DRILLING CONFIRMATION OF THE CASITA INDICATED GEOTHERMAL RESOURCE, NICARAGUA

P. White[1], K. Mackenzie[2], J. Brotheridge[2], J. Seastres[2], B. Lovelock[2] and M. Gomez[3]

[1]Panda Geoscience, M384 10/215 Rosedale Road, Albany, Auckland 0632, New Zealand

[2] SKM Limited, PO Box 9806, Newmarket, Auckland, New Zealand

[3] Cerro Colorado Power S.A., Ofiplaza El Retiro #723, Rotonda El Periodista, 150 mts al sur, Managua, Nicaragua

pwhite@pandageoscience.co.nz

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ABSTRACT

Following on from previous geological, geochemical and geophysical exploration activities, a vertical slimhole well (CSS-01) on the mid slopes of Casita volcano was completed to a depth of 842 m in November 2011 by Cerro Colorado Power (CCP). Wireline logging and flow testing of this well has confirmed the existence of a vapour-dominated reservoir at Casita, with a temperature of 230-250°C, and a total gas content of about 0.7 wt%. Based on the results from CSS-01, MT geophysics, and the distribution of surface thermal activity, the Indicated geothermal resource within the CCP concession covers an area of up to 6 km^2 as per the definition of the Canadian Geothermal Reporting Code. There is likely to be a liquid reservoir below the vapour zone around an upflow under Casita volcano, although this has yet to be proven by drilling.

Well CSS-01 (which has provided temperature and chemistry data) and the surrounding area with thermal activity constitutes an Indicated Resource. Prospective areas outside the Indicated Resource area, including La Pelona caldera and the lower flanks of Casita, are classified as Inferred Resource, based on the MT geophysical data.

A resource assessment prepared by SKM for CCP produced the following estimates:

- **Indicated Resource**: Based on a probabilistic stored heat estimate and considering the direct measurements of the well CSS-01, the indicated resource within the CCP concession is 85 MWe (gross) for 20 years (at P90).

- **Inferred Resource**: Based on a probabilistic stored heat estimate, the Inferred Resource within the CCP concession area has a capacity of 68 MWe (gross) for 20 years (at P90).

1. INTRODUCTION

1.1 Location

The Casita – San Cristobal geothermal concession covers an area of 100 km^2 in northwestern Nicaragua (Figure 1), and is held by Cerro Colorado Power S.A., which is majority owned by Ram Power Corporation. It lies approximately 20 km WNW of the San Jacinto geothermal project, which is being developed by Polaris Energy Nicaragua S.A. (also owned by Ram Power), and where construction of a 72 MWe power project is nearing completion.

The geothermal system within the Casita – San Cristobal concession generally underlies and extends northeast from Volcán Casita. The active volcanic centre of Volcán San Cristobal lies immediately to the west (Figure 2).

1.2 Previous Work

The geothermal potential of the Casita prospect was initially recognised following regional geothermal surveys undertaken by Texas Instruments, GeothermEx and Unocal. Between 1999 and 2005, Triton Minera S.A. commissioned SKM to perform integrated geological, geochemical and geophysical investigations into the geothermal potential of Casita.

An initial field reconnaissance survey in 1999 was followed by a detailed structural assessment of Casita, and then a magneto-telluric (MT) geophysical survey to help delineate the likely extent and depth of the resource. This work enabled a comprehensive definition of the resource and allowed planning of an exploration drilling program, including specific exploration well targets, to proceed.

The state of knowledge up to 2004 was reported by Bogie *et al* (2004). Subsequently, Nash (2011) incorporated the previous scientific data, together with new ASTER, SAR and a detailed (5 m) DEM into a GIS database. Some additional geological mapping and an aeromagnetic survey were undertaken by Ram Power between 2008 and 2011.

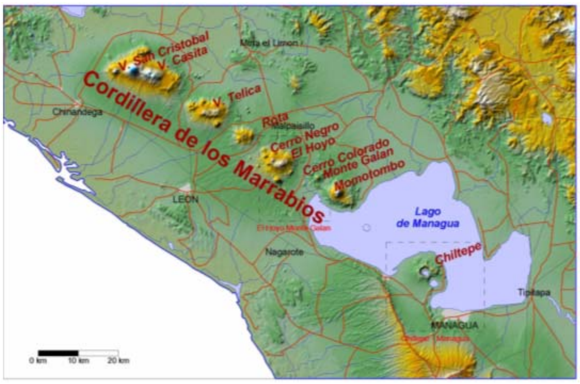

Figure 1: Location of Casita in northwestern Nicaragua.

2. GEOLOGY

The Casita ridge is made up of a series of overlapping volcanic centres that are broadly divided into three units: the San Cristobal, Casita, and La Pelona volcanics. All three units largely comprise andesitic lavas and pyroclastics, but the San Cristobal volcanics (youngest, to the west) may contain more basaltic rocks and the La Pelona volcanics (oldest, to the east) may include an uppermost dacitic pumice layer produced by the eruption that accompanied formation of the La Pelona Caldera. These units are considered to sit unconformably on the Upper Miocene Tamarindo Formation, described by Saginor *et al.* (2009) as "...*basaltic to andesitic lavas interlayered with thick ignimbrite deposits and volcaniclastic sediments*...".

Structurally, western Nicaragua is characterised by dextral trans-extension with north-south shortening (Weinberg 1992). This has produced north-west and north-east trending strike slip faults, with some associated pull-apart basins with north-south striking normal faults. This deformation has been superimposed upon a Pliocene structural regime which includes NNW and ENE strike-slip faults and north-west striking normal faults, some of which could be reactivated under the current tectonic regime. NNE and NNW striking faults predominate at Casita (Figure 2).

A structural study (SKM 2002) established potential targets for exploration drilling and assisted in planning the geophysical survey. As at San Jacinto, the N to NNE striking faults are considered likely to be the most permeable structures.

There is extensive argillic alteration with minor pyrite ± jarosite exposed to the east of Volcán Casita above about 900 m elevation. Some of the alteration is associated with current thermal activity, but much is not. There is a marked lack of silica deposition except for minor recrystallised residual silica crust near some of the steaming vents, consistent with a system that has a deep water level and is probably well capped. There is also a lack of sulphur, even close to the most active vents. Apart from some minor crystalline encrustations near the most active vents, alteration is principally produced by destructive steam heated processes, rather than by mineral deposition.

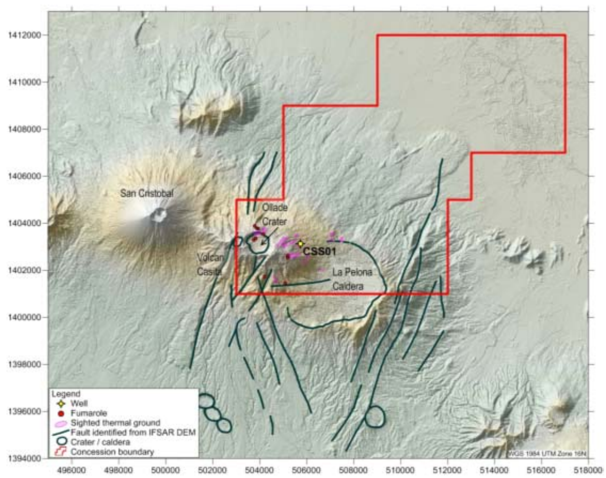

Figure 2: Casita – San Cristobal volcanic complex and geothermal concession, showing major structures (SKM 2012)

3. GEOCHEMISTRY

Thermal activity consists almost entirely of steam vents and steaming ground, spread over an area of about 5 km^2 (Figure 4). The most active fumaroles are on the northern edge of Ollade crater (elevation ~1200 m). Elsewhere on the mountain, activity is more diffuse but widespread. There are no known hot springs on the mountain, although high flowrate springs (up to 15 l/s and independent of seasonal rainfall) with temperatures up to 85°C occur in the lowlands 15 km northeast of Casita at Monte Largo and 5 km further out at El Bonete. In the intervening area there are numerous shallow wells with temperatures above ambient, although generally less than 50°C.

Fumarole steam within the Ollade crater fumaroles has a gas content of 2-3 wt%, comprising 95-97% CO_2 with gas proportions typical of benign, andesitic-hosted geothermal systems. Gas geothermometry indicates source temperatures in excess of 250°C with vapour-dominated conditions, at least at shallow depths. The oxygen-hydrogen isotopic composition (δ^2H, $\delta^{18}O$) shows a $\delta^{18}O$ shift of about +3.5‰ from local groundwater.

Steaming ground on the eastern flanks of the caldera has a high proportion of entrained air, which is a natural part of these diffuse vent discharges. The isotopic composition of this steam suggests that it is derived from secondary boiling of a steam-heated aquifer.

There is no direct evidence of a chloride reservoir at accessible depths beneath Casita, or in the lowlands to the northeast. If the thermal waters at Monte Largo, El Bonete (>80°C) or Las Grietas are derived from Casita, they are more likely to be outflows of steam-heated groundwater, rather than deep chloride water. If there is a deep chloride reservoir, it is likely to be saline, given the significant $\delta^{18}O$ isotopic shift.

4. GEOPHYSICS

A 70 station MT – TDEM survey in 2004-2005 revealed a conductive layer that drapes across the system, and which was interpreted to represent a hydrothermal clay cap above the main high temperature reservoir (SKM 2005).

The top of the conductor follows the terrain to some extent and rises to its highest elevation under Ollade crater and Casita ridge (Figure 3). The doming of the top of the conductor under Casita matches quite well with the area of thermal ground mapped in the area.

The base of the conductor rises to its highest elevation on the SE side of Casita ridge (Figure 3). This high elevation of the base of conductor is seen to continue west beneath Ollade crater, and to the NE through the northern part of the Argentina area. A local high in the base of conductor extends through the La Pelona caldera (Figure 3). This could represent an easterly extension of the Casita system or a separate geothermal upflow zone in this area.

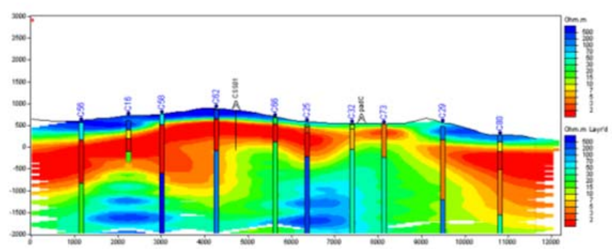

Figure 3: NW to SE 1D MT section through the NE flanks of Casita. Well CSS01 is located near point C62 near the centre of this figure, Pad C is located near point C32. The red (conductive) zone corresponds to the clay cap above the geothermal reservoir. The blue (resistive) zone corresponds to relatively fresh lavas near surface

5. WELL CSS-01

CSS-01 was drilled as a vertical well by a track mounted Christenson CS-1000 drilling rig to a total depth of 842 m between June and November 2011. Many days were spent cementing in the upper portion of the well due to repeated total losses of circulation encountered in highly permeable scoria, fractured lava flows and tuff layers. Once these zones were behind the intermediate casing, drilling down to the eventual total depth (TD) proceeded in a relatively straightforward manner, albeit with total losses of drill fluids from below the 3½” production casing shoe (PCS) at 495 m.

Below 495 m, NQ-diameter (2.98”) corehole was drilled to a depth of 842.85 m, however the NQ drill pipe became stuck in the hole at 733 m. It was decided to run a pressure-temperature (PT) wireline survey within the NQ pipe to this depth before fishing operations commenced. The PT survey was successful, however most of the pipe remained in the hole along with several other fish that were lost during the fishing operations. No further PT surveys were possible, but the well was successfully discharged.

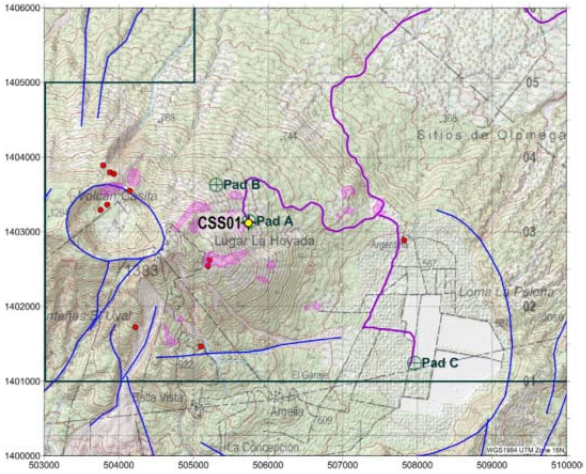

Figure 4: Location of slimhole well CSS01, along with other potential well pad sites, major structures (blue lines), thermal features (red dots), hydrothermal alteration (pink shading), access roads, and the concession boundary

5.1 Geology

The lithologies encountered in CSS-01 comprised predominantly andesitic to basaltic lava flows with minor intercalated tuff, lithic tuff and breccias, and some thin smectite-rich tuffaceous and scoriaceous material. No ignimbrites or pumice of the La Pelona Formation were encountered, indicating that the La Pelona caldera may not extend as far under the Casita volcanic pile as originally thought. Similarly, the Tamarindo Formation was not distinguished in this well.

5.2 Alteration

Alteration is weak in the top 250 m of CSS-01, and dominated by smectite, interlayered illite-smectite, kaolinite and iron oxides. The lavas are less altered than the tuffs, with only minor clay, iron oxides and possibly zeolites, mostly confined to the groundmass.

Between 250 and 400 m, alteration is moderately intense, dominated by illite-smectite clay, with minor iron oxides and calcite or cristobalite. At greater depth, alteration is moderate to intense, and the alteration mineralogy is dominated by one or more of illite-smectite, stilbite, and quartz. Other secondary minerals observed in these samples include calcite, chlorite or chlorite-smectite, adularia, anhydrite, kaolinite, opaques, iron oxides and chalcedony. Interlayered clays persist to TD, with the deepest sample analysed by XRD (710-713 m) containing interlayered illite-smectite with 60% smectite interlayers. The alteration minerals appear to have formed during a previous stage of the geothermal system, probably before the steam zone formed, as they indicate cooler conditions than measured temperatures and many of them indicate liquid dominated conditions.

5.3 Fluid inclusions

Fluid inclusion homogenisation temperatures were measured in vuggy quartz and calcite crystals in a sample from 799.4 m. These yielded temperatures of 250°C for quartz and 263°C for calcite. These temperatures are consistent with boiling point for depth and are slightly hotter than measured downhole temperatures. They are also out of equilibrium within the mineral geothermometry, which suggests a complex thermal history.

5.4 Permeability

Multiple lost circulation zones were encountered throughout the upper part of this well, where coarse scoriaceous material was highly permeable, and the many alternating layers within the lavas meant that no sooner had one zone been plugged than another loss zone was drilled into. Numerous cement plugs were used to plug these losses and regain circulation, and were a major factor in the length of time required to drill the well.

There were no specific structural targets for this well and being vertical it was not likely to intersect any near vertical structures. However at 503 m, drilling encountered a void space of 1.3 m (*i.e.* no core was recovered). The formation above and below this void appears to be the same, so the permeability was not related to a contact between two different lithologies. Below the void, the andesite was brecciated and cemented by quartz and calcite, suggesting that it might represent a major fault/permeable zone.

5.5 Temperatures

The well prognosis estimated that the top of the reservoir would be encountered at approximately 500 m based on MT data.

A maximum reading thermometer (MRT) survey was carried out during a break in the drilling at 544 m, and periodically after that down to 839 m. Generally the well was allowed to heat-up for 30 minutes or more, and then the thermometer was left at bottom hole for another 30 minutes. These measurements showed a rapid temperature increase from about 160 to 230ºC around 600 m, where possibly the top of a steam zone was encountered, and then temperatures were more or less isothermal to TD. The maximum temperature recorded was 232°C at a 696 m. The depth of the water table was determined to be at 275 m when the downhole PT survey was run.

On 25th October 2011, completion testing was carried out on CSS-01 behind NQ pipe down to 724 m. This included a shut-in survey prior to an injectivity test and a short pressure fall-off (PFO) test. The maximum temperature recorded at maximum logged depth was 225ºC (Figure 5).

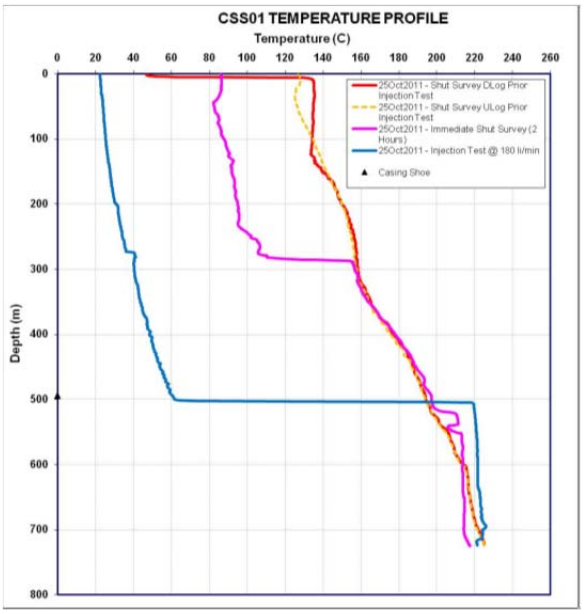

Figure 5: Downhole temperature profiles from CSS01 measured during injectivity tests

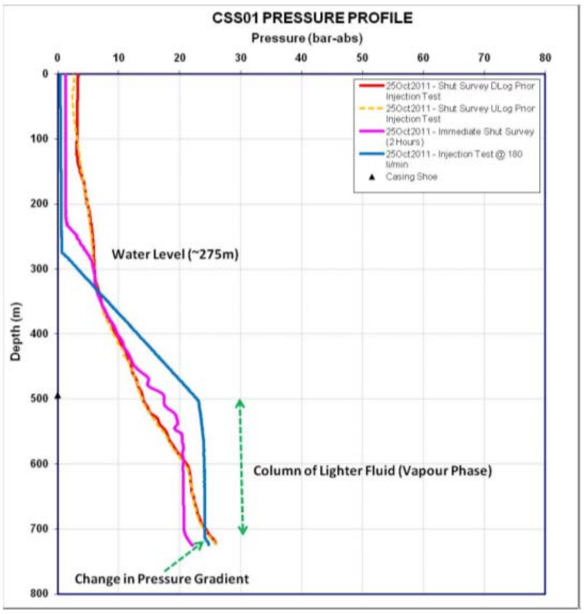

Figure 6: Downhole pressure profiles from CSS-01 measured during injectivity tests

The injection test at 180 l/min for 2 hours produced a decline in temperatures from surface to the production casing shoe (PCS) at 494 m. An increase in temperature after the PCS suggests that most of the injected fluid was lost just below the PCS. Interestingly, downhole temperatures down to maximum logged depth (225°C) are higher than the shut temperature profile prior to the injection test. None of these temperatures were quite as high as those indicated by the MRT during drilling.

The water level during the injection test was at approximately 275 m (Figure 6). A change in pressure gradient from ~508 m to ~710 m suggests the presence of less dense fluid (vapour phase). There is a slight pressure increase near the maximum logged depth around 710 m, but this could be condensate at the top of the fish.

The immediate shut survey 2 hours after injection showed recovery of downhole temperatures inside casing, but temperatures near the maximum logged depth were less than during injection. An estimate of the injectivity index from downhole pressures near the PCS is around 1.4 t/hr/bar, consistent with the total loss of circulation during drilling. The 2 hour PFO data indicates a good estimated permeability-thickness of around 0.9 darcy-meter.

5.6 Discharge testing

The well was initially shut-in with a standing wellhead pressure around 100 psig (6 barg) and then gradually opened to reach 100% opening at around 10:00am on 6 December 2011. The well discharge initially produced some hot water but quickly became a dry steam discharge after only a couple of minutes. Monitoring of the well's physical parameters commenced immediately at regular intervals over the following 10 days.

Wellbore modelling indicates that at a typical commercial wellhead pressure of 5 barg, approximately 4 tons/hr of steam flow could be produced, even with the restrictions within the wellbore due to the fish left in the hole. This steam flow equates to a power output of about 0.5 MWe assuming a steam conversion rate of 7.4 tons/hr-MWe.

The discharge steam from CSS-01 has a low gas content of 0.7 wt%, comprising mainly CO_2 (75% by volume) with relatively high H_2S (22%). The low gas content and isotopic composition (close to local groundwater) contrast strongly with the Ollade crater fumarole chemistry and suggest the CSS-01 steam is derived from late-stage boiling of a diluted reservoir water. There is considerable variability in gas geothermometer temperatures, but overall the gas proportions and geothermometry indicate deep source temperatures in excess of 250°C.

The discharge gas chemistry was stable over the 7 days of sampling, suggesting that it is representative of the reservoir steam.

Figure 7: Discharge testing of well CSS-01

7. RESOURCE ASSESSMENT

The Casita geothermal system was assessed in terms of a geothermal Resource, based on the reporting requirements specified by the Canadian Geothermal Code (CanGEA, 2010). Geothermal Reserves estimates, based on a full commercial and environmental assessment have not been considered. The resource estimates have been made using probabilistic stored heat calculations, assuming a base temperature of 50ºC and a cut-off temperature of 180ºC. The other assumptions behind these estimates are defined in a report to Cerro Colorado Power (SKM 2012).

The area around well CSS-01 (which gives temperature and chemistry data) and the surrounding area with thermal activity constitutes the Indicated Resource. Confidence in the Indicated Resource has been increased by the drilling and flow testing of well CSS-01. Prospective areas outside the Indicated Resource area, including La Pelona and the lower flanks of Casita, are classified as Inferred Resource on the basis of other evidence, in particular MT geophysics and surface thermal manifestations.

Based on probabilistic stored heat estimates and considering the direct measurements of well CSS-01, the **Indicated Resource** within the CCP concession is 85 MWe (gross) for 20 years (at P90). The total stored heat corresponds to about 2240 PJ (P90).

Based on probabilistic stored heat estimates, the **Inferred Resource** within the CCP concession area has a capacity of 68 MWe (gross) for 20 years (at P90). The total stored heat corresponds to about 1900 PJ (P90) relative to 50°C.

The Inferred Resource does not include the area of the Indicated Resource as they have different levels of confidence and thus different parameters are used in the calculations. The Indicated Resource has a much higher level of confidence than the Inferred Resource, and within the capacity ranges presented, the P90 value is the most conservative.

A gross conversion factor of 17% has been utilised. This is based on converting the recovered heat into electricity, which is largely a function of reservoir temperature, though several other factors such as silica saturation, separator pressures *etc*. are also important. It is assumed the power plant will be a condensing steam turbine, and a steam consumption rate of 7.4 t/hr/MWe has been used (similar to the new Fuji units at San Jacinto).

8. CONCLUSION

Completion of a slimhole well at Casita has enabled the temperature, chemistry and state of the geothermal reservoir to be characterised, and provided additional confidence in the resource estimates. Cerro Colorado Power is now in the process of obtaining exploitation rights to the geothermal resource, with the objective of mobilising a production drilling rig and proceeding with development drilling.

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