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Mita, a Newly Discovered Geothermal System in Guatemala

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ABSTRACT

Mita is a moderate temperature geothermal system that was discovered in 1997 during gold exploration in southeastern Guatemala. This system is associated with bimodal basalt-rhyolite volcanism, and occurs alongside (and overlapping with) the Cerro Blanco 2 million ounce epithermal gold deposit. Fluids at temperatures up to 180°C were encountered in 150-400m deep gold exploration drillholes. Geothermometry on hot springs and well fluids indicated that most fluids were derived from the shallow 180°C reservoir, but that deep temperatures were at least 220°C.

The shallow reservoir appears to be a localized outflow from a deeper hotter system. A comprehensive MT resistivity survey suggested that the deeper reservoir was to the northeast of Cerro Blanco, and gravity surveys indicated some very strong structural control on deep permeability. Four 1000-1500m deep slimholes were drilled in 2008-09 to confirm the nature of the deep reservoir. It is planned to develop the geothermal system to provide geothermal power for the proposed gold mine and surplus power for the national grid to reduce Guatemala's dependence on carbon fuels.

1. INTRODUCTION

The Mita geothermal system is located approximately 80 km east of Guatemala City, less than 10 km from the border with El Salvador. It is 5 km from the Pan American Highway near the town of Asunción Mita, in the region of Jutiapa. Cerro Blanco (White Hill in Spanish) is a small hill that rises from about 500 m above sea level in the south to 600 m in the north, on the northern side of a basin which is at about 450 m elevation.

In 1997, MarWest Exploration visited known gold prospects, thermal areas, and places with names that suggested the presence of hot water (*e.g.* salitre, salinas, aguas tibias) in Guatemala. The Cerro Blanco mineralization was found because it is immediately adjacent to active thermal springs. There is no evidence of historical mining activity in the Cerro Blanco area. The MarWest properties were bought by Glamis Gold Ltd in October 1998, and then in 2007, Glamis Gold was acquired by Goldcorp.

A resource of approximately 2 million ounces of gold and 8 million ounces of silver has been outlined at Cerro Blanco. The hot water at depth will be a major factor that will determine when or whether that resource can be converted into reserves, but could also benefit a mine by providing a relatively cheap local source of electrical power.

Goldcorp formed a subsidiary geothermal company (Geotermia Oriental de Guatemala S.V.), which obtained a license to explore and develop the Mita geothermal system.

2. GEOLOGY

The Mita area in southern Guatemala is located near the intersection of the North American, Cocos and Caribbean plates (Figure 1). To the southwest, the Cocos plate is being subducted beneath Central America along the Middle America trench, giving rise to a chain of active volcanoes. The boundary between the North American and Caribbean plates is marked by a zone of active sinistral strike-slip faults in central Guatemala. In southern Guatemala, the major structures strike N-S, E-W, NNE and NW to NNW, and a zone of east-west extension has produced north-south trending grabens.

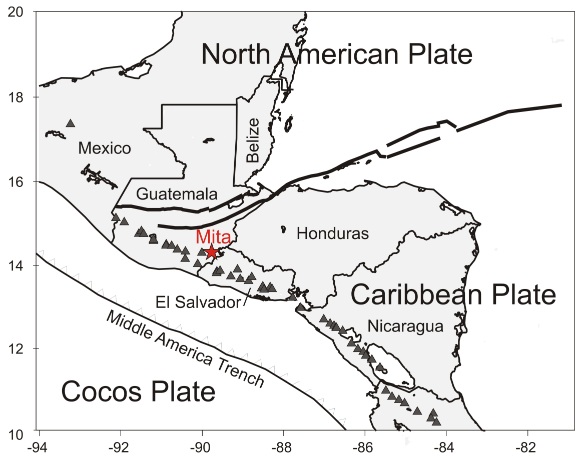

Figure 1: Tectonic setting of the Mita Geothermal System in southern Guatemala (after Monterroso and Kulhánek 2003)

While andesite stratovolcanoes are the most obvious expression of arc volcanism, the local geology is dominated by bimodal basalt-rhyolite volcanism associated with back arc rifting. Near surface units are mainly andesitic and rhyolitic tuffs, lithic tuffs and epiclastic deposits, with some basaltic and dacitic flows. These comprise a Pliocene(?) Salinas tuff/volcaniclastic sequence overlying a Paleocene-Eocene(?) Mita Group volcano-sedimentary sequence (Edwards 2006). The Mita Group includes terrestrial red-bed sandstone and conglomerate of the Subinal Formation, and older volcaniclastic deposits. These overlie a Cretaceous(?) sequence that includes altered andesites, dacites and limestones of the Tempisque Complex, which is intruded by andesite dykes and granitic intrusives. Older rocks exposed nearby include Cretaceous calcareous clastic sediments (Matapán Formation) and Paleozoic(?) schists.

The nearest large andesite stratovolcano is Volcán Suchitán, some 12 km to the northwest of Cerro Blanco. This volcano appears relatively old and eroded, with no known historic volcanic or thermal activity. Like many Central American gold deposits, Cerro Blanco is closely associated with the bimodal basalt-rhyolite volcanic association. There are a number of small basalt scoria cones and flows, and dacite and rhyolite flows and domes nearby. These include two well-preserved basalt scoria cones and lava flows about 5 and 8 km to the east of Cerro Blanco, dacite flows to the northeast and southeast, and the Ixtepeque obsidian flow-dome complex approximately 9 km north of Cerro Blanco.

Epithermal mineralization is found in and adjacent to Cerro Blanco. It is hosted by subhorizontal silicified zones up to 40 m thick that appear to be interbedded with the upper part of the Salinas Sequence. Mineralization largely occurs within quartz-adularia-calcite veins, which consist of colloform and crustiform banded quartz, adularia and calcite, including platy calcite, with dark sulfide rich bands containing pyrite, marcasite, acanthite and native gold (Economic Geology Consultants 2006). The mineralogy and textures are typical of low sulfidation epithermal mineralization.

Inventories of the geothermal resources of Guatemala make no mention of Cerro Blanco, although Ixtepeque (Palma and Garcia 1995) or Ixtepeque-Ipala is referred to (Lobato *et al* 2003, Manzo 2005). The Mita system appears to be separate from both the Ixtepeque obsidian complex and Volcán Ipala (9 and 25 km respectively to the north of Cerro Blanco).

2.1 Local Structure

Major structures that have been mapped at Cerro Blanco strike north-south, east-west, NNE and NW to NNW, as summarised in Table 1. The geological map of Cerro Blanco (Figure 2) indicates that the east-west faults are the youngest, since these offset all other faults. Hence, it can be reasoned that the east-west structures are likely to have the best permeability.

2.2 Thermal Features

Surface thermal activity comprises hot springs at Salitre, Bomba de Agua, Salinas, El Tule and Trapiche Vargas (Figure 2). In addition, several of the gold exploration drillholes around Cerro Blanco have encountered hot water, steam and gas, which has issued from some of those holes as fountains lasting for several weeks or months.

The hot springs at Salitre are surrounded by a large area of silica sinter, although there is little if any active silica deposition presently occurring around the springs. The silica sinter includes hollow mounds up to about 1 m high, from which it appears that the silica-depositing fluids issued, and some of these still discharge small amounts of hot water and gas.

In contrast, the Trapiche Vargas, El Tule and Bomba de Agua springs are surrounded by calcium carbonate deposits, which are up to 20-30 m in diameter at Trapiche Vargas. No mineral deposits were observed at the Salinas hot spring, which at 50ºC is the coolest of the springs visited, compared with up to 89°C at Salitre.

There is also some structural control on individual thermal features. At the Salitre hot springs, four separate sinter mounds are aligned north-south (175º). At the Bomba de Agua hot springs, there is an east-west (270º) alignment of six or seven separate hot springs along the north side of a small stream. This suggests that both east-west and north-south structures provide permeable channels for hydrothermal fluids.

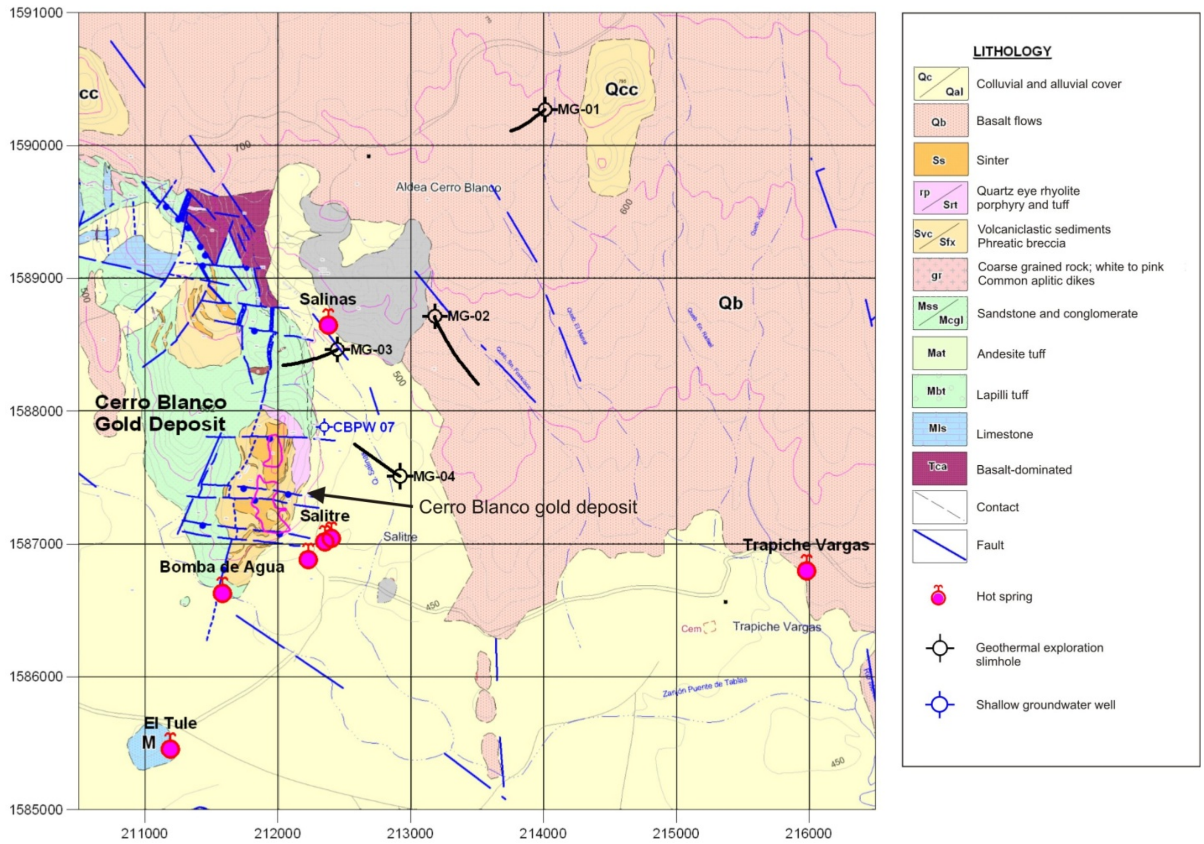

Figure 2: Geological map of the Mita – Cerro Blanco area (after Entremares 2005).

Table 1: Major structures at Cerro Blanco (from Edwards 2006)

Orientation	Description
E-W ± 10°	Paleocene-Eocene sedimentary basin-bounding, south-dipping normal faults. Reactivated; recent movement mostly post-dates vein deposition.
N10° to 15°E	Graben related normal faults. Primary vein control at Cerro Blanco.
N20° to 30°W	Provided principal control for andesite dike and quartz-rhyolite dike and dome emplacement. Primary vein control at Cerro Blanco.

2.3 Hydrothermal Alteration

Much of the hydrothermal alteration seen in drillholes and in surface outcrops appears to be related to the inactive epithermal system rather than the active geothermal system. Alteration assemblages mapped by Goldcorp at the surface include chlorite-calcite, clay, clay-sericite (illite)-pyrite, silica-clay, quartz-sericite, and silicification. The same assemblages are reported at depth, though quartz-sericite and chlorite-illite alteration are more common at depth compared with at the surface.

Petrographic analysis of samples from MG-03 indicates in addition the presence of skarn (garnet, clinopyroxene, amphibole, epidote) and potassic (biotite, K-feldspar) alteration assemblages, that are weakly overprinted by lower temperature alteration minerals (*e.g.* clays).

XRD analysis (SKM 2008, 2009) has confirmed the presence of kaolinite, corrensite, chlorite, interlayered illite-smectite and illite in drillholes, along with quartz, calcite and feldspars.

The mineralization and most of the alteration at Cerro Blanco appears to be old and unrelated to the active hydrothermal system, because:

- many of the alteration minerals formed at much greater depths than where they now occur. This includes chlorite, epidote, amphibole, garnet, clinopyroxene, and biotite, all of which must have formed at greater depth than they now occur, based on their temperatures of formation and boiling point for depth constraints.
- there is mineralogical evidence of overprinting (*e.g.* adularia by kaolinite, and biotite by chlorite and illite-smectite).
- the mineralized zones could not have formed on a hilltop. Silicification and gold deposition must have occurred from flowing thermal fluids at or below the water table. Therefore it will have formed in a low-lying area, and only forms a hilltop now because it has been uplifted and surrounding softer material has been eroded away. There has been more than 100 m of erosion around Cerro Blanco since the mineralization formed.

Thus, it appears that the MarWest exploration strategy was successful despite the mineralization at Cerro Blanco not being genetically related to the active geothermal system. It is simply fortuitous that the active geothermal system is located very close to a fossil mineralized system.

3. GEOCHEMISTRY

Hot springs have been sampled for analysis by Entremares (2005) and spring and well fluids by SKM (2008). Chemical analyses are presented in Table 2.

3.2 Spring Chemistry

The spring waters are dilute, near neutral pH, sodium-chloride-bicarbonate waters with TDS of up to 2200 mg/kg. The springs in the Cerro Blanco area have very similar chemistry to the shallow reservoir, indicating that they are fed directly from the reservoir with little modification apart from conductive cooling. The chloride concentration of up to 600 ppm suggests a deep magmatic origin.

For all the springs there is a clear trend of increasing magnesium with increasing bicarbonate which likely represents a cooling trend.

The oxygen and hydrogen stable isotope composition of the spring waters is plotted in Figure 3. Local meteoric waters probably have a composition close to that of the Salinas spring, which is relatively unmineralized. Across Guatemala, surface waters will plot along the meteoric water line, the position depending on elevation and distance from the coast. Along the prevailing wind direction, rainfall far from the coast and at high elevations will be most depleted in the heavier isotopes and therefore will plot in a more negative position.

The Trapiche Vargas water, which has the highest chloride, has a $\delta^{18}O$ shift of about +4‰ and a δD shift of about -8‰. The other springs lie along a mixing line with surface water. The negative δD shift from surface water to deep water suggests that the recharge water comes from inland highlands where rainfall is isotopically lighter, possibly with a composition of about $\delta^{18}O$ = -8.5‰, δD = -57‰. This recharge water then undergoes ^{18}O exchange with formation rocks to give a composition close to that of Trapiche Vargas, if this water is in fact the end-member. There is no boiling or steam-heating evident in the isotopic data, which would tend to shift compositions to the heavier values.

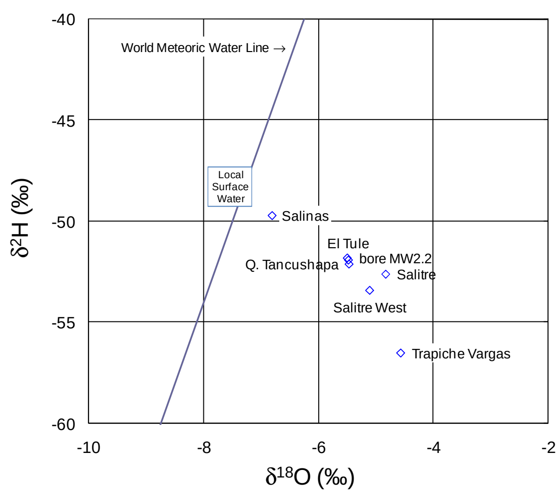

Figure 3: δ^2H versus $\delta^{18}O$ stable isotope plot

There are no surface steam discharges or steam-heated features at Mita. This is consistent with the spring temperatures, which are all below boiling point. Cooling appears to be largely conductive as the highest chloride concentrations are very close to well discharge values. There is also some additional cooling due to mixing with groundwater. The hottest spring in the Cerro Blanco group (Salitre, 89°C) has the highest chloride for this area (455 ppm), indicating that it is the least diluted by groundwater.

Of all the springs, Trapiche Vargas has the highest chloride concentration (640 ppm), the greatest $\delta^{18}O$ isotopic shift and quite promising cation geothermometer temperatures (T_{NaKCa} = 238°C).

3.1 Well Discharge Fluids

Exploration drilling at Cerro Blanco has encountered a hot water reservoir with measured downhole temperatures of 218°C in MG-02. This well has yet to be tested. Samples of atmospheric discharge water from MG-03 (T_{MAX} = 190°C) have an alkaline pH sodium chloride-bicarbonate composition with TDS of up to 2200 mg/kg. The gas content and calcite scaling potential of the well discharge waters has not yet been fully assessed.

The silica geothermometer temperature for MG-03 is about 209°C, somewhat above the maximum measured downhole temperature (190°C). The cation geothermometer values are in closer agreement (T_{NaKCa} = 197°C). The chloride concentration for MG-03 (540 ppm in total discharge) is lower than the concentration for Trapiche Vargas spring (640 ppm) which suggests that this well has not located the hottest part of the Cerro Blanco resource. More promising discharge chemistry results are expected for well MG-02.

4. GEOPHYSICS

Controlled source audio-magnetotelluric (CSAMT) and induced polarization (IP) surveys were conducted in 1998 over the central part of the epithermal gold deposit. The CSAMT survey was expanded in August 2006 to the east and south, and a combined gravity/magnetic survey was conducted along the same lines and with approximately the same coverage area.

In order to specifically examine the geothermal system with better depth penetration, a magnetotelluric (MT) survey was undertaken in January 2008, along with a broadly spaced gravity survey to complement the earlier gravity survey. The MT survey comprised 71 stations covering an area of 75 km^2, mostly to the east of the mining lease.

The MT surveys revealed a shallow layer of very low resistivity, of variable depth and thickness, but spanning most of the eastern part of the area surveyed. This layer has minimum resistivity values in the range of 1-3 Ωm, which is typical of the conductive clay caps found above and surrounding most high temperature geothermal systems.

The base of the conductor forms a dome-shaped anomaly centered to the NE of the mining lease (Figure 4). In general, this layer is deeper toward the east and south-east, and it is thickest near the Trapiche Vargas springs and in the southeast corner of the survey area. It becomes very thin in the western part of the surveyed area and just south of the Cerro Blanco deposit.

The dome in the conductive layer is underlain by a zone of higher resistivity that tapers off in the east. There is another high resistivity body in the west that is appears to be separate from the one in the east, and which closely coincides with a gravity high (Figure 5). This resistivity-gravity high appears to comprise a horst structure. The high resistivity implies that it has both low porosity and permeability, in which case it will act as a barrier to effectively prevent the circulation of geothermal fluids west of the Cerro Blanco ridge at depth.

On the basis of the MT results and what was known of the geology, geochemistry, and location of thermal features, four slimholes were targeted to the east and northeast of the Cerro Blanco mining lease. The first of these was sited near the centre of the dome in the low resistivity layer, with the others to the south and southwest.

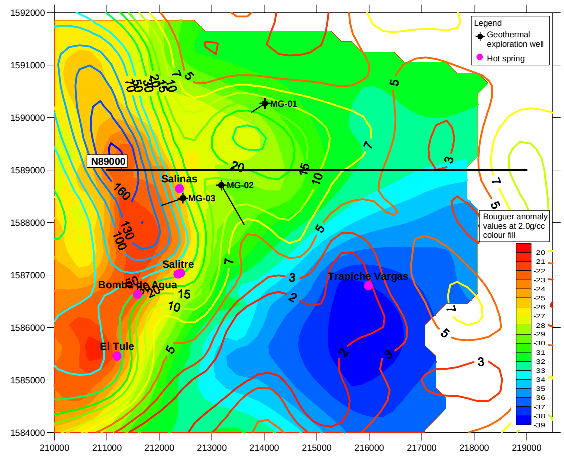

Figure 4: Bouguer anomaly map at 2.0g/cc (colour fill) and slice through the MT 3D resistivity model at sea level (contours, values in Ω.m)

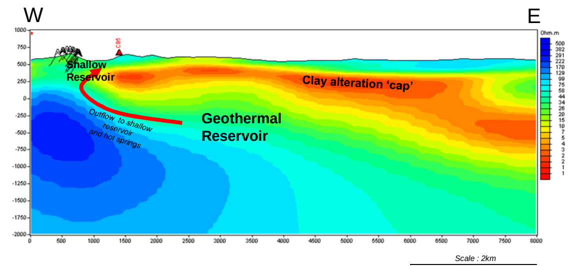

Figure 5: 3D modeled east-west resistivity section along profile N89000 (see Figure 4) showing the dome shaped conductive body thickening towards the east, and interpreted geothermal reservoir

5. DRILLING

Many holes had been drilled previously for gold exploration to a maximum depth of about 400 m in and around Cerro Blanco hill, which appears to be on the edge of the active geothermal system. The geology, geochemistry, geophysics, and locations of thermal features all point to the system being centered to the east or northeast of Cerro Blanco, but the precise location, depth and temperature of the deep reservoir were uncertain.

Accordingly, rather than regular diameter exploration wells, a slimhole geothermal drilling program commenced in late 2008. The locations of these wells are shown in Figure 2. MG-01 and MG-03 were inclined at 15° (from vertical) to the southwest, MG-04 at 20° to the northwest, and MG-02 at 30° to the southeast.

MG-01 was drilled near the centre of the main geophysical target to a depth of 1528 mMD (1497 mVD). MG-02 was located 1.75 km to the south-southwest, and drilled to 1500 mMD (1363 mVD). MG-03 was drilled near the Salinas warm spring, 2.5 km southwest of MG-01, to 1350 mMD (1271 mVD).

5.1 Lithologies

MG-01 and MG-02 encountered basalt lava flows at the surface overlying rhyolitic tuff (Salinas sequence), red bed sandstone and conglomerate (Mita Group), and siliceous volcaniclastics. MG-03 drilled into a thinner sequence of tuff, sandstone and conglomerate, and volcaniclastics before encountering veined and altered volcaniclastics and skarns (Tempisque Group), intruded by andesite dykes and granitic intrusives.

Formations occur several hundred meters higher in MG-03 than in the other two wells, which along with the presence of granitic intrusives near the bottom of this well, is entirely consistent with the geophysical interpretation of a horst structure beneath Cerro Blanco.

5.2 Alteration

The alteration mineralogy of these wells is predominantly argillic, comprising interlayered illite-smectite clay, along with calcite, quartz, chlorite, iron oxides and pyrite. Zeolites, including laumontite, were identified in MG-02 between 750 and almost 1200 mMD.

Epidote was only observed in MG-03, where it is associated with other relict alteration minerals including, amphibole, clinopyroxene, garnet and biotite, reflecting older propylitic, skarn and potassic assemblages. Interlayered clays occur throughout this well, and the argillic alteration partly overprints the other assemblages. The relict minerals may be related to the system that is responsible for epithermal gold mineralization, or a separate hydrothermal system.

5.3 Permeability

The first well, MG-01 was impermeable throughout, apart from the unaltered lava flows close to the surface. This indicates that the deep formations have low intrinsic permeability, except where they are fractured.

Permeability was encountered in MG-02 at a depth of ~1420 mMD, where the core is cut by numerous quartz veins and quartz-lined open fractures at a variety of orientations.

Minor permeability was encountered in MG-03 at 1000-1020 mMD. The core at this depth is fractured, and while most of the fractures are clay lined, several are open and free of mineral deposition.

5.4 Temperatures

The first deep well, MG-01 exhibited a near-linear conductive profile and a maximum temperature of 176ºC (Figure 6). MG-02 encountered the highest temperature of 217ºC at -800 masl and showed evidence of a convective profile. MG-03 reached a maximum temperature of 195ºC near -200 masl, with a temperature inversion below this depth.

The shallow dewatering wells in the mine area encountered a shallow, high temperature outflow. CBPW-7 had the highest measured temperature of the dewatering wells of 183ºC. All the dewatering wells exhibited temperature reversal at depth.

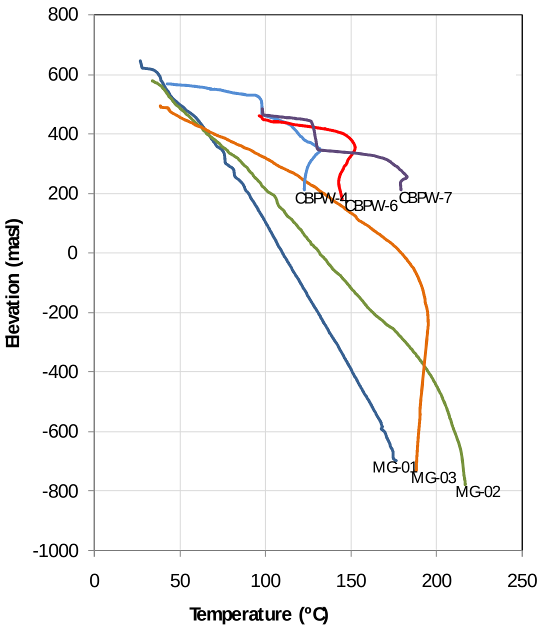

Figure 6: Stable formation temperatures for three shallow dewatering wells and three exploration wells

6. DISCUSSION

The first three completed geothermal slimholes indicate that the geophysical picture is complicated by several factors, and that alteration assemblages are affected by overprinting, while the heat source and upflow zone to the system have not yet been located. Positive outcomes from this work include the use of slimholes for exploration, and downhole temperature profiles during drilling to guide key decisions. Exploration of the Mita geothermal system will continue.

6.1 Geophysics

MT resistivity data for this geothermal system are difficult to interpret due to fossil hydrothermal alteration related to the epithermal mineralization, and the presence of detrital and/or diagenetic clays within sedimentary units.

6.2 Drilling

Slimholes have proven to be an economic method of exploring the subsurface geology and determining the permeability and temperature distribution within the system.

Downhole temperature measurements during drilling gave an accurate indication of stable downhole temperature profiles, even with just one or two hours heating time.

6.3 Permeable Structures

It was concluded that while there are a number of significant fault orientations, in general, the east-west faults are likely to have the highest permeability, based on the tectonic setting of east-west compression, and geological mapping, which indicates that the east-west faults are the youngest, offsetting faults at other orientations.

The good permeability encountered in MG-02 (oriented at 150) relative to minor permeability in MG-03 (250) and none in MG-01 (240) is consistent with this interpretation.

6.4 The Future

It is planned to drill one more slimhole (MG-04) to better understand the deep geology, permeability and temperatures before proceeding to exploration drilling using production scale wells. MG-04 will be drilled to intersect the horst fault and one of the east-west faults, and is expected to encounter good permeability.

Shallow temperature gradient holes might also be drilled, since the temperature profile in the upper few hundred meters appears to give a good indication of deep temperatures in this system, and such holes can be drilled at relatively low cost using rigs that are contracted to Goldcorp for gold exploration drilling.

REFERENCES

Economic Geology Consulting, 2006: Petrography of Cerro Blanco vein and wallrock samples, Guatemala. Unpublished report prepared for Glamis Gold Corporation, March 2006.

Edwards, J.M. 2006: Geology of the Cerro Blanco gold deposit, Guatemala: a progress report. Unpublished report prepared for Glamis Gold Ltd.

Entremares de Guatemala S.A., 2005: Reporte sobre las aplicaciones geotérmicas en el área Cerro Blanco, Jutiapa. Unpublished report prepared for Geopetrol S.A. Ambiente y Desarrollo, Guatemala.

Lobato, E.M.L., Palma, J, and Manzo, A.R.R., 2003: Geothermal Guatemala. GRC Bulletin May/June 2003: 117-121.

Manzo, A.R.R., 2005: Geothermal power development in Guatemala 2000-2005. Proceedings, World Geothermal Congress 2005.

Monterroso, D.A. and Kulhánek, O., 2003: Spatial variations of b-values in the subduction zone of Central America. Geofísica Internacional 42: 575-587.

Palma, J. and Garcia, O., 1995: Updated status of the geothermal development in Guatemala. Proceedings, World Geothermal Congress 1995: 135-140.

SKM 2008: Cerro Blanco geothermal system Guatemala, geoscientific study and review. Unpublished report prepared for Goldcorp Inc.

SKM 2009: Geology report on well MG-03 Mita Geothermal Project. Unpublished report prepared for Goldcorp Inc.

Table 2 Representative Spring and Well Chemistry

Well	Date	Type	Temp	pH	Na	K	Ca	Mg	Cl	SO_4	$tHCO_3$	B	SiO_2	T_{SiO2} (A)	T_{SiO2} (B)	T_{NaK}	T_{NaKCa}
			°C					mg/kg						°C	°C	°C	°C
Hot Springs:																	
Trapiche Vargas	Oct, 2007	hot spring	70	7-8	711	132	49.3	10.6	645	94	1057	11	81	126	123	276	238
Salitre	Oct, 2007	hot spring	89	7-8	479	50	22.1	1.0	455	101	543	9	134	154	147	221	202
Salitre (west)	Oct, 2007	hot spring	83	7-8	424	54	21.8	1.2	426	96	444	9	159	165	156	239	212
Q. Tancushapa	Oct, 2007	hot spring	78	7-8	451	39	47.3	4.6	371	100	712	6	116	146	140	205	183
Salinas	Oct, 2007	hot spring	50	7-8	48	1	6.9	0.1	4	3	137	5	95	134	130	-	47
El Tule / Finca	Oct, 2007	hot spring	79	7-8	507	41	59.9	7.8	372	108	834	6	88	130	127	198	178
Wells:																	
MW2.2	2-Oct-07	Atmos discharge		9.3	442	46	2.4	0.4	420	149	376	8	195	-	167	220	221
MG-03	30-Mar-09	Atmos discharge	190	9.0	745	56	9.8	0.1	650	188	641	10	393	-	209	194	197

Notes:
T_{SiO2} (A) - Silica Geothermometer, no steam loss
T_{SiO2} (B) - Silica Geothermometer, maximum steam loss
T_{NaK} - Sodium-Potassium, empirical (Fournier, 1979)
T_{NaKCa} - Sodium-Potassium-Calcium, empirical (Fournier and Truesdell, 1973)