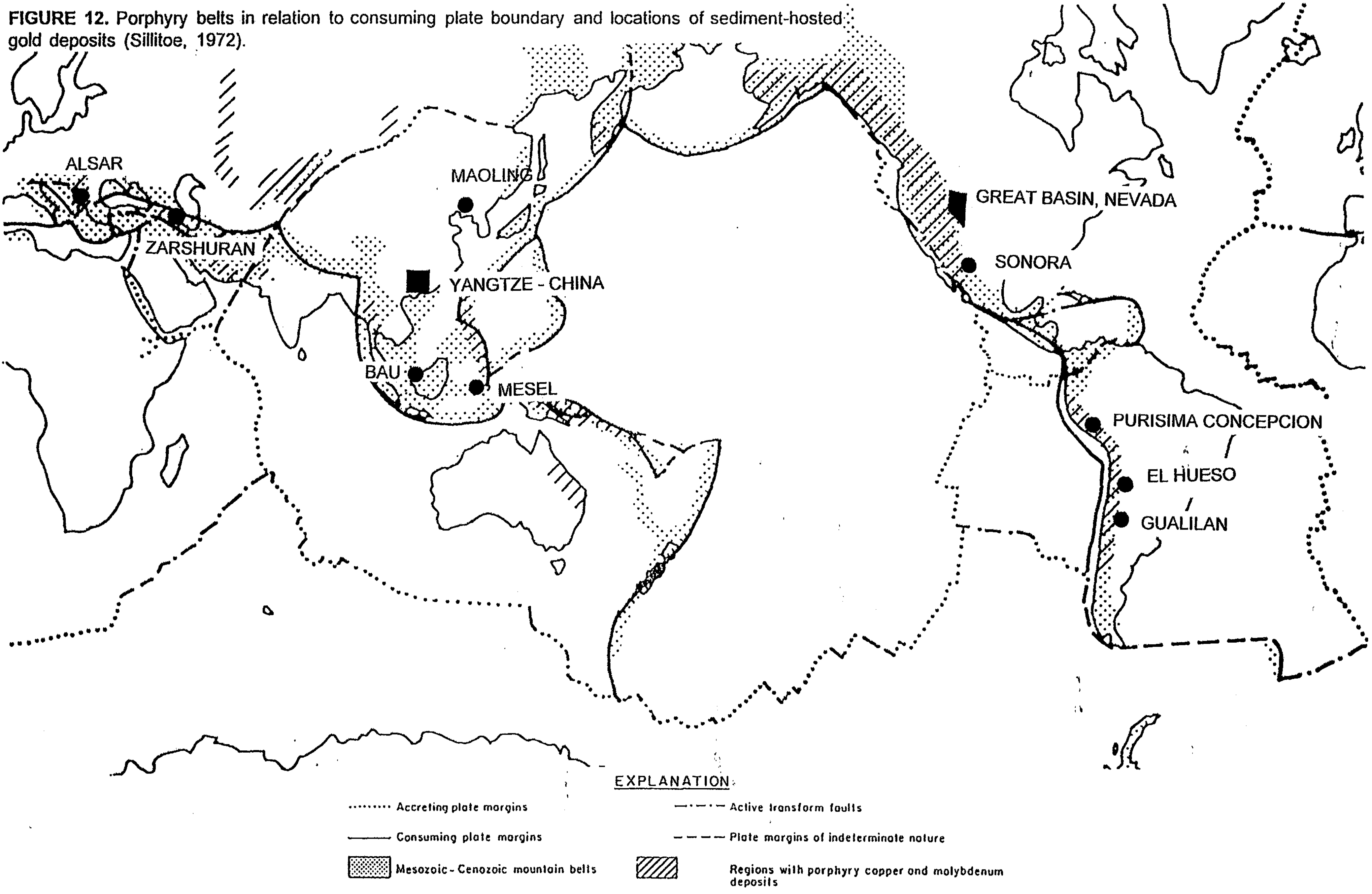
1. GEOLOGICAL CHARACTERISTICS

1.1. *Host Rocks*

Gold mineralization is hosted by a wide variety of sedimentary rock types of varying ages from Proterozoic through to Tertiary in selected newly discovered deposits.

The gold deposits of Guizhou province (e.g. Yata, Getang, Sanchahe, Ceyang) lie at

FIGURE 12. Porphyry belts in relation to consuming plate boundary and locations of sediment-hosted gold deposits (Sillitoe, 1972).



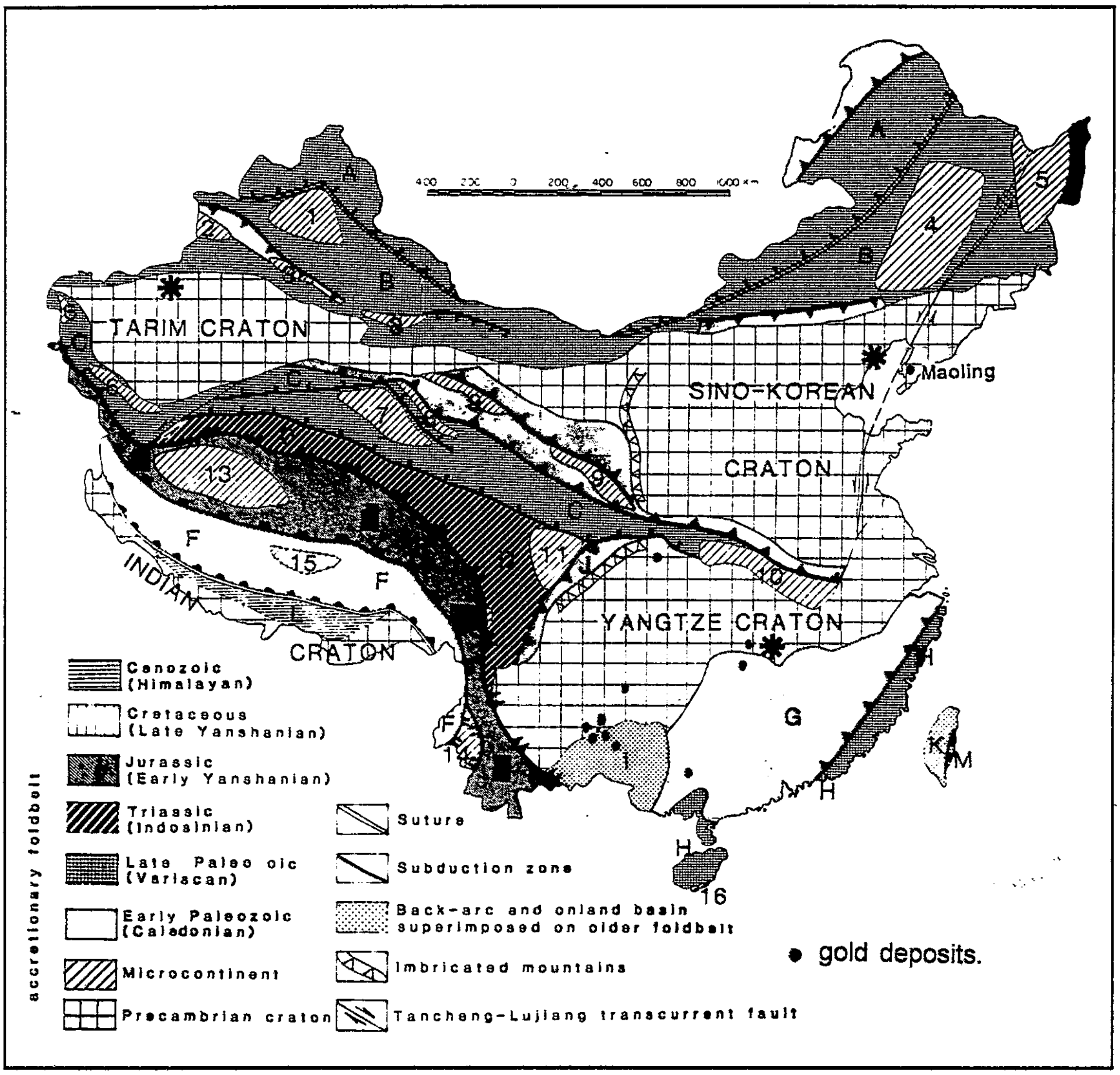


FIGURE 13. Sketch map of plate tectonics and locations of sediment-hosted gold deposits in China (modified from Zhang et al., 1984).

the edge of the Tangtze Craton which is overlain by shallow-marine platform deposits (Zhang et al., 1984; Ashley et al., 1991). They comprise turbidites, platform margin, reef-lagoon and open platform sediments which vary from thin-layered argillaceous limestone interlayered with shale, arkose and sandstone to coal layers containing massive limestone (Cunningham et al., 1988). Similarly, three other Chinese deposits (Maoling, Dongbeizhai and Jinya) are also hosted by several types of sediment such as; dolomitic sandstone, shale, mudstone, and limestone. These also form the most common host rocks in Great Basin sediment-hosted gold deposits. However, some notable differences are recognized in the host rocks of Maoling and Dongbeizhai which are likely to have formed in a regionally-thermally metamorphosed area. Phanerozoic unmetamorphosed rocks are the abundant host rock type in the Great Basin deposits. The Maoling deposit has a unique Proterozoic host rock which is not recorded in any other sediment-hosted deposits either in the Great Basin or in the newly discovered deposits (Cheng et al, 1994; Wang & Zhou, 1994).

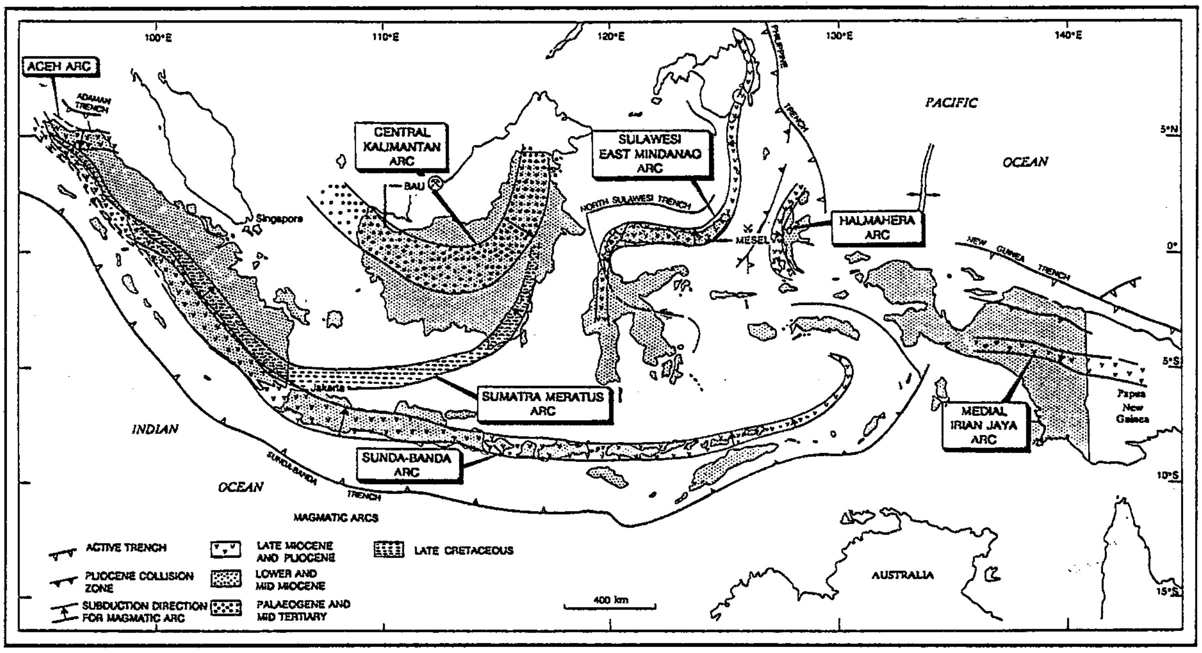


FIGURE 14. Distribution of Late Cretaceous to Pliocene magmatic arcs and locations of sediment-hosted gold deposits in Indonesia (modified from Carlile & Mitchell, 1994).

Mesel, Lobongan/Alason and Bau trend deposits in Indonesia occur within carbonate stratigraphy which contains similar host rock types to those of the Great Basin. However, karst development and karst infills serve as unusual types of host rocks for the Lobongan deposit (Turner et al., 1994). This peculiar feature is quite similar to the South Bullion deposit paleokarsts (Putnam & Henriques, 1991).

Most of the Great Basin deposits and Purisima Concepcion, Peru; Alsar, Macedonia; El Hueso, Chile deposits occur in host rocks of similar lithology, although these three newly discovered deposits have host rocks that are younger in age (Table 3).

TABLE 3. PRINCIPAL GEOLOGICAL CHARACTERISTICS OF NEWLY DISCOVERED SEDIMENT-HOSTED GOLD DEPOSITS, OUTSIDE OF U.S.A.

DEPOSIT	HOST ROCK	HOST ROCK AGE	FOLD	FAULTS	ALTERATION	MINERALIZATION	IGNEOUS ROCKS
MESEL (INDONESIA)	Silty limestone, calc-argilite, sedimentary debris flow	L. Miocene	n.d.	NNW, WNW high-angle faults. Sinistral strike-slip & oblique reserve faults	Decalcification, sanding, dolomitization, silicification, argillization (illite, kaolite, alunite). L.stage calcitization	Replacement style; along limestone-andesite contact & steep dipping, fault bounded silicified zone	Andesitic sills, plugs (subvolcanic intrusion)
LOBONGAN ALASON (INDONESIA)	Massive, micritic lagoonal limestone (karstification)	L. Miocene	n.d.	NE & NW conjugate set of fractures, ENE high-angle faults	Slicification (Karst breccia), argillization, oxidation	Replacement silicification at contacts (ENE strike) & open-space quartz+calcite veining in paleokarst breccias	Andesitic subvolcanic intrusions
BAU (INDONESIA)	Massive limestone & calcareous shale	L. Jurassic to Cretaceous	ENE striking anticline	NE to NNE high-angle faults, orthogonal set of subsidary faults & fractures	Decalcification, weakly to highly silicification (jasperoids+hydrothermal breccia), argillization	Ore body occurs near steepfaults at contact between limestone & shale, lenslike body hosted by shale which is cut by porphyr dyke	M. to L. Miocene microgranodiorite to dacite porphyr stocks, sills & dykes
YATA (CHINA)	Argillaceous limestone, shales arkoses & turbidite sandstone	M. Triassic	E-W trending anticline subsidiary folds	E-W trending high-angle faults (subparallel to fold axis)	Decalcification, silicification, argillisation (rare), potassium metasomatism, quartz-calcite veinlets	Ore bodies localized by high-angle faults (E-trending) & wall rock dissemination	n.d.
GETANG (CHINA)	Massive gray limestone containing a few coal beds, argillecous limestone, carbonaceous shale	E. Permian to L. Permian	Getang dome (NW trending 50 m long anticline)	Bedding plane thrust? & post mineralization normal & reverse faults	Decalcification, silicification (direct correlation with Au-Jasperoid), argillization, oxidization, organic carbon,	Lensoid paleokarst breccia bodies at the disconformity on the eastern limb of the dome	n.d.
SANCHAHE (CHINA)	Sandy shale with thin coal seams, shale & argillaceous limestone, siltstone, limestone	U. Permian, L. Triassic	E-W trending anticline cut by thrust fault	Thrust fault (trace is parallel to crest of anticline; fault plane dips with moderate angle)	Decalcification, silicification (mostly in limestone), argillization (illite, kaolinite), oxidation (supergene),	Near thrust fault & along the crest of anticline, lenticular ore body (65-200 m long, 15 m thick)	n.d.
CEYANG (CHINA)	Arkosic shale	M. Triassic	N-S-trending 30 km long anticline	NE-trending thrust faults, NW-trending strike-slip faults	Decalcification, silicification, argillisation	Along intersection of arkosic shale & NE-trending faults	n.d.

CONTINUED

Deposit	Host Rock	Host Rock Age	Fold	Faults	Alteration	Mineralization	Igneous Rocks
Maoling (China)	Mostly arenites, calcerous arenites & limestone, (metamorphosed)	E. Proterozoic	n.d.	NE & NW-trending conjugate faults (high-angle) & shear zones under compression regime EW & NE post-ore faults	Pervasive silicification, sericitization, pyrrhotitization; (qtz-carbonate-pyrrhotite); (biotite-chlorite-sericite)	Controlled by NE & NW high-angle shear zone & their intersections. NNE-trending zones control the strike of their ore bodies	Jurassic granites (at intersection of conjugate set), dykes (qtz-feldspar, dioritic porphyries) along NNE-SSW, NE-SW & NW-SE direction
Dongbeizhai (China)	Alternating beds of metamorphosed, carbon bearing, dolomitic sandstone & shale	U. Triassic	n.d.	Large? thrust faults	Silicification, argillisation, pyritization. Late stage calcite	Ore bodies (phyllitic & phyllitic breccia) occur in large fault (thrust?) & along the bedding or in tabular forms	n.d.
Jinya (China)	Sandstone, siltstone & silty mudstone	M. Triassic	Anticline or domal structure	NNE & WNW-trending normal & thrust faults	Silicification, pyritization, calcitization, arsenopyritization?	Ore bodies are related to thrust & normal faults	n.d.
Purisima Concepcion (Peru)	Limestone & slate	L. Cretaceous	Anticline plunging 50° (SE) in conjunction with a sill	High-angle Yauricocha Fault & shear zones	Decalcification, silicification, carbonization, sericitization (muscovite), oxidation, K-silicate?	Ore body located in the core of anticline & in crush-shear zones	L. Miocene granodiorite-quartz monzonite stock
El-Hueso (Chile)	Calcerous limestone & siltstone	Jurassic-Cretaceous	n.d.	N-S trending thrust fault (dipping 15° W), small scale high-angle faults (N-S)	Decalcification, silicification, argillisation, oxidation	Tabular ore body between limestone & volcanoclastics	Copper bearing Potrerillos porphyry (U. Eocene-L. Oligocene Andesitic-Rhyolite volcanics
Alsar (Macedonia)	Carbonates (marble), interbedded volcanic tuff & dolomite, felsic tuff	Triassic, Tertiary, Pliocene	n.d.	N, NW & NE trending high-angle sets of faults	Decalcification, sanding, silicification (jasperoid), argillization (kaolinite+illite+sericite+quartz veinlets+iron oxide+calcite+gypsum), weak dolomitization & supergene oxidation	Ore body located along high-angle faults, shearing zones, flat stratigraphic features & unconformity zones	Pliocene tuffaceous volcanics & volcanoclastics. hypabyssal intrusion (porphyritic) & subvolcanic intrusions (latite-andesite)

U: Upper; M: Middle; L: Late; n.d.: no data

Source: Cheng et al., (1994); Jankovic & Jelenkovic, (1994); Turner et al., (1994); Wang & Zhou, (1994); Jankovic, (1993); Ashley et al., (1991); Davidson & Mpdozis, (1991); Dongsheng et al., (1991); Sillitoe, (1991); Percival et al., (1990); Sillitoe & Bonham (1990); Colley et al., (1989); Alvarez & Noble, (1988); Cunningham et al., (1988).

1.2. *IGNEOUS ROCKS*

Igneous components of sediment-hosted gold depositional environments and their spatial relationship with mineralization are one of the major problems in understanding the genetic models for both Great Basin and other newly discovered gold deposits.

Only one deposit (Maoling) of seven Chinese sediment-hosted gold deposits is associated with igneous intrusives (Table 3). No igneous rocks are exposed in the immediate vicinity of Yata, Getang, Sanchahe, Ceyang, Dongbeizhai and Jinya deposits (Cunningham et al., 1988; Wang & Zhou, 1994). Dongsheng et al. (1991) also studied about 20 sediment-hosted gold deposits in China and indicated that intrusions are not abundant, but only a few are not directly related to mineralization. The Maoling deposit and many other smaller deposits occur at a short distance from Jurassic granitic intrusions. Dai and Fan (1990) suggested that re-activation of a conjugate structures system provided dilation zones for these intrusions. Genetic linkage is accepted between these intrusives and mineralization at the Maoling deposit (Cheng et al., 1994).

The Mesel, Lobongan and Alason deposits are associated with several forms of andesite volcanism. The Mesel deposit occurs around the edge of a possible plug of andesitic intrusion. Andesite provides a relatively impermeable cap role for mineralization. Andesitic lava, volcanoclastic sediments and shallow level intrusive rocks are recognised in the Lobongan/Alason area as overlying volcanic cover (Turner et al., 1994). Bau district deposits are located further from porphyry stocks, but, are in close association with microgranodiorite to dacite porphyry sills and dikes (Sillitoe & Bonham, 1990).

At Purisimo Concepcion, the Yauricocha Stock is a composite intrusive body of granodioritic and quartz monzonitic composition that is spatially and genetically related with ore deposits (Alvarez & Noble, 1988). Another South American example, the El Hueso gold deposit is considered as a distal component of Potrerillos porphyry copper mineralizations (Sillitoe, 1991).

A Pliocene age hypabyssal porphyritic intrusion cuts across the sediments in the Alsar deposit. Possible genetic relations between intrusion and mineralization are accepted by Percival et al. (1990); Jankovic (1993) and Jankovic & Jelenkovic (1994).

1.3. *STRUCTURE*

Thrust faulting is one of the major structures for six out of thirteen newly discovered sediment-hosted gold deposits.

There is no detailed information about Dongbeizhai, Jinya and Ceyang gold deposits which are intimately related to thrust faults (Table 3) (Cunningham et al., 1988; Wang & Zhou, 1994). Sanchahe Gold Deposit is closely related to a moderate-angle thrust fault that is parallel to the crest of the anticline. The Getang deposit has unclear, possible bedding-plane, thrust faulting (Cunningham et al., 1988).

The El Hueso deposit is located in a displaced thrust sheet of limestone which overlies, both topographically and structurally, the Potrerillos (Cobre) porphyry. The age and role of the thrusting event are not commonly agreed. Olson (1989); Colley et al. (1989) and Davidson & Mpodozis (1991) suggested that low-angle (15°) thrust faulting of post-mineralization age caused separation of the Potrerillos porphyry copper deposit from the upper part of the porphyry system which contains the El Hueso sediment-hosted Gold deposit (Fig. 15). Recently, Tomlinson (1994) recommended that the thrust fault is pre-mineralization and the syntectonic Potrerillos porphyry intruded into limestone along that thrust fault plane (Fig. 16).

High-angle faults are the predominant faults in many of the gold deposits in the Great Basin. They are mostly described as being normal and reverse faults both in Great Basin and in newly discovered deposits. The role of high-angle faults is also significant for newly discovered gold deposits.

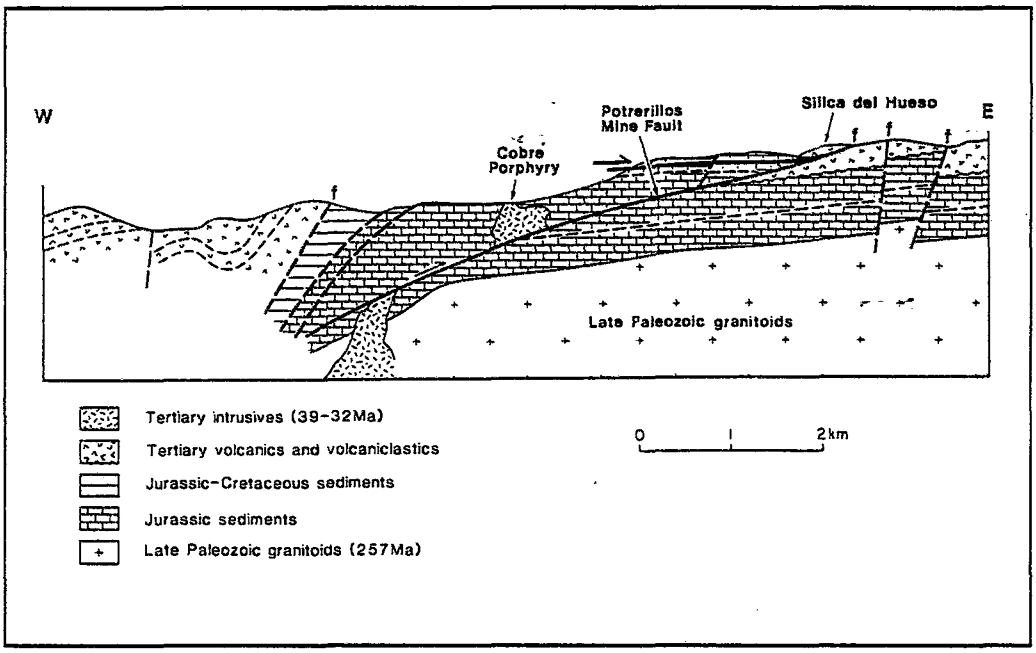


FIGURE 15. Structural cross section of the Potrerillos - Silica del Hueso porphyry-epithermal hydrothermal system. Post mineralization thrusting has displaced the ore bodies (Colley et al., 1989).

The Mesel deposits occur in the intersections of high-angle sympathetic fault sets and in the zone of a thrust fault. Turner et al., (1994) argued that interaction formed a dilational jog in the deposition area and focussed hydrothermal fluid flow.

The Maoling Deposit area has prominent conjugate faults and high-angle shear zones which formed under a regional compressional regime. High-angle faults and their intersections have provided the conduits for ore-forming fluids and depositional sites for mineralization (Cheng et al., 1994). The Yata gold deposit is intimately related to a series of high-angle faults which are subparallel to the axial planes of the folds (Ashley et al., 1991) (Fig. 17).

In the Alsar gold depositional environments, dilational conjugate sets of high-angle faults which formed in response to the major shearing are the locus for movement of hydrothermal fluids (Percival et al., 1990; Jankovic, 1993).

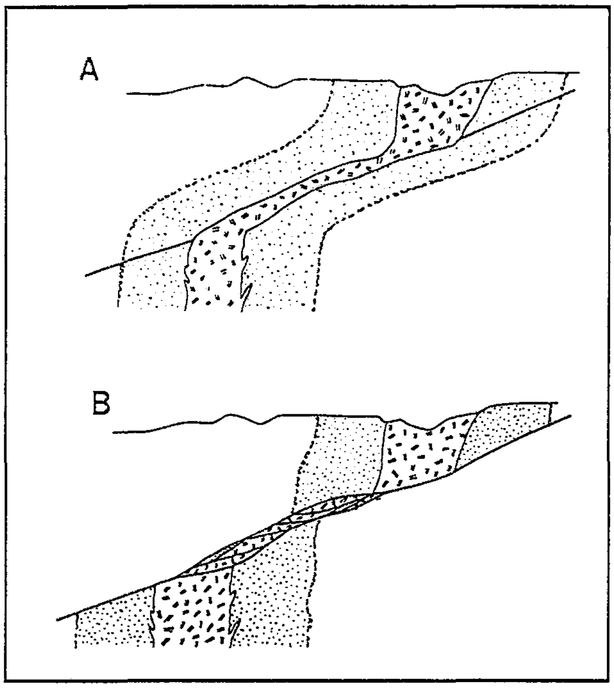


FIGURE 16. Proposed model for intrusion and Potrerillos porphyry. A- Porphyry intrusion along thrust; B- Reactivation of thrust fault (Tomlinson et al., 1994)

Four newly discovered Chinese gold deposits in Guizhou province are located on the flanks of **anticlines** or **domes** and in the cores of **folds** (Cunningham et al., 1988). Bau Deposit is also associated with anticline (Sillitoe & Bonham, 1990). They provide regional and local control for mineralizations. Similar anticline-dome and mineralization relationships are observed in Great Basin sediment-hosted gold deposits (e.g. Betze/Post, Genesis/Blue Star, Carlin). The Sanchahe gold deposit is located along the crest of an anticline which structurally influences the location of ore bodies (Fig. 18) (Cunningham et al., 1988; Ashley et al., 1991). Similarly, South Bullion Deposits (Putnam & Henriques, 1991) and Nighthawk Ridge Deposit (Carden, 1991) in Great Basin have close relationships with folding structures which provide structural preparation and focus the flow of mineralizing hydrothermal fluids.

Brecciation and breccia bodies are a common feature in most of the sediment-hosted gold deposits in the Great Basin. Some of the newly discovered deposits are also closely associated with brecciation. The Getang Deposit mineralized zone developed along a disconformity that represents a paleokarst surface. This surface hosts 3-15 m. thick, lenticular shaped ore bodies (Ashley et al., 1991).

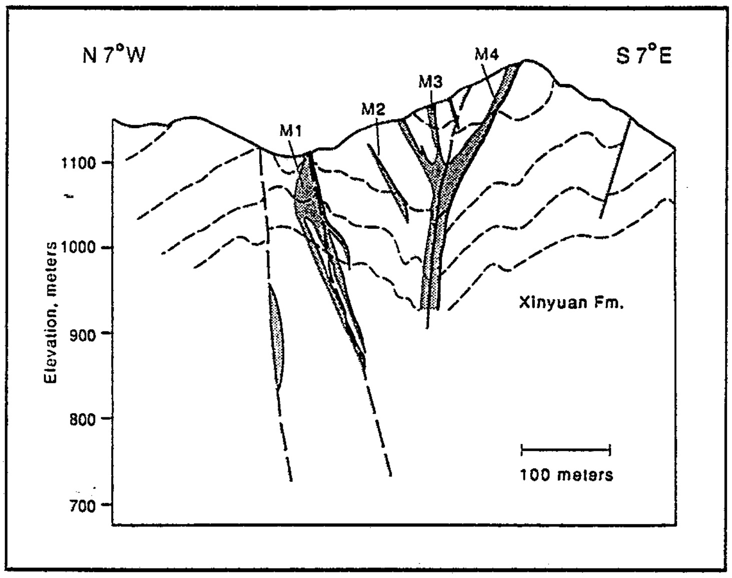


FIGURE 17. Cross section of Yata deposit. Ore bodies, designated M_1-M_4, are shaded. Light lines are contacts between lithologic subunits (interbedded, siltstone and sandstone) (Ashley et al., 1991).

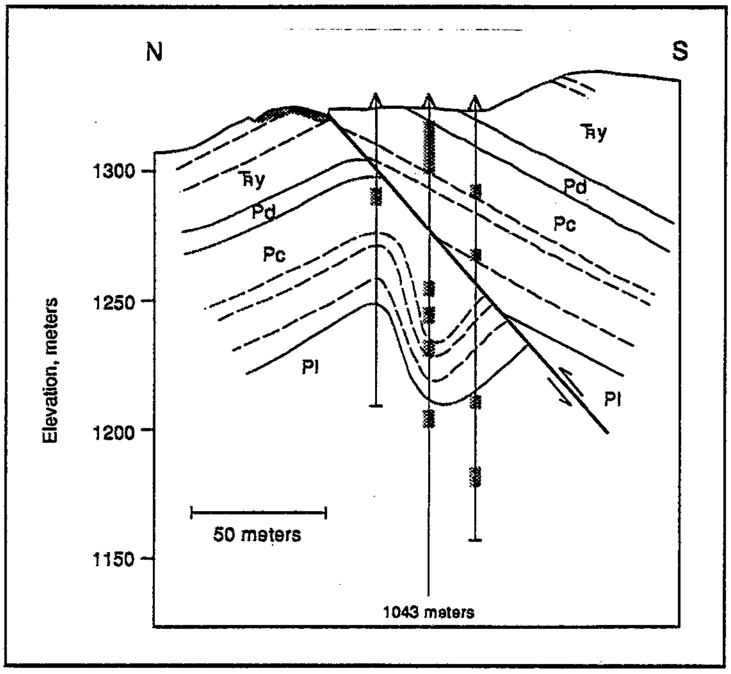


FIGURE 18. Cross section of Sachahe deposit. Pl- (Sandstone, limestone, siltstone and coal); Pc- (Silty limestone); Pd- (Limestone and siltstone); Try- (Arkosic silty limestone and siltstone). Dashed lines show orientation of bedding within formations, heavy line is a thrust fault, shading on drill hole lines shows ore intercepts (Ashley et al., 1991).

In the Ratatok district gold deposits (Mesel and Lobongan/Alason) brecciation is extensively developed, including a somewhat unusual type of breccia known as paleokarst breccia (Turner et al., 1994). Five different type of breccias are recognized in the Mesel Deposits: they are sedimentary breccias, early karst and micro-karst breccias, collapse breccias, fault breccias and hydrothermal breccias. This is a similar combination of breccia types to those described on the Carlin trend by Williams (1992). Paleokarst and residual breccias are the most important host for gold mineralization in Lobongan and Alason deposits. Thickness and shape of karst breccias and characteristics of the residual breccias (size of grains, color, matrix, consolidations) are variable. They reflect the fracture systems, karst topography, sub-aerial exposure, volcanic cover and later erosional effects (Turner et al., 1994). Turner et al. (1994) has simplified a mineralized paleokarst and residual breccia forming model, as shown in Fig. 19. Major structural intersections control the formation of paleokarsts. Ascending hydrothermal fluids used and are confined to these structural features. Karstified carbonate stratigraphy that is capped by andesite sill hosts the mineralization along the contact (Turner et al., 1994).

Some of the deposits in the Bau district are also described as fault controlled paleokarst and related residual breccias hosted gold deposits (Wolfenden, 1965).

1.4. *ALTERATION*

Three hypogene alteration types (decalcification, silicification, argillization) which have occurred in the Great Basin also occurred in various intensities in most of the newly discovered sediment-hosted gold deposits. Carbonization and oxidation are other two common alteration types in these deposits (Table 3) (Fig. 20).

In only four (Lobongan/Alason, Maoling, Dongbeizhai and Jinya) out of thirteen newly discovered deposits, **decalcification** has not been documented.

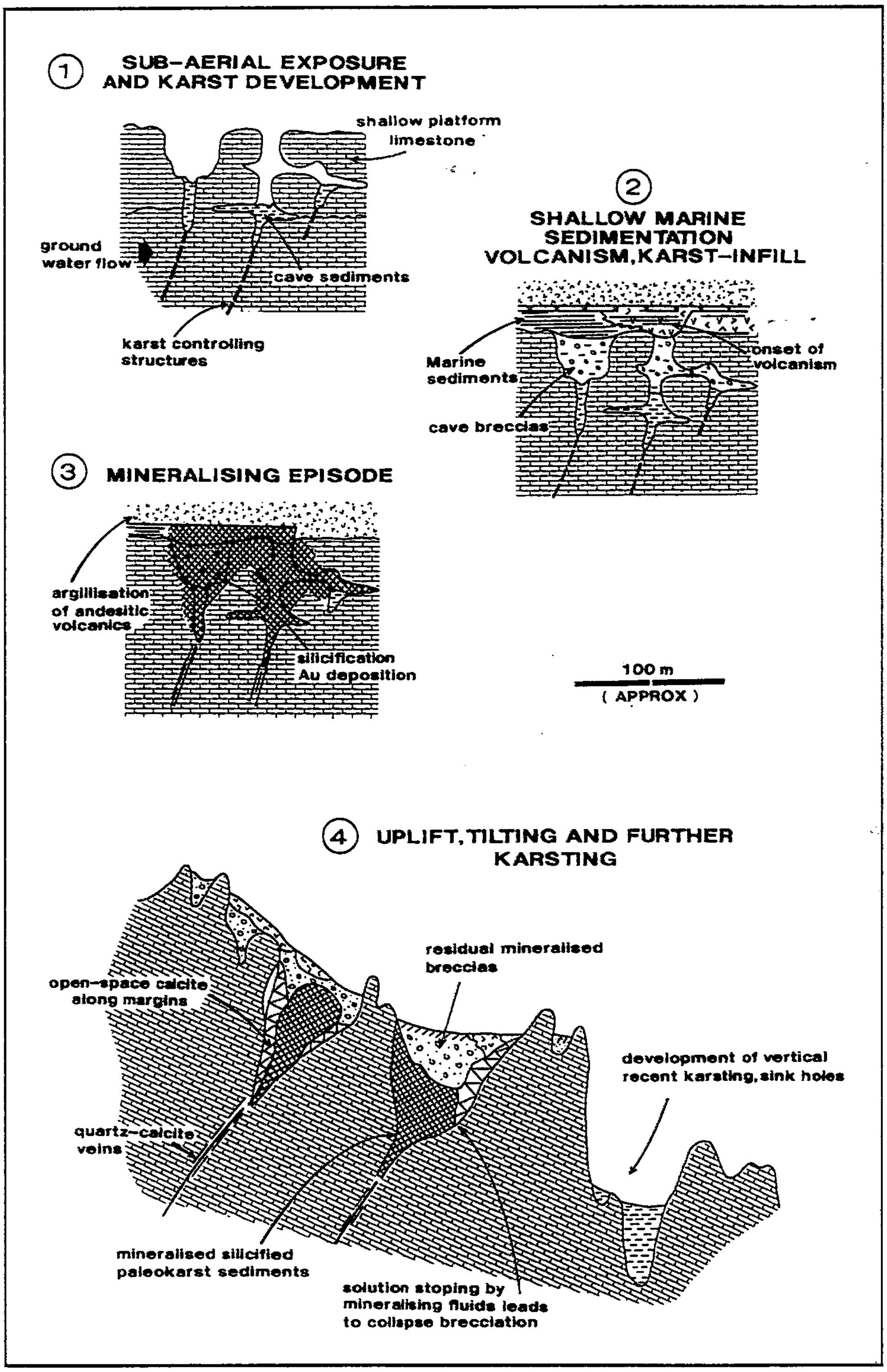


FIGURE 19. Formation model for mineralized paleokarst breccias and residual quartz-clay breccias (Turner et al., 1994).

At Alsar, two different carbonate rocks (Triassic carbonate and Tertiary dolomite) are affected by decalcification. It increased the porosity and permeability of these rocks and created a favourable environment for silica replacement. Both units show a lateral transition through variably bleached and partially decalcified rocks to fresh rocks (Percival et al., 1990; Jankovic, 1994). Sanding is another type of decalcification that does not accompany silica replacement in Alsar. Hydrothermal fluids removed the fine-grained matrix and left granular dolomite sand, disseminated iron oxide and some secondary minerals. The Ratto Canyon (Steinberger, 1987) and Windfall (Nolan, 1962) deposits in the Great Basin and the Alsar (Jankovic & Jelenkovic, 1994) and Mesel (Turner et al., 1994) deposits had a similar type of altered (sanding) dolomite.

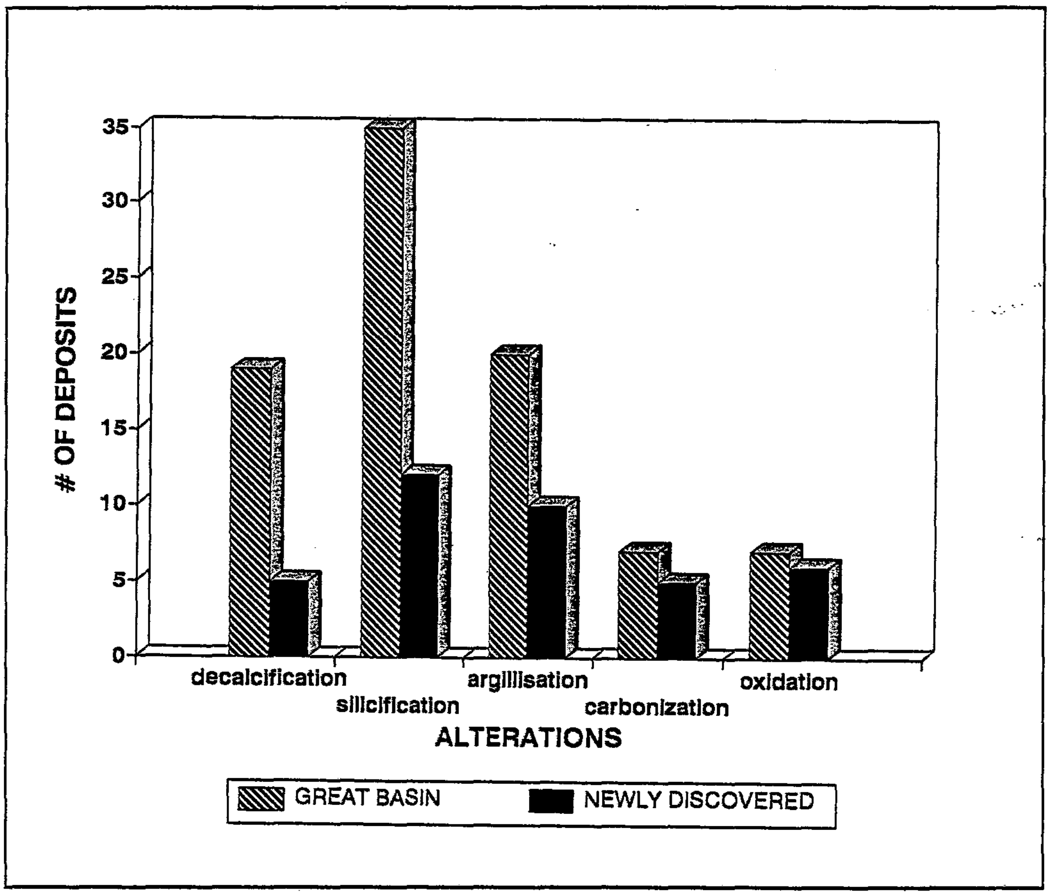


FIGURE 20. Distribution of alteration types both in the Great Basin and in newly discovered deposits.

At Mesel, collapse breccias are indications of significant volume loss associated with decalcification (Turner et al., 1994). Similarly, decalcification-related volume loss, collapse breccia and mineralization phases have been described in the Carlin, Betze/Post and Gold Quarry deposits in the Great Basin (Williams, 1992; Kuehn & Rose, 1992; Rota & Hausen, 1991).

Silicification is the main alteration and mineralization element of all newly discovered gold deposits. Silicified rocks are the results of hydrothermal silica introduction and replacement of host rocks along the fractures, faults, microscale stockworks, breccias, permeable beds, contacts, bedding plane and fold crest. The intensity of silicification varies from weak to total replacement (jasperoid) in the sedimentary host rocks. The intensity of silicification and gold grades correlation is highly variable both within and between the deposits. Therefore, silicifications and their characteristics show great similarity in the Great Basin deposits and in newly discovered deposits.

At Maoling deposit, silicification is pervasive and the intensity of silicification decreases away from the mineralizations (Cheng et al., 1994). At Mesel, intense silicification correlates with secondary permeability zones, (e.g. feeder faults) which corresponds with high gold grade (Turner et al., 1994). Weak pervasive silicification, microscale stockworks in fracture zones, fine grained grey to black colour jasperoids in breccia textures and pervasive jasperoid development occupying large volume of rock are various types of silicification in the Alsar deposit (Percival et al., 1990). Disseminated sulphides (pyrite, marcasite, arsenopyrite, stibnite, realgar) and their oxidation products occur within the jasperoid at Alsar. Other jasperoid associated gold deposits are the Bau and the Getang sediment-hosted gold deposits.

Argillic alteration has been recorded with different intensities and varies from minor to pervasive in the Great Basin deposits (Table 1). This significant alteration element has been observed in most of the newly discovered sediment-hosted gold deposits (Table 3).

Argillic alteration is associated with the Yata, Getang, Sanchahe and Ceyang Gold deposits in Guizhou, China (Ashley et al., 1991). At Yata, hydrothermal clay is very rare and all the aluminium content of the altered rock is in illite. At Getang and Sanchahe, kaolinite-group minerals and interstratified illite-montmorillonite occur as argillic alteration products. The kaolinite-group minerals are mostly kaolinite and occasionally dickite (Ashley et al., 1991).

At Mesel, the thickness of the argillic alteration zone varies from <1 to 20 m. from the highly mineralized part of sediments. This zone comprises early stage illite and illite-smectite mixed layers which are overprinted by kaolinite and dickite with minor alunite (Turner et al., 1994).

X-ray studies show that argillic alteration is more widespread and intense than it is in the sedimentary rock at Alsar deposit. The argillic alteration has affected rocks consisting of kaolinite, sericite, illite, pyrophyllite, subordinate chlorite, ephesite and relict biotite (Percival et al., 1990; Jankovic, 1994). The silicified zones are bordered by zones of argillic alteration in vertical and lateral directions. The intensity and mineral assemblages change with distance from the silicified rock. The mineral assemblage zonation from silicified zone to the distal fresh rock is: Silicified zones → intensely argillized zone (quartz + pyrophyllite + kaolinite ± calcite + sericite) → mixed sericite-rich zone (quartz + sericite + pyrite ± illite + kaolinite) → weakly argillized zone (quartz + illite + calcite + dolomite) (Percival et al., 1990; Jankovic, 1993). Many similar alteration assemblages have been identified in sediment-hosted gold deposits in the Great Basin (Percival et al., 1988; Berger & Bagby, 1991; Kuehn & Rose, 1992).

Carbonization has been reported from few deposits of the Great Basin (e.g. Gold Acres, Horse Canyon, and Nighthawk Ridge). In fact, a large majority of Great Basin deposits contain organic carbon; however, in only a few of them is it mobilized and deposited in fractures and fault zones.

All of the Guizhou Gold Deposits consist of abundant organic carbon that is not disturbed and mobilized extensively. Locally, strongly altered rocks have concentrations of mobilized organic carbon. At Getang, minor carbon mobilization is observed during the hydrothermal alteration phase, but a few milimetre movement could not produce the observed texture (Ashley et al., 1991).

Thus, carbonization is a minor alteration type in newly discovered sediment-hosted gold deposits.

At Labongan/Alason, Getang, Sanchahe, Purisima Concepcion, Alsar and El Hueso gold deposits, **oxidation** and oxidation products occur extensively.

At Purisima Concepcion, the oxidized zone contains abundant limonite (Alvarez & Noble, 1988). Most of the oxidized part contains goethite which fills fractures and vugs in Getang Deposit (Ashley et al., 1991). Widespread supergene alteration effect results as a product of oxidized iron sulphides (pyrite and marcasite), secondary iron oxides, jarosite and acid-leaching oxidation from the breakdown of iron sulphide minerals in the Alsar Deposit (Percival et al, 1990). The thrust plane which truncated the ore body also controls the level of oxidation in El Hueso. The oxidation zone is extreme leaving white clays (kaolinite) that are irregularly stained by jarosite and hematite.

2. MINERALOGY AND GEOCHEMISTRY

The main mineralogical and geochemical features of the Great Basin and newly discovered sediment-hosted gold deposits show great similarities (Fig. 21 and Table 4). Detailed mineralogical and geochemical studies have been performed in the Guizhou province, Dongbeizhai, Jinya and the Alsar deposits. Most of the other deposits can only give superficial information about ore types, trace element assemblages and/or paragenetic sequences.

TABLE 4. TRACE ELEMENT GEOCHEMISTRY OF SEDIMENT-HOSTED GOLD DEPOSITS, OUTSIDE OF U.S.A.

NAME	Au:Ag RATIO	As	Sb	Hg	Tl	Te	Ba	F	BASE METAL
Mesel (Indonesia)	10:1-2:1	√	√	√	√				
Lobongan Alason (Indonesia)	Low Ag	√	√						Cu+Pb+Zn Minor
Baũ (Indonesia)		√	√						
Yata (China)		√	√	√	√				Cu+Zn Minor
Getang (China)	High Ag	√	√	√	√		Minor	Minor	Cu+Zn Minor
Sanchahe (China)	High Ag	√	√	√	√		Minor	Minor	Cu+Zn Minor
Ceyang (China)		√	?						
Maoling (China)	High Ag	√	√						Zn Minor
Dongbeizhai (China)		√	Minor	Minor					
Jinya (China)		√	Minor	Minor					
Purisima Concepcion (Peru)	2.5:1	√	√	Minor	√	√	√	Minor	Zn Minor
El Hueso (Chile)	3:1	√	√	√					Cu Minor
Alsar (Macedonia)	Low Ag	√	√	√	√		√		Cu+Pb+Zn+Mo Minor

√: Anomalous values; Minor: Low values

Source: Cheng et al., (1994); Jankovic & Jelenkovic, (1994); Turner et al., (1994); Wang & Zhou, (1994); Jankovic, (1993); Ashley et al., (1991); Davidson & Mpdozis, (1991); Dongsheng et al., (1991); Sillitoe, (1991); Percival et al., (1990); Sillitoe & Bonham (1990); Colley et al., (1989); Alvarez & Noble, (1988); Cunningham et al., (1988).

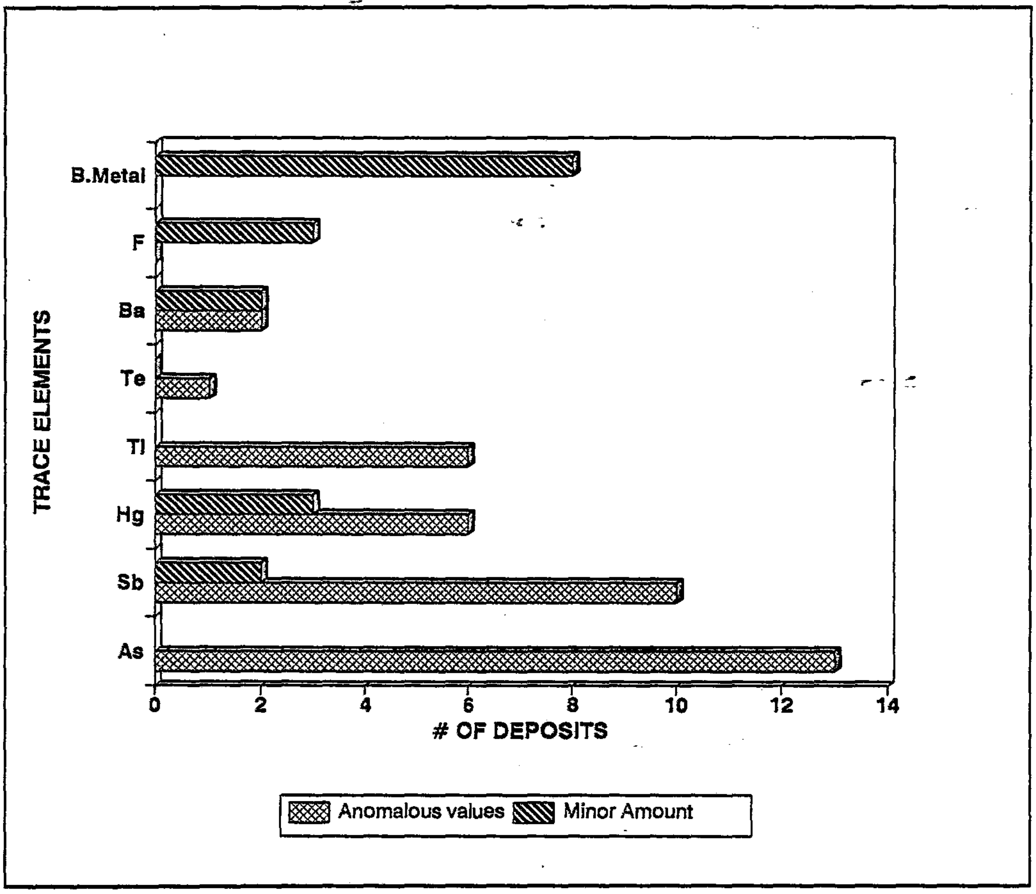


FIGURE 21. Trace element distribution in thirteen newly discovered sediment-hosted gold deposits.

Yata, Getang and Sachahe gold deposits' geochemistry can be summarized as: (1) Gold ores are usually associated with silicification probably early in the paragenesis, (2) Ore types are mainly pyritic and arsenical (e.g. pyrite, marcasite, arsenian pyrite and arsenopyrite), (3) The general sulphide paragenesis is pyrite, followed by arsenopyrite, realgar, cinnabar, stibnite and minor sphalerite, barite, fluorite, (4) Association of arsenic, mercury and thallium with gold is a common observation in all deposits, (5) There is no direct correlation between the presence of base metal, barite, fluorite and gold deposits (Ashley et al., 1991).

The Dongbeizhai and the Jinya gold deposits have similar characteristics. In both deposits, arsenian pyrite and arsenopyrite are principal ore-bearing minerals. Au content is generally higher in arsenical ores than in pyritic ore (Wang & Zhou, 1994). In the Jinya deposit, unoxidized carbonaceous matter has been recorded as minor ore type which occurs in many of the Great Basin gold deposits. Native gold occurrs as microscopic grains on the surface of pyrite and arsenopyrite in the Jinya Deposit (Wang & Zhou, 1994). Au content of arsenical and pyritic ores is highly variable. However, there is a positive correlation between Au and As, S, Fe - especially As (Wang & Zhou, 1994).

At Maoling, the majority of the gold grains occur together with marcasite, chalcopyrite, sphalerite, galena and around the arsenopyrite and pyrrhotite grains in the disseminated ore body. Other gold grains are hosted by grain boundaries of recrystallized quartz and in quartz-pyrite vein zones with the form of native coarse grained gold (Cheng et al., 1994). Arsenopyrite is the major As mineral and other As-bearing minerals (e.g. realgar and orpiment) are absent (Cheng et al., 1994).

Highly silicified (jasperoid) units and weakly silicified units are hosts of high grade gold in the Mesel deposit (Turner et al., 1994). The gold value is highest in arsenian pyrite. This gold deposit is associated with anomalous As, Sb, Hg and Tl trace element suite with very minor amounts of base metal occurrences. As, Sb, Hg occur as realgar, orpiment, cinnabar and stibnite in various stages and in various gold-rich rocks (Turner et al., 1994).

In the Lobongan/Alason deposits, silicified breccias are the hosts of the highest grade gold deposits. Oxidized mineralization, anomalous As, Sb, low Ag trace element assemblages and minor Cu, Pb, Zn contents are the main chemical characteristics of the deposit.

There are four different types of ore present at Alsar. Jasperoid ore, siliceous ore, arsenical ore and thallium ore (Percival & Radtke, 1990; Jankovic, 1993). Jasperoidal ore consists of fine grained marcasite, pyrite and stibnite (5-20 %) that was extensively mined for its antimony content and decreasing abundances of realgar, orpiment and As - Sb - Tl - Hg sulphosalts (Jankovic, 1982; Jankovic, 1993). Quartz pyrite veinlets cross-cut the ground mass of microcrystalline quartz. Siliceous was ore deposited in the tuffs and underlying of marble which contain a silicified component, clays, sericite and quartz stockworks. It contains fewer sulphide minerals than jasperoids. Pyrite, stibnite, marcasite and realgar are abundant minerals in siliceous ore. Argillized tuffs, dolomite and rarely carbonated rocks host arsenical gold ore that contain realgar, orpiment, marcasite and minor thallium bearing sulphosalt minerals. The arsenic amount of this ore is between 1-10 % and gold content is about 3 gr/t. Some highly altered carbonate and tuffaceous rocks contain high concentrations of thallium (2 %) and gold. This ore is named "thallium ore" and contains orpiment, realgar, pyrite, marcasite and rare thallium-bearing sulphosalts (Jankovic, 1993; Percival & Radtke, 1990).

At Alsar, three different types of unaltered mineralized rocks are anomalous in Au, As, Sb, Hg, Tl and Ba content. These hypogene minerals occur as stibnite (realgar, orpiment, arsenopyrite), antimony (stibnite), mercury (cinnabar), thallium (lorandite and sulphosalts), barium (barite). As and Sb enrichment at the periphery of the gold-bearing pyrite grains are observed in stibnite bearing jasperoid rocks. Cu, Pb, Zn and Mo are minor base metal contents of the mineralized rocks. This feature and most of other characteristics mentioned above about Alsar are also reported from many of the deposits in the Great Basin (Bagby & Berger, 1985; Percival et al., 1988; Berger & Bagby, 1991).

3. <u>ORE ZONES</u>

3.1. *ORE CONTROLS*

One of the main characteristics of the sediment-hosted gold deposits is the major mineralization role of structural features which prepare channel ways for movement of hydrothermal fluids and provide favourable depositional sites. In particular, high-angle faults and their intersections with other structural and stratigraphical features are abundant primary controlling factors in the Great Basin deposits. Ore controlling factors of the newly discovered sediment-hosted gold deposits have been studied and classified as primary, secondary and minor control (Table 5). Skead (1994) has classified twenty three of the Great Basin sediment-hosted gold deposits according to their ore controlling factors (Appendix 1). Comparison between the Great Basin and newly discovered deposits' ore control is shown in Figs 22 and 23.

In the Ratatok district deposits (Mesel, Lobongan/Alason), hydrothermal fluids are transported by high-angle fault conduit and the mineralization focused along the limestone-andesitic rock contact. Andesitic cover displays an impermeable and unreactive barrier role to ascending hydrothermal fluids (Turner et al., 1994). This chemical and physical barrier is regarded as mixing zone between upwelling mineralised fluids and oxidized meteoric fluids from overlying volcanic rocks.

High-angle faulting is a key ore controlling factor for Bau, Yata, Maoling, Purisima Concepcion and Alsar deposits. At Maoling, the emplacement of ore bodies is controlled by high-angle fault and intersections which provide both conduits and depositional sites (Cheng et al., 1994). Also, at Yata, high-angle faults provide both conduits for fluids and depositional sites. Ore bodies are localized primarily by the high-angle faults (Ashley et al., 1991). High-angle faults and combinations of stratigraphic features serve as hydrothermal fluid channels and suitable permeable, porous sites for deposition in the Alsar deposit. Along the basal unconformity, permeable debris material has been extensively silicified (jasperoid) and has localized the ore (Fig. 24) (Percival & Radtke, 1990; Jankovic, 1993). Above the unconformity, permeable and porous volcanic rocks are also depositional sites for extensive mineralizations.

TABLE 5. ORE CONTROLS OF SEDIMENT-HOSTED GOLD DEPOSITS, OUTSIDE OF U.S.A.

NAME	PRIMARY CONTROL	SECONDARY CONTROL	MINOR CONTROL
MESEL (INDONESIA)	* High-angle faults * Lithology * Impermeable cap	* Fault intersections (high-angle & thrust faults)	n.d.
LOBONGAN ALASON (INDONESIA)	* High-angle faults * Impermeable cap	* Lithology (fault controlled karst & infills)	n.d.
BAU (INDONESIA)	* High-angle faults * Lithology	* Faults & bedding plane intersections	* Anticline (regional control)
YATA (CHINA)	* High-angle faults	* Lithology	* Anticline & subsidary folds (regional control)
GETANG (CHINA)	* Disconformity * Bedding plane thrust ?	* Lithology (Paleokarst surface)	* Dome (regional control)
SANCHAHE (CHINA)	* Thrust fault (moderate angle)	* Lithology * Anticline (structural preparation-crest)	n.d.
CEYANG (CHINA)	* Thrust fault	* Lithology	* Anticline
MAOLING (CHINA)	* High-angle faults * Fault intersections	* Lithology	n.d.
DONGBEIZHAI (CHINA)	* Thrust fault * Lithology	* Lithology (bedding planes)	n.d.
JINYA (CHINA)	* Thrust faults * Lithology	n.d.	n.d.
PURISIMA CONCEPCION (PERU)	* High-angle faults * Lithology	* Fault intersections * Anticline	n.d.
EL HUESO (CHILE)	* Thrust faults * Lithology	* Unconformity * High-angle faults	n.d.
ALSAR (MACEDONIA)	* High-angle faults * Fault stratigraphy intersection * Lithology	* Unconformity (inpermeable cap)	n.d.

n.d.: no data

Source: Cheng et al., (1994); Jankovic & Jelenkovic, (1994); Turner et al., (1994); Wang & Zhou, (1994); Jankovic, (1993); Ashley et al., (1991); Davidson & Mpdozis, (1991); Dongsheng et al., (1991); Sillitoe, (1991); Percival et al., (1990); Sillitoe & Bonham (1990); Colley et al., (1989); Alvarez & Noble, (1988); Cunningham et al., (1988).

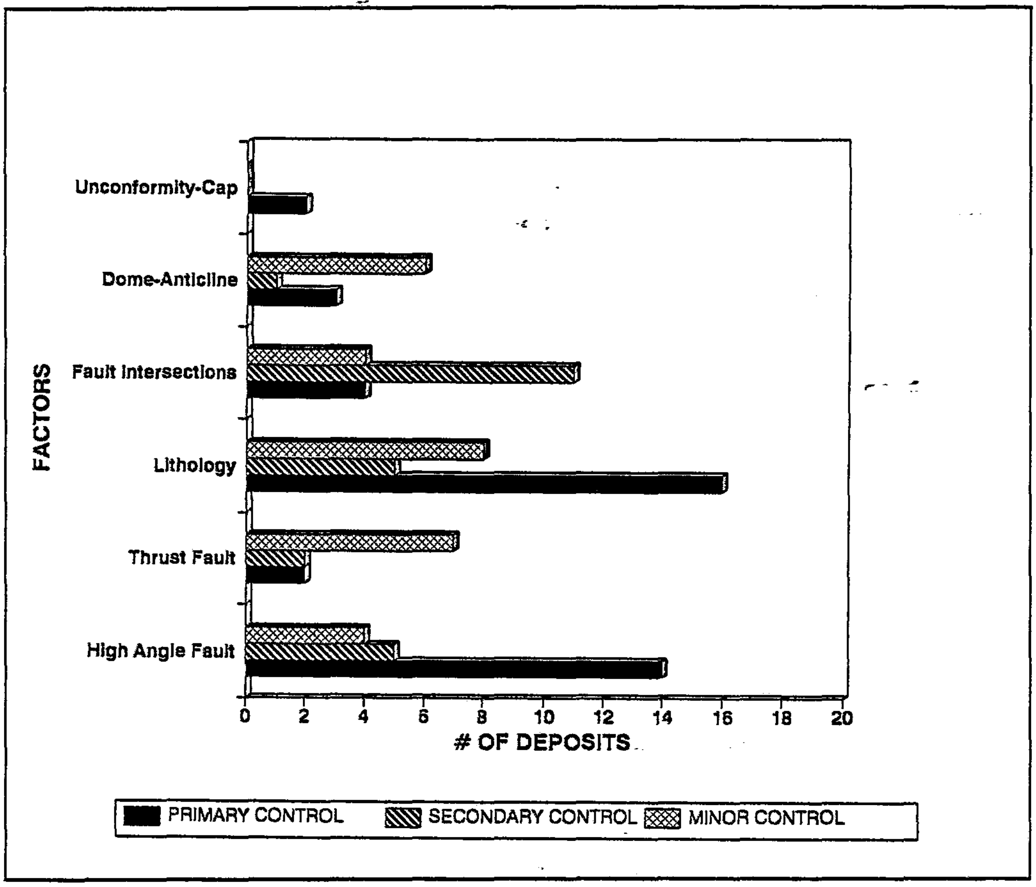


FIGURE 22. Distribution of the ore controlling factors in twenty three selected Great Basin gold deposits.

Many of the deposits in the Great Basin are associated with thrust faults (Roberts Mountains Thrust) but the primary control of mineralization of only two deposits (Hilltop and Tonkin Spring) can be attributed to thrusts. In contrast, at least five newly discovered gold deposits out of thirteen are controlled primarily by thrust faults. These are conduits for fluid flow and favourable depositional locality for mineralizations. El Hueso is an excellent example of the combination of ore controlling factors such as thrust faults, unconformity and lithology.

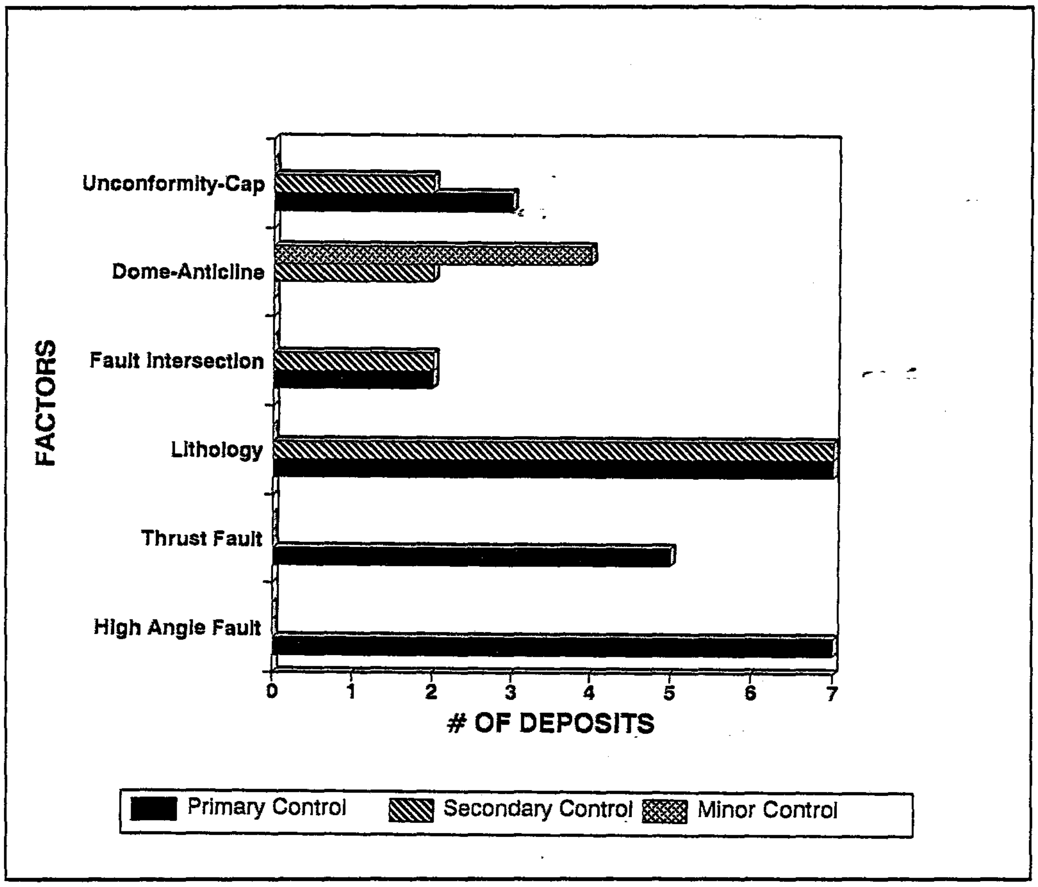


FIGURE 23. Distribution of the ore controlling factors in thirteen newly discovered sediment-hosted gold deposits.

Folds and anticlines are spatially associated with many deposits in the Great Basin. Two newly discovered deposits are very closely related with fold and anticlines. The crest of the anticline in Sanchahe and core of the anticline which are structurally prepared by fractures and shears in the Purisima Concepcion deposit are favourable hosts for gold mineralizations (Fig. 25).

Lithologies play a critical role in the controls of mineralization in the sediment-hosted gold deposits both in the Great Basin and in newly discovered deposits. Highly porous and permeable sedimentary rocks (e.g. thin, calcareous, carbonaceous silty limestone, siltstone and occasionally limestones), carbonate debris flow, transitional lithologies (because of their competency contrast) volume loss resulted collapse breccias are all

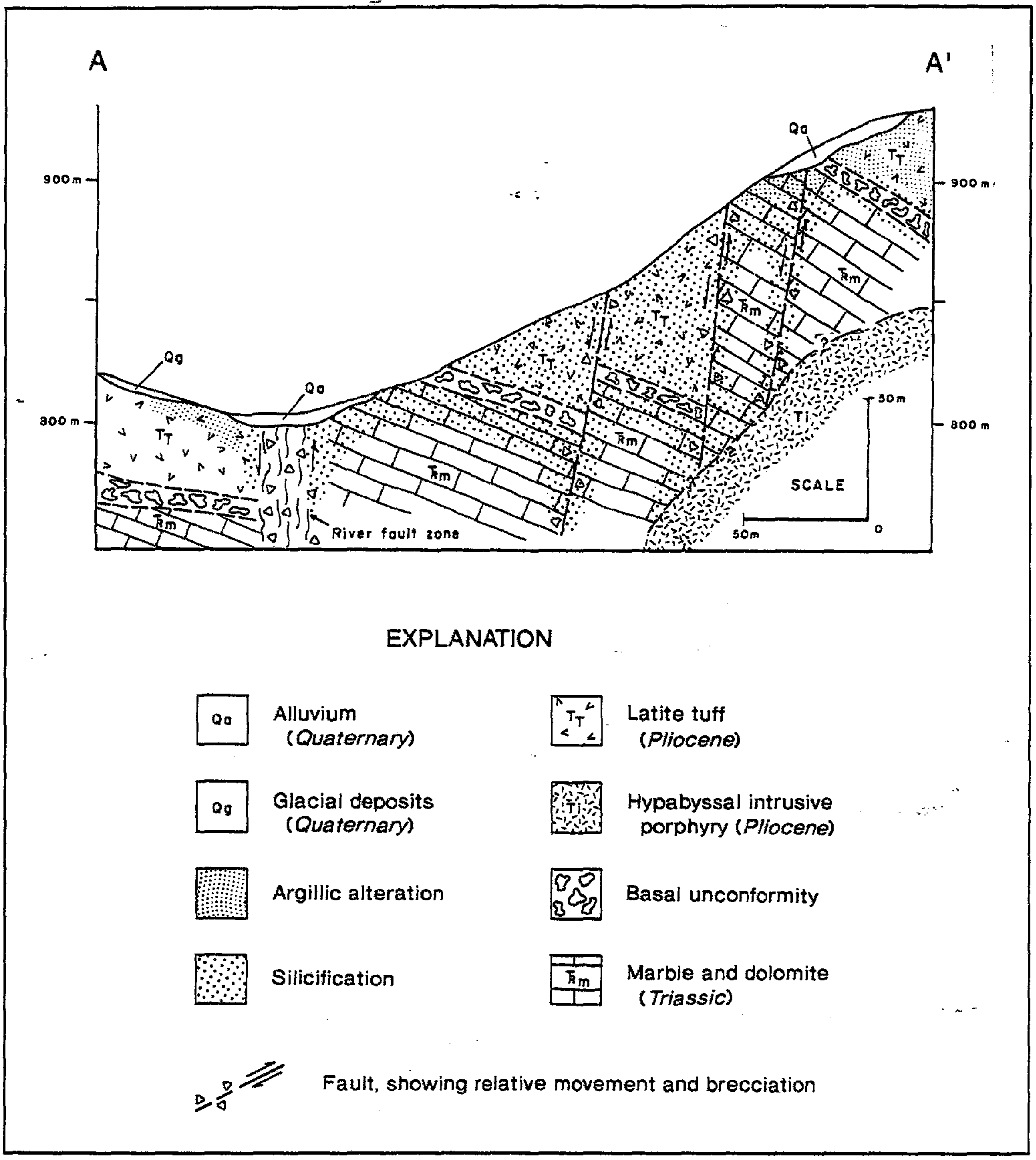


FIGURE 24. Generalized cross-section through central-southern Alsar district showing geological features and distribution of ore types (Percival et al., 1990).

favourable lithological elements for gold depositions. These features are primary factors for ore deposition in most of the newly discovered deposits. Structures are primary ore controlling factors and lithologies are secondary factors only in Lobongan/Alason and in Guizhou province gold deposits.

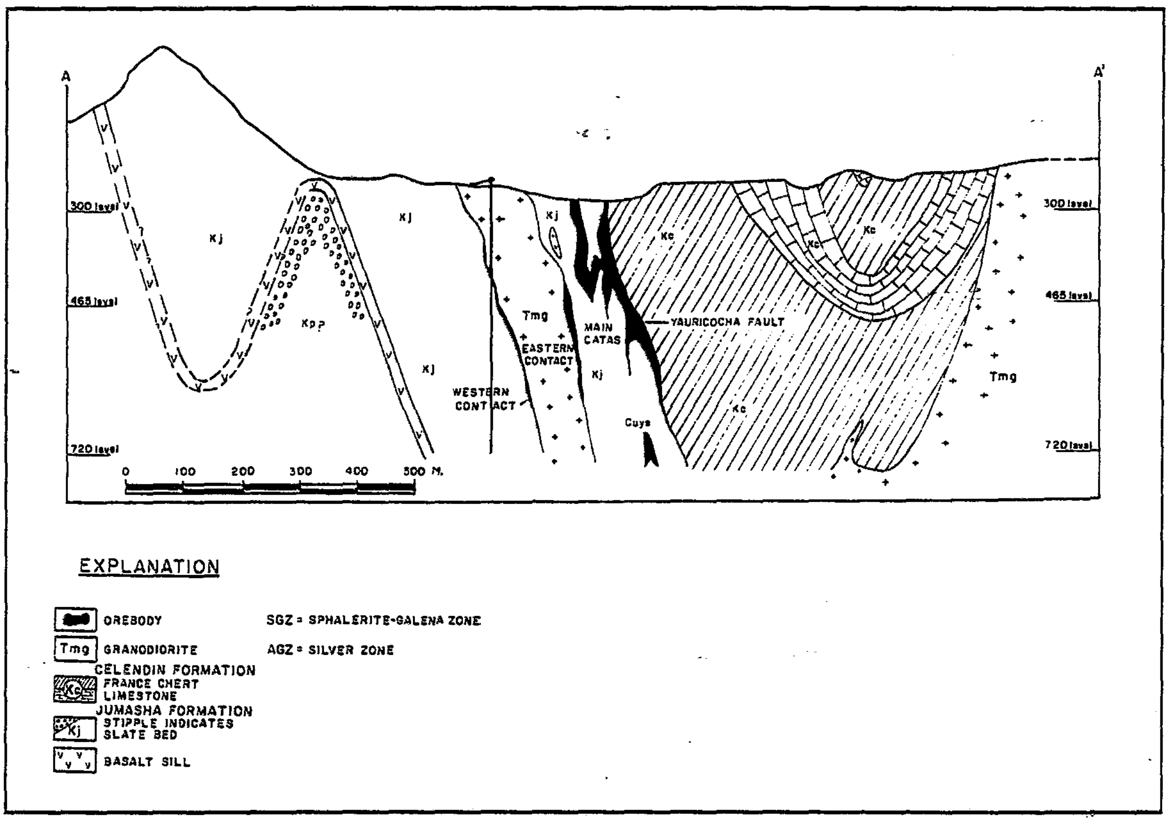


FIGURE 25. Generalized cross section showing the geology and mineral deposit of the Yauricocha district - Purisima Concepcion (Alvarez & Nable, 1988).

3.2. *SIZE AND GRADES*

Newly discovered sediment-hosted gold deposits are variable in size and grade. In fact, data about size and grade are not sufficient to compare with the Great Basin deposits (Fig. 26 and Table 6). Maoling is the biggest known deposit with a tonnage of 95 Mt. However, Dongbeizhai is reported as the biggest sediment-hosted type gold deposit in China (Wang & Zhou, 1994). Only few similar and bigger size deposits are recorded in the Great Basin (e.g. Betze/Post, South Pipeline, Gold Quarry). But other four newly discovered deposits are similar to the Great Basin deposits in size distribution. Grades also vary between 0.5 g/t and 9 g/t. This distribution is also similar to the grade distribution of the Great Basin deposits (90 % of the deposits have an average gold grade less than 7.8 g/t) (Berger & Bagby, 1991).

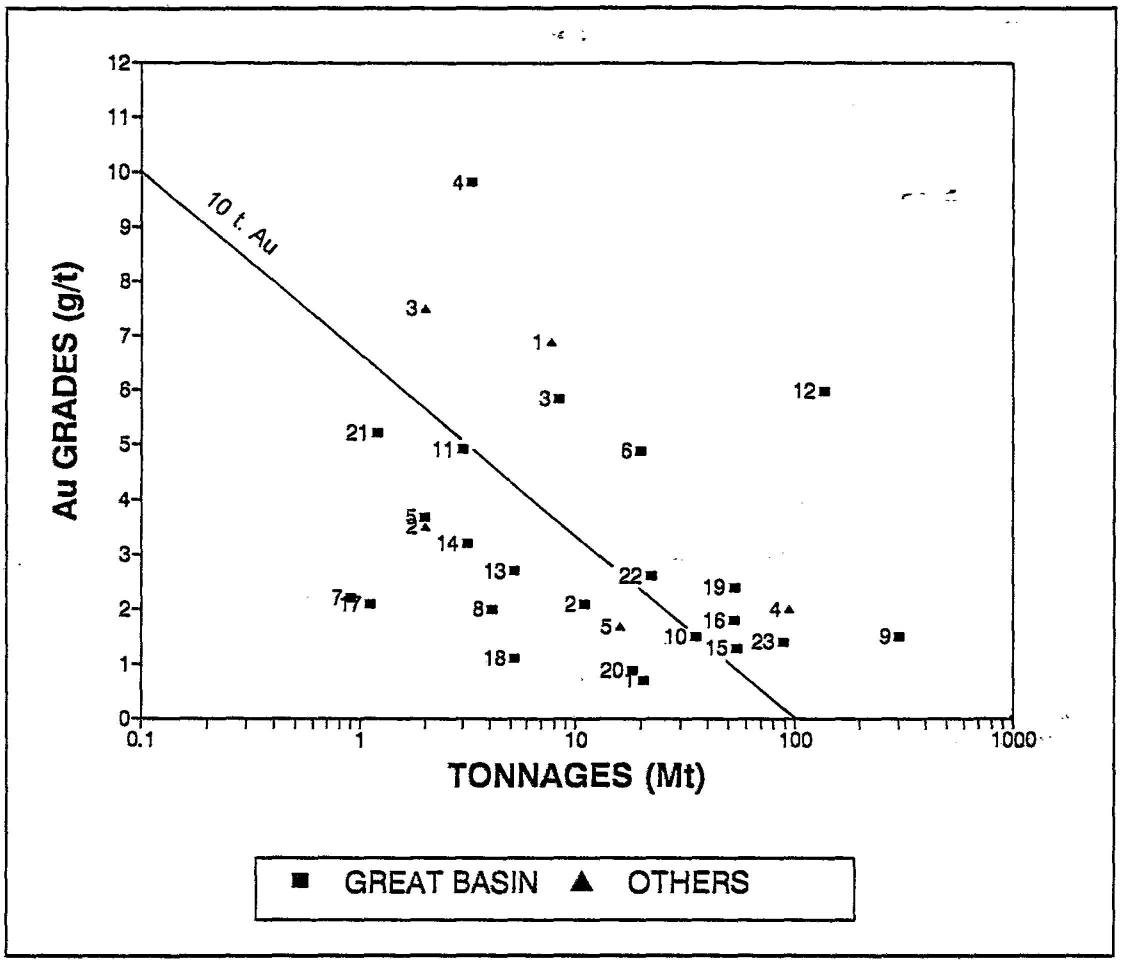


FIGURE 26. Grade-tonnage plot for 23 principal sediment-hosted gold deposits in Great Basin and five selected newly discovered sediment-hosted gold deposits. Great Basin: 1. Mercur; 2. Manhattan; 3. Northumberland; 4. Getchell; 5. Carlin; 6. Cortez; 7. Pinson; 8. Preble; 9. Gold Acres; 10. Jerritt Canyon; 11. Alligator Ridge; 12. Dee; 13. Tomboy-Minnie; 14. Gold Quarry; 15. McCoy-Cove; 16. Rain; 17. Horse Canyon; 18. Betze-Post; 19. Hilltop; 20. Gold Bar; 21. Genesis-Blue Star; 22. Chimney Creek; 23. Green Springs; 24. Easy Junior; 25. Rabbit Creek; 26. Cove; 27. South Bullion; 28. Winters Creek; 29. Ruby Hill-Archimedes; 30. South Pipeline; Others: 1. Mesel; 2. Lobongan/.Alason; 3. Bau; 4. Maoling; 5. El Hueso.

TABLE 6. SIZE AND DISCOVERY HISTORY OF SEDIMENT-HOSTED GOLD DEPOSITS, OUTSIDE OF U.S.A.

DEPOSIT	TONNAGE/GRADE	DISCOVERY METHOD
MESEL (INDONESIA)	7.75 Mt @ 6.89 g/t	Deep drilling beneath andesite cover around old working
LOBONGAN ALASON (INDONEISA)	<2 Mt @ 2-5 g/t	n.d.
BAU (INDONESIA)	2 Mt @ 6-9 g/t(Tai Parit) Total ~ 40 Mt (Bau Trend)	Exploration on old workings
YATA (CHINA)	1 Mt @ 5 g/t	Rock sampling from old working (for realgar)
GETANG (CHINA)	n.d.	Grid drilling
SANCHAHE (CHINA)	n.d.	Reconnaissance for mercury in old workings
MAOLING (CHINA)	95 Mt @ 2 g/t	Geophysical & geochemical anomalies during soil geochemical survey
DONGBEIZHAI (CHINA)	"Biggest" in Chine 4-6 g/t; >6 g/t	n.d.
JINYA (CHINA)	n.d.	n.d.
PURISIMA CONCEPCION (PERU)	3.3 g/t	Reevaluation of lead ores & reworking on structural features (shear zones)
EL HUESO (CHILE)	16 Mt @ 1.68 g/t	Gold rich silica flux which has found at Potrerillos porphyry smelter was traced to El-Hueso
ALSAR (MACEDONIA)	1-3 g/t (jasperoidal ore) 0.5-2 g/t (siliceous ore) 1-3 g/t (arsenical ore)	Regional reconnaissance at old As, Sb workings, delineation of Au (>1 g/t) values in As, Sb, Tl

n.d.: no data

Source: Cheng et al., (1994); Jankovic & Jelenkovic, (1994); Turner et al., (1994); Wang & Zhou, (1994); Jankovic, (1993); Ashley et al., (1991); Davidson & Mpdozis, (1991); Dongsheng et al., (1991); Sillitoe, (1991); Percival et al., (1990); Sillitoe & Bonham (1990); Colley et al., (1989); Alvarez & Noble, (1988); Cunningham et al., (1988).

4. COMPARISON

Adams & Putnam (1992) have defined sediment-hosted gold deposits in the Great Basin as: "Mostly high-angle controlled, and commonly strata-bound, generally tabular bodies of epigenetic, finely-disseminated, low to higher grade gold with variable amounts of Ag, As, Sb, Hg, Tl, F, Ba and W. The deposits occur dominantly in carbonaceous siltstones, cretaceous to argillaceous limestone and in lesser amounts in other rock types. Alteration of wall rocks includes decalcification, silicification, carbonization and argillization. Most of the deposits are associated with either thrust faults or with an interregional unconformity." Principal or key geological and geochemical features compiled in Table 1 and 2 for Great Basin deposits and in Table 3,4,5 and 6 for newly discovered deposits outside of the U.S.A. Similar features are shared with deposits in the Great Basin and the others. In fact, apart from very few exceptions, even some of the unusual characteristics of the Great Basin deposits have been observed in some of the newly discovered deposits.

Many typical characteristics of the sediment-hosted gold deposits that are present at Mesel include: micron-size gold in arsenian pyrite, distinctive Au-As-Sb-Hg-Tl association, assemblages of decalcification, dolomitization, silicification and argillization alteration suite, combination of different breccias as host rocks. Lack of deep oxidation zone, carbonaceous ore and barite at Mesel are the only dissimilarities to the Great Basin characteristics (Turner et al., 1994).

At Lobongan/Alason area, Turner et al., (1994) studied on several small (<2 Mt), individual deposits which are characterized by the presence of Au, As, Sb and minor Cu, Pb, Zn and low Ag associations, the occurrence of weak silica and clay-comprised wall rock alteration, and the presence of mineralization in the overlying volcanoclastic sediments. Mineralizations are closely related to fault-controlled paleokarst and karst controlled residual breccias which make these deposits an unusual sediment-hosted type with their lack of some common trace elements (Hg and Tl) and alteration elements (decalcification, carbonization).

Bau district gold deposits are also closely related with paleokarst and residual breccias (Wolfenden, 1965). However, the importance of the Bau Deposit is that it was studied and used by Sillitoe & Bonham (1990) to prove the similarities to some Great Basin sediment-hosted gold deposits (Bingham and Bald Mountain) in terms of general characteristics and especially genetic models.

The Guizhou deposits and many of the Great Basin deposits have similar features. The location of all Guizhou and many Great Basin deposits is near the buried margin of Precambrian cratons (Cunningham et al, 1988). Even tectonic stages such as regional compression and transition to extension stage show great similarities. The same type of host rock lithology, same alteration elements, abundance of organic carbon, same trace element suites, similar ore types and similar grade and tonnage figures have been pointed by Ashley et al., (1991). Primary importance of structures and secondary importance of lithologies for ore control and complete lack of igneous rock association are the only different or uncommon features of the deposits with Great Basin examples.

Maoling is another Chinese sediment-hosted gold deposit which has a few unique differences compared to other Chinese and Great Basin deposits. The Early Proterozoic age has not been recorded in any sediment-hosted gold deposit. Also, regionally-thermally metamorphosed host rocks (green schist to amphibolite-facies regional metamorphism and andalusite-grade contact metamorphism with the intrusion), ductile shear deformation, occurrence of biotite in wall rock alteration assemblages and lack of stibnite are the most outstanding dissimilarities to Great Basin deposits (Cheng et al., 1994). Most of the differences are interpreted by Cheng et al. (1994) as a result of higher temperature and higher pressure (deeper crustal level) than Great Basin deposits.

The geological and chemical characteristics of the Dongbeizhai and Jinya deposits compiled from very restricted number of sources are not enough to compare these deposits with Great Basin deposits. However, detailed mineralogical study has been performed by Wang & Zhou (1994) and they concluded that arsenopyrite and pyrite are the principal gold-bearing minerals, gold is present on the rims of arsenopyrite-pyrite and gold is closely correlated with As, S and Fe. These mineralogical features are abundant in most of the Great Basin deposits. Other features are compiled from several other studies that contributed more than enough information (Table 3).

Purisima Concepcion is one of the few sediment-hosted gold deposits of South America. Some authors (Alvarez & Noble, 1988 and Sillitoe & Bonham, 1990) used these deposits to support a model of genetic relation between intrusive and sediment-hosted mineralizations. Many similarities in physical and chemical properties exist between the Great Basin deposits and Purisima Concepcion deposits. Host rocks, primary structural controls, alterations, chemical composition of the ores, trace element assemblages (addition of unusual Te into Ag, As, Sb, Hg, Tl suite), Au/Ag ratio (2.5/1) of Purisima Concepcion are well known, common features of Great Basin deposits except higher concentrations of introduced Fe, Mn and Te. Large-scale base metal association (not as trace element) with this gold deposit is interpreted as a notable difference by Alvarez & Noble (1988).

El Hueso possesses features typical of sediment-hosted deposits in the Great Basin such as: calcareous, relatively porous host rock; characteristic alteration assemblages (except carbonization); abundance of antimony and arsenic sulphides; disseminated type gold and absence of base metals. Relationship between porphyry stocks and major thrust faults is not commonly agreed yet. In spite of this uncertainty, the deposit is shown as an example of the transition between sediment-hosted and volcanic hosted, high-sulphidation epithermal Au mineralization related to a porphyry system (Sillitoe, 1991).

Key physical and chemical features at Alsar, which are also characteristics of the sediment-hosted gold deposits in the Great Basin, include mineralization hosted in sedimentary rocks (tuffaceous dolomite), primary control of lithology and structural features (steeply dipping faults, shear zones and flat-lying stratigraphic features), chemical association among Au - As - Sb - Hg - Tl, sulphide and sulphosalt minerals, low content of base metals (Cu, Pb, Zn, Mo), alteration assemblages (decalcification, silicification, widespread argillization, sericitization) presence of extensive jasperoid and jasperoid gold ore with other arsenical, siliceous ore types, gold in micron to submicron particles. Few dissimilarities from the Great basin deposits are relatively younger age of mineralization (Pliocene age) and very large content of thallium (300-500 ppm) which is almost 10 to 1000 times greater than average Tl content of the Great Basin gold deposits (Percival et al., 1990). Ore formation in volcanics as well as in sedimentary rocks is an uncommon feature which also occurred in the El Hueso gold deposit. Usually, most of the volcanic covers predate the mineralization in the Great Basin deposits.

D. GENETIC MODEL

The main geological characteristics and local controls of sediment-hosted gold deposits have been compiled by several workers (Bagby & Berger, 1985; Percival et al., 1988; Berger & Bagby, 1991). Geological and geochemical similarities between many deposits in the Great Basin are fairly well-known. These similarities suggest the same general set of processes that have operated in various places to produce similar types of deposits. However, the source of gold and the processes of formation are still contentious.

Genetic model development of sediment-hosted gold deposits started with the discovery of the Carlin deposit in 1962. Adams & Putnam (1992) compiled most of the geological processes that have been proposed to be important in the formation of sediment-hosted gold deposits. Proposed ore-forming processes for this type of gold deposits and their various combinations and paths are shown in Fig. 27. Numerous authors have suggested that igneous activity provided heat to circulating shallow level meteoric waters. These fluids leached metals from sedimentary rocks and transported them to favourable sites (Radtke & Dickson, 1976; Rye, 1985). Fluid boiling processes for metal accumulation were proposed by Radtke et al., (1980) and Dickson & Rytuba (1988). They interpreted the strong alteration on top of the deposits to be the result of fluid boiling, oxidation, condensation and acid leaching. Metal accumulation by wall-rock alteration (Hofstra et al., 1991; Seward, 1973) and by fluid cooling are two other formation processes which are suggested in various ore districts.

As Kuehn & Rose (1995) mentioned, the shallow level of epithermal system driven by the heat of igneous activity is inferred from the following evidence: (1) the Au, As, Sb, Hg, Tl trace element suite is characteristic of epithermal and hot spring deposits; (2) a maximum depth of 300 m. for the Getchell ore bodies and (3) a maximum depth of 300 to 520 m. at Carlin; all these are suggested as based on boiling inferred from fluid inclusion studies. In contrast, the deep ores in the Post-Betze area (Bettles, 1989), near the Gold Quarry mine and recently, the Rabbit Creek deposit (Parrat & Bloomstein, 1989) show that sediment-hosted gold deposits in the Great Basin are not epithermal or hot spring-type deposits. However, recent detailed fluid inclusion studies of the Carlin deposit focused on re-evaluation of the P-T-X constraints and CO_2, H_2S inclusions. The high-density CO_2 content of the fluid, which will not exist near surface, represents pressures of 800 ± 400 bars and depths of 3.8 ± 1.9 km. for near-lithostatic gradient (Kuehn & Rose, 1995). High H_2S content is interpreted as an explanation of anomalous Au, As, Sb, Hg assemblages. Thus, high CO_2 and H_2S-rich character, recent deep ore discoveries and appreciable depths (3.8 ± 1.9 km.) of the Au deposits at Carlin combined with a lack of field evidence for paleowater table and paleosurface features, seem to rule out a shallow epithermal origin.

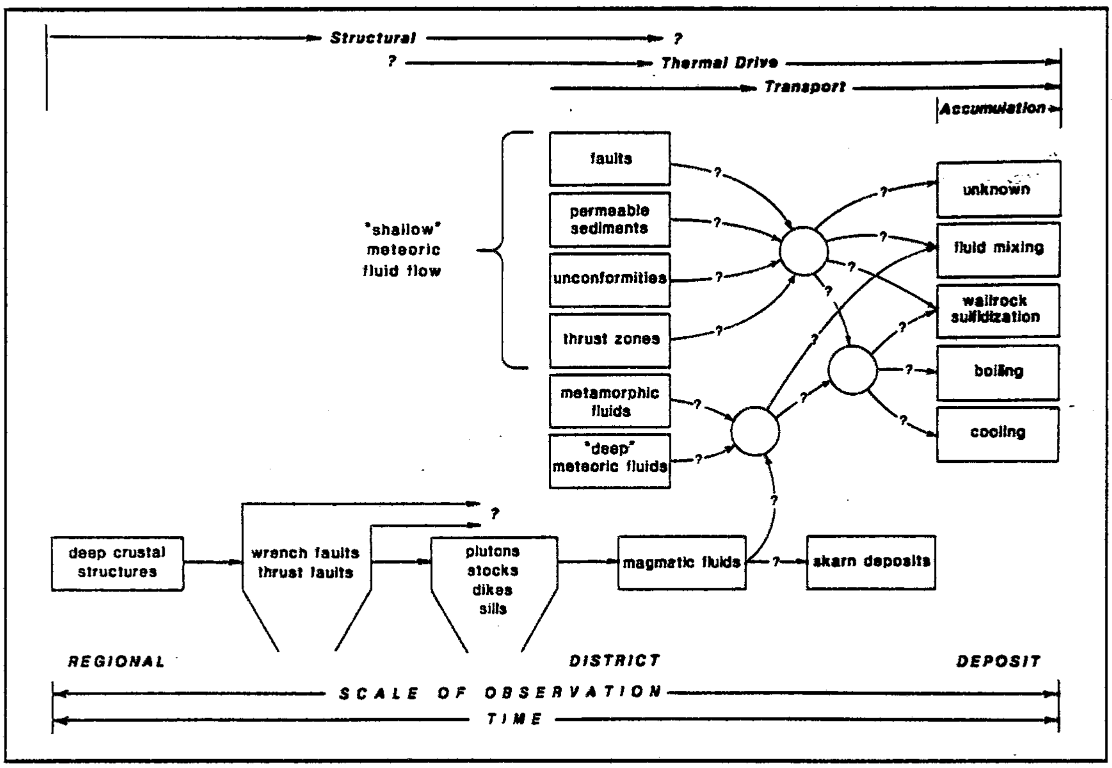


FIGURE 27. Proposed formation processes for sediment-hosted gold deposits, Great Basin (Adams & Putnam).

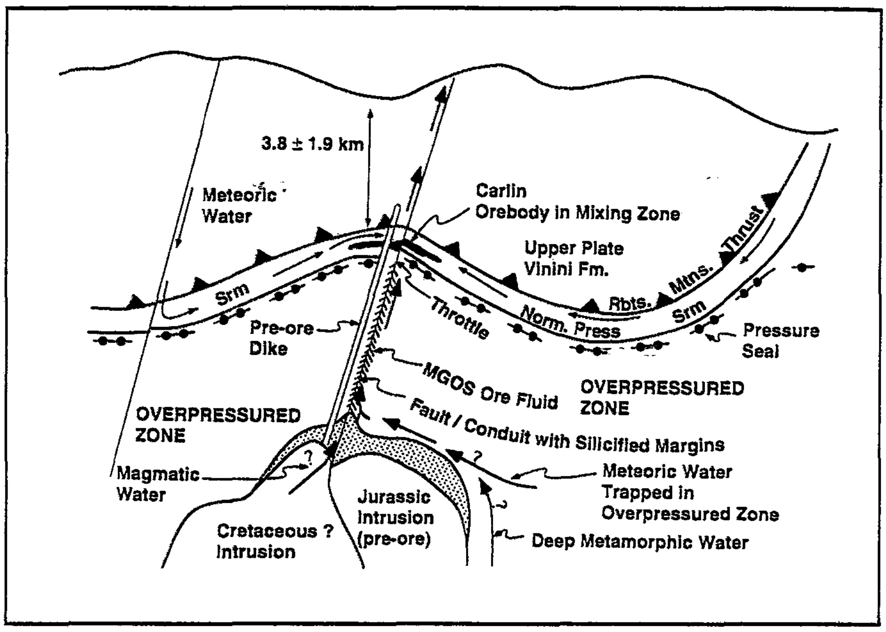


FIGURE 28. Environment of deposition of the Carlin ore at a throttling zone separating overpressuring from hydrostatic pressures, with resulting mixing of fluids. The deep CO_2-rich fluid may be derived from skarn formation, magmatic devolatization, or deep metamorphism.

The Jerritt Canyon (Hofstra et al., 1991) and Carlin (Kuehn & Rose, 1986, 1987 and 1995) deposits have been studied independently. Interpretation shows that the deposits formed by the interaction of two fluids. The possible deep mixing environment of the Carlin deposit is shown in Fig. 28. In this model (Kuehn & Rose, 1995), meteoric water trapped in sedimentary rocks prior to development of the pressure seal was set into circulation by a deeper heat source. The main gold ore-stage fluid was characterized by high CO_2 (possibly from metamorphism or direct magmatic contributions), high H_2S and Au contents (from magma or leaching of sedimentary rocks), temperatures of 215 ± 30° C and moderate salinity. This fluid moved from over-pressured zones and was channelled into permeable units which were filled with meteoric water (volatile-poor, low salinity, cooler and meteoric $\delta^{18}O$ signature). The two fluids mixed within and beyond the throttle zone and gold was precipitated.

After the proposed epithermal origin was ruled out by recent studies (Kuehn & Rose, 1995), two more likely competing models were left for the origin of sediment-hosted gold deposits. The first is exemplified by the major deposits in the Carlin Trend and in the Great Basin. It is the product of metamorphic dewatering of thick Proterozoic sediments underlying the Palaeozoic Great Basin (Seedorff, 1991). The other is generated by migration of highly evolved magmatic fluids to the distal parts of an intrusion-centred, magmatic-hydrothermal system (Sillitoe & Bonham, 1990; Berger & Bagby, 1991). Allochthonous siliciclastic rocks of the Ordovician Vinini and Valmy Formations are proposed as sources of gold and related metals for many deposits in the Great Basin (Nelson, 1991). Spatial relationship between ore bodies and metalliferous marine black shales which are known sources of petroleum as well, and geochemical suites of black shale are regarded as supporting evidence for proposed gold sources. However, in many of these sediments the lack of widespread hydrothermal alteration which commonly occurs at leached source-rocks ruled out this suggested model of origin (Skead, 1994).

Seedorff (1991) proposed that the formation of sediment-hosted gold deposits is the result of expulsion of metamorphic fluids from thick, sedimentary prisms. He strongly argues that magmas do not supply metals in the model for sediment-hosted gold deposits and do play only an indirect genetic role as a regional heat source. It is proposed that the formation of the deposits is closely linked to regional heating of the crust during periods of extensions and that Proterozoic and lower Palaeozoic source sediments consist of pelitic rocks. Average pelitic rocks have a moderate Au content and anomalous As, Sb, Hg assemblages with gold mineralization. Seedorff (1991) believes that the sediment-hosted deposits occur only where Proterozoic sediments are thicker than 5000 feet (1524 m.) in the Great Basin (Fig. 2). Struhsacker (1986) also supported a deep source-rock model with his interpretation that the heated Au-bearing fluids had been driven from a depth of 5 to 7 km. in the Beowawe-White Canyon area. Another requirement for the formation of this type deposit is an effective plumbing system to deliver hot, deep metamorphic fluids, which are derived by dehydration reactions of Tertiary metamorphism, to a suitable site of deposition. The inception of high-angle faulting provided the channels for fluids to travel up to much shallower levels during extensional tectonics.

The distal magmatic-hydrothermal model (Sillitoe & Bonham, 1990) is basically characterized by the presence of a large intrusive porphyry with Cu - Mo - Au in the centre, and metal zonation grading outwards from the porphyry centre (Cu - Mo - Au → Cu - Au and/or W - Mo skarn → Au- and/or Ag-bearing Zn - Pb skarns or carbonate replacements → sediment-hosted gold deposits with anomalous As and Sb) and commonly the presence of fault-controlled felsic dyke intrusions in and adjacent to the deposits. Absence of some mineralization zones which occurred at Bingham, Gold Acres and Gold Strike has been explained by telescoping of the ores. The fluids containing magmatic components from the intrusive sources move along highly permeable conduits (generally high-angle faults and permeable stratigraphic horizons) to the distal part of the system, beyond the skarn and carbonate-replacement environments (Fig. 29). Distances from the centre of the porphyry to the distal sediment-hosted gold mineralization can be up to eight kilometres as seen at Bingham (Sillitoe & Bonham, 1990).

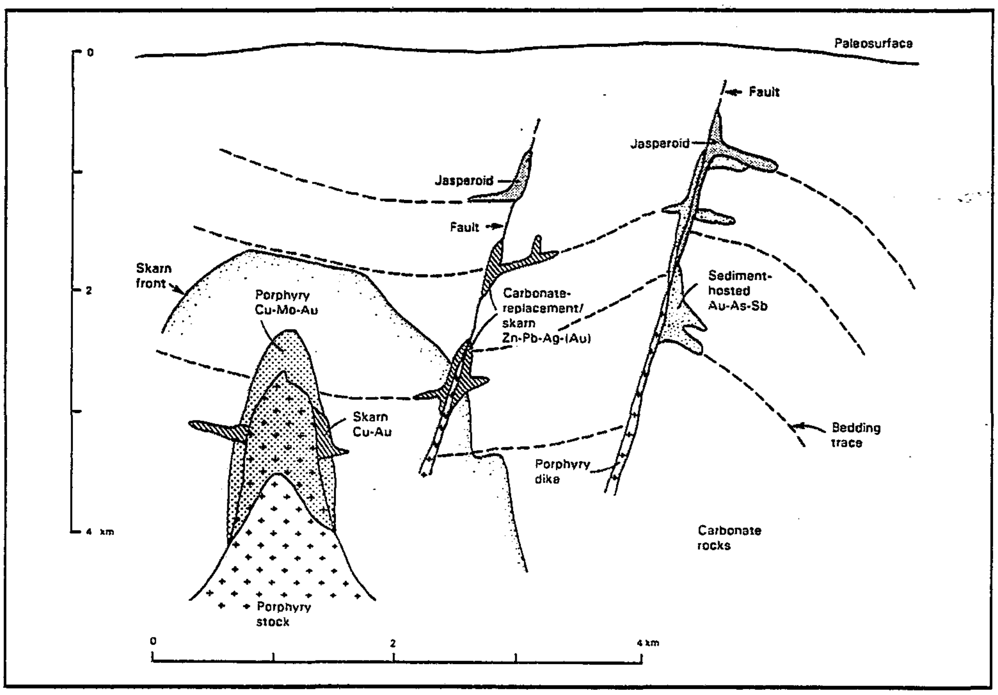


FIGURE 29. Sediment-hosted gold deposits on peripheries of intrusion-centred districts (Sillitoe & Bonham, 1990).

Berger & Bagby (1991) also suggested a strong link between magmatism and the formation of sediment-hosted gold deposits. According to their suggested model: (1)

ores were deposited from slightly to highly acidic, low-salinity, high-CO_2, and high-H_2S fluids; (2) high heat flow is related to magmatism; (3) in most of the deposits, the associated igneous rocks have granodioritic (dacitic) to granitic (rhyolitic) compositions; (4) mixed carbonate, siliciclastic and carbonaceous units are favourable host for sediment-hosted gold deposits in the Great Basin. The source of ore metals is not exactly determined and evolution of the deposits is as suggested below: (1) plutons were intruded into the middle and upper crust in regions of thick sedimentary sequences along deep-penetrating extensional faults; (2) initial mineralization consists of probable skarn and possible stockwork metallization in the immediate vicinity of the intrusive complex, and concurrent formation of early jasperoid distal to the complex; (3) second stage sediment-hosted gold mineralization occurs either close in, or distal to the intrusive complex and coincides with early, pre-ore jasperoid (Berger & Bagby, 1991); (4) tungsten-bearing skarns, scheelite and molybdenum occurrences in many deposits (e.g. Getchell, Gold Acres, Carlin, Gold Strike, Chimney Creek) of the Great Basin are interpreted as products of parent magmas associated with sediment-hosted gold deposits.

Seedorff (1991) agreed that gold deposits in porphyry districts have certain characteristics in common with sediment-hosted gold deposits in the Great Basin. He preferred to use "Carlin-like" deposits which include the deposits in the Bingham district, Utah, Purisima Concepcion deposits in the Yauricocha district, Peru, and various deposits in the Bau district. Lack of mineralized porphyry exposures, lack of heat (>300°), particularly abundant rhodochrosite and high Te contents at Purisima Concepcion, high arsenopyrite content in jasperoid at Bau are the uncommon features of sediment-hosted gold deposits (Seedorff, 1991). With the support of these dissimilarities Seedorff (1991) recommended the gathering of more data (ages, isotopic analyses and fluid inclusions) from deeper parts of sediment-hosted gold deposits and late-stage or distal products of porphyry systems. Another significant difficulty in choosing between these two different models is the restriction of most well-known sediment-hosted gold deposits into a single geological province in the Great Basin.

However, some newly discovered sediment-hosted gold deposits such as El Hueso, Chile; Mesel, Indonesia; Alsar, Macedonia and Zarshuran, Iran shed new light on the approach to genetic problems.

Kavalieris et al. (1992) pointed out the absence of a thick sedimentary sequence from the thin island-arc crust at Mesel which implies that Seedorff's (1991) metamorphic dewatering of thick sedimentary sequences seems unlikely. Despite the absence of isotope data or sufficient fluid inclusion results, Sillitoe (1994) assumed the intrusive model at Mesel with the support of the characteristic Au - As - Sb - Hg - Tl suite, Au-bearing jasperoids and other geological and chemical features such as control by high-angle faults; micron-sized Au; deficiency of base metals and Ag, Au in arsenian pyrite. Mesel and other sediment-hosted mineralization may be associated with low-sulphidation epithermal Au-veins present elsewhere in the Ratatok district, but also with nearby low-grade porphyry Cu - Au mineralization (Carlile & Mitchell, 1994).

A similar transition is also observed in a porphyry system at El Hueso, northern Chile (Sillitoe, 1991). Sillitoe (1991) concluded that overlying high sulphidation environment is preserved more completely and acts as the host for this gold deposit. The El Hueso sediment-hosted deposit is only 2 km. away from the Potrerillos porphyry copper deposit and it is most similar to the sediment-hosted gold deposits peripheral to the Ruth (Ely) porphyry copper-gold deposit in the Robinson district, Nevada, where quartz-clay and advanced argillic alteration are reported (Durgin, 1989).

Most of the physical and chemical features at Alsar, Macedonia show great similarities with the Carlin, Getchell and Mercur deposits in the Great Basin and Bau deposit in eastern Malaysia (Percival et al., 1990; Percival & Radtke, 1990), Mesel deposit in Sulawesi, Indonesia (Turner et al., 1994) and Zarshuran in Iran (Bariand & Pelisser, 1972). Apart from the key geological and chemical characteristics, additional data could support a possible genetic link between intrusion and mineralization at Alsar, Macedonia. Sulphur isotopic studies of stibnite, realgar, orpiment and marcasite have given 0.35 to -6.84 ‰ δS^{34} which implies a partial magmatic origin for the sulphur (Serafimovski et al., 1991). Anomalous levels of As, Sb, Tl, Te, Se, F, Bi, Mo, Zn, Cd and Mn are interpreted as characteristic of deposits genetically related to alkaline intrusions (Mutschler et al., 1985; Sillitoe, 1990) and are in strong support of a genetic tie at Alsar, Macedonia. An alternative dewatering model (Seedorff, 1991) seems unlikely at Alsar because at least part of the host rocks as well as the underlying sequences were dewatered and metamorphosed to marble long before mineralization took place. At Zarshuran, Iran similar evidence of metamorphosed and dewatered host and underlying rock have been reported (Briand & Pelisser, 1972).

Most of the sediment-hosted gold deposits in the Great Basin (Berger & Bagby, 1991) and other newly discovered sediment-hosted gold deposits outside the U.S.A. (except some of the Chinese deposits) are at least spatially related to intrusive rocks and porphyry-type Cu - Au-bearing stocks, with or without base-metal skarn and carbonate replacement mineralization being associated with many of these sediment-hosted gold deposits. Magmatic fluid moves from source intrusions and if it follows decreasing pressure gradients, chloride-complexed metals tend to remain longer in solution which maximizes the chances of Au being supplied to distal sites (Hemley et al., 1992). However, Berger & Bagby (1991) suggested that proximal W and/or Mo zones associated with intrusion-centred systems are the favourable and potential environments for sediment-hosted gold deposits in the Great Basin.

The deeply eroded very large Bingham deposit is the best example to explain the Sillitoe & Bonham (1990) intrusion-centred magmatic-hydrothermal model as well as sediment-hosted gold deposits (Fig. 30 and 31). Tooker (1990) described four types of zones which are, from a porphyry Cu core, through skarn Cu - Au, and carbonate replacement Zn - Pb - Ag - Au to distal sediment-hosted Au (at Barneys Canyon and Melco). A genetic relationship between intrusions and sediment-hosted gold deposits is not widely accepted. Some uncertainities still exist regarding the genesis. However, this model is not unrealistic, as >75 % of the contained ounces in the Great Basin

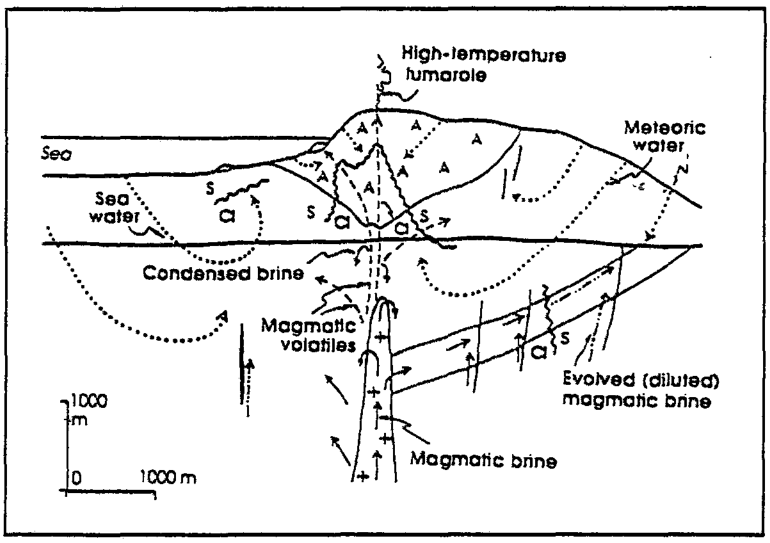


FIGURE 30. Hypothetical flow-paths for magmatic brines and volatiles, and meteoric water and seawater during ore formation in an intrusion-centred system (modified from Sillitoe, 1989)

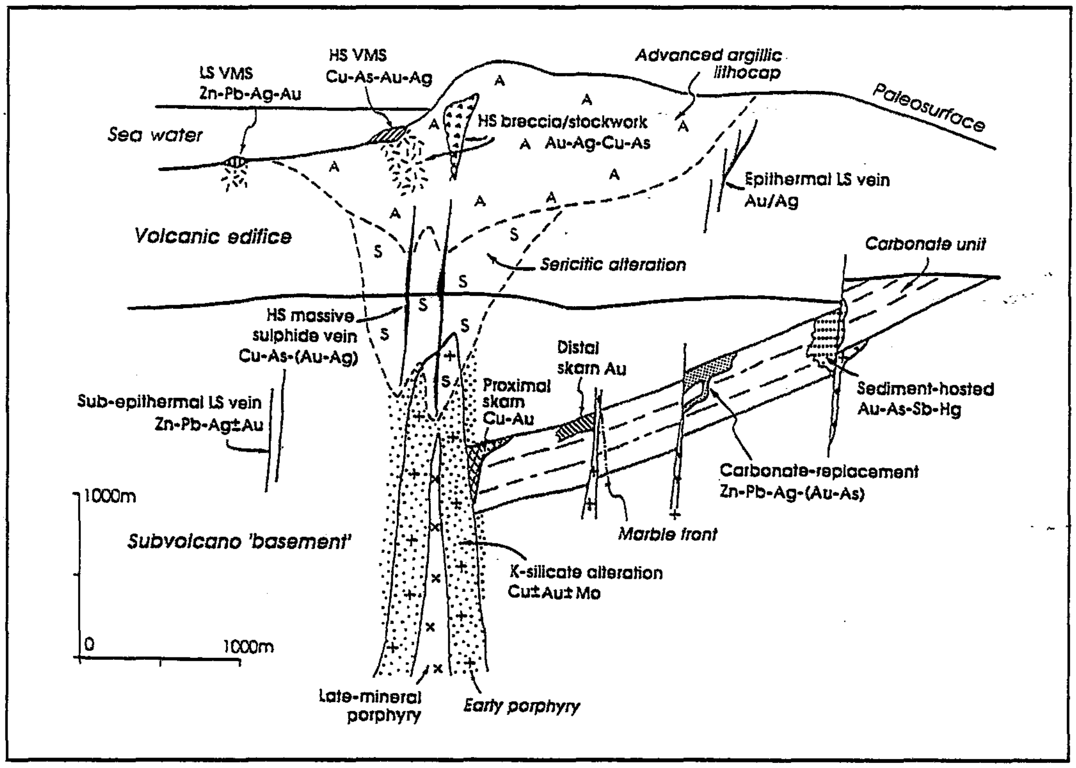


FIGURE 31. Idealized lateral and vertical zoning of deposit types and principal metals in an intrusion-centred system. LS= Low sulphidation; HS= High-sulphidation (modified from Sillitoe, 1989 and Sillitoe & Bonham, 1990)

deposits of this type occur immediately adjacent to or within the peripheral parts of mineralized intrusive-skarn systems. This is an empirical relationship that is hard to ignore (Thompson, 1993). Intrusion-centred districts must be studied extensively and the role of igneous process should be supported by reliable isotopic and fluid-inclusion data.

E. EXPLORATION CRITERIA AND RECOMMENDATIONS

1. TARGET GENERATION WITH EMPHASIS ON DEPOSIT MODEL IN THE GREAT BASIN, U.S.A.

All exploration geologists use deposit models to some extent. The use of models is only one aspect of exploration (Thompson, 1993). The empirical and genetic models are two end members of deposit models. The empirical model comprises direct observations and experiences which form the basis for successful exploration. The observable characteristic features or exploration criteria for sediment-hosted gold deposits in the Great Basin are summarized by Thompson (1993):

(1) The highest grade mineralization occurs in favourable permeable units, typically calcareous siltstone.

(2) Structural preparation in non-reactive sedimentary rocks may provide favourable sites for mineralization.

(3) Two different types of mineralization may occur at different levels, oxidized shallow-level mineralization and deeper unoxidized, generally refractory mineralization.

(4) Most of the deposits are associated with intrusions which commonly include dykes and/or sills.

(5) High-angle normal faults, thrust faults, anticlines and domes are the main structural features which control the deposits primarily or regionally.

(6) Decalcification, silicification and argillization are the common alteration types associated with mineralization. Intense silicification (jasperoid) commonly occurs in structures and along contacts with carbonate units.

(7) As, Sb, Hg, Tl, Ba is the most common trace element suite.

Apart from these criteria, erosional windows through the upper plate of a thrust and on trend with known deposits are widely used historical exploration criteria for sediment-hosted gold deposits in the Great Basin. Most deposits were discovered by direct prospecting and sampling of outcropping intensely silicified zones (jasperoids) (Table 2). The majority of the well exposed jasperoid and jasperoid-associated deposits have been studied and discovered in the Great Basin. However, discovery history of Gold Quarry (Rota, 1991) highlights that jasperoid outcrops at the surface are not always representative of the gold content of the system. Therefore, previously explored jasperoids outcrops that are associated with mineralization should be reexamined in the Great Basin.

Genetic models are based on theoretical concepts and attempt to describe the formation processes of an ore deposit and its related empirical features. Ideally, the understanding of the integrated deposit model (both genetic and empirical models) may provide new targets and also help to select appropriate exploration techniques. Lack of consensus on genetic modelling and origin of the sediment-hosted type gold deposits increases the importance of empirical models for exploration for this type of deposit (Thompson, 1993). This was an acceptable comment until the end of 1980's. As Thompson (1993) pointed out more than half of the deposits in the Great Basin were found by surface sampling and the others were discovered by drilling in or around existing mines. These remarkable discoveries cannot be attributed to any clear genetic concept. However, present and future exploration will require improved genetic models that predict locations of these deposits in the Great Basin. Some of the historical key exploration criteria (windows, trends, oxide ores, and near surface mineralizations) are no longer applicable or useful for choosing new potential sites in the Great Basin.

Recent deep discoveries (Gold Strike and Deep Star) fit both deep crustal metamorphic and/or magmatic process (Seedorff, 1991; Kuehn & Rose, 1995) and magmatic-hydrothermal (Sillitoe & Bonham, 1990) genetic models. However, the very recent examples of juxtaposition of sediment-hosted Au deposits and base metal (-Au) and/or Sb (-Au) (e.g. Gold Quarry and Ruby Hill/Archimedes) strongly increased the importance of magmatic-hydrothermal genetic models. Ruby Hill/Archimedes is covered by recent alluvium and it has approximately 1000 metres transitional distance from Pb -

Zn - Ag (-Au) to Au with As and Sb. This relationship could be easily recognized if the intrusion-related model was well understood and applied. Any Pb - Zn - Ag occurrences in the Great Basin require re-examination by applying the new genetic models and approaches. Pipeline and South Pipeline deposits are completely covered by alluvium. They are only 2.4 km. from the Gold Acres intrusive stock and located along the projected extent of the Cortez trend. The South Pipeline deposit was discovered during "condemnation drilling" of a planned construction site! In the case of these covered deposits, because of the very small use of surface geochemistry, structural observations and other "traditional" methods, application of intrusion-centred models and metal zonation would be the key exploration criteria.

The Great Basin is a relatively well-explored region for sediment-hosted gold deposits. However, the Great Basin is still one of the prime areas to explore for major sediment-hosted gold deposits. In the light of new observations and new models, exploration programs require persistence and new exploration criteria that were not emphasized previously. Additional blind deposits that may form at depths of many kilometres (Kuehn & Rose, 1995), near surface alluvium covered deposits, base metal associated sediment-hosted gold deposits and less oxidized higher grade deposits are future exploration targets in the Great Basin. Most of the discoveries made in the Great Basin in 1995 were high-grade underground target. These deep feeder type of targets will continue to be the most attractive at least in the near future. Centres of magmatism and intrusions which have been previously explored for lineaments and trend analysis should be considered as individual potential sources and targets for sediment-hosted gold deposits. The integrated intrusion-centred model depicted in Figure 30 and 31 provides a coherent framework in which to conduct exploration for a variety of base- and precious-metal deposits in the Great Basin.

2. SELECTION OF NEW AREAS FOR REGIONAL EXPLORATION OUTSIDE OF THE U.S.A.

Sediment-hosted gold deposits were and still are attractive exploration targets in the western United States. Newly discovered sediment-hosted gold deposits show a widespread distribution and quite a varied character in other parts of the world. About twenty deposits and occurrences in China, a few deposits along the South American Cordillera and the Alpine-Himalayan belt and very recent discoveries in the Circum-Pacific Rim are the only known and studied sediment-hosted gold deposits outside the Great Basin, U.S.A. (Fig. 12).

China, in terms of sediment-hosted gold deposits, is one of the richest countries in the world. Despite the lack of detailed information of the individual deposits, there are additional prospective areas for sediment-hosted gold deposits in China. Most of the Chinese deposits are distributed along the buried edge of the Yangtze craton (Cunningham et al., 1988; Dongsheng et al., 1991) (Fig. 13). This depressed area of the Yangtze craton is covered by Palaeozoic-Mesozoic strata consisting mainly of marine carbonates, clastics and graptolitic shale with minor coal-bearing sediments (Zhang et al., 1984). Cunningham et al. (1988) interpreted the position of the edge of the Yangtze craton as having a most significant effect on the depositional environment. Moreover, they pointed out the similarities to the position of the North American Craton and their tectonic histories. Several workers (Ashley et al., 1991; Dongsheng et al., 1991; Casaceli & Gemuts, 1985) concluded that the Precambrian Yangtze craton of China is especially favourable for sediment-hosted gold deposits because of its relationship to recent continental extension, high heat flow, hot spring activity and favourable host rocks. It should be noted that the eastern China sediment-hosted gold deposits coincide with the axes of regional anticlines, antiforms and structural domes (Cunningham et al., 1988).

Recently, the Maoling deposit (Cheng et al., 1994) was discovered within the Northern China platform (Sino-Korean Craton) (Fig. 13). In contrast to the previous cases, this deposit is closely associated with Mesozoic granites which are intruded along re-activated structures (dilation zones). The Sino-Korean craton is conformably overlain by well-developed neritic carbonates and terrestrial facies. During Mesozoic and Cenozoic times, the craton was marked by intrusions, block-like vertical movements and reactivation of the older structures (Zhang et al., 1984). All these features make the Sino-Korean craton an attractive exploration target for sediment-hosted gold deposits. The unique example of Proterozoic host rocks (Maoling), the igneous components of Yangtze deposits which have not been previously considered, and the Tancheng-Lujiang transcurrent fault of the Sino-Korean craton are the geological peculiarities of the region which should be re-examined during future exploration programs.

Other South-east Asian sediment-hosted gold deposits are: Mesel and a nearby prospect in North Sulawi, Wanagon in the Ertsberg district, Iranian Jaya and Cikotok district, west Java. Fifteen major arcs are identified with a total land extent of over 15,000 kms. Known ore bodies are confined to six arcs (Fig. 14) (Carlile and Mitchell, 1994). Sediment-hosted gold mineralization occurs where low sulphidation fluids encountered favourable calcareous marine sediments. In both Ratatok and Cikotok districts low sulphidation epithermal veins occur in sedimentary and volcanic rocks of similar age to that containing the sediment-hosted mineralization. All those small sedimentary basins along the Indonesian magmatic arc offer very promising prospecting potential. Mitchell & Leach, (1991) suggested Burma as one of the best potential areas for sediment-hosted gold deposits in south-east Asia. In the Philippines, limestones are rare in the basement and which are pure carbonate rocks. Still, those carbonate basement rocks which occur in the upper and lower plates of folded thrusts are favourable rocks for gold deposits.

Late-Palaeozoic orogenic belts in Uzbekistan, Kazakhstan and Kirghizstan have a number of porphyry, epithermal-type world-class gold deposits. Eastern Uzbekistan and Kirghizstan are located along the structurally complex Hercynian zone. This zone is marked by the juxtaposition of a platform sequence, oceanic sedimentary rocks, volcanic rocks and melange. All these sequences are intruded by alkalic to calc-alkalic, dioritic to granodioritic magmas. Andesitic and dacitic volcanic eruptions through central vents constructed volcanic edifices which host epithermal style mineralization at or near the surface and porphyry copper deposits were formed at deeper parts (Berger et al., 1994). Polymetallic and skarn deposits are the other two important components of the intrusive system where sediment-hosted gold mineralization can be emplaced in favourable structural and lithological conditions. Along the same Hercynian arc, Smirnow (1977) reported a few sediment-hosted antimony deposits characterized by the presence of permeable sedimentary host rocks, structural (fold crest, high-angle faults) and lithologic (bedding plane and lithologic change) controls of ore zone, jasperoid associations, intrusive components and similar trace element and alteration assemblages. The Terek and Kadamdzhai deposits in Kirghizstan and the Dzhizhikrut deposit in Tadjikistan need to be investigated for gold contents. In this region, plate tectonics form a familiar framework into which the sediment-hosted gold deposit model fits. The late Palaeozoic orogenies in Central Asia are important targets for sediment-hosted gold deposits.

During Late Jurassic-Early Cretaceous, subduction of the Afroarabian and Indian oceanic crust under the Eurasian plate was followed by the closure event of the Tethys ocean. These events formed a volcano-plutonic belt starting from the Carpatho-Balkanides, through east Pontide (Turkey), Little Caucasus, central Iran to Tibet (Jankovic, 1990) (Fig. 32). This belt hosts numerous intrusion-related gold and base metal deposits (the Recsk in Hungary; Rosia Poieni and Moldova Noua in Romania; Medet, Assarel and Elatsite in Bulgaria; Bor in Serbia; Kadzaran in Caucasus; Sarh Chesmeh in Iran; Seindak in Pakistan and Yulong in Tibet). Gold-bearing sediment-

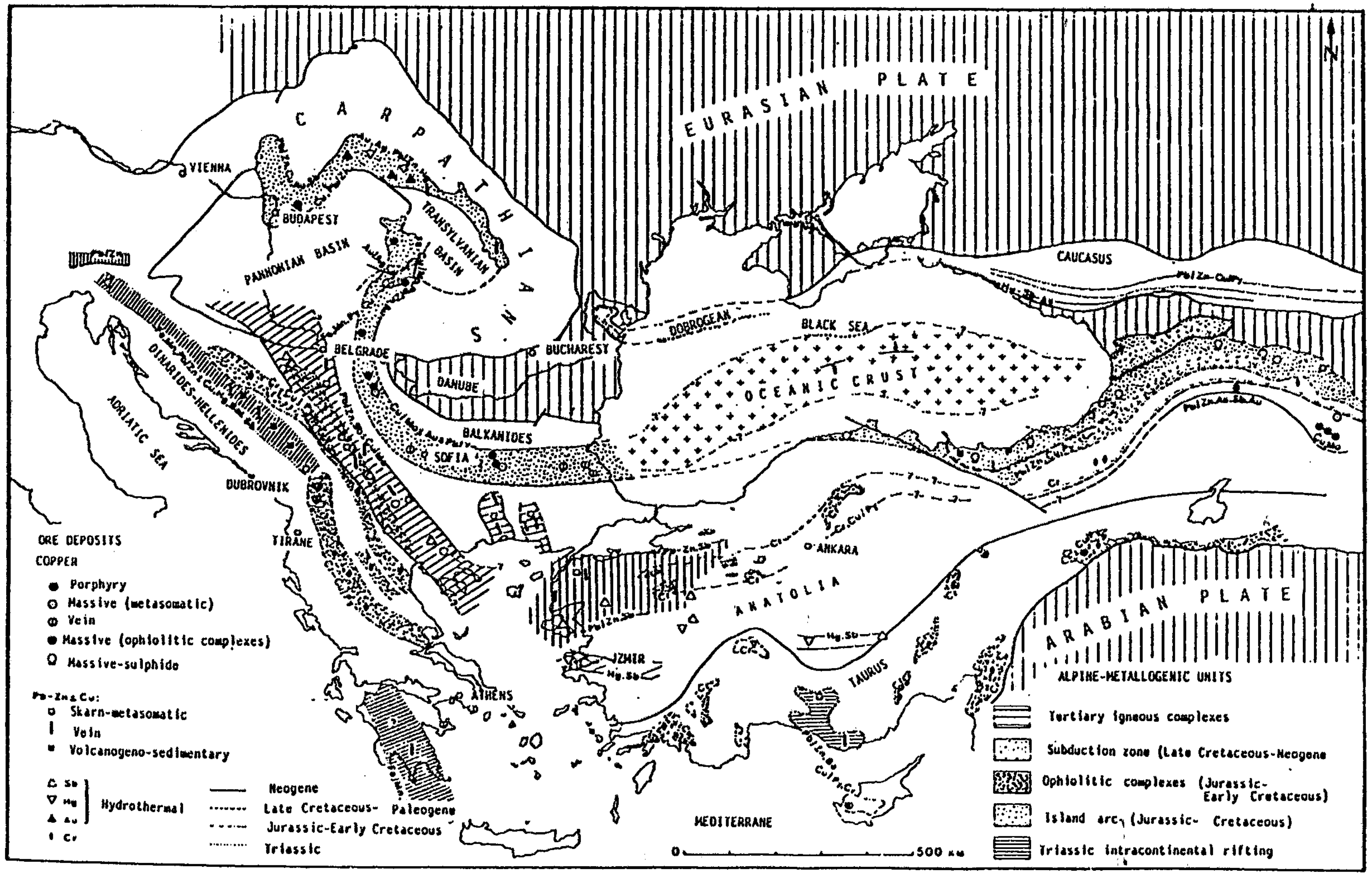


FIGURE 32. Main regional metallogenic units of the north-eastern Mediteranean area (modified from Jankovic, 1990)

hosted old antimony workings occur in the northern Apennines, Italy (Tanelli et al., 1991), as well as two Late Cenozoic sediment-hosted gold deposits (Alsar in Macedonia and Zarshuran in Iran). Numerous sediment-hosted types of gold occurrence are found in Bulgaria; suitable, geological settings in north-eastern Turkey and Georgia make these areas highly promising for prospecting.

According to Jankovic (1978) the Serbomacedonian and Anatolian metallogenic provinces (Pb - Zn, Sb, Mo - Cu) are two significant provinces of the Balkan peninsula. The Serbomacedonian belt has been studied by many authors (Fytikas et al., 1980; Nesbitt et al., 1988) who favoured extensional tectonics associated with Tertiary arc magmatism. Resulting hydrothermal solutions which migrated through well-defined fracture systems, subsequently deposited precious metals in chemically and physically favourable marble horizons. The Ridanj-Krepoljin zone which is characterized by deep faulting, dacito-andesite intrusions and limestone covers is suggested as a particularly favourable area in Serbia (Jankovic, 1990). The eastern extensions of the Serbomacedonian metallogenic belt in so-called "western Anatolia" are dominated by extensional tectonics much like the Basin and Range of the western U.S.A. (Larson, 1989). More than ten east-west-trending grabens and intervening hosts are associated with mercury, antimony, and gold occurrences. Furthermore, Sengor (1987) pointed out that two of the major graben-bounding faults are listric in character, and the western termination of the Basin and Range provinces in Nevada by the Walker Lane strike-slip fault is similar to the north Anatolian strike-slip fault termination effect in Turkey. North Anatolian horse tail / splay termination cause Miocene extension in the Rhodopes, Bulgaria and the southern region of the Greece - Chalkiditi zone (Fig. 33) (Dinter & Royden, 1993).

Jankovic (1982) recognized some of the antimony, mercury and gold occurrences hosted by intensely silicified (jasperoids) rocks in western Turkey. Erler & Larson (1992) and Larson & Erler (1993) also studied several jasperoid-hosted (associated with high-angle and thrust faults), Ag-, Au-, Sb-, Hg-, As-rich and interpreted to be sediment-hosted deposits in western Anatolia and southern Anatolia (Nigde), Turkey. In particular, melange-hosted, antimony-bearing precious metal occurrences at Orencik suggest further exploration along the Izmir-Ankara Melange belt, Turkey (Larson & Erler, 1993). At Orencik, precious metals are in jasperoid-formed melange rocks along both hanging wall and footwall of undulating low angle thrust faults (Fig. 34).

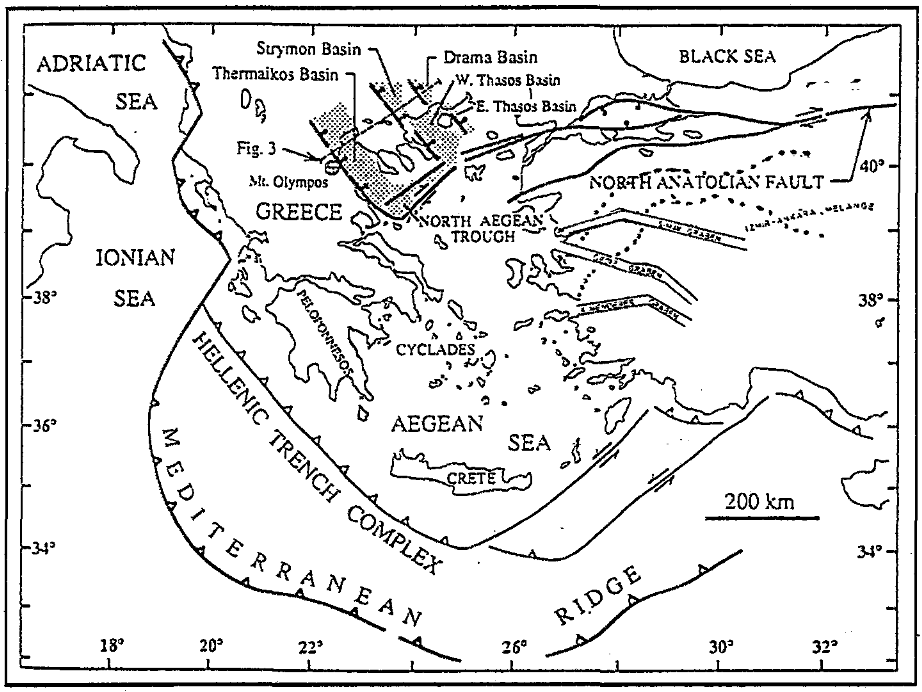


FIGURE 33. Tectonic elements of northeastern Mediterranean region (modified from Dinter & Royden, 1993; Larson & Erler, 1993).

In western South America, almost all current production of gold and copper is confined to metallogenic belts which are parts of volcano-plutonic arcs generated during eastward subduction of the Pacific oceanic lithosphere beneath the archetypal Cordilleran continental margin (Sillitoe, 1991). There is as yet no clear evidence that there are plentiful sediment-hosted gold deposits in the central Andes (northern and central Chile, southernmost Peru, western Bolivia and north-western Argentina). The Gualilan district which contains gold-bearing jasperoids (besides calcic skarns) and El Hueso in northern Chile are the only known deposits in the Central Andes. However, sediment-hosted gold deposits occur in many parts of Peru. The best-known deposit, Purisima Concepcion is closely spatially related to a porphyry stock and to polymetallic limestone replacement deposits bordering the stock. Santiago de Chuco, Sayapullo, Utupara and Michiquillay are newly discovered deposits and targets in Peru (Noble & Vidal, 1994). Noble & Vidal (1994) deduced that considerable potential existed around porphyry systems which were emplaced within a lithologically favourable sequence of Mesozoic strata. Similarly, in other south American countries (Ecuador, Colombia, Nicaragua) sediment-hosted gold deposits can be expected where Cretaceous or Tertiary intrusions cut Paleozoic or Mesozoic sedimentary sequences along the same volcano-plutonic belts.

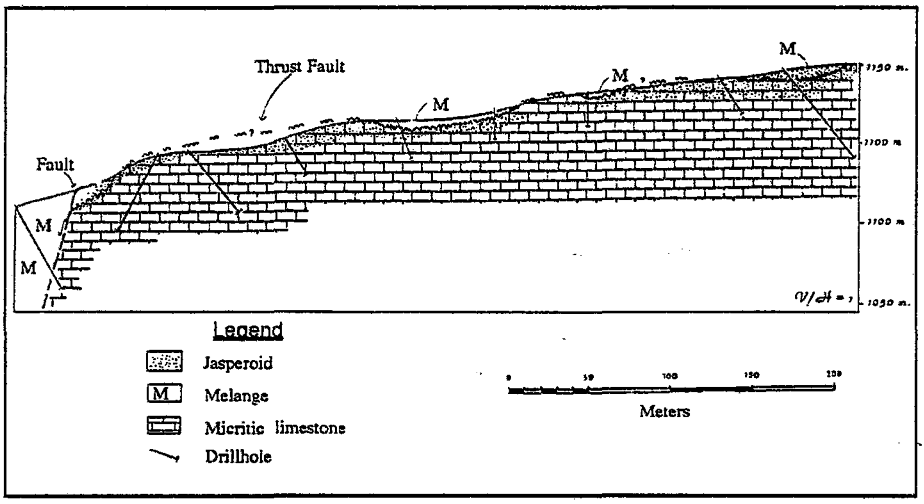


FIGURE 34. Geological cross-section of Orencik prospect (Larson & Erler, 1993).

Fig. 12 shows that most of the known sediment-hosted gold deposits and occurrences are associated with zones of present and recent subduction activity. Apart from known deposits, ongoing exploration in eastern Europe, mid-Asia, Pacific Rim and western South America point out the that volcano-sedimentary arcs on arc sequences are potential targets. It is evident from the many recent discoveries that sediment-hosted gold deposits should not be restricted to a continental setting. Relatively small carbonate sedimentary basins also have the potential to host sediment-hosted gold deposits (Turner et al., 1994). Finally, intrusion-centred systems in appropriate carbonate host rocks, especially thinly bedded, silty sequences deserve exploration for sediment-hosted gold deposits.

3. EXPLORATION TOOLS

Remote Sensing is a very effective exploration technique to find out structural and some of the mineralogical features. LANDSAT images that highlight structural trends and structural domains include colour enhanced bands, colour composites and edge enhancements. Alteration patterns around hydrothermal systems can be enhanced by the images as well. Using the different LANDSAT bands with airborne thermal survey is the best combination to improve quality of the images.

Structural features and mineralization-structure relationships are always the major problem to solve in sediment-hosted gold depositional environments. Furthermore, in many deposits, alterations are closely associated with fracture/fault systems. The content of clays can be reflected by the ratios of the TM band. For alteration mapping, LANDSAT TM imagery with bands 5/7 (which highlight the hydrothermal minerals) should be used in the colour composites.

The Rabbit Creek, Nevada deposit which was discovered by interpretation of aerial photographs is an outstanding example for the understanding of the importance of aerial photo - LANDSAT image combination (Bloomstein et al., 1991). Aerial photos can help to distinguish different units (carbonate / noncarbonate) and common structures (high-angle faults and anticlines).

Sabins (1987) noted that the climatic factor plays an important role in terms of image quality. He indicated that wet seasons provide the best image for structural studies. Apart from that, wet seasons also increase the amount of meteoric water circulating through conduits (structures) and infrared imagery technique helps to determine these subsurface structures.

Many different **geophysical methods** have been applied for sediment-hosted gold exploration in the Great Basin. In fact, all methods provide various amounts of useful information. However, there is no one specific method which works satisfactorily all the time, in all sediment-hosted gold depositional environments. Sediment-hosted gold deposits are not associated with high-content massive sulphide bodies. Sulphides have a disseminated character within the ore body. Therefore, the direct detection methods of geophysics are not applicable for sediment-hosted gold deposits. Geophysics, indirectly, (e.g. from silicic - high resistivity, low chargeability to argillic alteration - low resistivity, high chargeability) can detect gold-bearing lithologies or associated alteration envelopes (Corbett, 1991). As mentioned in the earlier part of this chapter, recent exploration programs are focused on subcropping intrusive bodies and related distal mineralizations, thick alluvium covered deposits and deeper unoxidized deposits in the Great Basin. Geophysical techniques which are inter grated with other techniques should be aimed at producing anomalies over these mineralizations and finding out these hidden features as well.

Many sediment-hosted gold deposits (in the Great Basin and others) are located at the edge of intrusives or at distal parts of intrusion-centred systems. Earlier, gravity and magnetic surveys were used to understand the linearity of the gold trends and concentrations of igneous rocks along these trends in the Great Basin. Gravity survey was not a successful technique to pick up the buried intrusion stocks (Shawe, 1991). Skead (1994) pointed out that the presence of variabilities in alluvium density because of compaction, grain size, water saturation and interclated volcanics, decreases the accuracy. Intrusives that can be roughly outlined by gravity methods and can be detected and delineated by regional aeromagnetics (Figs 6a, 6b and 6c) (Shawe, 1991). High resolution aeromagnetic survey revenes buried intrusives and depth of cover. Ground magnetics help to follow up regional anomalies. However, the exploration geologist should always expect some peculiar geological and mineralogical settings. The Maoling sediment-hosted gold deposits in China, were detected by magnetic methods. Biotite-bearing granitic rocks commonly display higher magnetic susceptibilities than sedimentary rocks. However, these granitic rocks had lower densities than metamorphosed sedimentary rocks. In this unusual case, the gravity survey was quite helpful in highlighting the batholith around Maoling, China (Cheng et al., 1994).

As Wilds & MacInnes (1991) and Corbett (1991) noted, electrical geophysical methods (e.g. resistivity, induced polarization and electromagnetic techniques) provide much useful data for exploration of sediment-hosted type gold deposits. CSAMT (controlled source audio frequency magnetotellurics) is an electromagnetic sounding technique that has superior resolution compared with most other electrical methods. High resolution and deep penetration make this method an excellent tool for mapping silicification, clay and graphite zones of hydrothermal alteration, and structural / lithological relationships associated with gold and silver.

The IP can distinguish the alterations but the presence of pyrite (diagenetic / hydrothermal) and carbonaceous units make IP data quite noisy and inconclusive.

Structural studies are vital during both regional and prospect scale exploration for sediment-hosted gold deposits. Structure plays a primary role in the distribution of hydrothermal systems (conduits and favourable sites). During regional scale exploration programs, the exploration geologist should understand the main structural features which create high-angle faults. Most of the deposits are associated with and controlled by high-angle faults adjacent to major strike-slip faults in the Great Basin. Other major extensional structures which are favourable for intrusives and related hydrothermal activity should be clarified.

Image interpretation to find out structural controls of the deposits according to different structural regimes and tectonic terrains is very necessary during regional studies. The structural history, known stress regime and structures (faults, lineaments) collected available literature should be used, in tandem with the structural analysis of the imagery. All known faults and lineaments should be added on the image and possible obscured structures that fit the stress history of the region should be added to this integrated work. Synthesis of known deposits and their structure, pre-, syn-, and post-mineralization stress regime interpretation from the imagery, structural preparation and models will show some favourable areas as an regional exploration target.

Structural analysis for fault intersections, especially between high-angle conducive fault and other low angle fault intersections, must be performed meticulously. As has been mentioned several times, jasperoids are a good exploration guide, but the structural setting and implications for the area around jasperoids should be well understood. Gold Quarry, Great Basin is an excellent example whereby exploration was centred around the jasperoidal discovery outcrop at 1962 and ten years later, the main ore body was discovered distal to the jasperoid (Rota, 1991). The jasperoid is parallel to penetrative structures (high-angle fault) and it was exposed onto the surface by subsequent erosion. However, the main ore body developed along the impermeable cap rock which is intersected by conducive high-angle fault (as well as jasperoid).

Structural studies are also key exploration techniques in the case of sediment-hosted gold deposit buried (by thick alluvium cover). Recently discovered gold deposits beneath gravels forced exploration geologists to develop a structural basin model and integrated exploration tools (structural analysis and seismic) (Effimoff & Pinezich, 1986).

Osterberg & Guilbert (1991) developed a new useful structural technique which is basically the detection of the fracture density and orientation of the micro-faults and fractures. These data can identify large areas of subtle solution and collapse. This volume loss caused by decalcification indicates the possible silicification and finally mineralization in the region.

All types of **geochemical techniques** can be used extensively in sediment-hosted gold depositional environments. During regional exploration programs, choosing the right geochemical technique is directly related to surface covers, topography, vegetation and drainages. Rock chip sampling is very useful in this type of deposits. Often, silicified fault zones and chip sampling of jasperoid have become the starting points of exploration programs. Favourable lithologies adjacent to jasperoids, silicifications and fault intersections are also attractive for lithogeochemical investigations. After the recognition of the deep origin of sediment-hosted ores, deep drilling methods have been emphasized. Thin-bedded calcerous siltstone, silty limestone or dolomite overlain by unmineralized, relatively poorly mineralized and post-mineral alluvium rocks are interpreted (with the support of structural observations) as preferential targets . Some recent deposits such as Rabbit Creek and Marigold in the Great Basin were discovered by drilling methods.

As, Ag, Sb, Hg, Tl, W and F constitute the best pathfinder element suite to detect the sediment-hosted gold deposits. As Albino (1994) noted, Au is probably the most useful indicator element. Trace element anomalies may not persist more than a hundred meters above the zone of mineralization as in the Ren gold prospect, Great Basin. The presence of erratically-distributed Au over a vertical range of more than 300 meters above the mineralized zone has been taken as a positive indication. In fact, at the early stages of exploration programs, focusing on deeply buried sediment-hosted gold deposits, geology is probably more useful than geochemistry, and Au should be considered as its own best pathfinder.

Stream sediment geochemistry is the most useful tool during regional exploration stages. The **BLEG** (bulk leach extractable gold) stream sediment sampling method is considered a most useful technique in the Great Basin. It has large (4-5 kg) sample size and large course fraction (-1mm). The amount of sample and mesh size help to pick up fine grained, disseminated, low grade golds in sediment-hosted environments. However, exploration geologists must be aware of the high possibility of having the so called nugget effect. Stream drained placer gold included in alluvials can give wrong BLEG anomalies.

Soil geochemical survey is another commonly used technique. In the case of poor outcrop buried deposits and sufficiently developed in-situ soil cover, soil geochemical survey is the best exploration tool to delineate the anomalous gold mineralizations.

F. SUMMARY AND CONCLUSION

The North American sediment-hosted gold deposits occur throughout the Great Basin which is one of the best exposed and stratigraphically complete geological provinces in the world. From Late Jurassic to Early Tertiary time two major compressional event and orogenies created some extensional structures, plutonism and regional uplift. The last extensional tectonic events (formation of Basin and Range) occurred from the Late Eocene to the present. Plutonism extended through the Tertiary and has been related to many sediment-hosted gold deposits by some authors.

Numerous gold deposits are aligned along trends in Nevada. The Carlin, Cortez, Getchell and Humboldt trends coincide with faults, intrusive rocks and geophysical discontinuities. Some of the sediment-hosted gold deposits seem to be isolated occurrences as well.

The general characteristics of the sediment-hosted gold deposits in the Great Basin, Nevada have been classified and summarized by several authors (Percival et al., 1988; Berger & Bagby, 1991). Gold mineralization is hosted in a number of different lithologies. Thinly bedded silty dolomites, limestones and carbonaceous shales are the most favourable hosts which provide the permeability for hydrothermal fluids. In all of the known deposits, high-angle faults are closely related with the formation of the ore bodies. They are channels of hydrothermal fluids and also hosts for the gold depositions. Decalcification, silicification and argillization are the most common alteration types in this type of deposits. Jasperoids are a very characteristic, easily recognizable silica form in sediment-hosted gold deposits. They are localized around structural planes of weakness (e.g. faults, breccia zones, bedding planes). Jasperoid was and still is a very useful exploration guideline. Carbonization is the dominant alteration type in some deposits. It contains up to three percent (by weight) organic carbon which is believed to act as a positive correlation of gold content. Sediment-hosted gold ores can be classified as oxidized and unoxidized ores. Unoxidized ores became economically desirable during the 1980's with the development of technology in metallurgy. Carbonaceous, pyritic, arsenical, siliceous and jasperoid ores are the subdivisions of unoxidized ores; oxidized ores, often encapsulated in silica, are associated with goethite jarosite and with quartz veinlets. During the main hydrothermal stage, high amounts of Si were precipitated together with the characteristic geochemical assemblages of Au, As, Sb, Hg, Ba and Tl. The positions, shape and sizes of ore bodies are closely related with high-angle faults in particular, as well as structural preparation of the rocks, host rock features and other structural features. In the Great Basin, Nevada impermeable rock above unconformity can block the moving fluids and provide chemical deposits vary widely in sizes and grades.

Similar sediment-hosted gold deposits have been discovered in many different countries outside western America. These newly discovered deposits share the same principal or key characteristics of the Great Basin deposits. Even some unusual features of the Great Basin deposits have been recorded in a few new discoveries. Of course, some dissimilar or uncommon geological and chemical characteristics have been observed in these newly discovered deposits. The most important of there are: lack of carbonaceous ore at Mesel, Indonesia; presence of karst controlled breccias related mineralizations and lack of Hg and Tl trace elements at Lobongan/Alason, Indonesia; complete lack of igneous rock association at the Guizhou deposits, China; presence of Early Preterozoic host rock and occurrence of biotite in the wall rock alteration assemblage at Maoling, China; high concentration of Te into trace element suite at Purisima Concepcion, Peru; large content of thallium (300-500 ppm) and relatively younger age of mineralization (Pliocene) at Alsar, Macedonia.

There are two more probable competing genetic models for sediment-hosted gold deposits. One is basically derived from metamorphic dewatering of thick sediments (Seedorff, 1991) and the other argues for the migration of highly evolved magmatic fluids to the distal parts of an intrusion-centred system, the so-called magmatic-hydrothermal model (Sillitoe & Bonham, 1990; Berger & Bagby, 1991). The main difficulty in choosing between these two different models is the restriction of most well-known and well-studied sediment-hosted gold deposits into a single geological province in the Great Basin. In spite of extensive studies done to date on sediment-hosted type deposits, many obscure points still exist regarding a genetic model. Stable isotope data from the same samples at some deposits have been interpreted by the same geologist to support different genetic models (Percival & Radtke, 1990). However, some newly discovered deposits outside of the U.S.A. permit support for the intrusion-centred magmatic-hydrothermal model. Kavalieris et al. (1992) noted the absence of a thick sedimentary sequence from the thin island-arc crust at Mesel, Indonesia. This is completely opposite to Seedorff's (1991) thick sedimentary sequence origin suggestion. His alternative dewatering model also seems unlikely at Alsar, Macedonia and Zarshuran, Iran, because part of the host rocks, as well as the underlying sequences, were dewatered and metamorphosed to marble long before mineralization took place (Percival et al., 1990; Bariand & Pelisser, 1972). A genetic relationship between intrusion and sediment-hosted gold deposits is not unrealistic. The well-known large Bingham deposit and recently discovered Ruby Hill/Archimedes, Pipeline and South Pipeline deposits in the Great Basin increased the significance and possible applicability of the intrusion-centred distal product sediment-hosted gold model.

In conclusion, the use of the intrusion-centred system model as a basis for exploration of sediment-hosted mineralization is strongly recommended. Each intrusion and its distal favourable litho-structural components should be explored as high potential targets for sediment-hosted gold deposits.

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APPENDIX

Ore Controls of Sediment-Hosted Gold Deposits along the Carlin, Battle Mountain - Eureka and Getchell Trends, Nevada.

Deposit	Faults			Unconformities	Folds (Anticlines)	Lithology				Impermeable Caps
	Thrust Faults	High Angle Faults	Fault Intersections			Carbonate	Siliciclastic	Debris Flows	Transitional Lithologies	
Bootstrap/ Capstone		P - SP, C	P			m - LP			✓	
Meikle	m - SP	P - SP, C	L - SP, L			S - LP	m	✓, S	✓	
Betze/Post	m - SP	P - SP, C	L - SP, L	✓?	R, L	P - LP	m	✓, S	✓?	Sills, marble, massive limestone
Genesis/ Blue Star	m- SP	P - SP, C	P - SP, L		R, L	S- LP		✓, m	✓	
Carlin		m - SP, C	m - SP, L		R	P - LP	m - SP		✓	L, Siliciclastic sediments
Tusc		P - SP, C	P - SP		m - L	P - LP			✓	
Gold Quarry	m - SP	P - SP, C	P - SP		m -L, R	P - LP	S	✓, m	✓	L, Siliciclastic sediments
Rain		m- SP, L, C	m - SP, L	P- LP	m, R	P - LP				
South Bullion	m - SP	m - SP, L, C	m - SP	P - LP		P - LP				
Vantage		S, C	m		m - L	P - LP			✓	
Lone Tree		P - SP, L & R, C	S - SP, L			m				
Hilltop	P - SP	m - SP, C	S, L - SP				✓			
Gold Acres	S - SP	S - SP, C	S -SP			P - LP	✓, m			Thrust faults, skarn
Cortez	m - SP	S - SP, C	S - SP		R & L	P - LP				Massive limestone
Horse Canyon	S - SP	S - SP, C	S- SP		S	P - LP	P - SP			
Tonkin Springs	P - SP	P - SP, C				m - LP	P - SP			Thrust and sills
Gold Bar		P - SP, C	S - SP, L			P - LP				
Ratto Canyon	m - SP	S - SP, C	S - SP, L		R & L	P - LP				Thrust
Nighthawk Ridge		P- SP, C	S - SP, L		P, R & L	P - LP				
Chimney Creek		P & S - SP, R & L, C	S - SP, L		P, R & L	P - LP				Argillised basalt, siliciclastics sediments
Rabbit Creek		P - SP, R & L, C	S - SP, L		P, R & L	S - LP		✓, m		As Above
Getchell		P - SP, R & L, C	P - SP, L		m, L	m - LP			✓	
Preble		P -SP, R & L, C	S - SP, L		R, m - L	S - LP	m - SP		✓	
TOTAL	P = 2;S = 2; m = 7	P = 14;S = 5; m = 4	P = 4;S = 11;m = 4	P = 2		P = 14;S = 4;m = 4	P = 2;S = 1;m = 4	5	10	

P - Primary Control; **S** - Secondary Control; **m** - minor Control; **C** - Conduit for hydrothermal fluids; **SP** - Structural Preparation; **LP** - Lithological Preparation; **R** - Regional Control; **L** - Local Deposit Control. ✓ = Present in the mine. Skead (1994)