HOW GEOTHERMAL EXPLORATION LED TO GOLD EXPLORATION: A CASE HISTORY - THE AFAR DEPRESSION

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INTRODUCTION

The term epithermal derives from the genetic classification scheme for hydrothermal ore deposits proposed by Lindgren (1933). On the basis of stratigraphic relationships in volcanic sequences, and by analogy with mineral and metal occurrences and mineral textures in active hydrothermal systems, Lindgren inferred that epithermal deposits formed at <200°C and <100 atmospheres (~100 bars).

In New Zealand, Japan, Philippines, United States, and other countries, the demand for alternative sources of electricity encouraged geothermal exploration drilling and development from the 1980's. Temperatures and pressures similar to those in the epithermal environment were encountered at depths of less than 1 km (e.g., White, 1981; Henley and Ellis, 1983), and precious and base metals were found deposited in springs, wells, and surface pipes (e.g., Weissberg, 1969, Hedenquist and Henley, 1985a; Brown, 1986; Krupp and Seward, 1987). The rapid increase in understanding at the time was such that the first two volumes of *Reviews in Economic Geology* focused on the nature of epithermal environments (Henley et al., 1984; Berger and Bethke, 1985). Thus, by the mid 1980s, genetic models were formulated to explain the occurrence and zonation of metals and minerals, to define the physical-chemical conditions of ore deposition in several epithermal deposits, and to provide a basis for speculation on the sources of fluids and metals (e.g., Barton et al., 1977; Kamilli and Ohmoto, 1977; Sawkins et al., 1979; Buchanan, 1981; Berger and Eimon, 1983; Henley and Ellis, 1983; Hayba et al., 1985; Heald et al., 1987; Stoffregen, 1987). In these models, hydrology was seen to be an essential factor in producing ore deposits, with boiling and fluid mixing being recognized as causative agents for metal deposition.

It was early recognised (e.g., Lindgren, 1933; White, 1955) that clear parallels exist between the near surface (~500 m) depositional environment of these deposits and that of modern hot spring systems and these were emphasized by the results of exploration activity through the Western U.S.A. (e.g., McLaughlin deposit, California).

BONANZA GOLD, BI-MODAL VOLCANISM & RIFTING

In a comprehensive analysis of the tectonomagmatic controls and styles of epithermal gold mineralization in the northern Great Basin of the western United States John (2001) distinguishes two contrasting environments: first, high sulphidation and base metal bearing low sulphidation hosted by calc-alkaline andesitic and dacitic volcanic rocks as part of a conventional arc assemblage: second, base metal deficient low sulphidation deposits associated with a bi-modal basalt-rhyolite suite generated during rifting.

Bimodal volcanic suites and low sulphidation gold deposits characterise several extensional arcs: the Palaeocene are in the central Andes of northern Chile hosts the rhyolite dome related El Penon veins; the middle to late Jurassic arc in Patagonia of southern Argentina hosts Cerro Vanguardia vein systems. Most of the low sulphidation gold deposits (Ivanhoe, Sleeper, Mule Canyon, Midas) in the northern Great Basin of the western United States were generated over a 2 m.y. interval of the Miocene within and near the northern Nevada rift, a product of back-arc extension related by some investigators to the Yellowstone mantle plume (John, 2001).

Bonanza epithermal veins are defined informally by Sillitoe (2002) as those containing roughly 1 million metric tonnes or more averaging at least ~1 oz/t Au (i.e. ~ 30 metric tonnes gold) occur sparingly in the epithermal environment. However, somewhat surprisingly nearly 60 per cent of them occur in rifts with bimodal volcanism. This conclusion lead to Stratex reviewing such rift environments and areas of hot spring activity.

THE AFAR DEPRSSION

The Afar Depression lies within the Afro-Arabian Rift System. This rift system extends from Syria in the north and passes through Jordan valley, Dead Sea, Red Sea, Afar Depression and the East African Rift and terminates in southern Africa. The Main Ethiopian Rift, the southern Red Sea and the western Gulf of Aden lie within the Afar Depression forming a rift-rift-rift triple junction between the Nubian, Somalian and Arabian Plates.

The triangular shaped Afar Depression covers an area ~ 200,000 square kilometres and is bounded by marginal escarpments which close at narrow axial rift zones and ranges. It is flanked by the Ethiopian Plateau in the west and the Somalian Plateau to the SE. The Ali-Sabieh and Danakil Blocks bound the eastern and northeastern sides of the Afar Depression, respectively. Further south, the NE segment of the Main Ethiopian Rift separates the Ethiopian and the Somalian Plateaux. The Ethiopian Escarpment extends north into Eritrea and closes the AD against the Danakil Block at the Gulf of Zula, which is a re-entrant from the Red Sea. The Gulf of Tajura extends westwards from the Gulf of Aden and separates the Ali-Sabieh Block from the Danakil Block.

The central part of the Afar Depression is dominated by lowland plains corrugated by horsts and grabens and rare local high relief peaks representing shield volcanoes. It can be divided into northern, east-central, south-western and south-eastern regions on the basis of similar structural trends.

The east-central Afar is bounded by the Danakil Block in the east and the Tendaho-Gobaad Discontinuity in the west and south-west. It is dominated by north-west trending grabens and horsts between the south-east propagating Manda-Hararo-Gobaad and the north-west propagating Asal-Manda Inakir rifts.

The southwestern Afar is a continuation of the northern part of the Main Ethiopian Rift that is interrupted by the Tendaho-Gobaad Discontinuity. It is dominated by north to north-east trending structures manifesting a series of right laterally offset grabens and horsts (Beyene & Abdelsalam, 2005).

The volcanism is strongly bi-modal.

Petrological indications suggest that silicic rocks may have been generated by fractional crystallization of transitional basaltic magmas in shallow level magma chambers with some degree of crustal assimilation. The chemistry of the 28 to 2.5 Ma old silicic rocks indicate a possible increase in crustal involvement with time, suggestive of a progressive thermal and mechanical weakening of the crust in response to thinning and magmatic modification of the lithosphere as imaged by geophysical data (Corti, 2009).

At shallow levels, magmas can fractionate in predominantly small magma bodies (dikes) and some larger magma chambers (e.g. nested calderas), where zoned reservoirs are produced with a peralkaline silicic upper layer and basalts at the bottom. In this system, eruption preferentially taps the silicic layer giving rise to the abundant silicic activity, whereas mafic melts reach the surface when fractures intersect the lower layer of the shallow chamber or reach some deep underplated basalt reservoir.

A temporal evolution from silicic volcanism from the shallow magma chambers to basaltic activity within the Wonji segments has also been suggested. In this model, the successive cooling, faulting and fracturing of the silicic centres may allow the upraising and eruption of basaltic lava flows which may have led to an increase in basaltic activity in the last 0.65 Ma. This temporal trend mimics the northward increase in basaltic volcanism toward Southern Afar. In Afar, during the last 4 Myr magmatism has been bimodal, but with predominance of basaltic rocks over silicic products. Volcanism indeed mainly consisted in the eruption of a thick stratiform sequence of fissure fed basaltic to hawaiite lava flows – Stratoid Series. Silicic (trachy-rhyolites to pantellerites) central volcanoes locally grew o the upper part of the Stratoid Series. Further to the north, in Central and Northern Afar, the zone of Quaternary extension and magmatism is marked by clusters of voluminous fissure basalts and basaltic shield volcanoes of a transitional alkali/tholeitic composition. These axial basalt ranges are interpreted to be sub-aerial equivalents of oceanic spreading centres.

GEOTHERMAL EXPLORATION

Geothermal exploration has been undertaken in the Tendaho graben of Ethiopia (Gianelli et al, 1998) and in Republic of Djibouti (Zan et al, 1990).

Hydrothermal activity, both active and extinct, was reported by Gianelli et al (1998) in Tendaho. They reported that the extinct hydrothermal activity is indicated by silica deposition within NW to NNW sub-vertical fractures crosscutting the rift sediments. The veins are made up largely of microcrystalline quartz with minor calcite, stibnite and smectite. Ur-Th absolute dating was performed on a quartz–calcite vein and yielded an age of 12.5 ka (Abbate et al, 1995). Active surface manifestations are represented by steaming grounds at Ayrobera, mud pots and fumaroles at Dubti, as well as silica sinter and hot springs at Alalobeda near or at boiling point.

No extinct hydrothermal activity was reported by the geothermal work in Djibouti however, epithermal potential had been recognised by the USGS in 1991.

Epithermal mineral occurrences have been observed at three localities, (Corbetti, Gademsa and Aluto-CanCan). Associated features were reported on the surface and at depth in drill core. These include alteration patterns that display characteristic low sulphidation type epithermal occurrences. The low sulphidation alteration commonly displays a broad propylitised (chlorite, epidote, quartz) area that envelopes a core of pervasive potassic alteration, together extending to as much as several kilometers. Locally, intermediate argillic alteration assemblages commonly overprint the potassic alteration. The alteration zone also displays broad propylitic zones, overprinted by advanced argillic alteration (kaolinite). Mineral phases include chlorite, kaolin, calcite, quartz and epidot, adularia, iron oxides, smectite and albite (Tadesse, 2001).

GOLD IN THE AFAR

Bonanza gold deposits make attractive targets because of their potential to yield high rates of return. The need for the discovery of high quality, high margin gold deposits (meaning higher grade) is essential to sustain a competitive industry position (Keith et al, 2010).

Stratex initiated a programme in January 2008 to prove the concept of gold potential of the African Rift valley. In March 2009 work commenced in the Lakes District of the Main Ethiopian Rift based on data from geothermal reports and that of Tadesse (2001). In October 2009 Stratex visited the Tendaho graben to investigate in and around known hot springs reported in Gianelli et al (1998). This resulted in the definition of the Megenta hot spring gold occurrence.

The Megenta prospect is the located at the triple junction where the north- and northeast-striking faults of the Main Ethiopian rift intersect the northwest-striking master fault that delimits the southern side of the Manda-Hararo-Gobaad rift, the position of the Tendaho-Gobaad discontinuity. The northwest-striking fault juxtaposes post-4-Ma basalt flows with a thick sequence of flat-lying, red-coloured, siliciclastic sedimentary rocks, which comprise claystone, siltstone, sandstone, grit and conglomerate. Some 2.5 km northwest of Megenta, a flow-foliated rhyolite plug is located along the rift-bounding fault, which may also have displaced it (Fig. 1).

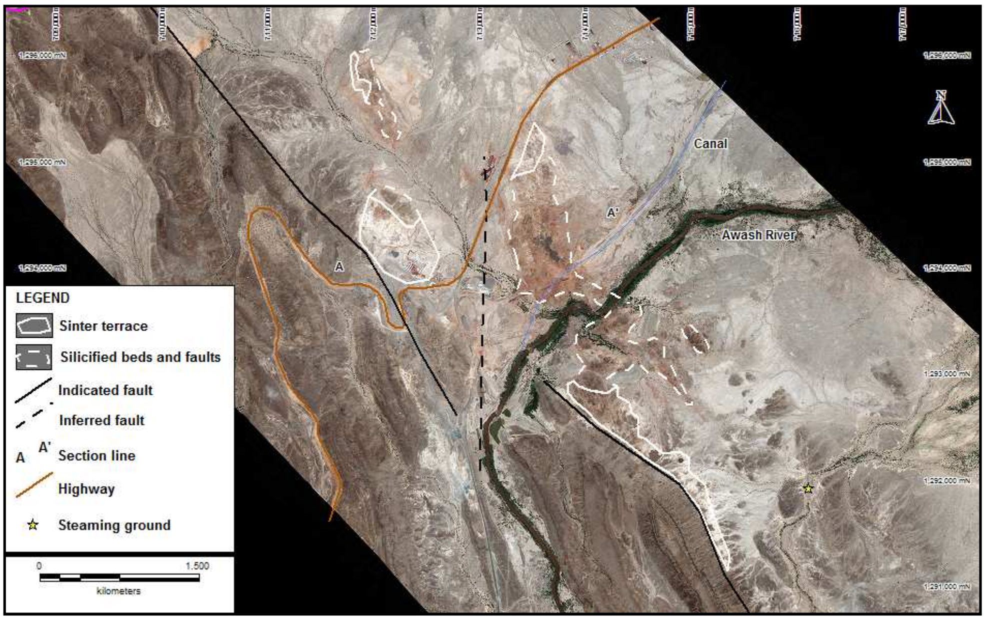

Fig. 1: Quickbird scene showing main geological features of the Megenta prospect

The rift-bounding structure and related subparallel faults immediately to the north localised an extensive hydrothermal system, which is roughly centred on their inferred intersection with one of the main north-striking faults (Fig. 1). The system, at least 6 km in a northwest-southeast direction and covering an area of >6 km^2 prior to dissection, is now extinct, although a small zone of steaming ground remains near its southern limit (Fig. 1). The Megenta system may have been active at ~4 Ka, the youngest accepted age for the host red-bed sedimentary sequence in the area.

The Alalobeda hot spring area, ~5 km southeast of the Megenta system, is localised by the same rift-bounding fault, and is highly active; it includes a geyser, fumarole, boiling mud pot and several thermal pools, all surrounded by an opaline sinter apron (Sillitoe, 2010).

The fossil Megenta hydrothermal system in outcrop comprises two closely related hydrothermal features: remnants of an extensive sinter terrace and immediately underlying silicification, the latter affecting both steeply dipping faults and subhorizontal sedimentary horizons, particularly coarse sandstone and grit beds (Figs. 1 and 2). In several places, the silicified faults, including tabular tectonic breccias, are observed to terminate at the base of the sinter terrace (Figs. 2). Elsewhere, silicified beds immediately underlie the sinter terrace.

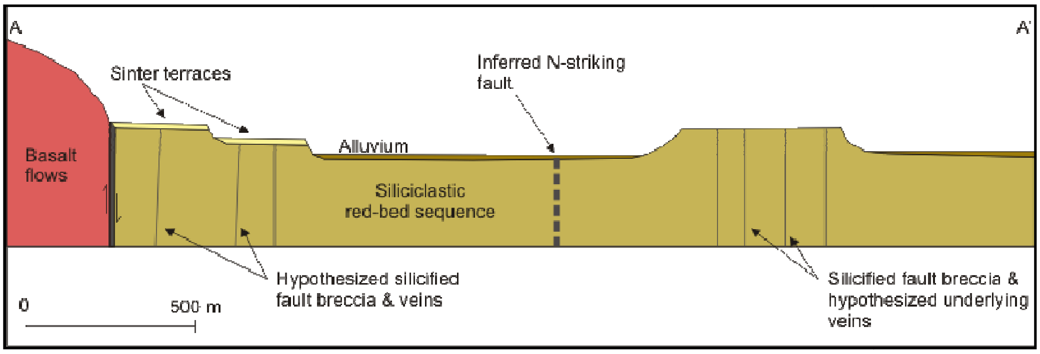

Fig. 2: Sketch section across the Megenta prospect (A–A' in Fig. 2)

The sinter terrace comprises two distinct components: typical banded opaline sinter containing a few reed stem moulds, and porous aggregates of reed stems transformed to opal. In the main Megenta area, where at least two sinter terrace levels may be distinguished in places (Fig. 2), the lower one is made up of the banded sinter and the upper one of the opalised plant matter. Although areally extensive, the sinter horizons generally do not exceed 2 m in thickness. Locally, the bacterial structure of the sinter is prominent and, in the northwesternmost sinter outcrop (Fig. 1), stromatolitic structures are evident. There, as well as locally elsewhere, paleo-water-table depression caused development of steam-heated alteration (probably mainly cristobalite) immediately beneath the sinter.

One or more individual siliciclastic beds beneath the sinter were preferentially silicified and comprise massive chalcedony. Similar chalcedonic silicification also affected the faults and their contained tectonic breccias, which range from <1 to >2 m wide. In places, at least four main, subparallel, silicified faults are present (Fig. 2). The chalcedony is everywhere limonitic as a result of supergene weathering of at least 5 volume % of contained pyrite and marcasite, which are locally preserved as disseminated grains within <1 m of the surface because of silica encapsulation.

The tectonic breccias defining parts of the faults comprise tightly packed, angular to subangular clasts of sedimentary rocks, including isolated larger pieces of reoriented sedimentary rock displaying prominent bedding. Very locally, short veins and veinlets of white chalcedony and/or crystalline calcite cut the silicified breccias. Smectite, indicative of relatively low-temperature hydrothermal conditions, is the only other alteration mineral recognised in and around the breccias.

Detailed rock channel sampling has returned highest grades of 16.7 g/t Au with anomalous gold values >0.1 g/t Au encountered over much of the prospect thus confirming the system as gold bearing.

Stratex intends to drill 3000 metres at Megenta in 2011 with view to defining if bonanza veins exist at depth within the controlling structures. In addition Stratex has taken up extensive exploration licences in the Afar of Ethiopia and also in the Republic of Djibouti.

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