Gold exploration: Deposits and methodology

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Gold exploration

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The search for gold

Exploration for the precious-metal accounts for almost half of the total non-ferrous metals expenditure

GOLD PROJECTS (sorted by contained gold in resource)

	Name	Country	Status	Type	Control	Ore resource (Mt)	Grade (g/t)	Contained gold (t)
1	Pebble East	US	Feasibility	OP	Anglo American, North Dynasty	10,777	0.31	3,337
2	Target North	South Africa	Prefeasibility	UG	Harmony	310	6.74	2,091
3	Oribi	South Africa	Conceptual	UG	Harmony	300	6.69	2,006
4	Sukhoy Log	Russia	Feasibility	OP	State of Russia	686	2.80	1,921
5	Sun South	South Africa	Conceptual	UG	Harmony	250	6.73	1,683
6	KSM	Canada	Prefeasibility	OP	Seabridge	2,894	0.53	1,535
7	Rekodiq	Pakistan	Feasibility	OP	Antofagasta, Barrick, State	4,887	0.28	1,368
8	Donlin Creek	US	Feasibility	OP	Barrick, NovaGold	566	2.32	1,315
9	Mitchell	Canada	Prefeasibility	OP	Seabridge	2,279	0.56	1,286
10	Central Rand	South Africa	Conceptual		CentralRandgold	127	8.29	1,054
11	Pebble West	US	Conceptual		Anglo American, North Dynasty	3,026	0.32	968
12	Cerro Casale	Chile	Prefeasibility	OP	Barrick, Kinross Gold	1,874	0.51	956
13	Snowfield	Canada	Conceptual	OP	Silver Standard	1,811	0.51	923
14	Salobo	Brazil	Feasibility	OP	Vale	1,713	0.52	891
15	Las Cristinas	Venezuela	Feasibility	OP	Crystallex	859	0.98	841
16	Hinoba-an	Philippines	Feasibility	OP	ENRC plc, Metorex	326	2.50	814
17	Caspiche	Chile	Conceptual		Exeter Resource	1,473	0.51	756
18	Detour Lake	Canada	Closed	OP	PDX Resources	597	1.17	698
19	Kibali	DRC	Feasibility	OP, UG	Anglogold, Randgold, State	183	3.36	615
20	Metates	Mexico	Prefeasibility	UG	Chesapeake	1,071	0.57	611
21	Cadia East	Australia	Feasibility	OP, UG	Newcrest	830	0.67	569

Source: Raw Materials Group, Stockholm, 2010

GLOBAL expenditure on the search for non-ferrous metals rose for six consecutive years to reach some US$13 billion in 2008, according to Metals Economics Group (MEG). The financial crisis saw last year's total expenditure retreat to under US$8 billion. However, the share of this amount spent on gold exploration increased to 48% in 2009 from a low of 40% in 2008 (having fallen from the proportional high of 50% in 2004); see graph.

As noted in the article opposite, the search for gold is global, with the deposits being more widely distributed through geological time, and present in more geological environments, than the economic concentrations of any other metal.

Yet spending on this search for gold represents a very real risk to investors, and the risk-reward balance varies from country to country (and from region to region within individual countries). As a result, the exploration picture is decidedly mixed – as we examine in articles on each of the six continents, starting on p6. (These articles summarise the most significant recent gold-exploration announcements.)

Apart from the variable prospectivity of the geology, politics play an important part in the destination of exploration dollars. There is also no doubt that the role of the State is increasing. As noted by David Humphreys in an article in this week's *Mining Journal*, there is growing government participation in the revenues and running of the mining sector.

In some countries, such as India, Chile, South Africa, Zambia and Ghana, Dr Humphreys notes that this has manifested itself as increases in mining taxes or royalties. Elsewhere, as in the Democratic Republic of the Congo, Guinea, Sierra Leone and Madagascar, it has taken the form of a review by the state of previously-awarded mining licences.

In still other cases, for example, Bolivia, Venezuela, Ecuador, Zimbabwe and Mongolia, it has expressed itself through measures to have the state, or nationals, take a larger stake in mining companies operating within their borders.

Despite this trend, overall exploration activity (as measured by MEG in its Pipeline Activity Index; PAI), increased in May and June from a recent low in April. (PAI measures the level and direction of overall activity in the supply pipeline, incorporating significant drill results, initial resource announcements, project development milestones, and significant financings into a single comparable index.)

This heightened activity was led by a sharp rise in the number of gold financings and the announcement of significant gold drilling results. In contrast, weaker base-metals prices in recent months have kept

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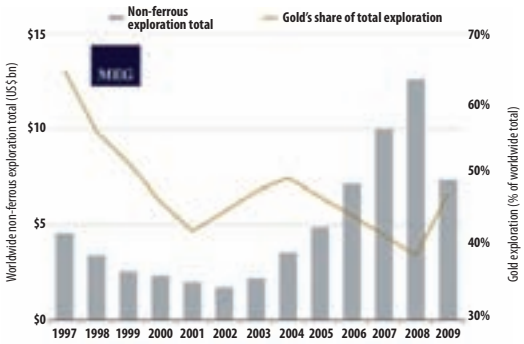
Cover:
Underworld Resources' White Gold property in the Yukon Territory of northern Canada, with a selection of gold exploration images inset from other companies



The graph shows the aggregate annual nonferrous exploration budget total by the companies covered in Metals Economics Group's (MEG) annual Corporate Exploration Strategies study and the share allocated to gold in each year. The study includes the budgets of companies spending at least US$100,000 on exploration in a given year (generally about 1,600-2,000 companies annually), which MEG estimates covers about 95% of commercially-oriented nonferrous exploration spending each year. The budget figures exclude exploration for iron ore, coal, bauxite, uranium, oil/gas, and some industrial minerals
Source: Metals Economics Group

base-metals activity relatively flat.

MEG reports that the number of significant drilling results (in total) reported in the May to June period was up 26% from the previous two months, and nearly double that of a year ago. Gold results continue to far outpace base-metals announcements, as has been the case so far in 2010.

MEG reports that the Americas (North and South) remain the dominant regions for overall drilling activity, while significant results from Africa increased noticeably during May and June.

MEG also notes that initial resource announcements (for both gold and base metals) continue to lag, still showing the effects of decreased drilling activity through early and mid-2009. The value of initial resources announced fell significantly as many of the deals were for smaller projects or new zones/satellite deposits at existing projects.

For the second consecutive bimonthly period, the total amount raised in significant financings by junior and intermediate companies increased, remaining evenly split between gold and base metals.

Despite weakening metals prices, interest in the equity markets continued to show signs of strength, according to MEG, as the proportion of debt financings more than halved compared with the previous two months, giving up share to equity placements and IPOs. The average amount raised per gold financing rose slightly over the previous two months.

The targets for much of this funding effort are highlighted in the table opposite from Stockholm-based Raw Materials Group.

Deposits and methodology

BY RICHARD SILLITOE AND JEFFREY HEDENQUIST

Aerial view of Barrick's Pascua-Lama on the Andean ridge

GOLD deposits are arguably more widely distributed through geological time, and present in more geological environments, than the economic concentrations of any other metal. Hence, gold occurs in both a majority of countries worldwide and a spectrum of deposit types.

Nevertheless, current production is dominated by mines in just four countries: China, Australia, the US (mainly Nevada) and South Africa. Chinese production exceeded 300t for the first time in 2009, while production ranged from 210t to 227t in the other three countries, each down from the amounts produced in 2008.

Russia, Peru, Indonesia and Canada form the next tier of producers, with 95-185t in 2009; and Russian and Indonesian output levels have risen markedly.

TYPES AND DISTRIBUTION

Gold deposit formation was maximised during two main periods of Earth history, namely the late Archaean (2,650-2,550 million years) and Mesozoic-Cainozoic (200 million years to present).

Archaean gold metallogeny is dominated by the palaeo-placer deposits of the Witwatersrand basin in South Africa, and mesothermal lodes, which are the products of deeply-derived metamorphic or magmatic fluids that flowed along major crustal structures.

In contrast, most of the Mesozoic and Cainozoic deposits were generated at shallower crustal levels, in some cases through to the Earth's surface, and were centred upon, and closely related to, volcanic and subvolcanic activity, typically in magmatic arcs.

In order of present-day global economic importance, the principal deposit types are orogenic, porphyry, palaeo-placer, sediment hosted (Carlin type), high-sulphidation (HS) epithermal, intermediate- and low-sulphidation (IS and LS) epithermal, a variety of other intrusion-related types (pluton related, skarn and iron oxide-copper-gold deposits) and volcanogenic massive sulphides (VMS) formed at former black-smoker sites on the seafloor.

Some porphyry copper deposits, the main source of the world's copper, also contain large amounts of co- or by-product gold, and a few of them (in Chile, Colombia and Turkey for example) even constitute gold-only deposits.

Notwithstanding the broad geographical spread of gold deposits, there is a distinct tendency for them to

Barrick's Pascua-Lama project in Chile-Argentina

be highly concentrated in relatively restricted regions, where the gold is commonly hosted by different deposit types formed during several restricted epochs.

Classic examples include the Archaean Superior and Eastern Goldfields provinces of Ontario-Quebec and Western Australia, and the Cainozoic Great Basin of Nevada and Andes of northern Colombia, northern Peru and northern Chile.

This preferential endowment suggests that the gold may be inherited from pre-existing, perhaps ancient, gold concentrations deep within the lithosphere.

Interestingly, some global plate reconstructions extend the gold-endowed Archaean lithosphere of the Superior province westwards beneath the Cainozoic Great Basin of Nevada.

DISCOVERY EXPENDITURE

According to Metals Economics Group (MEG), the search for gold accounted for 48% of global non-ferrous exploration expenditure of US$7.7 billion in 2009, with the greatest amount being devoted to South America, largely in the Andean Cordillera.

There, as throughout the circum-Pacific region, Tethyan belt of Eurasia and Altaid belt of the CIS, southern Russia, Mongolia and northern China, gold-rich porphyry and epithermal deposits are the prime exploration targets, although the pluton-related deposits are also sought in the Altaids and elsewhere.

Sediment-hosted deposits remain the main focus in Nevada, but exploration for epithermal deposits is again increasing.

Until three or four years ago, the world's gold companies tended to shy away from even the gold-rich porphyry deposits because copper production was considered likely to prejudice the gold premium enjoyed by their stocks.

However, today, most of the major and mid-tier gold companies, besides many juniors, are focusing on porphyry deposits because of the possibility of adding substantially to their inventories of the metal.

Pre-eminent examples of gold-rich porphyry deposits, discovered over the past decade, include Northern Dynasty Minerals Ltd and Anglo American plc's Pebble project in Alaska (some 67Moz), Ivanhoe Mines Ltd and Rio Tinto's Oyu Tolgoi in Mongolia (almost 27Moz), Exeter Resources Corp's Caspiche in Chile (over 24Moz) and Antofagasta plc and Barrick Gold Corp's Reko Diq in Pakistan (around 21Moz).

High-sulphidation epithermal deposits, in effect the shallow parts of porphyry copper-gold systems, are also targeted throughout the circum-Pacific region

Barrick drilling at Alto Chicama

and elsewhere because of the large size of several known examples, such as Newmont Mining Corp and Buenaventura's Yanacocha in Peru (43Moz) and Barrick's Pascua-Lama in Chile-Argentina (18Moz). Relatively recent epithermal discoveries include Barrick's Alto Chicama (14Moz) and Gold Fields and Buenaventura's Cañahuyre project (perhaps 6Moz) HS and IS systems in northern and southern Peru, respectively.

Meanwhile, the IS and LS epithermal deposits are favoured targets for the junior companies because they commonly occur as discrete vein sets with the potential to host bonanza-grade gold and silver values as well as being relatively inexpensive both to delineate and develop. Well-known examples include Sumitomo Metal Mining Ltd's Hishikari in Japan (11Moz) and Newmont's Waihi district in New Zealand (7Moz).

Coalescence of veins can lead to much larger, albeit still high-grade deposits, such as Comstock Lode in Nevada (8Moz; mined mainly in the 1800s) and Kinross Gold Corp's Fruta del Norte (almost 14Moz), discovered in a little-explored region of Ecuador in 2006, both IS deposits.

Nonetheless, large-tonnage, low-grade, disseminated LS deposits are also known, such as Kinross and Barrick's joint venture Round Mountain (over 12Moz) and the recently outlined Crowfoot-Lewis (8Moz) of Allied Nevada Gold Corp, both in Nevada. In the pluton-related category, International Tower Hill Mines Ltd's Money Knob (Livengood) in Alaska (nearly 11Moz) is a just-announced, bulk-tonnage example.

Orogenic deposits are perhaps not as widely sought as they were in the early decades of the 20th century, although they are still the major producers and being actively explored for in the Archaean and younger Precambrian terranes of Canada, Western Australia, Ghana, Tanzania and elsewhere.

However, deposit types more typical of the Mesozoic and Cainozoic are being increasingly recognised in these regions, such as Osisko Mining Corp's Canadian Malartic porphyry gold deposit (11Moz) in the Superior province.

Aggregate gold production from the Archean palaeo-placer deposits of the Witwatersrand goldfield is falling continuously as the mines become deeper, the grades lower and production costs higher.

South Africa, for decades the world's main gold producer, currently lies in fourth place.

Paleo-placer deposits are uncommon worldwide, the only other major producer being the much younger Tarkwa deposit in Ghana, and therefore do not merit much focused exploration attention.

APPROACHES AND TOOLS

Gold exploration, like that for most metals, is being conducted predominantly in brownfields settings, either near operating mines and defined deposits or by reappraisal of existing prospects.

Greenfields exploration, particularly in frontier or emerging gold belts, is unpopular with the junior and major sectors alike because of the long lead times to discovery and eventual production, and the high real and perceived risks involved.

Furthermore, most juniors avoid greenfield activities because the discovery timeframe is incompatible with investor expectations.

Tommy McKeith and colleagues (Society of Economic Geologists Newsletter, 2010) analysed the discovery trends for gold deposits over the past 60 years and noted a clear decline in the number of discoveries over the past couple of decades despite an increase in exploration dollars spent.

The suggested causes are numerous, but include the major companies' increased aversion to greenfield exploration and the need for quick results that is inherent in the business model of the juniors.

The current reduced levels of greenfield exploration documented by MEG will continue negatively to affect discovery rates because, historically, it was this activity that accounted for definition of new gold belts in the last century, such as the Carlin and associated trends of Nevada, and El Indio and Maricunga belts of northern Chile.

The few recent greenfield discoveries have further underscored the potential of several emerging gold belts, including the Andes of northern Colombia (AngloGold Ashanti Ltd's La Colosa porphyry gold deposit; 13Moz) and southern Peru (Chucapaca), and the eastern margin of the Yilgarn craton, Western Australia (AngloGold Ashanti Ltd's Tropicana; 5Moz).

Successful exploration today in all geological environments and for all deposit types is underpinned, as it has been for at least the past two decades, by a sound understanding of both the empirical and genetic models for the different gold deposit types

Core samples at Barrick's Alto Chicama

and the geology of the particular prospect under exploration.

Reconstruction of three-dimensional district, and deposit-scale, geological relationships, embodying rock-type distribution, structural framework, and alteration and mineralisation zoning, is a fundamental prerequisite.

Isotopic dating to determine whether the gold prospect under study was generated during a highly-fertile epoch, and therefore offering maximal potential, is being increasingly utilised.

Other tools, such as satellite imagery, geochemistry and various geophysical techniques, provide additional data to integrate into the geological picture, and help focus both regional-, and district-, scale exploration.

The characteristics of the shallow as well as distal parts of the different deposit types is becoming

AngloGold Ashanti's Tropicana project in Western Australia

Core logging by Tethyan Copper at Reko Diq in Pakistan

particularly critical, given that many future gold discoveries will be made beneath either pre- or post-mineralisation cover.

Since gold is commonly invisible to the naked eye, even with a hand lens, geological study needs to be dovetailed with geochemistry; indeed, conventional drainage, soil and rock-chip methods are just as effective today as they were 20 years ago.

However, top-of-bedrock geochemical samples, collected by RAB or air-core drilling, are of increasing importance for gold exploration beneath post-mineralisation cover.

Geophysical methods can assist with geological understanding at both regional and prospect scales, but cannot directly detect gold; although they may define gold-bearing rock volumes rich in pyrite (chargeable or conductive), magnetite (magnetic) or quartz (resistive), for example.

Despite the advances in geophysical techniques and their input to exploration over the past several decades, Ken Witherley argues in a Society of Economic Geologists Newsletter this year that geophysical tools are approaching their ultimate limits, and explorers should not be waiting for the apocryphal silver bullet to appear.

Rather, much-improved integration of the available data from all sources, with better communication between workers in different disciplines, is more likely to provide the major advances in the coming years.

As with so many endeavours, gold exploration comes down to the people involved.

The exploration community may be subdivided into the energised learners, the doers and the inspirers, and each of these groups is essential to long-term discovery success. Discoverers are a tiny minority and, when recognised, they must be given the necessary support and freed from the bureaucracy that can so easily stifle innovation and calculated risk taking.

Concurrently, the exploration industry is faced with the dichotomy of needing the most experienced people in the field in times when temporary economic downturns lead to expedient budget and staff reductions that result in loss of this corporate ability and memory.

The essence of exploration programmes that maximise the chances of discovery remains detailed and imaginative, boots-on-the-ground geological fieldwork, preferably conducted by seasoned practitioners, who really are worth their weight in gold.

Richard Sillitoe is a past president (1999-2000) and Jeffrey Hedenquist is the current president of the Society of Economic Geologists. Detailed reviews of gold deposit types and their distribution can be found in Society of Economic Geologists publications (www.segweb.org)