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LETTER

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The giant Carlin gold province: a protracted interplay of orogenic, basinal, and hydrothermal processes above a lithospheric boundary

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Abstract Northern Nevada hosts the only province that contains multiple world-class Carlin-type gold deposits. The first-order control on the uniqueness of this province is its anomalous far back-arc tectonic setting over the rifted North American paleocontinental margin that separates Precambrian from Phanerozoic subcontinental lithospheric mantle. Globally, most other significant gold provinces form in volcanic arcs and accreted terranes proximal to convergent margins. In northern Nevada, periodic reactivation of basement faults along this margin focused and amplified subsequent geological events. Early basement faults localized Devonian synsedimentary extension and normal faulting. These controlled the geometry of the Devonian sedimentary basin architecture and focused the discharge of basinal brines that deposited syngenetic gold along the basin margins. Inversion of these basins and faults during subsequent contraction produced the complex elongate structural culminations that characterize the anomalous mineral deposit "trends." Subsequently, these features localized repeated episodes of shallow magmatic and hydrothermal activity that also deposited some gold. During a pulse of Eocene extension, these faults focused advection of Carlin-type fluids, which had the opportunity to leach gold from gold-enriched sequences and deposit it in reactive miogeoclinal host rocks below the hydrologic seal at the Roberts Mountain thrust contact. Hence, the vast endowment of the Carlin province resulted from the conjunction of spatially superposed events localized by long-lived basement structures in a highly anomalous tectonic setting, rather than by the sole operation of special magmatic or fluid-related processes. An important indicator of the longevity of this basement control is the superposition of different gold deposit types (e.g., Sedex, porphyry, Carlin-type, epithermal, and hot spring deposits) that formed repeatedly between the Devonian and Miocene time along the trends. Interestingly, the large Cretaceous Alaska–Yukon intrusion-related gold deposits (e.g., Fort Knox) are associated with the northern extension of the same lithospheric margin in the Selwyn basin, which experienced an analogous series of geologic events.

Keywords Carlin gold province · Northern Nevada · Sedex gold · Carlin-type · Devonian sedimentary basin · Subcontinental lithospheric mantle

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Introduction

Carlin-type deposits in northern Nevada were first recognized in the early 1960s. This province has since become the third largest gold-producing province in the world with historic production and reserves of >6,000 t. Extensive exploration for a similar provinces elsewhere has led to the discovery of several similar sedimentary rock-hosted disseminated deposits with gold contained in arsenical pyrite; host rock decalcification, sulfidation, and variable silicification; high Au/Ag ratios (~10), enrichments in As, Sb, Hg, Tl, (Te, W); and a paucity of base metals. Despite these similarities, the deposits in these provinces are one to two orders of magnitude smaller (Hofstra and Cline 2000; Cline et al. 2005; Hofstra et al. 2005b). Thus, viewed in the context of deposit-scale characteristics and gold endowment, Carlin-type deposits in Nevada are unique, which raises the question "Why are they so large?"

This region is remarkable for its superimposed gold deposits and occurrences (Devonian, Mississippian, Jurassic, Cretaceous, Eocene, Miocene, and Pliocene) related to different tectonic events, magmatic petrogeneses, and fluids, albeit with different geochemical and alteration signatures (Emsbo et al. 2003).

The age and genesis of Carlin-type deposits have been intensely controversial largely due to the physical characteristics of the ore and the complex geologic and hydrothermal history of the region (Hofstra and Cline 2000; Cline et al. 2005). Now that the age of Carlin mineralization is well-established as mid-Eocene (Hofstra et al. 1999; Ressel et al. 2000; Arehart et al. 2003; Cline et al. 2005), controversy is focused on source(s) of heat, fluids, and gold that formed these giant deposits. Historically, genetic hypotheses for Carlin-type deposits comprise three general groups, advocating magmatic, metamorphic, or circulated meteoric waters for their generative fluids. Magmatic models propose that magmas provided the fluids, ore components, and thermal energy to drive the fluid flow that transported and deposited gold beyond the source intrusion (Sillitoe and Bonham 1990; Ressel et al. 2000; Kesler et al. 2005). In both metamorphic and circulated meteoric models, adherents suggest that gold was scavenged from sedimentary or metasedimentary rocks below the deposits, transported to shallower levels, and deposited along dilatant faults during mid-Tertiary extension (Ilchik and Barton 1997; Hofstra et al. 1999; Hofstra and Cline 2000). Emsbo et al. (1999, 2003) proposed a variant of the meteoric circulation model in which meteoric water evolves to an ore fluid by shallow circulation through Sedex Au- and S-enriched rocks that formed during the mid-Devonian basin evolution. The model proposed by Cline et al. (2005) involves deeply sourced magmatic and metamorphic fluids and convecting meteoric water that derived gold from several locations in the crust.

It is evident from the ongoing debate (e.g., Muntean et al. 2004) that no single model neatly explains the features of all Carlin-type deposits in northern Nevada. It is also clear from the occurrence of Carlin-type deposits in China (Hofstra et al. 2005a) and other parts of the world, with deposit-scale features similar to those of the Nevada ores but with orders of magnitude smaller gold endowments, that the reasons for the anomalous size of the deposits in the Carlin province lies at a larger scale. In particular, previous studies of giant vs smaller deposits invariably show that deposit-scale characteristics are not different despite major differences in metal endowment (Whiting et al. 1993; Cooke and Pongratz 2002). From similar observations, Bierlein et al. (2006) postulated that endowment of a given province is fundamentally controlled by factors that operate at the orogen to lithosphere scale. Thus, the objective of this paper is to take a holistic view in incorporating tectonic/lithospheric setting, geologic and geochemical features of deposits, together with the now generally accepted temporal constraints on the complicated history of the region, to seek an explanation for the remarkable gold endowment and clustering of giant deposits in northern Nevada. Many of these regional characteristics have been discussed in individual papers, and summaries are provided in the reviews by Hofstra and Cline (2000) and Cline et al. (2005). Data are reexamined and interpreted in a new way to illustrate recursive regional controls on processes and products that help explain the unique gold endowment of this province.

Tectonic and lithospheric setting of the Carlin province

For most of its history, the Carlin province was not situated in a tectonic setting characteristic of arc-related porphyry–epithermal gold deposits nor orogenic gold deposits (Goldfarb et al. 2001). It was in a distal foreland setting and underlain by a sequence of miogeoclinal sedimentary rocks well inboard of accreted terranes and the main Cordilleran magmatic arc (Barton 1996). In Eocene time, subduction-related magmatism swept southward across the province in response to foundering or rollback of the Farallon slab after a period of shallow subduction associated with the Laramide orogeny (Humphreys 1995).

A set of highly anomalous mineral deposit “trends” in Nevada were initially defined by the alignment of diverse mineral deposit types (Fig. 1a: Ordovician and Devonian Sedex barite, Jurassic/Cretaceous/Tertiary porphyry Cu–Mo–W–Au, and epithermal Ag–Au deposits) along regional structural fabrics and igneous intrusions, thought to be controlled by deep basement faults (Roberts 1960). With subsequent discovery of Carlin-type gold deposits/districts, these same trends became synonymous with the elongate clusters of giant gold deposits in the Carlin, Battle Mountain-Eureka, Getchell, Jerritt Canyon, and Alligator Ridge trends (e.g., Hofstra and Cline 2000). Strontium and Pb isotope data for Mesozoic and Tertiary granitoids in north-central Nevada, combined with gravity and magnetic gradients (Tosdal et al. 1999; Grauch et al. 2003), establish that the trends are sited near the boundary between the Precambrian and Phanerozoic subcontinental lithospheric mantle (SCLM), where deep basement faults (Fig. 1a) formed during the Neoproterozoic/Cambrian rifting of the continental margin (Stewart and Suczek 1977; Crafford and Grauch 2002). Neoproterozoic and Lower Cambrian sediments that filled the thinned basement form a clastic wedge that has its feather edge in central Utah and is >6 km thick in central Nevada (Stewart 1980). Sedimentation along this trailing continental margin continued from the middle Cambrian until the upper Devonian time, forming a 5-km thick carbonate platform sequence (Cook and Taylor 1991; Cook 2005). At the regional scale, the essentially autochthonous continental margin sedimentary sequences show broad facies controls related to inferred underlining basement architecture, particularly the deep basement faults close to the SCLM discontinuity (Fig. 1b).

Basement faults, basin architecture, and syngenetic gold

Lower to Middle Devonian syndepositional extensional faulting along the Carlin trend is defined by abrupt lateral

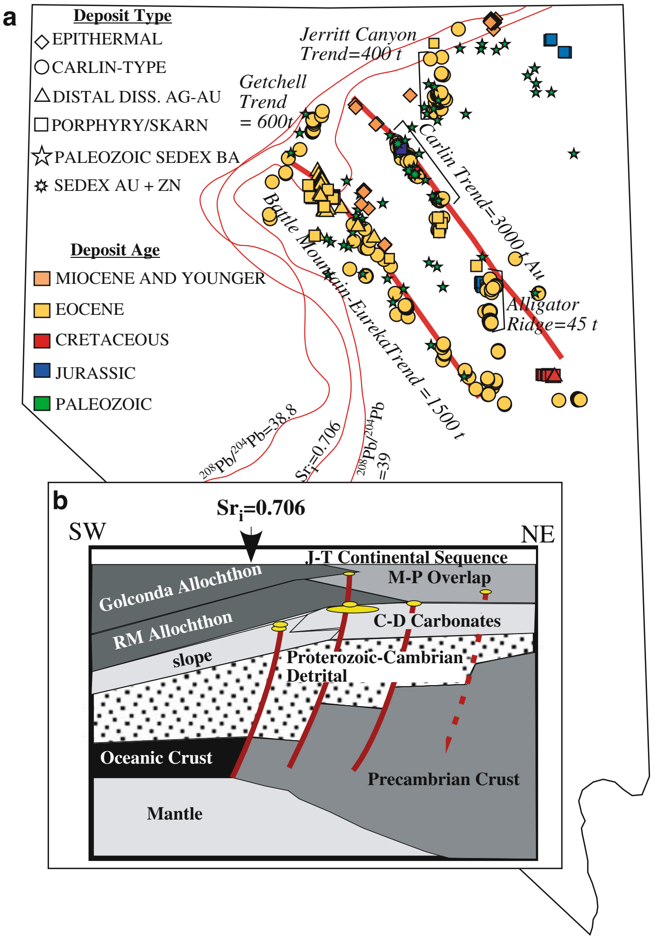

Fig. 1 **a** Map of northern Nevada showing the distribution of Carlin-type gold deposits and associated trends. Contained Au (historic production and reserves), other gold deposits types (by type and age), and Sedex deposits relative to recognized crustal-scale features (in *red*) including isotopic and geophysical boundary, and initial $^{87}\text{Sr}/^{86}\text{Sr}$ and $^{208}\text{Pb}/^{204}\text{Pb}$ isopleths (Crafford and Grauch 2002; Grauch et al. 2003). **b** Schematic SW–NE cross section across northern Nevada showing the inferred architecture of the Precambrian North American paleocontinental margin separating Precambrian from Phanerozoic SCLM, with major basement faults, overlying stratigraphic sequences, and allochthons, and locations of Carlin-type gold deposits (*yellow ovals*). Modified from Hofstra and Cline (2000). *C* Cambrian, *D* Devonain, *M* Mississippian, *P* Permian, *J* Jurassic, *T* Tertiary, *RM* Roberts Mountains

and vertical facies changes, thick debris flows, and synsedimentary slump structures (Emsbo et al. 1997, 1999; Jory 2002). Extensional foundering of the carbonate platform resulted in small, fault-controlled, restricted basins on the outer continental margin (Emsbo et al. 1997, 1999; Crafford and Grauch 2002). Silurian to Middle Devonian isopach maps (Fig. 2) show remarkable alignment between sequence thickness trends and underlying basement architecture. This implies that deep crustal Neoproterozoic faults reactivated during Devonian extension and localized synsedimentary extensional faults that controlled basin topography and sedimentation on the outer carbonate platform (Fig. 2a).

These faults on the northern Carlin trend appear to have localized major venting of Au-rich reduced basinal brines in middle Devonian time (Emsbo et al. 1999). These brines pervasively dolomitized and locally silicified vertical fault zones, deposited base metals, barite, and minor gold, locally vented into overlying seawater, and formed massive barite mounds. Basin reconstruction suggests that these dense brines accumulated in a brine pool in paleobathymetric lows leading to the formation of up to 2 Moz of Sedex Au in the upper zone of the Rodeo deposit (Emsbo 2000). Sedex gold ore (up to 68 g/t Au) is stratiform in the carbonaceous (15% total organic C) Devonian Upper Mud Member of the Popovich Formation, where, unlike Carlin-type ore, Au correlates with Zn, Cd, V, Se, Ni, Cu, Hg, and Sb throughout the deposit. It is important to note that Au, Zn, and Ba in stream sediment from northern Nevada (Fig. 2b) shows a remarkable correspondence between elevated metal abundances, Devonian basin architecture, and underlying lithospheric structure (Fig. 2). Detailed chemostratigraphic and isotopic study of drill core from an area >30 km^2 of the northern Carlin trend shows that the ore horizon in the Upper Mud Member contains 0.2–3.0 ppm Au (and highly elevated abundances of other ore-related elements) and is systematically zoned around the Rodeo deposit. Importantly, the stratigraphic age and section at Rodeo is similar to the ore-hosting unit of major Carlin-type gold deposits on the southern Carlin trend. Sha (1993) presents compelling evidence for syn/diagenetic gold in this unit at Gold Quarry. Moreover, this stratigraphic horizon contains enough Zn at the Mike deposit that weathering of the gold deposits yielded a >400,000 t supergene Zn resource derived primarily from stratiform (Sedex) mineralization (Bawden et al. 2003). The large areal extent of Sedex mineralization on both the northern and southern Carlin trends suggests that rifting along the entire Carlin trend triggered a massive release of Au-rich basinal brines that enriched middle Devonian rocks in Au and other metals, a conclusion supported by regional stream sediment anomalies (Figs. 2b and 3).

Thus, there appears to have been feedback between initial Neoproterozoic to early Cambrian basement faulting above a major SCLM boundary, lower to middle Devonian basin–margin faulting, synsedimentary hydrothermal activity, and gold enrichment in the northern and southern Carlin trends.

Basement faults and compressional deformation

The two main accretionary events that significantly affected the province were the Devonian–Mississippian Antler and Permo–Triassic Sonoma orogenies that thrust thick sequences of western basin facies, siliciclastic sediments eastward onto the miogeocline (Stewart 1980; Dickinson 2004). In middle Triassic time, an Andean-style active margin was established in western Nevada; episodes of foreland contraction and intrusion periodically affected the province into the Cretaceous (Barton 1996). During the Late Cretaceous to early Tertiary Laramide orogeny, magmatism and contraction migrated out of the province

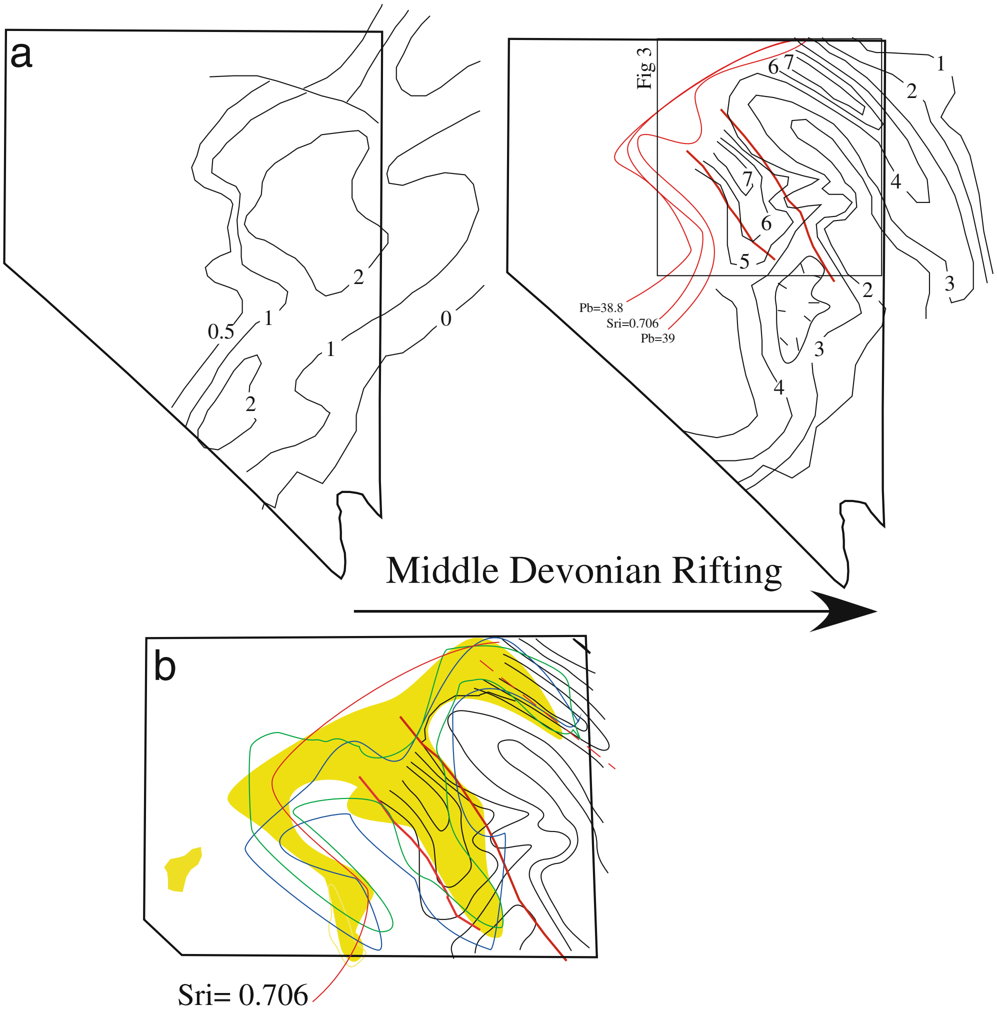

Fig. 2 **a** Lower Silurian and middle Devonian isopach maps (in hundreds of meters) of northern Nevada showing a shift in middle Devonian depositional patterns (Poole et al. 1977) and its correspondence with the underling lithospheric architecture (*red* in Fig. 1). **b** Enveloping surface of stream sediment values for Au >30 ppb (*solid yellow*), Zn >100 ppm (*green line*), and Ba >1,500 ppm (*blue line*) (plots from http://geopubs.wr.usgs.gov/open-file/of02-227/) showing the correspondence of regional metal values (related to deposits of different types and ages) are associated with underling lithospheric architecture and Devonian depositional patterns

into Colorado in response to shallow subduction (Lipman et al. 1972; Dickinson and Snyder 1978).

The basement faults close to the boundary between Precambrian and Paleozoic SCLM continued to play an important role. Numerical modeling by (Wijns et al. 2004) suggests that the basement faults influenced stress fields in the overlying thrust plates, leading to the formation of thrust duplexes with elongate anticlinal zones such as those that are broadly coincident with the Carlin and Battle Mountain Eureka trends (Fig. 4). Muntean and Tosdal (2005) demonstrate that the faults and folds in these structural culminations exhibit classic features of structural inversion. Such an architecture was ideal for focusing subsequent hydrothermal fluid flux into anticlinal zones, where an impermeable seal of shales in the upper plate above the Roberts Mountain thrusts, over reactive and permeable carbonate sedimentary sequences. Such geometries compare well with those of many orogenic gold deposits (e.g., Groves et al. 2000).

Burial associated with the emplacement of the Roberts Mountain Allochthon during the Antler orogeny caused thermal maturation of organic matter in the underlying rocks (Gize et al. 2000). Consequently, carbonaceous Sedex ores generated petroleum, which mobilized and dispersed Au and some Sedex metals in rocks that host Carlin-type deposits (Emsbo and Koenig 2005).

Mesozoic–Tertiary magmatism

Between Middle or Late Triassic time and Oligocene time, the western margin of North America was the site of continuous subduction. East-dipping subduction resulted in calc-alkaline magmatism that was most voluminous in northern Nevada during Late Jurassic, Cretaceous, and mid-Tertiary times (Barton 1996). During the Late Jurassic, the largest pulse of magmatism (~159 Ma) on the northern Carlin trend (Ressel et al. 2000) resulted in the emplacement of the dioritic Goldstrike Stock and associated monzonite and lamprophyre dikes. The lamprophyre dikes strike northwest parallel to the Carlin trend and provide additional evidence for deep-penetrating fault zones that served as conduits for mantle-derived magmas (Rock 1991). Jurassic magmatism is associated with reduced intrusion-related, polymetallic gold veins around the Goldstrike Stock (Emsbo et al. 2003) and a 2-Moz, intrusion-related gold deposit with distal disseminated deposits on the periphery associated with the Bald

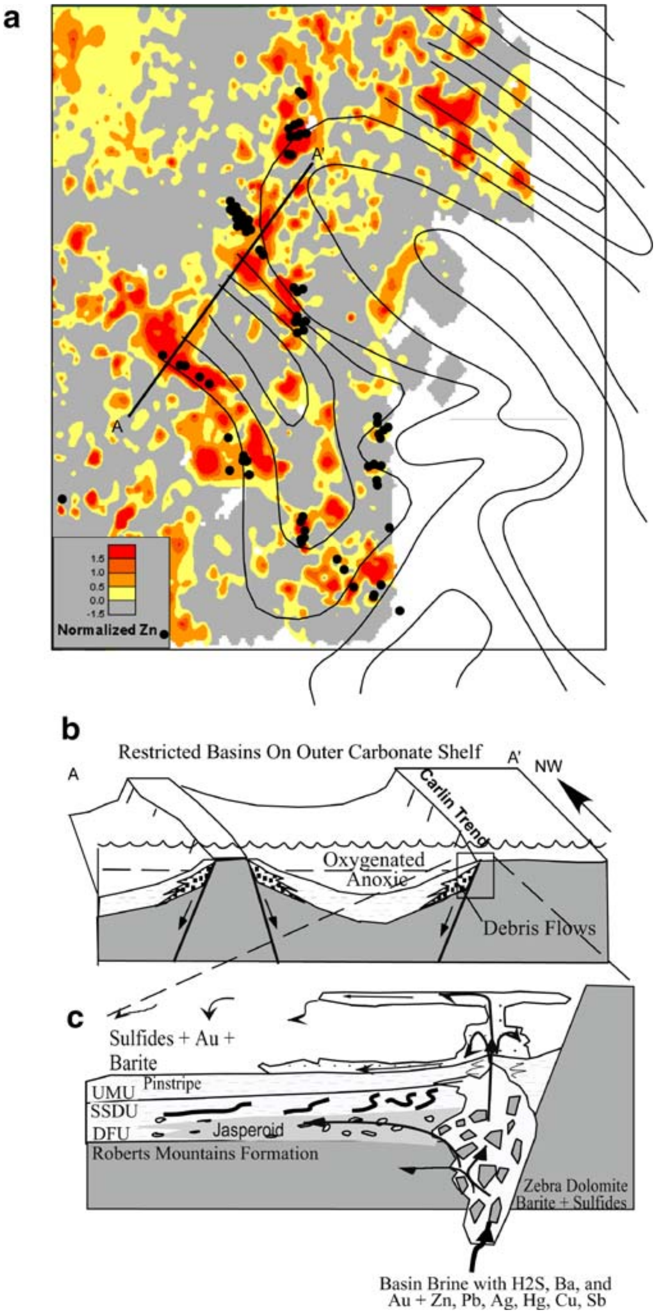

Fig. 3 **a** Middle Devonian isopach map showing correspondence of underling lithospheric and Devonian architecture (*inset* in Fig. 2a), Carlin-type deposits hosted in Silurian–Devonian,and younger host rocks (*black dots*), and stream sediment Zn values (Yager and Folger 2005). **b** Schematic cross sections of outermost carbonate shelf during Middle Devonian time showing inferred fault-controlled restricted anoxic basins (modified from Emsbo et al. 1999). **c** Schematic geologic model for Devonian Sedex mineralization on the northern Carlin trend. *DFU* is debris flow unit, *LMU* is laminated mudstone unit, *SSDU* is soft-sediment deformation unit, and *UMU* is upper mudstone unit (modified from Emsbo et al. 1999)

Mountain stock 100 km to the southeast (Nutt et al. 2000; Hofstra et al. 2005b). Similarly, Cretaceous magmatism resulted in the formation of several gold-rich porphyry, scarp, and distal disseminated Ag–Au deposits along the major trends (e.g., Mike deposit, Carlin trend).

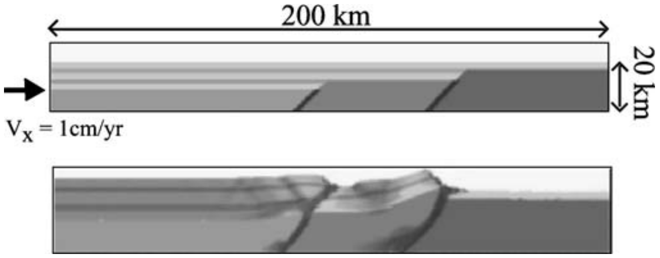

Fig. 4 Numerical simulations of the structural evolution of the Precambrian North American paleocontinental margin during compressional tectonism (Wijns et al. 2004). Note the propagation of basement faults into overlying sedimentary rocks and resulting complex stress fields, brittle faulting, uplift, and the formation of anticlinal zones that now represent the major mineral trends of northern Nevada that have a remarkable similarity to the cross section through the trends of Crafford and Grauch (2002)

The Mesozoic geologic history in the province again emphasizes the important role that basement faults and metasomatized Precambrian SCLM had on the nature and localization of magmatism, including lamprophyres, along the trends. Rigid Jurassic stocks also appear to have caused heterogeneous stresses within the trends, thereby focusing subsequent Carlin-type fluids (Hofstra and Cline 2000; Cline et al. 2005).

Calc-alkaline magmatism and rapid extension began at approximately 43 Ma in northernmost Nevada. Magmatism and extension spread southward to cover most of central Nevada by 34 Ma as the asthenosphere impinged on hydrated fertile lithosphere in the far back-arc position beneath the Carlin province as slab rollback associated with foundering of the Farallon plate began (Humphreys 1995). The timing of mid-Tertiary magmatism overlaps with the formation of Carlin-type gold deposits. While there is no exact spatial correspondence between exposed Eocene intrusive rocks and Carlin-type ores (e.g., Cline et al. 2005; Hofstra and Cline 2000), aeromagnetic data and known exposures indicate buried Eocene plutons within the trends in the province (Johnston and Ressel 2004). Whether these magmas contributed fluids and Au to the Carlin hydrothermal systems is potentially less important than the fact that magmas of this type produce high-level stocks and dikes that represent ideal bodies for the generation of convective hydrothermal systems above them, as evidenced by the apatite fission track anomaly in the Carlin trend (Chakurian et al. 2003; Cline et al. 2005). This is also shown through studies by Hart et al. (2004) and Mair et al. (2006) of deeper-level, intrusion-related gold systems (Sillitoe and Thompson 1998; Lang and Baker 2001) in a similar tectonic setting in Alaska/Yukon along the Precambrian margin of North America.

Eocene hydrothermal activity

The formation of Carlin-type deposits (42 to 37 Ma) is temporally coincidental with Eocene crustal extension and magmatism in north-central Nevada (Ilchik and Barton

1997; Henry and Boden 1998; Hofstra et al. 1999; Hofstra and Cline 2000; Cline et al. 2005). Several intrusion-related gold deposits also formed peripheral to calc-alkaline granitoids intruded along the trends during this brief time (Henry and Ressel 2000; Johnston and Ressel 2004; Johnston 2005). The Battle Mountain district, for example, contains several Cu–Mo–Au porphyry and skarn deposits, as do the Hill Top and McCoy/Cove districts that also formed along the Battle Mountain–Eureka trend (Theodore 2000; Kelson et al. 2005). Along the southern Carlin trend, the Bullion stock formed W–Cu–Au skarn and rich Ag–Pb–Cu vein and replacement deposits (LaPointe et al. 1991). An epithermal Ag–Au deposit formed in the Tuscarora Volcanic Field, west of the Jerritt Canyon district (Castor et al. 2003). Many porphyry deposits are associated with peripheral distal-disseminated gold deposits, such as Lone Tree (~150 t Au) in the Battle Mountain district (Theodore 2000). Although these deposits are sediment-hosted and share similarities with Carlin-type deposits (Theodore 1998), they display unequivocal temporal, spatial, geochemical, and isotopic characteristics that indicate a genetic relationship with a nearby intrusion (Hofstra and Cline 2000; Theodore 2000; Hofstra et al. 2005a). In contrast, the genetic relationships between Carlin-type deposits and intrusions are more tenuous, as discussed above.

The temporal coincidence between these clearly igneous-related deposits, which contributed to the gold endowment along the trends, have been invoked as evidence for the role of magmatism in the genesis of Carlin-types deposits (Johnston and Ressel 2004). Certainly, the thermal energy provided by magmatism during crustal extension is the most likely energy source driving hydrothermal circulation (Henry and Boden 1998; Hofstra et al. 1999). However, evidence indicative of direct magmatic inputs into Carlin-type deposits is scarce. Most δD_{H2O} analyses of fluid inclusions and alteration clay minerals from Carlin-type deposits (with the possible exception of Deep Star) show that they formed from meteoric water (Hofstra et al. 1999; Hofstra and Cline 2000; Emsbo et al. 2003; Cline et al. 2005). The Getchell deposit is the only Carlin deposit with compelling isotopic evidence for a deep-sourced metamorphic or magmatic fluid (Hofstra and Cline 2000); less compelling evidence of this sort is present at Deep Star (Heitt et al. 2003) and Screamer (Kesler et al. 2005) in the Carlin trend.

The dominance of meteoric-sourced hydrothermal fluids, combined with $\delta^{34}S$ evidence that Au was transported by H_2S derived from Paleozoic or Precambrian sedimentary rocks and deposited by sulfidation of rocks containing reactive Fe (Hofstra et al. 1991, 1999; Vikre 2000), has fostered models proposing that Au was leached from Paleozoic and Precambrian rocks (Seedorff 1991; Titley 1991; Ilchik and Barton 1997; Hofstra et al. 1999; Hofstra and Cline 2000; Emsbo et al. 2003). Strong enrichments of ore metals in older Sedex and intrusion-related deposits along the northern Carlin trend (which contains about 30% of gold in Nevada) suggests that the interaction of heated meteoric waters with pre-enriched sedimentary rocks generated a H_2S-rich fluid, which suppressed the solubility of base metals and scavenged Au and other trace elements. Upon migration into rocks containing reactive Fe, auriferous pyrite was deposited by sulfidation, thus forming the epigenetic Carlin-type deposits.

It is important to note that the spatial overlap of Devonian Sedex gold mineralization, Mesozoic gold-bearing magmatic systems, and subsequent Eocene magmatism was likely a consequence of reactivated basement faults along a major lithospheric boundary. Without these structures, the coincidence of critical factors (enriched source rocks, fluid conduits, and thermal energy) would not have occurred, and the gold endowment of the province would likely have been greatly diminished.

Basement faults and post-Eocene gold deposits

Economic gold deposits continued to form along the trends even after the formation of Carlin-type ores. For example, Miocene tholeiitic basalt/rhyolite magmatism generated significant gold deposits at ca. 15 Ma (e.g., Carlin Trend; Ivanhoe and Midas districts; Battle Mountain-Eureka trend; Buckhorn and Mule Canyon deposits). Epithermal mineralization in all deposit types was formed from meteoric water circulation; contained S, Se, and Au were likely derived from sedimentary rocks (John et al. 2003). These again illustrate the remarkable superposition of various gold-bearing deposit styles in one relatively small segment of the Earth's crust.

Discussion and conclusion: conjunction of critical factors for Carlin province

The tectonic and lithospheric setting of Carlin-type deposits in Nevada is anomalous on a global scale. Neoproterozoic rifting of the Precambrian paleocontinental margin established a lithospheric and structural architecture that was periodically reactivated and focused important components of the subsequent geologic, magmatic, and hydrothermal history of northern Nevada. In central Nevada, early basement faults close to the boundary between Precambrian and Paleozoic SCLM seem to have controlled overlying Devonian basin architecture and the localization of significant syngenetic gold mineralization with distinctive metal associations (e.g., Ba, Zn). Modeling shows that these structures also had the potential to control the inverted basin architecture of complex and elongate anticlinal/domal zones above basement faults, forming areas favorable for fluid flow along the structural trends and beneath the hydrologic seal of the Roberts Mountains thrust contact. Deep basement structural zones also served as conduits for anomalous magmatism in Jurassic, Cretaceous, and Eocene times. Felsic to lamprophyric calc-alkaline magmas above metasomatized SCLM are typically enriched in incompatible elements including Au and contributed to regional gold endowment. Although evidence for Eocene intrusions as a direct contributor of Au to Carlin-type mineralization is scarce, recent data indicate that they are the most obvious thermal energy source for driving Carlin-type fluid circulation. Jurassic/Cretaceous stocks/dikes along the trends promoted heterogeneous stress distribution during later Eocene reactivation and focused fluid flow that resulted in high-grade gold lodes in many districts. Paleozoic syngenetic gold provided an enriched gold source in essentially the same position as Eocene hydrothermal activity due to the progressive inheritance of spatial position of superimposed events because of long-lived basement faults and their reactivation. Hence, there was positive feedback between a number of spatially superimposed factors, all enhancing the potential of the Eocene system to produce giant gold deposits. Multiple hydrothermal events occurred both before (Devonian, Mississippian, Jurassic, and Cretaceous) and after (Miocene and Pliocene) the formation of Carlin-type deposits; each event related to distinct tectonic events with different structural orientations and various igneous compositions. These events caused a variety of ore fluids with distinctive chemical and alteration signatures to deposit gold repeatedly in the major trends, reflecting a resonance effect that was ultimately controlled by the architecture of basement faults at a lithospheric boundary.

Previous studies of many giant mineral deposits have shown that they are not distinctive in their deposit scale characteristics (Whiting et al. 1993; Cooke and Pongratz 2002; Bierlein et al. 2006). In the case of the Carlin province of Nevada, although deposit scale factors are important in controlling the localization and deposition of gold, crustal- to lithospheric-scale architecture are responsible through the conjunction of a number of important feedback mechanisms for its repeated mineralizing events and anomalous gold endowment. Given the anomalous tectonic setting and lithospheric architecture of the Carlin province, it is not surprising that other deposits with similar deposit-scale features in other parts of the world are at least an order of magnitude smaller. An analogous tectonic and lithospheric scenario may explain the siting of the large Cretaceous Alaska–Yukon intrusion-related gold deposits (e.g., Fort Knox). These deposits are along the northern extension of the same lithospheric margin in the Paleozoic Selwyn basin that experienced a similar geologic evolution and an analogous series of hydrothermal events (Turner et al. 1989; Mair et al. 2006).

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