GOLD DEPOSITS

Herrington R.J. and **Stanley C.J**

The Natural History Museum, London, UK

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Summary

Gold is a rare element in crustal rocks due to its generally chalcophile properties; it is increasingly enriched in mantle rocks and particularly the metallic core. In nature, gold is often alloyed with silver or copper, although tellurides and selenides are common components in some systems. Gold may substitute into the sulfides pyrite and arsenopyrite, where it is termed refractory, complicating mineral processing. It follows that gold becomes concentrated as magmas fractionally crystallize reporting to sulfide segregations that scavenge gold from the silicate residue. In crustal processes, gold is generally soluble as either chloride or sulfur complexes depending on fluid parameters. Colloids are implicated for the further transport of gold under certain conditions. Gold contents in hydrothermal fluids are generally low and a world-class gold deposit demands the migration of world-class volumes of fluids through an ore-bearing system to produce it. It is no surprise then that fluid-focusing structural conduits—the hydrothermal plumbing system—are essential components of most gold-rich environments. At surface, gold is largely concentrated physically by residual, fluvial,

and eolian processes, except in extreme weathering conditions. Given these variables, there are six or seven recognized world-class primary gold deposit types—excluding secondary deposits, such as placers. These are:

1. orogenic gold deposits
2. Carlin-type gold deposits
3. epithermal deposits
4. porphyry copper-gold deposits
5. iron oxide copper-gold deposits
6. gold-rich massive sulfide deposits

The seventh type—the Witwatersrand pebble-conglomerate type— may be an ancient alluvial placer, but which others include in the orogenic gold type. In highly saline brines, such as those typical for porphyry systems, gold is transported as a chloride, although fluid boiling in such systems may allow gold to be transported in the vapor phase to form high sulfidation epithermal deposits. Low-sulfidation epithermal deposits and orogenic gold deposits are characterized by low-salinity brines, often with a significant carbonic component, where gold is mobilized as a reduced sulfur complex. The origins of both Carlin-type and iron oxide copper–gold systems are the subject of much debate. Aspects of the genesis of many gold deposits remain unanswered, highlighted by the continued debate into the origins of the gold deposits of the Witwatersrand basin.

1. Introduction

Gold is considered to be a rare metal since, on average, the earth contains less than one-third of a gram of gold for each tonne of its mass. The earth's metallic core is enriched in gold relative to this average value, while the earth's crust, which makes up the continents and the ocean floors, contains an average of only 0.005 g of gold for each tonne of rock. At this concentration, it would require all the gold from at least 2000 tonnes of average crust to make a 10 g wedding ring. Such minute concentrations are present as isolated atoms of gold distributed as impurities in the minerals that make up the rock. However, in very localized places gold is found in concentrated amounts or deposits where it can be profitably extracted by mining. Gold may be considered the most biocompatible of all elements since it appears not to be implicated in any harmful reactions or catalysis within animal bodies.

Gold is also present in our oceans in trace quantities. The actual concentration is in the order of 20 μg of gold per liter of seawater, which, considering there are over $1\text{x}10^{21}$ L of seawater, means that the oceans contain over 20 million tonnes of gold. At a typical gold price of around US$300 per troy ounce (31 g) this makes the sea worth US$$2\text{x}10^{14}$ in gold value alone. However, a cost-effective method for recovering this gold from seawater has yet to be devised.

Oceanic crust	0.007–0.005 grams per tonne (g t^{-1})
Continental crust	0.005–0.003 g t^{-1}
Slates and shales	0.004 g t^{-1}
Conglomerates	0.03 g t^{-1}

Coal measures	up to 2.1 g t^{-1}
Mantle	0.001–0.04 g t^{-1}
Earth's core	between 0.4 and 2.5 g t^{-1}
Seawater	0.000012 g t^{-1}

Table 1: Average values for gold on the earth (various sources)

Gold ore deposits are found in rocks throughout the earth's geological history, from the earliest Precambrian—more than 3.1 billion years old—to the present. Gold deposits can still be seen today forming in some active geothermal areas. There are six "world-class" settings for magmatic-hydrothermal gold deposits:

1. orogenic gold deposits
2. Carlin-type gold deposits
3. epithermal deposits
4. porphyry copper-gold deposits
5. iron oxide copper-gold deposits
6. gold-rich massive sulfide deposits.

Nevertheless, more than 35% of the world's gold historically has been sourced from the Witwatersrand region of South Africa, from coarse clastic sediments of Archean age; these deposits are still of highly controversial origin and may form a deposit class of their own.

Deposit name, location	**Class**	**Age**	**Contained gold**	**Grades**
Witwatersrand, South Africa	Conglomerate-hosted, paleoplacer/orogenic	Archaean	>45 000 tonnes	>5g t^{-1}
Muruntau, Tien Shan, Uzbekistan	Orogenic gold, thermal aureole gold	Permo-Carboniferous	>3400 tonnes	3 g t^{-1}
Timmins District, Canada	Orogenic gold, Archaean	Archaean	1990 tonnes	6.6 g t^{-1}
Carlin-Gold-Quarry-Goldstrike, NV, USA	Sediment-hosted gold	U. Cretaceous-Tertiary	1900 tonnes	1.5–4.3 g t^{-1}
Grasberg, Irian Jaya, Indonesia	Porphyry Cu–Au	Pliocene	1500 tonnes	1.2 g t^{-1}
Lihir Island, PNG	Porphyry-epithermal	Pleistocene	1350 tonnes	2.8 g t^{-1}
Bingham, UT, USA	Porphyry Cu–Mo–Au	U. Eocene	>1200 tonnes	~0.45 g t^{-1}
Golden Mile, Kalgoorlie, Australia	Orogenic gold, Archaean	Archaean	1200 tonnes	>10 g t^{-1}
Las Medulas, Galicia, Spain	Palaeoplacer	Miocene	960 tonnes	~1 g t^{-1}
Kumtor, Tien Shan,	Orogenic gold thermal aureole gold	Permo-Carboniferous	715 tonnes	3.6 g t^{-1}

Kygyzstan				
Far South East, the Philippines	Porphyry Cu–Au	Miocene	700 tonnes	1.33 g t^{-1}
Pueblo Viejo, Dominican Republic	Epithermal, high sulfidation	Cretaceous	544 tonnes	1.98 g t^{-1}
Bajo de La Alumbrera, Argentina	Porphyry Cu–Au	Miocene	450 tonnes	0.63 g t^{-1}
Salobo, Brazil	Iron oxide copper–gold	Proterozoic	410 tonnes	0.52 g t^{-1}
Bulyanhulu, Tanzania	Orogenic gold, Archaean	Archaean	>350 tonnes	12 g t^{-1}
Horne Mine, Abitibi, Canada	Gold-rich VMS	Archaean	330 tonnes	5.9 g t^{-1}
Sar Cesmeh, Iran	Porphyry Cu–Au	Miocene	330 tonnes	0.27 g t^{-1}
Bousquet-La Ronde, Quebec, Canada	Gold-rich VMS deposit	Archaean	310 tonnes	7.7 g t^{-1}
Olympic Dam, South Australia	Iron oxide copper-gold	Proterozoic	>300 tonnes (1200 t Au resource)	0.5 g t^{-1}
Homestoke, SD, USA	Iron-formation host	Proterozoic	300 tonnes	
Porgera, PNG	Alkalic intrusion-related mesothermal	Miocene	300 tonnes	3.7 g t^{-1}
Round Mountain, NV, USA	Epithermal, low sulfidation	Oligocene	300 tonnes	1.5 g t^{-1}
El Indio, Chile	Epithermal, high sulfidation	Miocene	295 tonnes	4.4 g t^{-1}
Emperor, Fiji	Epithermal, low sulfidation	Pliocene	270 tonnes	10 g t^{-1}
Hishikari, Japan	Epithermal, low sulfidation	Pleistocene	250 tonnes	25 g t^{-1}
Gai, Urals, Russia	VMS deposit	U. Devonian	240 tonnes	0.8 g t^{-1}
Chelopech, Bulgaria	Epithermal, high sulfidation	U. Cretaceous	180 tonnes	5.3 g t^{-1}
Nambija, Ecuador	Skarn Au	Jurassic	155 tonnes	15–30 g t^{-1}

Note: g t^{-1} = grams per tonne.

Table 2: Selected gold deposits to illustrate productivity of diverse geological associations

Gold is an intrinsic component of the earth's metallic core (see Table 1) and is enriched in the mantle. Melts derived from the mantle can have above-average gold content; given favorable ascent and evolution gold may become even more enriched in late melts or immiscible sulfide melts. Many sulfide deposits formed by igneous processes from deep-sourced melts are enriched in gold. Closer to the earth’s surface, gold is enriched by a further two mechanisms. Because of the resistant nature of gold during weathering, gold survives the process of rock erosion at the surface and can become mechanically concentrated into “placer” or alluvial deposits. The other method of gold concentration is through hydrothermal activity, where gold is mobilized from its primary site in rock-forming minerals or early discrete phases and then precipitated from solution into a new phase.

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Biographical Sketches

Chris Stanley, mineralogist and economic geologist, is Deputy Head of the Department of Mineralogy at the Natural History Museum, London, UK. He obtained his B.Sc. in Geology at the University of Aston in Birmingham, UK, in 1976 and his Ph.D. at the same university in 1980. In 1980 he was appointed as an ore mineralogist at the Natural History Museum, and has worked in this field since that time. His contributions to ore mineralogy were recognized by the naming of the silver palladium selenide chrisstanleyite in 1998. He served as Acting President and Past President of the International Association on the Genesis of Ore Deposits from 1998 to 2002. Current research interests include characterization of opaque mineral species, particularly using microscope spectrophotometry and electron microprobe analysis; mineralogy and origin of ore deposits; environmental mineralogy; adsorption and chemisorption mechanisms in precious metal deposition; mechanisms and reaction pathways in hydrothermal mineralization and mineral alteration; and Transeurasian metallogeny, especially of Cornwall, Carpatho-Balkans, Tien Shan, and Siberia.

Richard Herrington, economic geologist, is leader of the Mineralogy and Origins of Ore deposits program in the Department of Mineralogy at the Natural History Museum, London, UK. He obtained his B.Sc. in Geology at the Royal School of Mines, Imperial College, UK, in 1980. From 1980 to 1987 he worked in industry as an exploration geologist, initially for Falconbridge and then Cominco. During that time he worked throughout Europe and for short periods in Canada, the United States, and Africa. In 1991 he completed a Ph.D. at the Royal School of Mines on gold deposits in the Archean of Zimbabwe, supported by a bursary from Rio Tinto. Since 1991 he has been a researcher in the Department of Mineralogy working on ore deposit problems with particular focus on gold deposits and volcanic-hosted massive sulfides. He is a past Chairman of the Mineral Deposits Studies Group of the Geological Society of London (1995–8) and serves on a committee of the Society of Economic Geologists. His group has been at the forefront of research into the association of hydrothermal systems and the evolution of associated vent fauna communities in the geological record. Currently his research is focused on the geodynamic setting of the ore deposits of the Urals, the nature and evolution of ore forming systems on the seafloor, gold in hydrothermal systems, and the development of transition metal isotope study applied to ore deposits.