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Major Gold Deposits and Belts of the North and South American Cordillera: Distribution, Tectonomagmatic Settings, and Metallogenic Considerations

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Abstract

A compilation of economically viable gold concentrations containing ≥10 Moz in the North and South American Cordillera reveals the existence of 22 discrete belts in addition to five major isolated deposits, most formed over the last 150 m.y. The gold concentrations are attributed to eight widely recognized deposit types, of which porphyry, sediment-hosted, and high-sulfidation epithermal are economically the most important. Individual gold belts are typically several tens to hundreds of kilometers long, dominated by single deposit types, and metallogenically active for relatively brief periods (<5–20 m.y.).

Many of the gold belts and major isolated deposits were generated under extensional or transtensional tectonic conditions in either arc or back-arc settings. Nevertheless, the two main high-sulfidation epithermal gold belts were generated in thickening or already-thickened crust during low-angle subduction. Eight other gold belts or districts also accompanied compression or transpression, with two of them, the main orogenic gold belts, occupying fore-arc sites. There is a strong suggestion that the preeminent Cordilleran gold concentrations formed either during or immediately following prolonged contraction. The major gold deposits and belts occur along the craton edge as well as in adjoining accreted terranes, but almost all are of postaccretionary timing. Many of the gold belts and isolated deposits were localized by crustal-scale faults or lineaments, which may be either parallel or transverse to the Cordilleran margin.

The gold concentrations accumulated during active subduction, commonly in close spatial and temporal association with intermediate to felsic, medium- to high-K calc-alkaline igneous rocks. By contrast, the low-sulfidation epithermal gold deposits accompany bimodal volcanic pulses of calc-alkaline, tholeiitic, or alkaline affinity. However, a gold-alkaline rock association is uncommon. A genetic link between gold mineralization and coeval magmatism is widely accepted for most of the deposit types, the exceptions being the sediment-hosted and orogenic gold deposits.

Notwithstanding the small cumulative extent of the gold concentrations relative to the entire Cordilleran margin, there is a marked tendency for two or more belts or isolated deposits of different ages and genetic types to occur in close proximity within relatively restricted arc (including fore- and back-arc) segments. In the case of the western United States, for example, six belts and four isolated major deposits make up a particularly prominent cluster. If fortuity is discounted, this clustering or pairing of gold concentrations must imply a predisposition of certain arc segments to gold mineralization. An analogous situation is evident for other metals, particularly copper and tin. The reason for the recurrent generation of major deposits and belts dominated by one or more metals remains uncertain, although heterogeneously distributed metal preconcentrations, favorable redox conditions, or other parameters somewhere above the subducted slab, between the mantle wedge and upper crust, are widely contemplated possibilities. Elucidation of the reason(s) for this metallogenic inheritance at the scale of limited arc segments poses an important and challenging series of research questions as well as being critical to the planning of potentially successful greenfield exploration programs.

Introduction

GOLD DEPOSITS occur at numerous localities along the full length of the North and South American Cordillera, from Alaska in the north to Patagonia in the south. The Cordillera has a long and colorful gold-mining history dating back to the 16th century, since when the cumulative production plus current reserves of the yellow metal total >1,000 Moz (30,000 metric tons), ~20 percent of the known global total. Today, six of the top 20 gold-producing countries of the world are located there. Cordilleran gold is contained in a spectrum of widely recognized and well-documented ore deposit types (e.g., Robert et al., 2007; Fig. 1; Table 1) generated in a variety of tectonomagmatic settings, a situation in marked contrast to the majority of tin or copper resources, which in the western Americas are hosted almost exclusively by single deposit types (e.g., Turneaure, 1971; Sillitoe and Perelló, 2005).

Most of the major Cordilleran gold deposits and belts are Mesozoic or Cenozoic in age (Table 2), although it should be remarked that the major Homestake deposit in South Dakota, not considered further herein, is Paleoproterozoic and part of the cratonic basement to the North American Cordillera (Slaughter, 1968; Fig. 2).

This analysis incorporates all gold belts and isolated deposits in the western Americas that are estimated to contain ≥10 Moz (≈300 t) of gold (Fig. 2; Table 2), an approach that probably takes account of at least three-quarters of the region's gold endowment. Only gold concentrations with demonstrated economic potential or a reasonable chance of commercial production are considered. By-product gold in base metal and silver deposits is ignored, although gold-rich...
porphyry copper deposits are included if either the value of the contained gold roughly equals or exceeds that of the copper, or the gold endowment is metallogenically outstanding (e.g., Bingham Canyon, Utah; Pebble, Alaska; Fig. 2). The individual gold belts are defined by either single or several ore deposit types, one of which tends to predominate, and were generated during relatively restricted metallogenic epochs, most of which have been reasonably well defined by isotopic dating (Table 2).

The paper summarizes the distribution and tectonomagmatic settings of the principal gold concentrations in the western Americas (including the Caribbean region) and, thereby, highlights the preeminent tectonic and associated igneous activity that controlled and influenced gold deposit formation here over the last 150 m.y. or so. Tectonomagmatic aspects are emphasized over deposit-scale physicochemical conditions and mechanisms throughout this discussion. The paper is organized by gold deposit type, although skarn deposits are not considered further in view of their relatively minor contribution (Table 1) and typical close association with other intrusion-related deposit types. A prefatory section provides a brief summary of gold deposit types and their relative economic importance in the American Cordillera. A concluding synthesis of the tectonomagmatic settings for gold and comparisons with the main Cordilleran copper and tin belts provides the basis for comment on broader metallogenic issues, particularly the concepts of provinciality and inheritance. Finally, some suggestions for future research are offered.

**Gold Deposit Types**

The western American Cordillera contains most of the world’s economically important gold deposit types (Fig. 1; Table 1). The gold deposits are attributable to five broad categories: epithermal deposits in shallow volcanic environments; porphyry copper-gold or gold-only deposits in the subvolcanic environment; sediment-hosted (or Carlin-type) deposits in nonmetamorphosed, carbonate-rich sedimentary sequences; pluton-related deposits in deeper, but still epiizonal intrusive environments; and orogenic deposits in metamorphic rocks, commonly assignable to greenschist facies.

Some investigators currently subdivide the epithermal deposits of both vein and disseminated styles into high-, intermediate-, and low-sulfidation types, as defined by mineralogic criteria (Hedenquist et al., 2000; Sillitoe and Hedenquist, 2003; Table 1). The porphyry deposits are typically large and always in the form of stockworks, whereas the sediment-hosted deposits are predominantly disseminated in style and controlled by a combination of faults and receptive stratigraphy. The pluton-related deposits range from veins and vein swarms to stockworks, but include other styles (Thompson et al., 1999; Lang and Baker, 2001; Fig. 1). The pluton-related deposits are divisible into two distinct classes depending on the redox state (e.g., Ishihara, 1977) of their
genetically related plutons: deposits related to relatively reduced, magnetite-poor (and commonly ilmenite-bearing) intrusions contain minor amounts of lithophile elements but no appreciable base metals (Thompson et al., 1999), whereas those with oxidized, magnetite-bearing intrusions contain modest amounts of base metals (Table 1). The orogenic deposits are typically in the form of quartz veins and vein arrays. Clearly, depth of erosion is a cogent control on the distribution of outcropping gold deposit types. For example, many epithermal deposits are removed once erosional depths exceed 1 km (Sillitoe, 1993; Fig. 1) whereas orogenic gold deposits are only exposed once erosion has reached paleodepths ranging from 3 to 15 km (Goldfarb et al., 2001).

The perceived role of magmatism as a source of the gold-bearing fluids responsible for the different deposit types is far from straightforward. Porphyry and pluton-related gold deposits are generally accepted to be products of dominantly magmatic fluids derived from subjacent parental intrusions, and a similar—albeit generally more distant—magmatic connection is now widely accepted for epithermal deposits (e.g., Sillitoe and Hedenquist, 2003; Table 1). However, continued discussion surrounds the origin of sediment-hosted gold deposits, with heated meteoric, metamorphic, and diluted magmatic fluids preferred by different investigators (see Muntean et al., 2004). Orogenic gold deposits are widely considered to lack a close genetic association with intrusions (Goldfarb et al., 2001), although both deeply sourced metamorphic and magmatic fluids remain viable alternatives (Table 1). It should be cautioned, however, that distinction between pluton-related and orogenic gold deposits is commonly not straightforward because both typically formed from dilute, CO$_2$-rich fluids as a consequence of their relatively deep settings (Sillitoe and Thompson, 1998; Groves et al., 2003). A case in point is the Pataz-Parcoy belt in northern Peru (Fig. 2), which is assigned herein to the oxidized pluton-related category because of the close association of the quartz veins with porphyry dikes, but considered as orogenic by others (Haeberlin et al., 2004). Of course, if pluton-related and orogenic gold deposits were both products of magmatic fluids, the distinction would become largely arbitrary anyway.

### Table 1. Key Features of Main Gold Deposit Types in the American Cordillera

<table>
<thead>
<tr>
<th>Gold deposit type</th>
<th>Contribution to total Cordilleran gold endowment (%)</th>
<th>Principal mineralization style(s)</th>
<th>Characteristic accompanying elements</th>
<th>Typical host rocks</th>
<th>Typical proximal alteration type(s)</th>
<th>Ore fluid</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-sulfidation epithermal Au</td>
<td>16</td>
<td>Stockwork, disseminated, veins, breccias</td>
<td>Cu, As, Ag</td>
<td>Andesitic to dacitic volcanic rocks + basement</td>
<td>Advanced argillic</td>
<td>Mixed magmatic-meteoric</td>
<td>Simmons et al. (2005)</td>
</tr>
<tr>
<td>Intermediate-sulfidation epithermal Au</td>
<td>6</td>
<td>Veins, stockwork</td>
<td>Ag, Zn, Pb, Cu, As, Sb, Mn</td>
<td>Andesitic to dacitic volcanic rocks</td>
<td>Intermediate argillic ± adularia</td>
<td>Mixed magmatic-meteoric</td>
<td>Simmons et al. (2005)</td>
</tr>
<tr>
<td>Low-sulfidation epithermal Au</td>
<td>6</td>
<td>Veins, disseminated</td>
<td>As, Sb, Zn, Pb</td>
<td>Felsic and basaltic volcanic rocks</td>
<td>Intermediate argillic ± adularia</td>
<td>Mixed magmatic-meteoric</td>
<td>Simmons et al. (2005)</td>
</tr>
<tr>
<td>Alkali low-sulfidation epithermal Au</td>
<td>3</td>
<td>Disseminated, veins</td>
<td>Te, V, F</td>
<td>Alkaline volcanic rocks</td>
<td>Intermediate argillic ± adularia</td>
<td>Magmatic</td>
<td>Simmons et al. (2005)</td>
</tr>
<tr>
<td>Porphyry Cu-Au</td>
<td>20</td>
<td>Stockwork + disseminated</td>
<td>Mo</td>
<td>Quartz diorite to granodiorite porphyry stocks + wall rocks</td>
<td>Potassic, intermediate argillic, sericitic</td>
<td>Magmatic</td>
<td>Sillitoe (2000)</td>
</tr>
<tr>
<td>Porphyry Au</td>
<td>2</td>
<td>Stockwork</td>
<td>Cu, Mo</td>
<td>Diorite to quartz diorite stocks + wall rocks</td>
<td>Potassic, intermediate argillic</td>
<td>Magmatic</td>
<td>Vila and Sillitoe (1991)</td>
</tr>
<tr>
<td>Skarn Au</td>
<td>4</td>
<td>Irregular to strata-bound replacements</td>
<td>As, Bi, Te or Cu, Zn, Pb</td>
<td>Carbonate rocks</td>
<td>Calc-silicate</td>
<td>Magmatic</td>
<td>Meinert et al. (2005)</td>
</tr>
<tr>
<td>Reduced pluton-related Au</td>
<td>5</td>
<td>Sheeted veins, stockworks</td>
<td>As, Bi, Te, W, Mo</td>
<td>Felsic plutons + wall rocks</td>
<td>Alkali feldspar, sericitic</td>
<td>Magmatic</td>
<td>Thompson et al. (1999)</td>
</tr>
<tr>
<td>Oxidized pluton-related Au</td>
<td>4</td>
<td>Sheeted veins, stockworks</td>
<td>Zn, Pb, Cu, Mo</td>
<td>Felsic plutons + wall rocks</td>
<td>Alkali feldspar, sericitic</td>
<td>Magmatic</td>
<td>Sillitoe (1991)</td>
</tr>
<tr>
<td>Sediment-hosted Au</td>
<td>21</td>
<td>Disseminated</td>
<td>As, Sb, Hg, Tl</td>
<td>Impure carbonate rocks</td>
<td>Decalcification, silification</td>
<td>Mixed magmatic-meteoric, meteoric, or metamorphic</td>
<td>Cline et al. (2005)</td>
</tr>
<tr>
<td>Orogenic Au</td>
<td>13</td>
<td>Veins, stockworks</td>
<td>As, Te</td>
<td>Greenschist-facies metavolcano-sedimentary rocks</td>
<td>Sericite (Cr mica)-carbonate</td>
<td>Metamorphic and/or deep-seated magmatic</td>
<td>Goldfarb et al. (2005)</td>
</tr>
</tbody>
</table>

1 Based on production and/or reserves plus resources (measured + indicated categories), as listed in Table 2
<table>
<thead>
<tr>
<th>Gold belt/deposit</th>
<th>Au content (Moz)</th>
<th>Preeminent deposit(s)</th>
<th>Main (subsidiary) Au deposit type(s)</th>
<th>Mineralization age, Ma</th>
<th>Regional tectonic setting</th>
<th>Related magmatic rocks</th>
<th>Synthetic reference(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kuskokwim belt, Alaska</td>
<td>23</td>
<td>Donlin Creek</td>
<td>Reduced pluton-related</td>
<td>71–65</td>
<td>Back-arc transpression</td>
<td>Reduced calc-alkaline stocks and dikes</td>
<td>Hart et al. (2002), Goldfarb et al. (2004)</td>
</tr>
<tr>
<td>Pebble, Alaska</td>
<td>82</td>
<td>Pebble</td>
<td>Porphyry Cu-Au</td>
<td>~90</td>
<td>Uncertain, possible compression</td>
<td>Calc-alkaline stocks and sills</td>
<td>Bouley et al. (1995)</td>
</tr>
<tr>
<td>Fairbanks-Tombstone belt, Alaska-Yukon Territory</td>
<td>29</td>
<td>Fort Knox, Pogo</td>
<td>Reduced pluton-related</td>
<td>104; 93-91</td>
<td>Back-arc weak extension</td>
<td>Reduced calc-alkaline stocks and plutons</td>
<td>McCoy et al. (1997), Hart et al. (2002)</td>
</tr>
<tr>
<td>Klondike district, Yukon Territory</td>
<td>13</td>
<td>Klondike placers</td>
<td>Orogenic</td>
<td>Early-Middle Jurassic (?), (&lt;178)</td>
<td>Localized extension following compression</td>
<td>None</td>
<td>Rushton et al. (1993), MacKenzie et al. (2007)</td>
</tr>
<tr>
<td>Independence trend, Nevada</td>
<td>14</td>
<td>Jerritt Canyon</td>
<td>Sediment-hosted</td>
<td>~42–36</td>
<td>Low-magnitude extension</td>
<td>Calc-alkaline dikes</td>
<td>Cline et al. (2005)</td>
</tr>
<tr>
<td>Getchell trend, Nevada</td>
<td>35</td>
<td>Twin Creeks</td>
<td>Sediment-hosted</td>
<td>~42–36</td>
<td>Low-magnitude extension</td>
<td>Calc-alkaline dikes</td>
<td>Cline et al. (2005)</td>
</tr>
<tr>
<td>Battle Mountain-Enreka trend, Nevada</td>
<td>57</td>
<td>Pipeline, Cortez Hills</td>
<td>Sediment-hosted (skarn)</td>
<td>~42–36</td>
<td>Low-magnitude extension</td>
<td>Calc-alkaline felsic stocks + dikes</td>
<td>Cline et al. (2005)</td>
</tr>
<tr>
<td>Bingham district, Utah</td>
<td>55</td>
<td>Bingham Canyon</td>
<td>Porphyry Cu-Au (skarn, sediment hosted)</td>
<td>39–37</td>
<td>Initiation of extension or termination of compression</td>
<td>High-K calc-alkaline stocks and volcanics</td>
<td>Babcock et al. (1995)</td>
</tr>
<tr>
<td>Round Mountain, Nevada</td>
<td>14</td>
<td>Round Mountain</td>
<td>Low-sulfidation epithermal</td>
<td>26</td>
<td>Extension</td>
<td>Calc-alkaline volcanics</td>
<td>Henry et al. (1996)</td>
</tr>
<tr>
<td>Walker Lane, Nevada</td>
<td>47</td>
<td>Comstock Lode</td>
<td>Low-sulfidation epithermal</td>
<td>21–4</td>
<td>Transtension</td>
<td>Calc-alkaline volcanics and stocks</td>
<td>John (2001)</td>
</tr>
<tr>
<td>Sierra Foothills belt, California</td>
<td>100</td>
<td>Mother Lode</td>
<td>Orogenic</td>
<td>135–115</td>
<td>Forearc transpression</td>
<td>Calc-alkaline plutons in nearby batholith</td>
<td>Böhlke and Kistler (1986), Marsh et al. (2007)</td>
</tr>
<tr>
<td>Cripple Creek, Colorado</td>
<td>30</td>
<td>Cripple Creek</td>
<td>Alkaline low-sulfidation epithermal</td>
<td>31.6–28.4</td>
<td>Transition from compression to backarc (Blimodal volcanic rocks and minor intrusions) extension</td>
<td>Bimodal alkaline volcanics and minor intrusions</td>
<td>Kelley et al. (1998), Bampe et al. (2005)</td>
</tr>
</tbody>
</table>
Epithermal, porphyry, and sediment-hosted deposits account for three-quarters of Cordilleran gold endowment (Table 1). Sediment-hosted deposits clearly dominate in western North America, whereas high-sulfidation epithermal deposits are preeminent in the Andes, including the Caribbean region (Fig. 2; Table 2). These types are followed in importance by orogenic and pluton-related deposits if appreciable quantities of derivative placer gold are included (Fig. 2). Individually, the low- and intermediate-sulfidation as well as the skarn-type deposits make only modest contributions to the total Cordilleran gold inventory.

**Tectonomagmatic Settings**

*High-sulfidation epithermal gold deposits*

The Cajamarca-Huaraz belt in northern Peru and El Indio-Maricunga belt in northern Chile, each ~400 km long, and the Pueblo Viejo district in the Dominican Republic are the three main concentrations of large high-sulfidation epithermal gold deposits in the American Cordillera (Fig. 2; Table 2), although smaller examples occur in the Walker Lane, Nevada (Goldfield, Paradise Peak; Fig. 3) and Sierra Madre Occidental, Mexico gold belts, and elsewhere. The large, high-sulfidation deposits are hosted by either voluminous, long-lived volcanic complexes of medium-K andesitic-dacitic-rhyolitic composition (e.g., Yanacocha, northern Peru; Longo and Teal, 2005) or basement rocks unaffected by appreciable contemporaneous volcanism (e.g., Pascua-Lama, northern Chile-Argentina; Bissig et al., 2001; Pueblo Viejo, Dominican Republic; Sillitoe et al., 2006).

Both the Cajamarca-Huaraz and El Indio-Maricunga belts occur within the two late Miocene to Recent, amagmatic, flat-slab segments of the central Andes defined by Barazangi and Isacks (1976). However, the temporal and, hence, genetic relationships between the major high-sulfidation gold deposits and the slab flattening and eventual cessation of magmatism are not everywhere the same.

In the Cajamarca-Huaraz belt, the oldest major high-sulfidation gold deposits (e.g., Alto Chicama, Pierina), along with the porphyry copper-gold deposits at Minas Conga and Cerro Coroza (Fig. 4), were formed from ~17 to 14 Ma (Noble and McKee, 1999; Gustafson et al., 2004) during a noncompressive interval between the Quecha I (19.5–17 Ma) and Quecha II (~9 Ma) tectonic pulses (Noble and McKee,

<table>
<thead>
<tr>
<th>Gold belt/ deposit</th>
<th>Au content (Moz)¹</th>
<th>Preeminent deposit(s)</th>
<th>Main (subsidiary) Au deposit type(s)</th>
<th>Mineralization age, Ma</th>
<th>Regional tectonic setting</th>
<th>Related magmatic rocks</th>
<th>Synthetic reference(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Middle Cauca belt, Colombia 16</td>
<td>Colosa, Marmato</td>
<td>Porphyry Au (intermediate-sulfidation epithermal, porphyry Cu-Au)</td>
<td>8–6</td>
<td>Transpression</td>
<td>Calc-alkaline volcanics and stocks</td>
<td>Cediel et al. (2003)</td>
<td></td>
</tr>
</tbody>
</table>

¹ Gold belts and isolated deposits listed from north to south (Fig. 2)
² Production and/or reserves plus resources (measured + indicated categories)
In contrast, development of the giant Yanacocha highsulfidation gold district spanned the 13.6 to 8.2 Ma interval (Longo and Teal, 2005), temporally closer to the final cessation of magmatism in the Peruvian flat-slab segment at ~4 Ma (Noble and McKee, 1999). A change at Yanacocha from dominantly andesitic volcanism to emplacement of small volumes of highly oxidized, dacitic to rhyolitic magma at 9.8 Ma (Longo and Teal, 2005) may chart an advanced stage of slab flattening, contraction, and crustal thickening.

The major highsulfidation gold deposits in the El Indio-Maricunga belt (Pascua-Lama, Veladero, and El Indio-Tambo) formed from ~10 to 6.2 Ma (Jannas et al., 1999; Bisssig et al., 2001; Charchaflié et al., 2007), after andesitic volcanism in the segment had ceased (Kay et al., 1999) and compressive tectonism had migrated eastward (Bissig et al., 2003; Charchaflié et al., 2007). The gold mineralization accompanied volumetrically minor silicic magmatism (cf. Yanacocha district) in tectonically thickened crust at high elevations during flat-slab subduction (Kay and Mpdozis, 2001, 2002; Bissig et al., 2003). However, the upper crust may have been weakly extended in places at the time of gold mineralization as a result of gravitational instability consequent upon the high elevation (e.g., Veladero: Charchaflié et al., 2007).

Recently presented alteration and lithogeochemical evidence suggests that the Pueblo Viejo high-sulfidation gold deposits in the Dominican Republic were generated as part of a regionally extensive Late Cretaceous to Paleogene volcanic-plutonic arc (e.g., Lebrón and Perfit, 1994) rather than being genetically related to the hosting bimodal volcanic succession of island-arc tholeiite composition and Early Cretaceous age (Sillitoe et al., 2006). The tectonic regime that prevailed in the Late Cretaceous to Paleogene arc, defined by both calc-alkaline intrusive and extrusive rocks, remains to be defined, although extensional conditions are a distinct possibility given the inferred existence of a broadly contemporaneous back-arc basin (Mann et al., 1991).

Cross-arc zones of Miocene tectonomorphic activity, up to several tens of kilometers wide, appear to have localized the Alto Chicama and Yanacocha high-sulfidation gold deposits in the Cajamarca-Huaraz belt. In the case of Yanacocha, Quiroz (1997), followed by Turner (1999) and Longo and Teal...
(2005), defined the 200-km-long, northeast-striking, Chicama-Yanacocha structural corridor, which encompasses the 25-km-long alignment of volcanic and hydrothermal centers at Yanacocha as well as nearby high-sulfidation gold and porphyry copper-gold deposits (Fig. 4a). An apparently similar, but northwest-striking basement feature is present in the El Indio part of the El Indio-Maricunga belt, with the 6-km-long Pascua-Veladero trend coincident with its northern margin (Bissig et al., 2001; Charchaflié et al., 2007; Fig. 4b). A comparable transverse structure was also recently proposed as a localizing influence on the Goldfield high-sulfidation gold deposit in the Walker Lane (Berger et al., 2005).

**Low-sulfidation epithermal gold deposits**

Two of the less important gold belts in the western Americas, the Patagonian province in southern Argentina and contiguous Chile and the Northern Nevada rift in Nevada, are dominated by low-sulfidation epithermal deposits. The Walker Lane in western Nevada and Sierra Madre Occidental belt in Mexico also contain several additional examples (Fig. 2; Table 2). The Patagonian province and Walker Lane cover extensive areas, ~200,000 km² in the case of the former, which encompasses the easternmost foothills of the Southern Andes (Esqueld deposit) besides the extra-Andean Somuncura and Deseado massifs (Cerro Vanguardia deposit; Fig. 5a). In contrast, the Northern Nevada rift is ~500 km long and 4 to 7 km wide, but is paralleled westward by other similar coincident gravity and magnetic trends (Ponce and Glen, 2003; Fig. 5c). The most important concentrations of low-sulfidation epithermal gold in the western Americas, however, are the isolated Round Mountain, Nevada (Fig. 3) and Cripple Creek, Colorado (Fig. 2) deposits, which are of disseminated and subordinate vein type and vein and subordinate disseminated type, respectively, rather than exclusively vein systems as in the Patagonian province, Northern Nevada rift, Walker Lane, and Sierra Madre Occidental (Table 2).

The two low-sulfidation epithermal-dominated belts, the Patagonian province and Northern Nevada rift, possess a number of tectonomagmatic similarities. Compositionally bimodal, rhyolite and basalt-basaltic andesite volcanic suites characterize both belts, but rhyolite dominates the former province whereas basalt is volumetrically preeminent in the latter (Kay et al., 1989; Pankhurst et al., 1998; John, 2001). The silicic component in Patagonia constitutes oxidized, peraluminous, medium- to high-K calc-alkaline ignimbrites, defining an ash-flow caldera province (Kay et al., 1989;
Pankhurst et al., 1998). In contrast, the rhyolites of the Northern Nevada rift comprise volumetrically restricted domes and dikes that are chemically reduced and plot in the tholeiitic field (John, 2001). The silicic volcanic rocks are inferred to be products of lower-crustal anatexis in response to mafic underplating (Pankhurst and Rapela, 1995; John, 2001).

In concert with the bimodal volcanic association, both the gold belts were generated during extension in back-arc settings while subduction-related arc magmatism was active farther west. The Chon Aike rhyolites accumulated in a series of regionally continuous, north-northwest-striking half grabens, which underwent reactivation during the low-sulfidation epithermal gold mineralization and accompanying final-stage (<160 Ma) volcanism in the western parts of the province (Pankhurst et al., 2000; Ramos, 2002). The Northern Nevada rift and similar parallel structures farther west, all underpinned by mafic dike swarms (Zoback et al., 1994; Ponce and Glen, 2003), were the sites of low-sulfidation epithermal gold mineralization during a short interval (16–14 Ma) at the end of the early rift-related volcanism (John, 2001).

The Chon Aike rhyolite province and Northern Nevada rift are both products of mantle plume activity: the Discovery-Shona-Bouvet group of plumes for the former and the inception of the Yellowstone hotspot for the latter (Riley et al., 2001; Zoback et al., 1994; Glen and Ponce, 2002; Fig. 5b, c). The Patagonian gold province is located at the paleo-Pacific margin of Gondwana and—along with the partially time-equivalent Karoo and Ferrar flood basalt provinces (Fig. 5b)—formed during rifting preparatory to South Atlantic Ocean opening and breakup of western Gondwana (Pankhurst et al., 1998, 2000; Riley et al., 2001). In contrast, the Northern Nevada rift aborted before any separation of the North American plate could take place.

The low-sulfidation epithermal gold deposits in the Walker Lane (e.g., Bodie) along with the Round Mountain deposit just to the east (Fig. 3) are associated with rhyolitic centers, including a major ash-flow caldera at Round Mountain (Henry et al., 1996). The Walker Lane is a dextral transtensional belt (Stewart, 1988), whereas extension prevailed at 26 Ma when the Round Mountain deposit was formed and in the Sierra Madre Occidental during the Oligocene (El Oro low-sulfidation epithermal deposit). Cripple Creek, located along the eastern margin of the North American Cordillera (Fig. 2), has a very different magmatic affiliation, being part of a diatreme complex related to bimodal phonolite-alkaline lamprophyre rocks (Kelley et al., 1998). The alkaline magmatic activity may be related to small degrees of mantle melting triggered by the transition, between 40 and 35 Ma (Chapin and Cather, 1994), from Laramide compression to...
the extensional regime that culminated in opening of the Rio Grande rift (Kelley et al., 1998; Rampe et al., 2005).

Intermediate-sulfidation epithermal gold deposits

Intermediate-sulfidation epithermal deposits, mostly of vein type, make important contributions to the 600-km-long Walker Lane in Nevada (Comstock Lode; Fig. 3), the 750-km-long Sierra Madre Occidental belt in Mexico (Tayolita), the 100-km-long Zamora belt in southern Ecuador (Fruta del Norte), and the 300-km-long Middle Cauca belt in Colombia (Marmato; Fig. 6). All these deposits are closely associated with medium- to high-K calc-alkaline volcanism, which ranges from andesitic in the Comstock Lode area (Castor et al., 2005) to voluminous rhyolitic ignimbrites in the Sierra Madre Occidental (McDowell and Clabaugh, 1979; Ferrari et al., 2007).

As noted above, the Walker Lane developed under dextral transtensional conditions (Stewart, 1988) and the Sierra Madre Occidental belt is part of an extensional arc, the southern continuation of the Basin and Range province of the western United States (Henry and Aranda-Gomez, 1992; Staude and Barton, 2001; Ferrari et al., 2007). Extension in the Sierra Madre Occidental culminated in opening of the Gulf of California (Ferrari et al., 2007). Although not well studied, the Late Jurassic Zamora belt may have been extensional (Table 2) prior to the onset of Late Cretaceous collision-related compression (Pratt et al., 2005). Generation of the Fruta del Norte deposit, the main product of this event, overlapped with subaerial graben formation, coarse clastic sedimentation, and nearby dacitic ash-flow eruption (Stewart and Leary, 2007). The Middle Cauca belt lies along the Cauca-Romeral fault system, the site of a collisional suture, and appears to

**Fig. 5.** Geologic comparison of the Patagonian and Northern Nevada rift low-sulfidation epithermal gold belts and their relationship to hot spots. a. Outcropping Chon Aike Group volcanic rocks (from Riley et al., 2001) and main gold deposits in the Patagonian province. b. Large Igneous Provinces (Chon Aike rhyolites and Karoo and Ferrar basalts) related to the Discovery-Shona-Bouvet plume group (from Riley et al., 2001). c. Northern Nevada rift and similar magnetic feature farther west (after Ponce and Glen, 2003; heavy dashed lines), main low-sulfidation epithermal gold deposits, present and approximate initial (16.5 Ma caldera) positions of the Yellowstone hot spot, hot spot-related Columbia River Basalt Group, and western graben of Snake River Plain (hachured lines). East-west lines along the Pacific coast show approximate southern margin of the Farallon plate that was being subducted beneath North America at the ages indicated (from John et al., 2000).
have been subjected to dextral transpression during the Miocene (Rossetti and Colombo, 1999; Cediel et al., 2003)—a prominent exception to the extensional or transtensional settings of the other major intermediate-sulfidation epithermal gold deposits.

**Porphyry copper-gold deposits**

The three preeminent porphyry copper-gold deposits, Bingham Canyon in the Bingham district of Utah, Bajo de la Alumbrera in the Farallón Negro district of northwestern Argentina, and Pebble in Alaska, dominate the major, isolated gold concentrations rather than helping to define belts (Fig. 2). However, relatively small porphyry copper-gold deposits also contribute to the gold inventory of the Cajamarca-Huaraz belt in northern Peru (Figs. 2, 4a).

The Bingham and Farallón Negro districts occupy a superficially similar position at the landward extremity of the American Cordillera (Fig. 2). Both are centered on high-K calc-alkaline porphyry stocks that have partially preserved coeval volcanic edifices (Waite et al., 1997; Sasso and Clark, 1998). Waite et al. (1997) also hypothesized a primitive mafic alkaline contribution to the Bingham magmas because of their unusual enrichment in chromium, nickel, and barium. In both districts, as well as at Pebble, the magmatic rocks have typical supra-subduction zone petrochemistry.

Bajo de la Alumbrera and other porphyry copper-gold deposits and prospects in the Farallón Negro district were emplaced above a rapidly shallowing subduction zone during the initiation of contractional tectonism, crustal shortening, and surface uplift. The resulting high-angle reverse faults led to formation of the basement-cored blocks that characterize the northernmost Sierras Pampeanas structural province (Ramos et al., 2002). Uplift was initiated some time between 7.6 and 6.0 Ma and is still ongoing (Ramos et al., 2002) while porphyry copper-gold deposit generation at Bajo de la Alumbrera spanned the 8- to 6-m.y. interval (Harris et al., 2004, 2008). The Bingham district occupies a broadly similar position in the context of low-angle Laramide subduction, but rather than being linked to slab shallowing, like the Farallón Negro district, it presaged slab steepening. Presnell (1997) related the magmatism and ore formation to the initial onset of post-Laramide extension, although end-stage contraction, basement uplift, and basin sedimentation may still have been active (Dickinson et al., 1988).

Both districts lie along fundamental transverse tectonomagmatic discontinuities: the Farallón Negro district on an east-northeast–striking feature, the Tucumán transfer zone, marking the southern limit of the Arequipa-Antofalla craton (Sasso and Clark, 1998) where it intersects a northwest-oriented, trans-Andean lineament (Chernicoff et al., 2002); and the Bingham district on the east-northeast–striking Uinta axis (Fig. 3), the shallow manifestation of an Archean-Proterozoic suture zone, at its confluence with other regional-scale structural elements (Billingsley and Locke, 1941; Ericksen, 1976; Presnell, 1997). Kutina (1991) considered the Uinta axis to be part of a mantle-penetrating structure that transgresses the entire Cordilleran margin.

The plate-tectonic setting of the mid-Cretaceous Pebble deposit is much less certain, although both Goldfarb (1997) and Young et al. (1997) inferred a continental-margin arc setting, possibly during northward subduction beneath the previously accreted Wrangellia superrterane. Crustal shortening, thickening, and uplift may have followed Wrangellia accretion (Nokleberg et al., 2005). The structural setting of Pebble remains to be defined, although it does lie near the major, northeast-striking Lake Clark fault zone. The small porphyry copper-gold deposits in the Cajamarca-Huaraz belt, which are broadly contemporaneous with the earliest high-sulfidation gold deposits (Noble and McKee, 1999; Longo and Teal, 2005), appear to coincide with a noncompressive interval (see above).

**Porphyry gold deposits**

Significant porphyry gold deposits, distinguished by much lower (e.g., <~0.25 %) copper contents than those defining
the porphyry copper-gold category dealt with above, are confined to the Maricunga portion of the El Indio-Maricunga belt in northern Chile and the Middle Cauca belt in Colombia (Fig. 2). The Maricunga belt hosts porphyry gold deposits of two discrete ages (~24–21 and ~14–11 Ma; Sillitoe et al., 1991; McKee et al., 1994), both of which are closely associated with fine-grained diorite to quartz diorite porphyry stocks emplaced into andesitic stratovolcanoes. These magmatic products have a medium- to high-K calc-alkaline affinity (Kay et al., 1994; Mpodozis et al., 1995). Porphyry gold formation in the Middle Cauca belt (Fig. 6) took place in association with porphyries of similar composition (R. H. Sillitoe, personal observations, 2007).

The trace element characteristics of magmatic rocks in the Maricunga belt suggest that during the earlier porphyry gold event (Refugio deposit) a relatively thick crust was subjected to regional extension as a consequence of the steep subduction angle (Kay et al., 1999; Kay and Mpodozis, 2001, 2002). Slab flattening, contractional tectonism, crustal thickening, and magmatic quiescence followed from 20 to 18 Ma, but stress relaxation and mild extension were reinitiated during the later porphyry gold event responsible for the Marte, Lobo, and Cerro Casale deposits (Kay and Mpodozis, 2001, 2002). At least the northern part of the Maricunga belt coincides with the transverse tectonomagmatic discontinuity that influenced the localization of the Farallón Negro copper-gold district farther east (Sillitoe et al., 1991; Sasso and Clark, 1998; see above).

The tectonic setting of the Middle Cauca belt (Fig. 6) at the time of porphyry gold mineralization in the late Miocene (R. Padilla, pers. commun., 2007) is less precisely defined, although dextral transpression linked to accretion of the Baudó allochthonous oceanic terrane farther west in Northwestern Colombia certainly characterized much of the Miocene (Cediel et al., 2003; see above).

Sediment-hosted gold deposits

The Carlin, Cortez, Independence, and Battle Mountain-Eureka gold trends in northern Nevada are defined by the only major sediment-hosted gold deposits in the American Cordillera, although small deposits of this type are also part of the Bingham district, Utah, farther east (Fig. 3). The Carlin, Cortez, and Independence trends have lengths of up to about 130 km but widths of only 5 km, whereas the Battle Mountain-Eureka trend is longer (320 km) as well as also containing important skarn gold deposits (e.g., Copper Canyon district).

Only small volumes of coeval igneous rocks, chiefly minor felsic dikes of high-K calc-alkaline affinity, accompany the sediment-hosted gold deposits (Hofstra et al., 1999; Ressel and Henry, 2006). The presence of these dikes in combination with spatially related magnetic anomalies points to the existence of an extensive subsurface plutonic complex beneath the Carlin trend (Ressel and Henry, 2006). Areally extensive volcanic fields accumulated at broadly the same time in nearby areas as part of the mid-Tertiary southward migration of the volcanic front (Ressel and Henry, 2006).

There is general consensus that the sediment-hosted gold trends of Nevada developed during a relatively short, late Eocene interval (~42–36 Ma) marked by the initiation of low-magnitude extension (Hofstra and Cline, 2000; Cline et al., 2005), but prior to the large-scale crustal attenuation that characterized the Great Basin during the Oligocene and Miocene. The late Eocene extension gave rise to several fault-bounded, fluviallacustrine basins as well as to reactivation of suitably oriented high- and low-angle faults in underlying Paleozoic rocks (Cline et al., 2005). At least some of the gold trends may have acted as accommodation zones across which extension histories differed (Tosdal and Nutt, 1999; Muntean et al., 2001). The contemporaneous extension and volcanism may have been triggered by processes linked to removal of the shallowly inclined Farallon plate from the base of the North American lithosphere, its position during the preceding Laramide orogeny (Sonder and Jones, 1999); however, any volcanic products along the sediment-hosted gold trends have been lost to erosion.

Notwithstanding the incipiently extended crust during the late Eocene, the aftermath of a complex history of much older deformation and intrusive activity had profound effects on sediment-hosted gold deposit localization. Particularly important ore-localizing sites are provided by the following: receptive carbonate rock types juxtaposed with overlying, relatively impermeable siliciclastic units along low-angle, reverse faults, especially the Roberts Mountain thrust; structural culminations formed by inversion of high-angle faults during Paleozoic contractional tectonism; and Mesozoic plutons that caused perturbation of the late Eocene stress field and helped to focus fluid upflow (Cline et al., 2005 and references therein).

The gold trends of northern Nevada are located near the western margin of the North American craton (Fig. 3) and are inferred to reflect the basement fault fabric (Roberts, 1960). The northwest and northeast gold trends may follow fundamental, crustal-scale faults that controlled Neoproterozoic rifting to form a passive continental margin as well as influencing subsequent sedimentation, contractional deformation, magmatism, and hydrothermal activity (Tosdal et al., 2000; Crafford and Grauch, 2002; Grauch et al., 2003).

Orogenic gold deposits

The Sierra Foothills belt in California, including the Mother Lode and Grass Valley districts plus a major contribution from derivative placer deposits of Eocene and younger age (Lindgren, 1911; Garside et al., 2005), is the premier orogenic gold concentration in the American Cordillera (Fig. 2; Table 2). It dwarfs the second- and third-largest orogenic gold concentrations, the Juneau belt in southeastern Alaska and Klondike district in the Yukon Territory, the latter dominated by Plio-Pleistocene placers derived from numerous, apparently small orogenic gold veins (Rushton et al., 1993; Knight et al., 1999; Fig. 2; Table 2). The primary gold deposits comprise quartz veins and veinlet swarms, the largest of which in the Sierra Foothills belt were exploited downdip for >1 km (Knopf, 1929). The overall geologic settings of the Sierra Foothills and Juneau belts, 270 and 200 km long, respectively, but both no more than 5 km wide, have many similarities, notwithstanding their appreciable age difference (see below). The Klondike placer district occupies an area of approximately 1,200 km².

The Sierra Foothills and Juneau belts both occur on the western, fore-arc sides of Andean-type magmatic arcs defined
by the major Sierra Nevada and Coast batholiths, respectively (Fig. 7). The deposits reveal intimate relationships to major fault zones, but no clear-cut connections to individual intrusions. Nonetheless, both belts were generated during emplacement of the flanking calc-alkaline batholiths. New 40Ar/39Ar ages for gold mineralization in the Sierra Foothills belt suggest formation between ~135 and 115 Ma (Marsh et al., 2007). Emplacement of the western parts of the Sierra Nevada batholith, immediately east of the Sierra Foothills belt (Fig. 7a), overlaps with this Early Cretaceous interval (Bateman, 1992). Moreover, just south of the gold belt, the batholith transgresses the Sierra Foothills terrane, which continues only as a series of contained roof pendants (e.g., Wolf and Saleeby, 1995; Fig. 7a), and subjacent plutons remain a distinct possibility farther north where erosion level is shallower. Gold mineralization in the Juneau belt is dated at 56 to 53 Ma, essentially coeval with Early Eocene (55 ± 2 Ma) Coast batholith emplacement (Miller et al., 1994; Goldfarb et al., 1997). Gold introduction in the Klondike district, probably in the Early to Middle Jurassic (Table 2), was not accompanied by any known intrusive activity (MacKenzie et al., 2007).

The primary orogenic gold mineralization of the Sierra Foothills, Juneau, and Klondike is hosted by lithotectonic terranes that underwent deformation and greenschist facies metamorphism during their accretion to the North American craton. The accretion events clearly predated the gold mineralization, by several tens of million years in the case of both the Sierra Foothills and Juneau belts (e.g., Dickinson, 2004, 2006). The gold deposits are hosted by steep, relatively minor brittle faults and shears related to regionally extensive reverse fault zones that display complex and incompletely understood ductile and brittle histories (e.g., Paterson and Wainger, 1991; Wolf and Saleeby, 1995). These structures are exemplified by the Melones fault zone (Fig. 7a), which contains abundant serpentinitized ultramafic bodies and acts as a fundamental control to the Mother Lode and other deposits in the Sierra Foothills belt (Knopf, 1929; Landefeld and Silberman, 1987; Böhlke and Kistler, 1986; Fig. 7a). These major fault zones appear to be crustal-scale, terrane-bounding features active
during mid-Jurassic island-arc accretion responsible for the Nevada orogeny (e.g., Schweickert and Cowan, 1975; Paterson and Wainger, 1991; Gehrels, 2000; Hildenbrand et al., 2000); however, fault initiation may have been as part of the California-Coahuila sinistral transform of Permo-Triassic age (Dickinson, 2006).

Miller et al. (1994, 2000) and Goldfarb et al. (1997) proposed that generation of the Juneau gold belt immediately followed the transition from orthogonal to oblique subduction of the Kula oceanic plate, an event that initiated dextral transpression along the controlling fault zones as well as concomitant uplift. A broadly similar scenario may be envisioned for the origin of the Sierra Foothills gold belt, which is coeval with reinvigorated eastward subduction of the Farallon plate—following the Nevada collisional orogeny—and batholithic arc construction (Ernst et al., 2008). At that time, the major crustal-scale, gold-localizing faults may have been reactivated in a dextral transpressive regime (Glazner, 1991).

Accretion of the Yukon-Tanana terrane, host to the Klondike placer district, is an Early Jurassic event (e.g., Plafker and Berg, 1994), with orogenic vein formation taking place during localized extension that concluded the collision-induced thrust stacking (MacKenzie et al., 2007; Table 2).

Reduced pluton-related gold deposits

Two temporally distinct belts of pluton-related gold deposits in the Yukon Territory and Alaska are commonly assigned to the Tintina gold province (Flanigan et al., 2000; Hart et al., 2002; Nokleberg et al., 2005). The older is the 470-km-long Tombstone belt, Yukon and its extension, dextrally displaced ~430 km to the northwest, in the Fairbanks district, Alaska, and the younger is the 550-km-long Kuskokwim belt still farther west in Alaska (Fig 2). Both belts are characterized by varied styles of gold mineralization, which range from sheeted quartz veins in the apical parts of plutons to distal disseminated, vein, and skarn-type mineralization within their hornfels aureoles (Newberry et al., 1995; McCoy et al., 1997; Thompson et al., 1999). Emplacement depth, ranging from 2 to 10 km, is an important control on exposed deposit style (Thompson et al., 1999; Lang and Baker, 2001; Hart et al., 2002).

The deposits are related to small (~5 km across), felsic intrusions, which are parts of areally more extensive plutonic suites. The intrusive rocks are metaluminous to locally peraluminous, calc-alkaline, isotopically evolved, and I-type (Newberry et al., 1995; McCoy et al., 1997; Aleinikoff et al., 2000; Hart et al., 2004); all of them are moderately reduced, broadly spanning the boundary between Ishihara’s (1977) magnetite and ilmenite series (Thompson et al., 1999; Thompson and Newberry, 2000). Those in the Tombstone belt are both magnetite and ilmenite poor (Hart et al., 2004). High Sr (~0.709) and δ18O values suggest an appreciable crustal contribution to the magmas (Hart et al., 2002). Although the intrusive rocks in the Fairbanks-Tombstone belt span the ~110 to 88 Ma interval (Mortensen et al., 2000), the most important gold mineralization appears to cluster at 92 ± 1 Ma (McCoy et al., 1997), except for the Pogo deposit, at 104.2 ± 1.1 Ma (Selby et al., 2002). The Kuskokwim belt is appreciably younger, ~71 to 65 Ma (Hart et al., 2002).

Most investigators assign both parts of the Tintina gold province and its contained plutonic rocks to a subduction-related arc on the basis of overall petrochemical characteristics (Newberry et al., 1995; Bundtzen and Miller, 1997; McCoy et al., 1997; Aleinikoff et al., 2000; Flanigan et al., 2000). Arc construction postdated Early Jurassic to mid-Cretaceous terrane accretion, contractional deformation, and metamorphism in southern Alaska. The Tombstone belt was generated during north- to northwest-directed, low-magnitude extension (Rubin et al., 1995; Ryhs et al., 2003; Hart et al., 2004), whereas dextral transpression on the orogen-parallel Iditarod-Nixon Fork fault was coincident with gold mineralization in the Kuskokwim belt (Bundtzen and Miller, 1997; Miller et al., 2002; Goldfarb et al., 2004).

Reconstruction of the Fairbanks-Tombstone belt, by restoring the ~430 km of Cenozoic dextral offset on the Tintina fault, results in a broad, >400-km-wide magmatic arc (Flanigan et al., 2000) suggestive of relatively low-angle subduction (Plafker and Berg, 1994); moreover, the Fairbanks-Tombstone gold belt is confined to the landward periphery of the arc. Indeed, both the Fairbanks-Tombstone and Kuskokwim belts may be considered to occupy back-arc settings (Thompson et al., 1999; Fig. 2). Notwithstanding the inferred existence of low-angle subduction, contractional tectonism is not reported.

The relatively reduced nature of the host intrusions and, as a direct consequence, the auriferous fluids themselves are atypical of western American arc terranes and remain poorly understood. Nevertheless, it is tempting to suggest that either assimilation of material from the reduced, siliciclastic host-rock sequences—Neoproterozoic and Paleozoic in the Fairbanks-Tombstone belt and Late Cretaceous in the Kuskokwim belt (McCoy et al., 1997; Thompson et al., 1999; Thompson and Newberry, 2000)—or contamination by reduced fluids expelled from them played an influential chemical role (Thompson et al., 1999; Thompson and Newberry, 2000; Hart et al., 2002, 2004).

Oxidized pluton-related gold deposits

The principal gold deposits related to oxidized plutonic rocks are located in the northern Central Cordillera of Colombia where they define the Segovia belt (Fig. 2, Table 2). The Segovia belt (Fig. 6), about 300 km long and up to 75 km wide, is dominated by quartz veins and vein swarms containing minor amounts of zinc, lead, and copper sulfides, although half of the gold production has come from derivative placers. Substantially smaller is the 160-km-long Pataz-Parcoy belt in northern Peru, where the auriferous, sulfide-rich quartz veins also contain subsidiary quantities of zinc and lead.

Both belts occur within and around composite, calc-alkaline, metaluminous batholiths of I-type, magnetite series, and subduction origin (González, 2001; Haeberlin et al., 2004). Compositonally, these equigranular plutons are similar to the porphyry stocks that host Cordilleran porphyry copper-gold and gold deposits (see above). The Segovia batholith, considered to be of Late Jurassic age, is dominated by hornblende diorite and tonalite intrusions, whereas the Carboniferous (Mississippian) Pataz-Parcoy batholith comprises mainly tonalite and granodiorite (Haeberlin et al., 2004). The
batholiths were emplaced into greenschist- to amphibolite-grade metasedimentary sequences, which accumulated along the edge of the Amazon craton during the Neoproterozoic and early Paleozoic (Cediel et al., 2003; Haeberlin et al., 2004).

The Segovia batholith was emplaced under extensional tectonic conditions as part of the late Paleozoic through Jurassic “Bolivar aulacogen” rifting and continental sedimentation event in northwestern South America, which was linked to opening of the Caribbean basin (Cediel et al., 2003). Postcollisional crustal thickening and uplift characterized the Pataparcoy belt during batholith emplacement and the subsequent gold mineralization, which took place along a major, north-northwest–striking crustal lineament under conditions of east-directed crustal shortening (Haeberlin et al., 2004).

**Tectonomagmatic Synthesis**

**Tectonic associations**

The major gold deposits and belts in the western Americas occur both along the craton margin and in some of the many accreted terranes. However, all the major gold deposits and belts were generated after their host terranes were accreted to the craton edge, a situation that contrasts with the preaccretionary timing of some other Cordilleran mineral deposits (e.g., volcanogenic massive sulfides; McMillan, 1991; Mortensen et al., 2008). Nonetheless, the placer deposits that constitute the Chocó belt in the northern Colombian Andes (Fig. 6; Table 2) are likely to have been derived from preaccretionary gold concentrations, although not necessarily from the porphyry copper-gold prospects that are the only significant deposit type currently known in the belt (Sillitoe et al., 1982; Table 2). The craton-hosted gold deposits and belts were formed independently of whether tectonic erosion, as in the central Andes (Rutland, 1971), or accretion, as in much of the North American Cordillera and northern Andes (Coney et al., 1980; Cediel et al., 2003), dominated at the continental edge at the time of mineralization.

Many of the major Cordilleran gold deposits and belts were generated within active, subduction-related magmatic arcs, although back-arc and fore-arc environments are also mineralized in places: the low-sulfidation epithermal and reduced pluton-related gold deposits typically occur in back arcs, whereas the orogenic gold deposits are confined to fore arcs (Figs. 2, 8). Approximately two-thirds of the major gold deposits and belts occupy a variety of extensional or transtensional tectonic environments. Broadly contractional settings, consequent upon shallow subduction, appear to be less common at the times of major gold deposit formation, although they host the largest high-sulfidation epithermal gold deposits in the Cajamarca-Huaraz and El Indio-Maricunga belts, the porphyry copper-gold deposits of the Farallón Negro district, and, rather less certainly, the Bingham Canyon and Pebble porphyry copper-gold deposits. The Middle Cauca belt in Colombia, Kuskokwim belt in western central Alaska, and Sierra Foothills and Juneau orogenic gold belts were most likely generated during transpression, induced either by oblique subduction or, in the case of the Middle Cauca belt, oblique terrane docking. Notwithstanding the prevalence of extension at the times of major gold deposit and belt formation, the largest Cordilleran gold concentrations (Fig. 2) either coincide with (Cajamarca-Huaraz, El Indio-Maricunga, and Sierra Foothills belts) or conclude or immediately follow (Bingham district and Carlin and Battle Mountain-Eureka trends) long-standing contractional episodes. This observation may suggest that the consequent crustal thickening and uplift may somehow have

![Fig. 8. Cartoon sections showing generation of selected gold belts at different times and places along the American Cordillera, all during active, east-directed subduction. a. Cajamarca-Huaraz high-sulfidation (HS) belt during the Miocene. b. Pebble porphyry (P) copper-gold deposit and Kuskokwim reduced pluton-related (RPR) gold belt in west-central Alaska during the Late Cretaceous. c. Sediment-hosted (SEDH) gold trends of Nevada and porphyry (P) copper-gold, skarn, and sediment-hosted deposits of the Bingham district, western United States during the Eocene. d. Walker Lane low-, intermediate-, and high-sulfidation (LS, IS, HS) and Northern Nevada rift low-sulfidation (LS) gold belts, western United States during the mid-Miocene. e. Sierra Foothills orogenic (ORO) gold belt in California during the Early Cretaceous. See Figures 2 and 3 for belt and deposit locations.](image-url)
been conducive to the formation of different types of major gold concentrations.

Tectonic relaxation, extension, or transtension following contractional episodes responsible for crustal thickening accompanied the generation of several of the gold belts and isolated deposits. This extension was due to slab steepening following Laramide low-angle subduction in the case of the Bingham Canyon and Cripple Creek deposits and the sediment-hosted gold trends of Nevada, whereas tectonic relaxation consequent upon eastward migration of crustal compression prevailed in the El Indio part of the El Indio-Maricunga belt (Charchafilé et al., 2007) and during generation of the younger Maricunga porphyry gold deposits in the El Indio-Maricunga belt (Kay et al., 1994). Exactly the opposite situation, the transition from extension to contraction, prevailed when the Cajamarca-Huaraz belt and Farallón Negro district were formed. In contrast, extensional collapse of overthickened crust produced by terrane accretion may have occurred in the reduced pluton-related Tombstone-Fairbanks belt of the Yukon and adjoining Alaska.

These and some other porphyry, epithermal, sediment-hosted, and orogenic gold deposits were generated during magmatic pulses that accompanied marked changes in tectonic regime, a scenario that has been considered to favor major gold deposit generation elsewhere in the circum-Pacific region (Solomon, 1990; Richards, 1995; Sillitoe, 1997; Barley et al., 2002; Mungall, 2002; Garvin et al., 2005). The time gaps between major contractional episodes and the gold-related tectonic regimes may be minimal (e.g., Bingham district, sediment-hosted gold trends of Nevada) or amount to a few million years (e.g., El Indio belt, Klondike) or even several tens of million years (e.g., Sierra Foothills and Juneau belts). However, other major gold deposits in the western Americas are not so readily correlated with tectonic change at the convergent margin, as exemplified by the epithermal deposits of the Walker Lane and at Round Mountain in Nevada and Pueblo Viejo in the Dominican Republic. Elsewhere in the western Americas, the extension that was synchronous with gold mineralization was not immediately preceded by a compressive regime, as observed in the smaller gold concentrations of the Segovia belt of Colombia, the Patagonian province, and the Northern Nevada rift.

Notwithstanding the fact that all gold mineralization is at least partly structurally controlled, the positions of some of the deposits appear to have been influenced by fundamental arc-parallel or arc-transverse fault zones or lineaments. The linkage between reactivation of terrane-bounding, brittle-ductile fault zones parallel to active arcs and the Sierra Foothills and Juneau orogenic gold belts is widely appreciated (Goldfarb et al., 2005), as are the arc-parallel transtensional (e.g., Walker Lane) and, locally, transpressional faults (Kuskokwim belt, Middle Canca belt) that were active during gold mineralization elsewhere. Arc-transverse features are considered important in the Cajamarca-Huaraz high-sulfidation epithermal belt in northern Peru (Quiroz, 1997) and elsewhere, as well as in the localization of the isolated porphyry copper-gold deposits in the Bingham and Farallón Negro districts. Deep-seated fault zones inherited from a late Neoproterozoic rifting event are proposed as first-order controls on the sediment-hosted gold trends of Nevada (Tosdal et al., 2000). Elsewhere, however, major gold concentrations, such as the isolated Pueblo Viejo and Cripple Creek epithermal deposits and the Fairbanks-Tombstone pluton-related belt, lack any recognized controlling structures of continental-margin scale.

**Magmatic associations**

This review shows that a broad petrochemical spectrum of intrusive and/or volcanic rocks is temporally and spatially related to the major gold deposits and belts in the American Cordillera. The most common magmatic rocks accompanying the gold mineralization events are undoubtedly parts of oxidized, magnetite-series, medium- to high-K calc-alkaline suites. Porphyry copper-gold and gold, high- and intermediate-sulfidation epithermal, and oxidized pluton-related deposits are everywhere genetically related to such suites. In sharp contrast, the fractionated, calc-alkaline intrusions genetically linked to the reduced pluton-related gold deposits are themselves moderately reduced and span the ilmenite-magnetite series transition (Thompson et al., 1999). The low-sulfidation epithermal gold belts are alone in accompanying compositionally bimodal volcanism, which is calc-alkaline in Patagonia (Pankhurst et al., 1998) but tholeiitic in the Northern Nevada rift (John, 2001). Alkaline rocks are not abundant in the Cordilleran arc and back-arc environments, and the only major gold concentration with this affiliation is the isolated Cripple Creek low-sulfidation epithermal deposit in Colorado, where compositional bimodality is also evident (Kelley et al., 1998).

Sediment-hosted and orogenic gold deposits have less clear-cut magmatic connections, as noted above, although the premier belts of both deposit types do coincide spatially and temporally with well-defined magmatic arcs. In the case of the sediment-hosted deposits in Nevada, minor felsic dikes were intruded during the gold mineralization and, on the basis of the broadly coincident magnetic anomalies, appear to be upward offshoots of an underlying plutonic complex (Ressel and Henry, 2006). In contrast, the Sierra Foothills and Juneau orogenic gold belts lie along the western margins of major calc-alkaline batholiths, which may have transcrustal thicknesses as great as 35 km (Ducaea, 2001). The intrusive rocks coeval with the sediment-hosted and orogenic gold belts would offer a ready source for any magmatic contributions to the respective ore-forming fluids or, alternatively, may simply have provided the thermal impetus required to either circulate or liberate nonmagmatic fluids (e.g., Jia et al., 2003; Ressel and Henry, 2006).

**Comparison with copper and tin belts**

Porphyry deposits containing co- or by-product gold and/or molybdenum completely dominate the copper inventory of the western Americas (e.g., Sillitoe and Perelló, 2005; Perelló, 2006). Like the gold deposits dealt with in this review, porphyry copper deposits are emplaced in a variety of tectonic settings, which range from extensional to contractional. Furthermore, the three preeminent copper belts, in northern Chile-southern Peru (42–31 Ma), central Chile (11–4 Ma), and southwestern North America (Laramide: 74–52 Ma; Fig. 9), were generated during intervals of regional compression, crustal thickening, and rapid surface
uplift and exhumation (Sillitoe, 1998; Cooke et al., 2005; Sillitoe and Perelló, 2005; Perelló, 2006). These compressional events may be related to low-angle subduction of topographically prominent, buoyant features such as aseismic ridges on the downgoing oceanic plates in conjunction with subduction erosion of the fore arcs (e.g., Henderson and Gordon, 1984; Stern, 1991; Kay et al., 2005), although gravitational delamination of the lithospheric mantle has been proposed recently as a cause of the Laramide slab flattening (Wells and Hoisch, 2008). Additional outstanding copper concentrations occur in the isolated porphyry copper-gold deposits at Bingham Canyon and Pebble (Figs. 2, 9; see above), as well as the isolated, ~65 Ma (Land et al., 2002) Butte porphyry copper-molybdenum deposit in Montana, also emplaced during Laramide compression (e.g., Kalakay et al., 2001; Fig. 9). Nevertheless, a far greater percentage (>90%) of the copper than of the gold (<50%; Table 2) is confined to contractional settings. In common with gold deposits, arc-transverse structures are also considered important for porphyry copper localization by some investigators, particularly in the central Andes and southwestern North America (e.g., Richards, 2000).

The magnetite-series, medium- to high-K calc-alkaline magmas responsible for copper deposit formation in the three premier belts (e.g., Lang and Titley, 1998; Sillitoe and Perelló, 2005, and references therein) appear to have been largely confined to mid- to upper-crustal chambers because the synmineralization contraction inhibited widespread arc volcanism (e.g., Mpodozis and Ramos, 1990). The extreme size of the giant deposits that make major contributions to these three copper belts may be directly related to the large size of the parent magma chambers, which may be reasonably assumed to fractionate efficiently and evolve larger volumes of magmatic fluid than do their smaller counterparts (Sillitoe, 1998; Richards, 2003). However, such reasoning cannot be applied to all the major gold deposits and belts, except perhaps for the principal high-sulfidation epithermal gold concentrations, because, as noted above, many of them formed during extension.

Nearly all Cordilleran tin resides in the Bolivian tin-silver belt, which occupies a unique behind-arc position in the Andean Cordillera, extending from southernmost Peru through the Eastern Cordillera of Bolivia to northwesternmost
The tin mineralization is related to emplacement of peraluminous, ilmenite-series, and locally S-type magmas (Sugaki et al., 1985; Clark et al., 1990; Lehmann et al., 1990) bearing some similarities to those linked to the reduced pluton-related gold (and nearby major tungsten) deposits in the back arc of Alaska and the Yukon Territory (see above). In common with the Alaskan and Yukon back-arc gold belts, a thick prism of reduced, siliciclastic marine sedimentary rocks of early Paleozoic age hosts the Bolivian tin-silver belt and seems likely to have influenced the redox state of the crustally derived magmas, which were generated as a result of the deep emplacement of mafic mantle melts (Lehmann et al., 1990; Redwood and Rice, 1997; Hoke and Lamb, 2007).

A noteworthy aspect of the distribution of the preeminent copper and tin concentrations in the North and South American Cordillera is their clear spatial separation from the major gold belts (Fig. 9). Although the isolated giant porphyry copper-gold deposits at Bingham Canyon, Pebble, and Bajo de la Alumbrera combine major quantities of the two metals, this mutual exclusivity suggests that the fundamental controls on copper and gold belts are different. This mutually exclusive pattern of major gold and copper concentrations is further emphasized by the spatial separation of the major porphyry copper and high-sulfidation epithermal gold belts in the central Andes (Fig. 9), notwithstanding the well-documented fact that the latter deposit type typically forms above the former as parts of single hydrothermal systems (Fig. 1; Sillitoe, 2000). Difference in erosion level alone does not seem to adequately explain this spatial separation of major gold and copper belts because the known porphyry copper and copper-gold deposits in the Cajamarca-Huaraz belt, including those beneath the Yanacocha high-sulfidation gold deposits (Gustafson et al., 2004; e.g., Fig. 4a), are all of low to moderate grade and probably relatively small.

**Metallogenic Considerations**

The 22 Phanerozoic gold belts and five isolated giant gold deposits defined herein together occupy only a small proportion of the American Cordillera, perhaps <5 percent of its area (Fig. 2). This situation mirrors that for most metals, whereby the majority of the resources are concentrated in a few giant deposits and highly endowed belts (e.g., Singer, 1995). Each Cordilleran gold belt was typically generated in <5 to 20 m.y. (Table 2; see above), with individual giant deposits having lifespans of <0.5 to >5 m.y. (e.g., Henry et al., 1996; Harris et al., 2004, 2008; Longo and Teal, 2005). The central Andean copper and tin belts (Fig. 10) are analogous in being constructed by one or more metallogenic epochs of comparable duration (11–20 m.y.).

All the major gold deposits and belts formed during subduction-related magmatic activity (Fig. 8), with each gold deposit type tending to occupy a reasonably well-defined tectonomagmatic niche rather than occurring randomly. However, when taken together, the major gold deposits and belts span a spectrum of tectonic settings and magma compositions, although the largest concentrations formed either during or immediately after major contractional episodes in association with calc-alkaline magmatism. Fundamental arc-parallel and arc-transverse faults and lineaments or abrupt changes in tectonomagmatic regime at the Cordilleran margin seem to have acted as localizers of some, but by no means all, of the major deposits and belts. Another possibility, optimization of ore-forming physiochemical processes at the deposit scale, can be invoked for at least some of the isolated, major deposits, but would fail to satisfactorily explain the origin of the several deposits needed to define the individual gold belts. Therefore, although the spatial and temporal restriction of the major belts and isolated deposits can be ascribed to specific tectonomagmatic events, the overall distribution of the premier Cordilleran gold concentrations at the orogen scale remains enigmatic, because apparently similar
events elsewhere resulted in only relatively small or no gold deposits.

Perusal of Figure 2 (and Fig. 8) reveals that at least six Cordilleran arc (including fore- and back-arc) segments contain at least two gold belts or major isolated deposits, typically comprising different deposit types, formed at different times under different tectonomagmatic conditions. The Great Basin and contiguous areas of the western United States and the northern Andes of Colombia are perhaps the most striking examples. The Great Basin and environs comprise a cluster of six relatively short belts (Carlin, Getchell, and Independence sediment-hosted gold trends, Battle Mountain-Eureka sediment-hosted and skarn gold trend, Walker Lane epithermal gold belt, and Sierra Foothills orogenic gold belt), the Bingham district (Bingham Canyon porphyry copper-gold and nearby sediment-hosted gold deposits), and the isolated Round Mountain epithermal gold and Cripple Creek alkaline epithermal gold deposits. To these gold concentrations may be added the Paleoproterozoic Homestake deposit (Fig. 2) and spatially associated, but subordinate Tertiary gold mineralization (Paterson et al., 1988). In the Colombian Andes, the three main belts are defined by pluton-related, porphyry and epithermal, and placer gold deposits, respectively, to which may be added two less important gold districts of completely different age to the three main belts (Fig. 6). The pairing or clustering of gold belts and isolated major deposits might be dismissed as fortuitous or, alternatively, ascribed to some fundamental predisposition of the particular orogen segments concerned to upper-crustal gold concentration. The close proximity of both the major copper and the major tin belts in the central Andes provides closely analogous situations (Fig. 10). Explanations involving differences in erosion level and preservation potential (see above) do not convincingly account for the observed proximity of the metal-enriched and poorly mineralized arc segments.

One of the more widely debated hypotheses for recurrent metallic mineralization within relatively restricted orogen segments is inheritance from preexisting metal concentrations (e.g., Noble, 1970; Routhier, 1976). The site of any such available metal preconcentration is commonly assumed to be in the middle to upper crust (e.g., Titley, 1987; Hodgson, 1993; Fig. 11), a concept inherent in the proposal that much of the gold in the sediment-hosted trends of the Great Basin came from subeconomic sedimentary-exhalative mineralization in some of the late Paleozoic eugeoclinal host rocks (Emsbo et al., 1999, 2006). Keith et al. (1991), however, preferred the notion that crustal redox state, rather than crustal metal preconcentration, is the ultimate metallogenic control, with reduced crust like that beneath much of the Great Basin being conducive to repeated gold mineralization; by contrast, oxidized crust, as beneath southwestern North America, results in a dominance of copper mineralization. The likely role of carbonaceous sedimentary sequences in the development of reduced magmas was alluded to above for the Alaskan and Yukon pluton-related gold belts and Bolivian tin-silver belt.

Fig. 11. Cartoon section of a convergent margin to show possible sites of gold (or other metal) concentrations that may be tapped during the magmatism or transcortical fluid flow responsible for upper-crustal mineralization. Alternatively, another chemical parameter, such as redox state, may influence metal availability. See text for further discussion.
The lower crust or underlying subcontinental lithospheric mantle, including underplated mafic igneous rock produced by mantle melting and ultramafic to mafic restites or cumulates resulting from mantle-plume or lower-crustal melting, may offer a viable alternative site for either gold preconcentration or influential redox conditions (e.g., Noble, 1970; Fig. 11). Lower- or subcrustal influences would be eminently feasible given the ubiquitous petrochemical evidence for mantle contributions to ore-related, arc and back-arc magmatism (e.g., Kelley et al., 1998; Riley et al., 2001; Richards, 2003; Hart et al., 2004; Kay et al., 2005; Hoke and Lamb, 2007) and geophysical evidence for penetration of some gold-localizing fault zones and lineaments to deep crustal levels (e.g., Hildenbrand et al., 2000; Grauch et al., 2003). Furthermore, the gold contents of porphyry copper deposits are completely independent of upper crustal structure and composition and, hence, most likely subcrustally imposed (e.g., Sillitoe and Perelló, 2005). Core et al. (2006) furnished evidence for a localized, copper-enriched magma source, in either the deep crust or subcontinental lithospheric mantle (Fig. 11), for the Bingham Canyon porphyry copper-gold deposit, and further suggested that similar, but areally more extensive copper preconcentrations may have been tapped to form premier copper belts elsewhere. A tin-enriched segment of behind-arc crust (± upper mantle), extending eastward to the Rondônia tin province of contiguous Brazil (e.g., Dardenne and Schobbenhaus, 2001), has also been invoked beneath the Bolivian tin-silver belt (Schuiling, 1967; Halls and Schneider, 1988). However, the concept was refuted by Lehmann et al. (1990), who related the tin concentration to the reduced nature of the magmatism, a factor favoring tin (Sn^{2+}) partition into the magmatic aqueous phase (Ishihara, 1978). Nevertheless, acceptance of the latter hypothesis does not necessarily preclude the former when the trivial amounts of tin throughout the rest of the American Cordillera are taken into account.

In both the Great Basin and contiguous regions of the western United States and the northern Andes of Colombia, the gold deposits and belts are situated both at the craton edge and in the adjoining accreted terranes of oceanic affinity (Sierra Foothills belt and Middle Cauca and Chocó belts, respectively; Figs. 3, 6). Similarly, the paired Kuskokwim gold belt and giant Pebble porphyry copper-gold deposit in Alaska (Fig. 2) lie within different accreted terranes. Therefore, a lower-crustal or subcontinental lithospheric mantle gold preconcentration may not offer an adequate explanation for the recurrence of gold mineralization events unless the accreted terranes were originally rifted from the craton near their sites of eventual accretion (Colpron et al., 2007) and/or overthrust the continental margin along shallow-level décollements (Snyder et al., 2002). Kutina’s (1991) concept of ore deposit localization by mantle-rooted, latitudinal discontinuities cutting across both the craton and accreted terranes fails to adequately explain the gold belts, most of which are oriented parallel, not transverse, to the Cordilleran margin. Alternative explanations might include preexisting metal concentrations in the mantle wedge (e.g., McInnes et al., 1999; Fig. 11) or highly oxidized conditions, imposed by slab-derived aqueous fluids, conducive to efficient stripping of gold and copper from residual sulfides that are broken down in the mantle wedge (e.g., Mungall, 2002). Furthermore, gold might be preferentially stripped under more oxidized mantle-wedge conditions than those that favor copper removal (Richards, 2005).

Although the gold and associated chalcophile and siderophile metals in Cordilleran ore deposits are ultimately derived from the dehydration of subducted oceanic crust (e.g., Sillitoe, 1972; Richards, 2003, 2005; Fig. 11), anomalously metal-rich slab material cannot be convincingly invoked to explain highly gold endowed Cordilleran segments because such material would have had to have been intermittently subducted for 120 to 150 m.y. to explain both the Great Basin and Colombian Andes provinces and even longer elsewhere (northern Peru: ~300 m.y.). Similarly, central Andean copper belts were formed recurrently over a time span of 130 m.y. (Fig. 10). Nevertheless, protracted subduction of oceanic lithosphere, perhaps coupled with episodic erosion of the leading edge of the overthrust plate (e.g., Stern, 1991), may play a key role in the progressive enrichment of metals in as well as above the mantle wedge.

The complex and varied Precambrian and Phanerozoic histories of the American Cordillera and subjacent subcontinental lithospheric mantle and mantle wedge undoubtedly resulted in profound chemical heterogeneity. Notwithstanding the effects of episodic and relatively localized delamination, and related processes (Menzie et al., 2007), the subcontinental lithospheric mantle and overlying lower crust seem likely to be the longest-lived and, hence, potentially most heterogeneous parts of the crust-mantle system, particularly beneath Archean cratons. Some of this chemical heterogeneity, in particular with regard to the highly siderophile elements like gold, may even date from formation of the Earth’s core some 4.5 billion years ago (Marty, 2008). Some aspect of the resulting chemical provinciality, whether it is in metal content, redox state, or some other parameter, seems the most likely reason for the predisposition of certain arc segments to repetitive epochs of gold mineralization. A redox control, imposed in the mantle wedge (e.g., Richards, 2005), crust (Keith et al., 1991), or possibly somewhere in the subcontinental lithospheric mantle where oxidation state varies markedly (e.g., Haggerty, 1990), might explain the mutual exclusivity of major gold and copper belts documented above (Fig. 9), as well as perhaps permitting the local co-concentration of the two metals under intermediate redox conditions. However, the effective upper-crustal concentration of gold in association with both oxidized and reduced magnas (see above) seriously complicates comprehension of mechanisms that might be involved. Metal acquisition or redox imposition could be accomplished by interaction of either magnas or, in the case of anamagmatic gold belts, deeply derived fluids (cf. Hodgson, 1993) with the lithosphere, particularly at times of stasis in subepizonal magma or fluid reservoirs. These subepizonal magnas or fluids would, of course, have their own intrinsic metal contents prior to any supplementation from external sources.

General Conclusions

Consideration of Cordilleran gold belts along with the central Andean copper and tin belts strongly suggests that certain upper-crustal segments are subjected to repeated concentration of individual metals or metal suites, whereas adjoining
segments are relatively poorly mineralized. The same metallogenic provinciality is observed for gold and other metals worldwide in orogens as old as Archean (e.g., Robert et al., 2005). The processes involved appear to be inherently independent of tectonic and magmatic settings, which commonly differ between closely spaced metallogenic belts within restricted arc segments. Whether or not mantle or crustal metal preconcentrations or other factors, such as specific redox conditions, are called upon, some fundamental predisposition of certain orogen segments with regard to particular metals or metal suites seems inescapable.

This conclusion, if accepted, has profound implications for exploration because diligent search beyond the favorable orogen segments is unlikely to be rewarded by major gold discoveries. So the gold explorer may either focus attention on orogen segments containing two or more belts or isolated giant deposits, and therefore with proven metallogenic credentials but almost certainly well explored, or try to define new parts of the orogen predisposed to exceptional gold endowment. The latter course of action implies that the reason for the predisposition, perhaps the most critical as well as intractable metallogenic research topic, can be successfully deciphered.

### Future Directions

Classification of the gold deposit types present in the American Cordillera (and elsewhere), their defining alteration assemblages and mineralogy, the physicochemical characteristics of the fluids involved, and the timing of their formation are reasonably well documented. Nevertheless, this review underscores many aspects of Cordilleran gold metallogeny that require additional investigation, with improved understanding of genetic controls having a direct effect on exploration at the regional scale.

Further clarification of the regional tectonic settings of many of the major gold deposits and belts in the Cordillera would help to ascertain whether or not specific deposit types occupy unique upper-crustal tectonic niches or whether they may form across a spectrum of tectonic settings. Several of the more fundamental questions relate to the economically preeminent high-sulfidation epithermal, sediment-hosted, and orogenic categories: The largest high-sulfidation epithermal gold deposits are restricted to the two central Andean arc segments presently characterized by flat-slab subduction (Fig. 2). Is this fortuitous and unrelated to the modern slab configuration or does decreasing subduction angle somehow favor major high-sulfidation deposit formation, perhaps by allowing direct crustal input of slab-derived anfierous fluids (Bissig et al., 2003) or, as in the case of major porphyry copper deposits, by inducing crustal compression and generation of large epizonal magma chambers capable of voluminous fluid discharge (Sillitoe, 1998)? Major sediment-hosted deposits are largely responsible for definition of the four closely spaced gold trends in northern Nevada (Fig. 3), but such deposits appear unimportant elsewhere in the American Cordillera. Is this a reflection of the role played by the deeply penetrating structures inherited from Neoproterozoic rifting (Tosdal et al., 2000) or are other processes involved? The Sierra Foothills belt is the only world-class orogenic gold concentration in the American Cordillera, which is somewhat surprising if such deposits are one of the hallmarks of accretionary tectonic settings (Goldfarb et al., 2001). Is the apparent absence of orogenic gold deposits from the Late Cretaceous and Tertiary collisional collage of the northern Andes of Colombia and Ecuador (Cediel et al., 2003) due to insufficient erosion to allow deposit exhumation (cf. Goldfarb et al., 2001) or to some other factor(s), such as absence of suitable deeply tapping fault zones and/or major associated batholiths?

Additional detailed petrochemical studies of well-dated magmatic suites associated with the major Cordilleran gold deposits and belts, like those carried out in the El Indio-Marcopper belt (Kay et al., 1994, 1999; Kay and Mpodozis, 2001), Patagonian province (Pankhurst et al., 1995; Riley et al., 2001), and Bingham district (Waite et al., 1997), would assist with assessment of any direct links between specific gold deposit types and specialized magma chemistries or evolutionary paths. In this regard, Richards and Kerrich (2007) show, contrary to recent proposals, that adakitic (high Sr/Y and La/Yb) magmatism is unlikely to be a requirement for major porphyry copper-gold deposits (e.g., Waite et al., 1997; Hattori and Keith, 2001; Halter et al., 2004) and perhaps even the intrusive rocks of the Carlin sediment-hosted gold trend (Ryskamp et al., 2008). Is similar magma mixing involved in the formation of other major Cordilleran gold deposits and belts? If so, it is important to systematically collect the supporting petrologic and petrochemical evidence, with a view to defining possible exploration criteria. Cordilleran gold belts accompany both oxidized and reduced magma suites, although the latter are restricted to the northern Cordillera of Alaska and the Yukon Territory. Is generation of reduced magmas an exclusively upper-crustal process or can deeper crustal or mantle redox controls, such as those proposed by Keith (1991) and Richards (2005), have an influence too? And why are the reduced magmatic rocks of the Bolivian tin-silver belt so poor in gold mineralization? As described above, the largest Cordilleran sediment-hosted and orogenic gold belts are likely underlain by concealed plutons emplaced at the time of mineralization. Is the gold derived from nonmagmatic sources, as currently preferred by most investigators, or could it have been liberated during cooling of these deep intrusions? An approach using lead isotopes may be applicable, as employed recently to link the low-sulfidation epithermal gold of the Northern Nevada rift to mafic volcanic products of the Yellowstone mantle plume (Kamenov et al., 2007).

Although these and numerous other tectonomagmatic problems need our attention, the most fundamental questions of all relate to the concepts of metallogenic inheritance and provinciality as explanations for the metal distribution patterns highlighted in this review and elsewhere, as a fortuitous association seems an unsatisfactory explanation, particularly to the avid explorationist. Perhaps the best long-term means of addressing this topic would be to routinely acquire analytical data for gold, copper, tin, and associated metals as well as information to determine the associated redox conditions while conducting integrated tectonic, geochemical, and geophysical studies of the lower crust and
upper mantle, like that recently synthesized by Karlstrom et al. (2005) for the Rocky Mountains region of the western United States. The analytical data could be obtained from outcropping rocks in deeply eroded, high-grade metamorphic terranes as well as from xenoliths of both upper mantle and lower crustal provenance. Such analytical data are needed for both well-endowed and poorly mineralized belts in order to properly define the nature and environment of any metal preconcentrations. Particular attention might be paid to high-grade terranes containing Precambrian mineralization in proximity to Phanerozoic belts defined by the same metal(s), as exemplified by the Paleoproterozoic Homestake gold deposit in the context of the major Meso-Cenozoic gold deposits and belts in the western United States (Fig. 2).

These are just a few of the basic questions, and possible approaches, which investigators may consider when identifying research topics of merit.

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