Geodynamic processes that control the global distribution of giant gold deposits

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Abstract: This paper address the question of why giant gold deposits are so unevenly spread over the continents, what processes control their distribution, and how more might be found? Using the source–migration–trap paradigm, it is proposed that the regional distribution of gold deposits is controlled by fluid access to gold sources on a regional scale, and by large-scale migration mechanisms. Local distribution is controlled by migration and trap processes, not discussed in this paper. Our current levels of understanding of gold suggest a strong geodynamic control in the generation of enriched source rocks and the fluids that may carry gold, particularly the influence of subduction and accretion during orogeny. A new six-fold geodynamic classification system that emphasizes subduction and accretion processes has been used here qualitatively to assess the potential for gold-bearing source areas. The resulting classification is compared to the distribution of 181 known giant gold deposits (those with more than 100 t contained gold). The results confirm the proposition that the distribution of giant gold deposits is ultimately a function of the amount of oceanic crust consumed during the orogenic episode that built that part of the crust. Of the six geodynamic classes described, large ocean closure orogens were found to contain the most gold, with nearly half of the world's gold held in known giant deposits. Implications for understanding ore genesis, exploration for other giant deposits, and for other empirical explanations of the distribution of gold are discussed further.

Giant gold deposits, defined in this paper as those with a resource of more than 100 tonnes of contained gold, are not spread evenly across the globe and, intriguingly, are not evenly distributed across the world's orogenic belts (Fig. 1). The distribution of these deposits is controlled by complex hydrothermal processes that operate within specific geodynamic settings that can be unravelled at a series of scales of observation, from global to deposit-scale, by consideration of mineralizing fluids in the context of the source–migration–trap paradigm and tectonic setting. In this paper gold-bearing fluid sources and regional migration mechanisms are regarded as an integral part of a new framework of crustal growth and orogeny. Understanding these processes at the regional scale sheds light on some interesting conundrums, such as why some orogenic belts are endowed with giant gold deposits, whereas others are entirely barren – a prime example being why none are found in the Himalayas yet the Altaids have a major gold endowment.

Source of gold

At the regional scale, gold prospectivity relates predominantly to the presence of gold source rocks in the crust or mantle, and to the availability of fluids with the capability of scavenging and transporting gold.

Mantle sources

Subduction-related gold sourced from the mantle has been demonstrated convincingly (e.g. Sillitoe 1993). In this setting, fluids mobilized from descending oceanic plate

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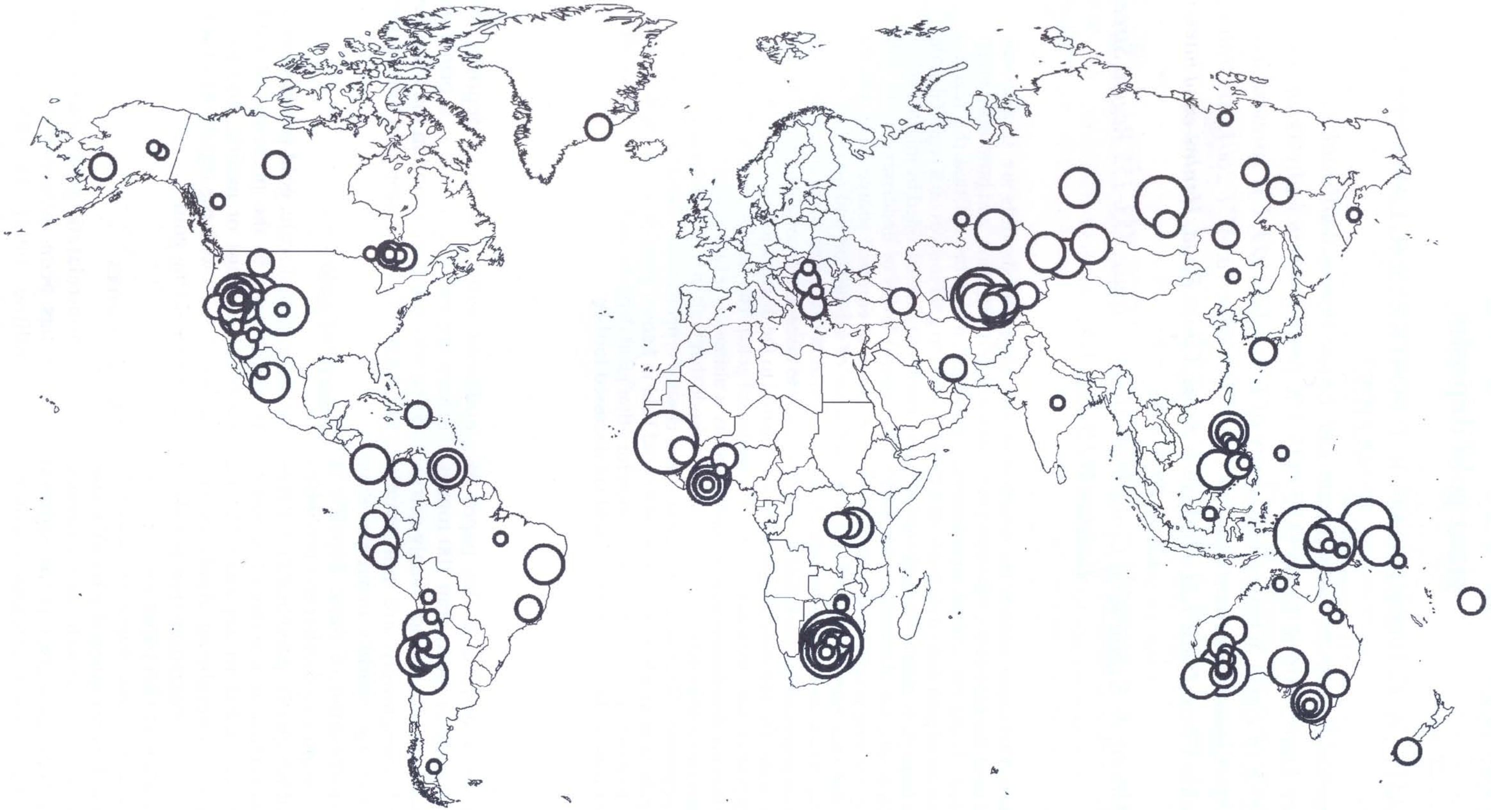

Fig. 1. Location of all known giant gold deposits. Symbol size relates to gold deposits size: smallest circles are deposits in the range of 100 t to 160 t, largest circles are deposits with >1500 t contained gold. Note that deposits with less than 100 t contained gold, and historical or exhausted mines are not shown.

hydrate the overlying lithospheric mantle of the continent and liberate gold into the magmatic–hydrothermal systems of the arc. A large volume of work, recently summarized by Blundell (2003), indicates that giant gold deposit formation is not a steady-state passive response to ongoing subduction, but rather a punctuated active response to the fluctuating stress regime in the overlying plate and to thermal variations in the lower plate. High heat-flow events in the subducting plate can be brought about by various mechanisms, including slab detachment, roll-back, and ridge subduction. These transient effects on the upper and lower plates are often linked dynamically, and can be caused by changes in plate configuration and, ultimately, by instabilities in mantle convection.

Gold-bearing fluids with a mantle source have only been demonstrated (so far) in an active margin context, as discussed above. Gold sources from non-subduction mantle environments, usually attributed to plumes and rifts, have yet to be proven, although these events are believed to lead to higher heat flow, and hence indirect activation of gold sources in the crust may be possible.

Crustal sources

Given the considerable amount of continental crust available, it is important to recognize that potential source areas for gold are restricted to specific environments. Only crustal material with a predominantly basic bulk composition (i.e. ophiolites or other crustal mafic rocks, pelites and organic-rich sediments) contains enough gold as a trace element (Wedepohl 1978; Boyle 1979), together with sufficient quantities of mineral-hosted H_2O, to be considered a potential source on a regional scale. Significant devolatilization (and implied gold mobility) only starts to occur when pressure and temperature exceed those of sub-greenschist metamorphic facies (Cameron 1989; Groves *et al.* 2003; Jia *et al.* 2003). Furthermore, once a rock, even if basic in bulk composition, has exceeded amphibolite metamorphic facies, it is unlikely to contain sufficient H_2O to be capable of significant gold mobilization. These conditions rule out a great deal of the continental crust because:

- the crust is dominantly felsic in composition;
- much of the upper crust has been subjected to sub-greenschist metamorphic facies or lower grade; and
- much of the middle and lower crust has been subjected to metamorphism exceeding upper amphibolite facies.

The requirement of intermediate grades of metamorphism on a regional scale is met only during orogenesis, so the most favourable crustal gold-source areas are within orogenic belts (both inactive and active), in which rocks (or their protoliths) with hydrated 'bulk mafic' composition are dominant. Geodynamic terranes that may meet this requirement include: accretionary prisms, ophiolites (*sensu lato*), passive margin and foredeep sediment sequences and back-arc basins.

Hydrous fluids that can carry crustal gold are liberated most effectively during upper greenschist to amphibolite metamorphism and anatexis, as described for the Archaean Yilgarn (Kent *et al.* 1996; Weinberg *et al.* 2004), or the Mesozoic North China Craton (Yang *et al.* 2003), or in a high heat flow or other extraordinary, transient pressure–temperature regime (Kerrich 1999). These regimes are probably the same sort of punctuated active responses to plate reorganization described above for mantle sources above, and go some way to explaining the occurrence of accretionary (or 'slate') belt mesothermal giant gold deposits in active margin settings (Fig. 2) as discussed by Groves *et al.* (2003). It is possible that the orogenic trigger for mobilization of gold-bearing fluids is not related to oceanic subduction but could be brought about during continent–continent collision, particularly if this leads to delamination of the attached mantle lithosphere and associated thermal boost at the base of the crust (e.g. Yang *et al.* 2003). The fact that continent–continent collision can generate the required transient *P–T* events to lead to giant gold deposits is underpinned by the analysis of crustal setting and distribution of gold deposits presented in this paper.

Origins of gold-bearing fluids

Naturally-occurring fluids with the capability to carry significant amounts of gold fall into four broad groupings, all of which exhibit high sulphur contents but otherwise have varied physical and chemical parameters, as defined by field observations supported by studies using Geochemists Workbench^{TM} and other published data (gold and associated elements generally in Heinrich & Eadington 1986; Gammons & Williams-Jones 1995; Huston 1998; Wood & Samson 1998; Heinrich *et al.* 1999; and for specific fluids as listed below):

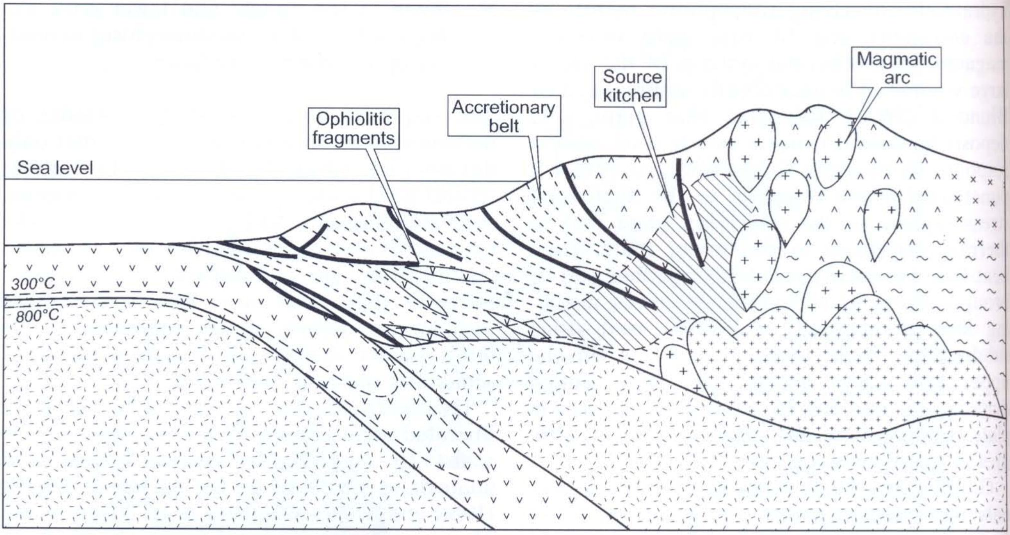

Fig. 2. Schematic cross-section of an accretionary subduction zone, with a shaded area indicating the 300–800 °C window typical of greenschist and lower amphibolite facies, where major devolatilization occurs, and from which gold may be mobilized.

Deep magma-dominated fluids (DMF); Davis & Bickle 1991; Hedenquist 1995; Thompson *et al.* 1999. These fluids are characterized by high temperature, high salinity, moderate fO_2 and weak to moderate acidity. They are predominantly magmatic and are associated with arc-intrusive hydrothermal–magmatic systems at depths from 2 km down to the base of the crust. Gold is derived from mantle sources in the subduction zone environment as discussed previously.

Shallow magma-dominated fluids (SMF); Hedenquist *et al.* 1998; Berger & Silberman 1985; Daliran 1999; Mehrabi *et al.* 1999; Richards 1995. These fluids are moderate to high temperature, moderate to high salinity, high fO_2 and weakly to moderately acidic. Gold source and fluid origin are similar to DMF, but the fluids are modified at high crustal levels by interaction with meteoric waters or other crustal fluids.

Multi-source fluids (MSF); Barnicoat *et al.* 1997; Bagby & Berger 1985; Colvine *et al.* 1988; Wood 1992. This diverse family of fluids encompasses a wide temperature range, low to moderate salinity, moderate fO_2 and are neutral to weakly acidic. They are rock-buffered fluids from a variety of crustal sources, mainly metamorphic, but also including sedimentary formation water and possible magmatic contributions. Gold is derived predominantly from crustal sources, with possible mantle input in near-arc settings.

Basinal fluids (BF); Hoeve & Quirt 1986; Kirkham 1986; Wilde *et al.* 1989. These fluids are of low temperature and very high salinity, with the potential to carry gold, but have a limited capability to form giant gold deposits. However, they are very important for other giant deposit-types such as MVT and Athabasca-type uranium.

The discussion presented so far suggests that specific geodynamic processes of crustal growth, namely subduction and orogeny, are essential to the mobilization of fluid types that can form giant gold deposits. With this perspective, a new six-fold classification system has been constructed to subdivide regions of the Earth's continental crust firstly in terms of its orogenic constituents ('domains'), and subsequently in terms of the relative quantity and quality of fluid types each domain could generate.

Geodynamic classification

Plate tectonics has played a critical role in crustal growth throughout the Phanerozoic the Proterozoic, and possibly even as far back as the Late Archaean (e.g. de Wit & Hart 1993; Windley 1995; de Wit 1998). The recognizable temporal and spatial links between the accretionary process (as the main mechanism for crustal growth) and derivation of gold from both mantle (through subduction) and crustal sources (through metamorphism) thus forms the basis of the geodynamic classification and analysis presented in this paper.

Accretionary complexes can grow on the edges of continental blocks or within an oceanic setting as multiple arcs amalgamate, the key requirements being large oceans (e.g. Pacific-sized) and long time-periods (tens to hundreds of millions of years) that ensure the continual delivery of accretable material. This accreted material includes juvenile crust such as arcs, oceanic plateaux, and obducted oceanic crust, plus more diverse sedimentary terranes (fore-arc, intra-arc, back-arc and retro-arc basins, carbonate platforms, deep-sea fans), and micro-continental slivers and blocks spalled off other continents by rifting (Ben-Avraham *et al.* 1981; Howell 1989). The accretionary complexes are intruded by trenchward-advancing calcalkaline arcs that step, rather than creep, forward as large terranes become accreted (e.g. in the Central Asian Palaeozoic orogenic belt; Sengor & Natal'in 1996). Major crustal structures are dominated by transpression, especially along terrane boundaries, although pure compression and possible back-arc extension are also significant. As long as subduction continues around parts of the complex, the orogen may be termed 'open', or 'unconsolidated'. They become 'closed' or 'consolidated' by collision with another large continental mass which blocks the direct effects of subduction and deforms the whole complex. In this way the large ocean closure (LOC) orogenic type is formed (named 'Altaid' or 'Turkic' type by Sengor after the Central Asian Palaeozoic LOC).

Not all collisional orogenic belts comprise accreted terranes. Many of the world's best-studied orogenic belts have either none (e.g. Western Alps) or only one or two (e.g. Himalayas). This coincidence alone may explain why accretionary orogenic belts and complexes have not been satisfactorily understood in terms of their geodynamic evolution until workers started to synthesize the total framework of tectonics, magmatism, metamorphism and basin evolution for active complexes (starting with Coney *et al.* 1980), Phanerozoic complexes (e.g. Sengor & Natal'in 1996) and even Archaean accretionary complexes (de Wit *et al.* 1992).

There is a continuum between collisional orogens, that lack intervening accreted terranes, and the large ocean-closure orogens described above that contain vast tracts of accreted terranes. The key difference between these two end-members is the width of oceanic plate that was consumed between the two colliding masses, because this controls both the amount of material that is available for accretion and the degree to which continental magmatic arcs can develop on the over-riding plate. To accommodate this range we have classified consolidated orogenic domains into three types:

- large ocean closure (LOC) orogens, epitomized by the Altaids;
- moderate ocean closure (MOC) orogens, for example the Appalachians; and
- small ocean closure (SOC) orogens, for example the Western Alps.

Unconsolidated orogenic belts comprise those areas that are currently undergoing crustal growth by accretion and subduction. The most obvious of these are the large accretionary-arc complexes (such as Alaska) but they range through active continental margins to nascent island arcs in the Pacific. These are classified into three types:

- island arcs (IA), also known as intra-oceanic or juvenile arc, exemplified by the western Aleutian chain;
- continental arcs (CA), for example the Chilean Andes; and
- large accretionary-arc complexes (LAAC), for example the northern Rockies.

Schematic cross-sections illustrating the key features of known orogenic systems representing the different domains are shown in Figure 3 (Pfiffner 1992); others drawn from crustal structures discussed in Windley (1995) and Sengor & Natal'in (1996).

This classification is based on a series of 'critical features' and 'additional features' (Tables 1 & 2). Critical features describe defining elements of a domain that are essential to their characterization; additional features identify the commonly occurring features (e.g. terrane types) that are not defining but contribute to the definition process. Terranes within these domains are subdivided into accreted types (or exotic terranes; micro-continental blocks, island arcs, oceanic fragments and sedimentary terranes), and local types (basement massif, accretionary wedges, passive margins, extinct continental arcs, and foreland, back-arc and intermontane orogenic basins)

The consolidated domains are the end-products of continent–continent collision events that have caused subduction to cease. Key discriminators between the different

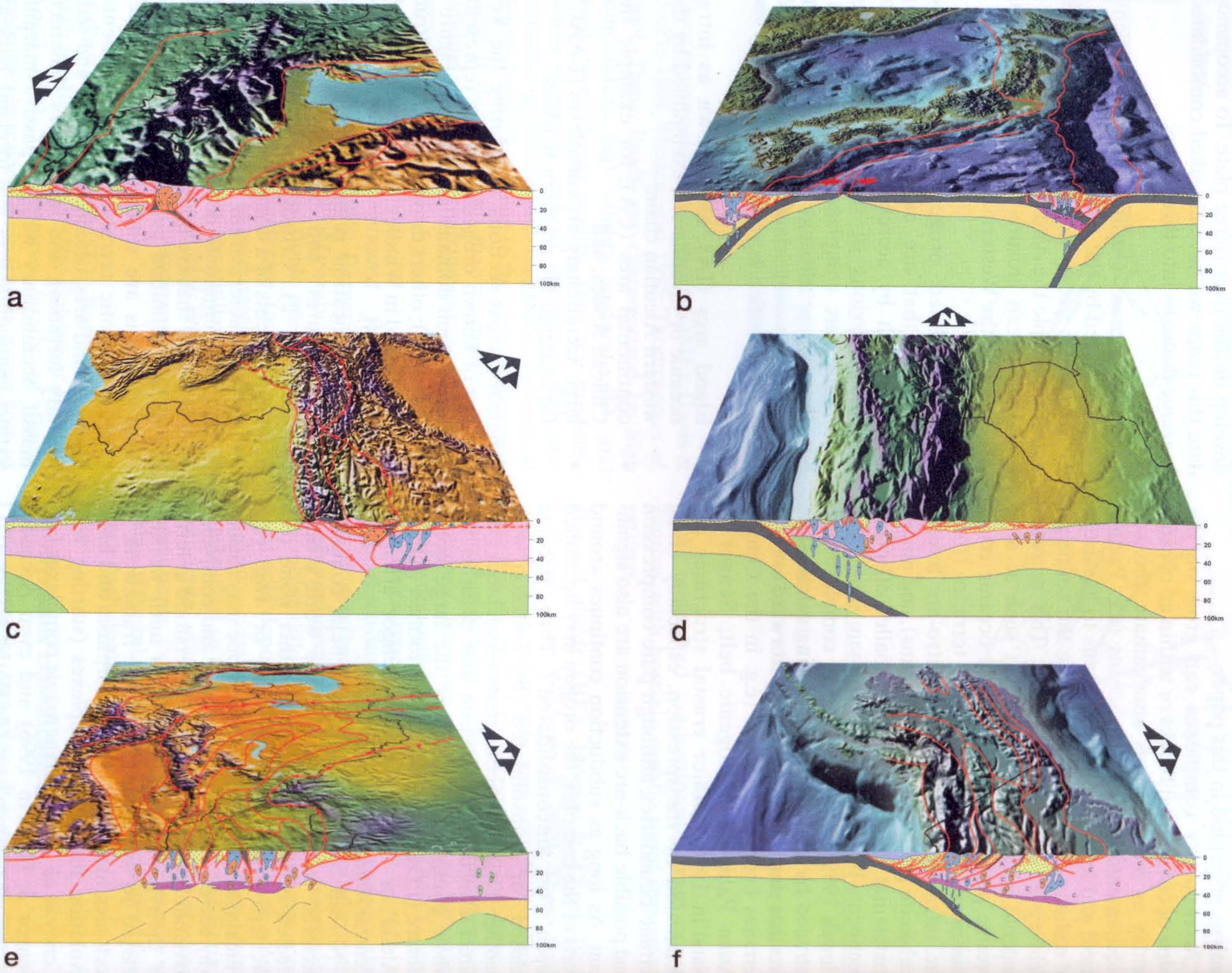
a
b
c
d
e
f
N
0
20
40
60
80
100km

Table 1. *Definition of the consolidated domain classification*

Domain type	Critical definition	Additional features	Example
Small ocean closure orogen	Linear orogenic belts with aspect ratios of >4–1. No continental arc, or highly discontinuous and poorly developed if present, no back-arc terrane.	Local accretionary wedge and foreland basin terranes, basement massif, passive margin sequence, few or no accreted terranes (those present do not touch one another). They have experienced less than a few hundred kilometres of oceanic plate subduction, usually over less than 50 Ma.	Damara belt, Western Alps; Figure 3a
Moderate ocean closure orogen	Linear orogenic belts with aspect ratios of >4–1. Extinct continental arc ranging from slightly discontinuous to very well developed.	Various local terranes (especially forelands and accretionary wedges), basement massif, passive margin sequence, few to many accreted terranes (may be adjacent), post orogenic granites. They have experienced a few hundred to a few thousand kilometres of oceanic plate subduction, usually over less than 100 Ma.	Appalachians, Himalayas, Figure 3c
Large ocean closure orogen	Ovoid or irregular orogenic belts with aspect ratios of <3–1. Includes many accreted and local terranes of variable type, but especially extinct continental arcs. These large areas are the consolidated equivalents of LAAC.	Common post-orogenic granites, basement massifs rare, especially in the interior. Because of their size, more than two continents may be required to encircle the orogen to define the domain margins. They have experienced more than a few thousand kilometres of oceanic plate subduction, usually over many hundred of millions of years.	Pan-African North Africa, Yilgarn Block, Altaids, Figure 3e

consolidated types are the identification of continental arcs formed prior to collision, the number of entrained terranes, and the aspect ratio (length–width) of the orogenic tract (Table 1).

The unconsolidated domains (Table 2) are those with active or recently active margins. The oldest allowable age for this classification depends on preservation. Inactive arcs are defined here as those in which the upper 1–2 km of arc crust have not yet been removed by erosion. The oldest examples are probably of Miocene age.

To be able to classify the entire continental area of the world, a further non-orogenic type of Domain is required to describe areas of undeformed sedimentary or volcanic cover (e.g. intra-cratonic sag basins and flood basalt provinces) that completely obscure the underlying crust.

Fig. 3. Schematic crustal sections of the type-examples of the six orogenic domains, surface area tiles have variable scales. (**a**) Small ocean closure (SOC), view of the Western Alps, with Italy to the right. (**b**) Island arc (IA) view of the Isu–Bonin arc, Japan to the north. (**c**) Moderate ocean closure (MOC), view of the Himalayas, northern India and Pakistan to the left. (**d**) Continental arc (CA), view of the Andean arc in northern Chile. (**e**) Large ocean closure (LOC), view of the Altaids, Tarim basin on the left. In the schematic sections lithospheric mantle is yellow, asthenospheric mantle is green, oceanic crust is dark grey, continental crust is pink, basins are yellow with fine stipple, mafic underplating is purple, orogenic and post-orogenic granites are red, and magmatic arc is in blue. (**f**) Large accretionary-arc complexes (LAAC), for example the northern Rockies.

Table 2. *Definition of the unconsolidated domain classification*

Domain type	Critical definition	Additional features	Example
Island arc	Subduction-related volcano-plutonic belt on oceanic basement, active or recently active.	Various local terranes (especially back-arc and accretionary wedge), plus 1 other accreted terrane. If further terranes have been added it is then considered an LAAC.	Aleutian chain, Izu-Bonin Arc; Figure 3b
Continental arc	Continental or AAC basement, active or recent arc, with less than 3 accreted terranes.	If on a continental basement; various local terranes (especially retro-forelands and extinct arcs), overprinted passive margin sequence, plus 2 other accreted terranes (3 or more will constitute an AAC). If on an AAC basement, only the actual active chain and any adjacent local accretionary wedge terrane is delineated as part of the domain, all the other associated terranes are included in the AAC domain that the continental arc is overprinting.	AAC basement – eastern Alaska arc, continental basement – Peruvian Andes; Figure 3d
Large accretionary arc complex	3 or more accreted terranes, with adjacent or overprinting active continental arc. May be either intra-oceanic e.g. Borneo, or peri-continental e.g. Alaska.	Local-type terranes (especially extinct arc belts and retro-foreland), overprinted passive margin sequence (peri-continental only). Possibly hundreds of mappable accreted terranes.	Borneo or Alaska; Figure 3f

The seven-fold domain classification is summarized in Table 3.

Gold prospectivity within domains

Potential fluid source regions are not evenly distributed throughout the crust, and may occur within specific settings within each domain type, as illustrated on crustal sections through representative orogens (Fig. 4). The overall potential for each fluid type in a given domain is a function of the presence and number of all potential fluid source regions within the crustal section. For example SMF potential in SOC orogens is nil because magmatic arcs are, by definition, absent or very poorly developed, whereas in IA orogens the potential is very high. The fluid potentials are summarized in Table 4.

The implication of fluid habitat variation according to domain-type is that gold source areas are primarily related to subduction and to the presence of 'bulk basic' accretionary

Table 3. *General features of each domain classification*

Domain	Accretionary	Collisional	Terranes	Arcs
Large ocean closure	yes	yes	very many	many
Moderate ocean closure	possibly	yes	several	yes
Small ocean closure	no	yes	few	no
Large accretionary arc complex	yes	no	very many	yes
Continental arc	possibly	no	several	yes
Island arc	possibly	no	few	yes
Non-orogenic (e.g. sag basin)	no	no	no	no

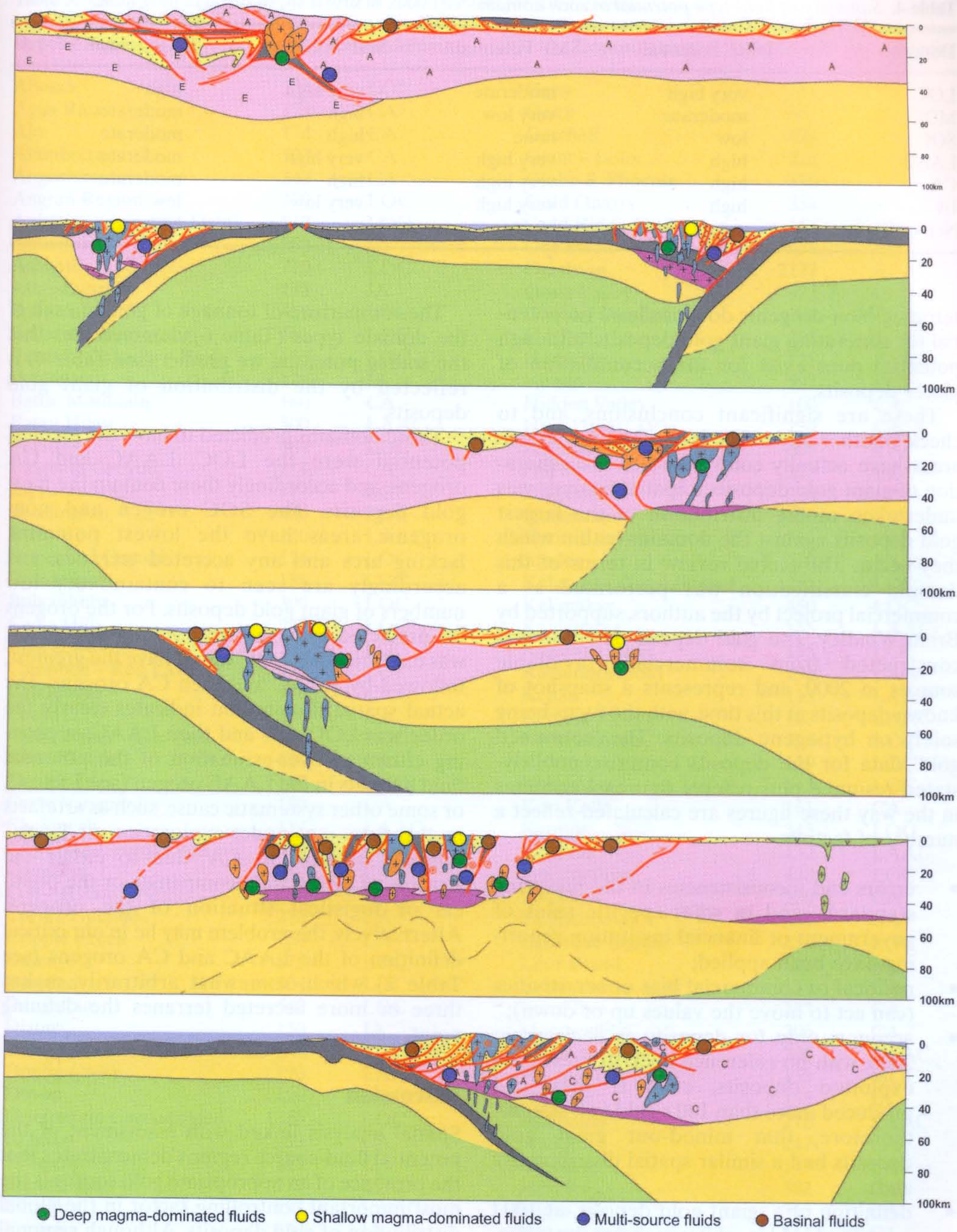

Fig. 4. Crustal sections of the type-examples of the six orogenic domains, showing schematic potential fluid habitats in circles.

terranes. Thus the domains with the greatest potential are LOC, LAAC and CA orogens, as these have had greatest exposure to subduction and arc activity, and contain the largest volumes of 'bulk basic' accreted material, often including vast swaths of 'slate belt' rocks. By the same criteria SOC orogens have the lowest potential, lacking arcs and any accreted

Table 4. *Summary of fluid-type potential in each domain*

Domain	DMF Potential	SMF Potential	MSF Potential	BF Potential
LOC	very high	moderate	very high	high
MOC	moderate	very low	high	moderate
SOC	low	none	high	moderate
LAAC	high	very high	very high	moderate
CA	high	very high	high	moderate
IA	high	very high	very low	low
Non-orogenic	none	none	none	high

terranes. Non-orogenic domains have no potential for generating giant gold deposits, although potential does exist for the accumulation of placer deposits.

These are significant conclusions, and to check whether any of the high-potential source areas have actually contributed to the generation of giant gold deposits a spatial analysis was undertaken of the distribution of the largest gold deposits against the domains within which they occur. The global review in terms of this domain classification was performed as a commercial project by the authors, supported by Brian Windley. The gold deposit database was constructed from commercially available sources in 2000, and represents a snapshot of known deposits at this time, with the focus being solely on hypogene deposits. The 'contained gold' data for the deposits comprise publicly-stated resource plus reserve figures. Variations in the way these figures are calculated reflect a number of factors:

- errors and inconsistencies in the reporting standards, and in what specific rules of government or financial institution reporting have been applied;
- political or commercial bias or sensitivities (can act to move the values up or down);
- accounts only for deposits as declared in 2000, with no reference back to previously exploited deposits, even if they had produced more than 100 t gold (we assume, therefore, that mined-out giant gold deposits had a similar spatial distribution); and
- definition of a 'giant gold deposit' at 100 t contained gold is arbitrary and at the judgement of the authors, rather than any international standard.

A total of 181 deposits were used in the spatial analysis: their names, contained gold (with the caveats described above) and host domain is presented in Table 5 below.

The comparison of tonnage of gold in each of the domain types (Table 6) demonstrates that the source potential we predict (see Table 4) is reflected by the distribution of giant gold deposits.

Those domains predicted to have the greatest potential were the LOC, LAAC and CA orogens, and accordingly these contain the most gold deposits. The SOC orogen and non-orogenic areas have the lowest potential, lacking arcs and any accreted terranes, and accordingly are seen to contain very low numbers of giant gold deposits. For the orogens we predicted to have high potential for gold it was expected that LOC would have the greatest, followed by LAAC and then CA orogens. The actual spatial distribution indicates clearly the order was LOC, CA and then LAAC, suggesting either an over-estimation of the potential fluid habitats in the LAAC orogen (see Table 4), or some other systematic cause, such as artefacts in the data, e.g. under-exploration of LAAC domains relative to CA, due to either the strategy of exploration companies, or the political or logistical situation of the orogens. Alternatively, the problem may lie in our critical definition of the LAAC and CA orogens (see Table 2) which, somewhat arbitrarily, makes three or more accreted terranes the defining point.

Discussion

Spatial analysis linked with assessment of the potential fluid-source regions demonstrates that the presence of an appropriate gold source is the most important controlling factor in the global distribution of gold deposits. Although regional to local-scale geodynamic variations, such as upper-plate stresses and lower-plate thermal perturbations, are recognized as important in the hydrothermal mobilization and transportation (and hence localization) of the gold, ultimately there must be a source for the gold and for the fluids that mobilize the element. This

Table 5. *Giant gold deposits of the world in 2000 (see text for limitations)*

Deposit Name	Au (t)	Host domain	Deposit name	Au (t)	Host domain
Abosso	204	LOC	Gaby	188	CA
Agua Rica	173	CA	Geita	311	MOC
Ajo	174	CA	Getchell	498	CA
Alumbrera	523	CA	Giant – Lolor	225	LOC
Angostura	342	CA	Globe & Phoenix	120	LOC
Angren Region	270	LOC	Gold Quarry	251	CA
Ankerite – Aurnor – Delni	143	LOC	Gold Ridge	154	IA
Antamok	350	IA	Goldstrike	659	CA
Ashanti	710	LOC	Grasburg	2127	CA
Atlas-Lutopan	135	IA	Grass Valley	323	CA
Bakyrchik	412	LOC	Gunung Pongkor	102	IA
Ballarat – Buninyong	161	LOC	H J Joel	205	LOC
Barnat – Canadia – East	165	LOC	Harmony	125	LOC
Batangas	129	IA	Hemlo	597	LOC
Battle Mountain	180	CA	Hidden Valley	100	CA
Batau Hijau	500	LAAC	High Desert JV	124	CA
Bendigo	684	LOC	Highland Valley	600	CA
Bingham Canyon	1219	CA	Hill 50	227	LOC
Blyvooruitzicht	727	LOC	Hishikari	260	CA
Boddington	486	LOC	Homestake	1200	CA
Bralorne	120	LAAC	Jerritt Canyon	215	CA
Brisas Del Cuyuni	174	LOC	Jundee	210	MOC
Bronzewing	158	LOC	Kalgoorlie Consolidated	1282	LOC
Bulyanhulu	390	LOC	Kal'makyr	450	LOC
Cadia Hill	222	LOC	Kamchatka	155	LAAC
Cam & Motor	146	LOC	Kanowna Belle	155	LOC
Campbell – Red Lake	435	LOC	Kassandra Gold	196	LAAC
Candelaria	100	CA	Kelian	113	LAAC
Carlin	135	CA	Kemess	127	LAAC
Castlemaine – Chewton	180	LOC	Kerr Addison	324	LOC
Cerro Casale	676	CA	Kidston	139	LOC
Cerro Leste	148	LOC	Kokpatass	613	LOC
Cerro Vanguardia	100	CA	Kori Kollo	161	CA
Chelopech	114	LAAC	Kumtor	343	LOC
City Deep/Crown Tlngs	331	LOC	Kyuchus	132	LAAC
Comstock	260	CA	Las Cristinas	428	LOC
Con – Rycon – Negus	165	LOC	La Coipa	120	CA
Cortez/Pipeline	276	CA	La Escondida	422	CA
Cripple Creek	750	CA	Lamaque-Sigma	258	LOC
Dalneye	875	LOC	Lihir Island	1692	IA
Darasun	304	LOC	Lobo-Marte	139	CA
Daugiztau	540	LOC	Lone Tree	133	CA
Dizon	130	IA	Macraes Flat	206	CA
Dome	143	LOC	Majdanpek	300	LAAC
Donlin Creek	170	LAAC	Malanjkand	158	MOC
Doyon	129	LOC	Masbate	155	IA
Driefontein Consolidated	1326	LOC	Mcdonald	218	LAAC
El Indio	293	CA	Meikle	147	CA
El Sauzal	112	CA	Mesquite	147	CA
Elandsrand	577	LOC	Metates	382	CA
Elnichny	192	LAAC	Midas	313	CA
Emperor	270	IA	Minas Conga	354	CA
Evander	1331	LOC	Mokrsko	100	SOC
Famatina	178	CA	Morila	242	LOC
Far Southeast	295	IA	Morro Velho	278	MOC
Fort Knox	155	LAAC	Mt Charlotte	103	LOC
Frazenda Braziliero	600	LOC	Mt Kare	114	CA
Free State Consolidated	1683	LOC	Muruntau	4500	LOC
Frieda River	302	CA	Myutenbai	618	LOC

Deposit Name	Au (t)	Host domain	Deposit name	Au (t)	Host domain
Nezhdaninskoe	235	LAAC	Sons of Gwalia	105	LOC
Norseman	150	LOC	South Pipeline	324	CA
Obuasi	423	LOC	St Helena	228	LOC
Ok Tedi	321	CA	St Ives	113	LOC
Olimpiada	700	LOC	Sukhoi Log	1035	LOC
Olympic Dam	391	MOC	Sunrise Dam	162	LOC
Original Goldstrike	771	CA	Svetlinskoye	147	LOC
Oryx	848	LOC	Syama	276	LOC
Pajingo	150	LOC	Target	446	LOC
Pamour-Hahnor	145	LOC	Tarkwa	417	LOC
Panguna	529	IA	Teberebie	143	LOC
Pascua	395	CA	Telfer	321	LOC
Pavlik	303	LAAC	Timmins Division	111	LOC
Petaquila	672	CA	Tuanjigou	120	LOC
Pierina	203	CA	Twangiza	222	MOC
Pikes Peak	134	CA	Twin Creeks	342	CA
Pogo	161	LAAC	Unisel	101	LOC
Poplar	308	LOC	Upper Kumar	300	LOC
Porgera	980	CA	Vaal River	1129	LOC
Prestea	219	LOC	Vasilkovskoye	414	LOC
Pueblo Viejo	338	LAAC	Veladero	182	CA
Randfontein	400	LOC	Wafi	155	CA
Refugio	263	CA	West Witwatersrand	158	LOC
Rosia Montana	145	LAAC	Western Areas	4280	LOC
Round Mountain	201	CA	Western Deeps	726	LOC
Sadiola Hill	2494	LOC	Williams	138	LOC
Santo Tomas	233	IA	Wilson Creek	156	CA
Sar Cheshmeh	324	CA	Yamfo-Sefwi	135	LOC
Sheba – Fairview	126	LOC	Yanacocha	633	CA
Sipalay	301	IA	Yimuyn Manjerr	101	LOC
Skaergaard	166	SOC	Zarmitan	200	LOC
Skouries	235	LAAC			

Table 6. *Distribution of gold in giant deposits by tonnage and by number of deposits*

Domain	% of world's total by tonnage of gold	% of world's total by number of deposits
LOC	57.4%	46.4%
CA	28.7%	31.5%
LAAC	6.1%	10.5%
IA	5.3%	7.2%
MOC	2.1%	3.3%
SOC	0.4%	1.1%
Non-orogenic	0.0%	0.0%

The data used in this analysis are partly derived from commercial sources, but consist of the locations of 181 deposits, with a total contained gold of 73 286 t. The Witwatersrand Basin accounts for about 20% of world's tonnage and strongly skews this data. It formed in a foreland basin of the Kalahari LOC.

is clearly demonstrated by the notably small number of large gold deposits that have been found in SOC orogens. This is because SOC orogens by definition lack well-developed arcs and accretionary terranes. This conclusion also provides the mechanism that explains the observations about orogenic geometry (i.e. 'rotund' and 'skinny') being in some way related to gold endowment (Goldfarb *et al.* 2001).

The gold-transporting capabilities of the fluid types alone are not likely to define the potential to generate giant gold deposits; they merely define a potential for generation of any size of deposit. In the case of crustal sources, exceptional volumes of fluid and access to major structures are key factors in forming the giant deposits; in magmatic systems it is the highly focused nature of fluid (and magma), but interactions of unusually enhanced physical (e.g. temperature or pressure) and chemical (e.g. salinity) characteristics also play key roles. Clearly, these mineralizing systems are complex, but the source–migration–trap framework can be applied to successively finer-scale analysis. Further subdivision of domains on the basis of their arc and accreted components (terranes) is an essential exercise to understanding fully the controls on the genesis of giant gold deposits.

Conclusions

In an effort to understand the global distribution of giant gold deposits the geodynamic setting of both potential gold source areas and the fluids that can mobilize the gold were analysed. The analysis confirms the premise that the global distribution of giant gold deposits is controlled by the occurrence of gold in a specific range of lithologies and by the availability of fluids that can actually mobilize the metal. Gold source areas are generated during normal crustal growth processes, but in many cases unusual (non-steady-state) conditions are required to mobilize both fluids and the metal. Our evaluation suggests a simple paradigm for gold mineralization: the more long-lived the subduction, (i) the more the arc develops, and (ii) the more voluminous the accretionary belt, and hence (iii) the greater the potential for the non-steady-state events that lead to giant gold deposits. These findings explain the processes that drive the distribution of gold deposits within the crust, and are in contrast to the empirical approach of time- and space-controlled 'golden epochs' adopted by some workers. We conclude that apparent epochs of gold mineralization are either spurious (artefacts introduced by focusing on known deposit groups or districts) or coincident (e.g. with major periods of crustal growth), or both. Either way, consideration of 'golden epochs' does not contribute to the understanding of the processes that form gold deposits, and is an example of empirical observation rather than scientific thought.

It is our conviction that a fundamental understanding of the spatial distribution and geodynamic context of gold- and fluid-sources is an essential foundation for fine-scale analysis of orogenic components and their timing to produce a better-resolved gold prospectivity model. This will lead to improved exploration and target-generation strategies at the continent, country and district-scale, and a predictive insight of the process that may have formed giant gold deposits in the study area.

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Mineral Deposits and Earth Evolution

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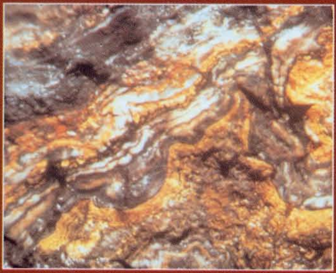

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Cover illustration:

Banded bonanza gold ore consisting of electrum and opaline silica from the Sleeper deposit, Nevada. Sleeper formed as a low-sulphidation, epithermal deposit circa 15 Ma, possibly related to the Yellowstone Hotspot. Finely laminated bands of electrum and silica are interpreted to have formed from aggregation of colloidal electrum and silica particles

Photographer: Professor Jim Saunders, Auburn University, Alabama