Client:	Renewable Resources and Energy Efficiency Fund
Well:	B1
Field:	Karkar
Country:	Armenia
Date:	31-Oct-2016
Revision:	II

Well Logging and Well Test Results for Slim Well: Karkar B1

Prepared by:

JRG Energy Consultants Ltd

Malcolm Grant

Maxwell Wilmarth

John Gilliland

CONTENTS

TABLES AND FIGURES

I. EXECUTIVE SUMMARY

The Armenian Renewable Resources and Energy Efficiency Fund (R2E2) is exploring the Karkar Geothermal Field to assess the geothermal energy potential of the site. The work is funded by the World Bank's Geofund 2: Armenia Geothermal Project, with bank-funded technical oversight by ISOR of Iceland. JRG Energy of New Zealand is providing well testing and geoscience services for the project. The first exploration well, B-1, has been completed and preparations are under way to drill the second Karkar slim well (B-2).

This report summarizes and analyses the resource data collected from well B-1. Furthermore, it integrates the newly acquired results into the conceptual model for the Karkar Geothermal Field as a whole. The location of B-2, previously selected by R2E2, is confirmed and the drilling of well B-2 is recommended to prove higher temperature and permeability than found in B-1. Additional conclusions and recommendations are offered.

Well B-1 supports the high temperature gradients and elevated temperatures of the Karkar Geothermal Field first discovered in well B-4. It has been observed that well B1 has two permeable zones, between 700-815m and 1080-1120m, with a possible minor zone at 1200-1260m. Permeability of the well is considered low by traditional Geothermal Reservoir criteria, but there is a possibility it is obstructed with debris. If this is indeed the case, the reservoir can be improved by flowing or reservoir stimulation. Reservoir temperature at the upper zone is around 60°C and the lower zone around 90°C, resulting in a producible liquid fluid at around 75°C, varying depending on the ratio of the mixture from the two zones. Well B1, with no additional drilling or alterations, will produce a low enthalpy geothermal fluid. The elevated conductive gradient at the bottom of B-1 has proven temperatures >110°C at less than 1500 m, and projected as high as 160°C at depths of 2000 m, or >200°C at 3000 m. At these depths, comparable temperatures and permeability are encountered in similar basement rocks in other areas of the world, demonstrating a potentially commercially viable geothermal energy resource.

II. INTRODUCTION

Well B-1 was spud on 15-July-2016 at a location in the volcanic depression (basin) ~500 m southeast of a volcanic dome (Figure 7). The target of the well was the low-resistivity anomaly in the basin and hot geothermal flowing fluid that may have been located in the N-S fault zone (ISOR, 2012). The well was drilled to a total depth (TD) of 1500 mRKB (1496.7 mCHF) and completed on 21-September-2016.

i. Well Data

Table 1: Summary of Well B-1

Well	B1
Date Drilled	21-September-2016
Well Test Date	22-29 September 2016
Working flange	Recovery tube in BOP
Total drilled depth	1496.7m CHF
Production Casing	7”; 0 – 658.5m CHF
Liner	4 ½”; 646.5 – 1493.5m CHF
RKB to CHF	3.55m
Max deviation	n/a
Loss zone - TLC	1100m CHF
Loss zone(s) - PLC	1450m CHF; ≈ 800m - drill string stuck at this depth

CHF = Casing Head Flange

Depth (m CFH)	Hole Diameter	Casing
12	17 ½”	13 3/8” cemented
149	12 ¼”	9 5/8” cemented
682	8 ½”	7” cemented
641	6 1/8”	Top of 4 ½” slotted liner
1497	6 1/8”	Bottom of 4 ½” slotted liner

CHF = Casing Head Flange

ii. Lithology

Well B-1 encountered young Quaternary volcanic rocks consisting largely of tuffs with occasional interbedded lava flows to a depth of 1075 m where the Paleozoic basement rocks were reached. The interbedded lavas included basalt flows to 205 m, but not below. The basement rocks consist largely of mica-schist occasionally interbedded with other types of meta-sediments including dolomitic marble, greywacke and ophiolites. A granitic body, likely an intrusion, was encountered from 1124 to 1180 m. Below the granitic body and to TD the meta-sediments do not include greywacke. Table 2 below summarizes the lithologies encountered in B-1.

Hydrothermal alteration of the primary lithologies, in general, is of low intensity and low temperature. Smectite alteration was first logged at ~960 m. Higher-grade alteration minerals such as illlite were not observed, however they may exist and could be identified with laboratory analysis of the cuttings. The Paleozoic basement rocks are of course highly altered, but this is due to ancient metamorphism.

Table 2: Summary of well B-1 lithologies.

Depth (m CFH)	Lithology
60-205	Tuffs interbedded with occasional basalt lava flows, andesites, and diorites
205-1075	Tuffs interbedded with occasional andesites and diorites
1075-1124	Meta-sediments (dolomitic marble, greywacke, ophiolite)
1124-1180	Granite
1180-1500	Meta-sediments (mica-schist, marble)

CHF = Casing Head Flange

The lithology of B-1 differs significantly from the reported lithology of B-4, ~1.5 km to the west. B-4 encountered alluvium and volcanics to 123 m and then a quartz monzanite/granosyenite intrusive from 123 m to the TD of 1000 m. The difference in lithologies may be attributed to the highly variable geology of volcanic provinces and the fact that B-1 was drilled in an extensional pull-apart basin which has likely down-dropped relative to the B-4 location and has a deeper basement contact as identified by gravity modeling (Georisk, 2012; White et al, 2015).

III. DRILLING OBSERVATIONS

JRG Energy was not involved with the drilling operations directly. A JRG Energy geologist was sent at the end of the production zone to help perform analysis of cuttings, draw conclusions from drilling reports, and aid in other areas of discussion where needed. The following sections describe the summary and analysis of these conclusions.

i. Gas

During the drilling of well B-1 little gas was detected by the mud logging unit's gas detectors. The one exception to this was while drilling at ~1106 m when total losses were encountered and a flux of H_2S gas was detected (>50 ppm, the upper limit of the detector) which corresponded to dark black fluid produced over the shale shakers. This occurred repeatedly during bit trips. This zone is within the package of meta-sediments containing dolomitic marble, greywacke and ophiolite.

ii. Loss Zones

Well B-1 encountered several zones of permeability during drilling where drilling fluids were partially or totally lost to formation. Table 3 below summarizes the loss zones encountered during drilling. The loss zone at 850 m resulted in a stuck pipe situation and was later cemented.

Table 3: Summary of well B-1 loss zones.

Depth (m CFH)	Losses
152-155	Total Losses
550-554	Total Losses
850	Total Losses, zone cemented, stuck pipe observed
1000-1006	Total Losses
1057	Total Losses
1106	Total Losses, H_2S and black water produced on subsequent bit trips

CHF = Casing Head Flange

All of the total loss zones occurred in the Quaternary volcanics overlying the Paleozoic basement rocks, except for the zone at 1106 m which produced H_2S gas and black water. This zone is located within the package of meta-sediments containing dolomitic marble, greywacke and ophiolite. Both the H_2S gas and black water may be related to hydrothermally-altered sulfur-bearing rocks and/or organic material within the buried sediments.

iii. Temperatures During Drilling

Mud in and Mud out temperature were continuously logged during the drilling of well B-1. Mud out temperatures generally increased steadily with depth from ~30°C near the surface to ~50°C at TD.

A static temperature survey was completed with a HOBO U-12-015 data logger while waiting on cement at the production casing shoe at 682 m. This survey is plotted in Figure 10 and indicated a maximum temperature at bottom of ~42°C and a generally conductive temperature gradient of ~35°C/km. Shallow groundwater permeability down to ~240 m was apparent in the log as a zone of temperature reversal, and permeability associated with the total loss zone at ~555 m is apparent as non-conductive zone.

An additional bottom hole temperature was measured with the HOBO temperature logger at 700 m, where a temperature of 41.9°C was measured. The HOBO temperature logger was reportedly allowed to equilibrate for 24 hours inside of drill pipe.

iv. Cutting Samples

At the request of Iceland GeoSurvey (ISOR), JRG was instructed to assist in selecting cuttings for further analysis at ISOR labs. Samples were collected at 21 depths that the mud log indicated may have hydrothermal alteration minerologies. These depths (in meters) were:

Table 4: Samples selection.

Depth (m CFH)	Losses
120	Sample 1
220	Sample 2
343	Sample 3
411	Sample 4
489	Sample 5
580	Sample 6
650	Sample 7
675	Sample 8
795	Sample 9
815	Sample 10
900	Sample 11
1025	Sample 12
1080	Sample 13
1115	Sample 14
1130	Sample 15
1231	Sample 16
1330	Sample 17
1367	Sample 18
1420	Sample 19
1475	Sample 20
1495	Sample 21

IV. WELL LOGGING AND TESTING

JRG Energy began completion testing of well B-1 on 23-September-2016. A dummy tool was run initially to verify the maximum open depth of the well for safe logging. This depth was found to be ~1490 mCHF, indicating ~10 m of fill material had accumulated on bottom. An initial static pressure-temperature-spinner (PTS) log was completed on slick line with a Kuster Quantum memory logging tool. Flowing PTS logs were completed on 24-September-2016 during the injectivity testing consisting of a three flow rate injection test followed by a pressure fall off test during which the Kuster tool was hung ~10 m off bottom at ~1480 m.

Additional dummy tool runs and heat-up static surveys were completed at approximately the 24 hour mark after injection ceased, at the 48 hour mark, at the 4-day mark and at the 6-day mark. Material continued to fill the bottom of the well between each survey, resulting in progressively shallower maximum logging depths. The 48 hour, 4-day, and 6-day surveys logged to ~1460 m depth. A summary of the logging runs is tabulated in Table 5 as well as in Appendix A: Table 7: Well Test Summary.

Table 5: Summary of logging runs.

Date and Time	Type of Survey	Maximum Logging Depth (m CFH)
23 September 2016	Static PTS	1490
24 September 2016	Flowing PTS	1480
25 September 2016	Static PTS	1460
27 September 2016	Static PTS	1460
29 September 2016	Static PTS	1460

i. Temperature and Pressure

Logging after the 96 hour survey indicates that the maximum temperature is ~116°C at ~1460 m. The first four static temperature surveys show a gradual heating of the well, as can be seen on the summary well log in Appendix B: Figure 10: Well Test Summary Plot as well as Figure 1 and Figure 2 below.

The small isothermal anomalies in the first and third static surveys are likely due to the Kuster tool being buried in the muddy fill material at the bottom of the well. The anomalously high bottom hole temperature in the second static survey, when a temperature of ~118°C was measured, may be due to transient temperature effects. These effects may include faster heating rates due to the higher thermal conductivity of mud than water, coupled with exothermic chemical reactions. These exothermic chemical reactions may be caused by the minerals in the cuttings reacting with water and with each other, such as oxidation of pyrite. These effects may be transitory and the 118°C measurement may not be representative of natural state temperatures at 1460 m.

Prior to the fourth static PTS survey on 27 September 2016 (96 hour survey), the HOBO temperature logger was run to 1470 mCHF inside the dummy wireline tool. This was ~10 m into the muddy fill on bottom. A temperature of 122.0°C was measured after ~1 hour. This anomalously high temperature may be continued transitory temperature increase as per the mechanisms discussed above. The temperature in the mud on bottom may continue to rise for some time, perhaps days or weeks, before declining to a natural state temperature of 115-120°C at TD.

The temperature gradient in the bottom ~150 m of the well is up to 100°C/km and similar to the bottom hole gradient in well B-4 at ~850 m (~120°C/km), although somewhat lower. The final natural state bottom hole gradient is not yet clear, but temperature gradients of this magnitude are indicative of high heat flow and are typical of geothermal systems around the world.

The bottom hole temperature and temperature gradient in B-1 support the existence of the geothermal anomaly at the Karkar geothermal Field as first identified in well B-4.

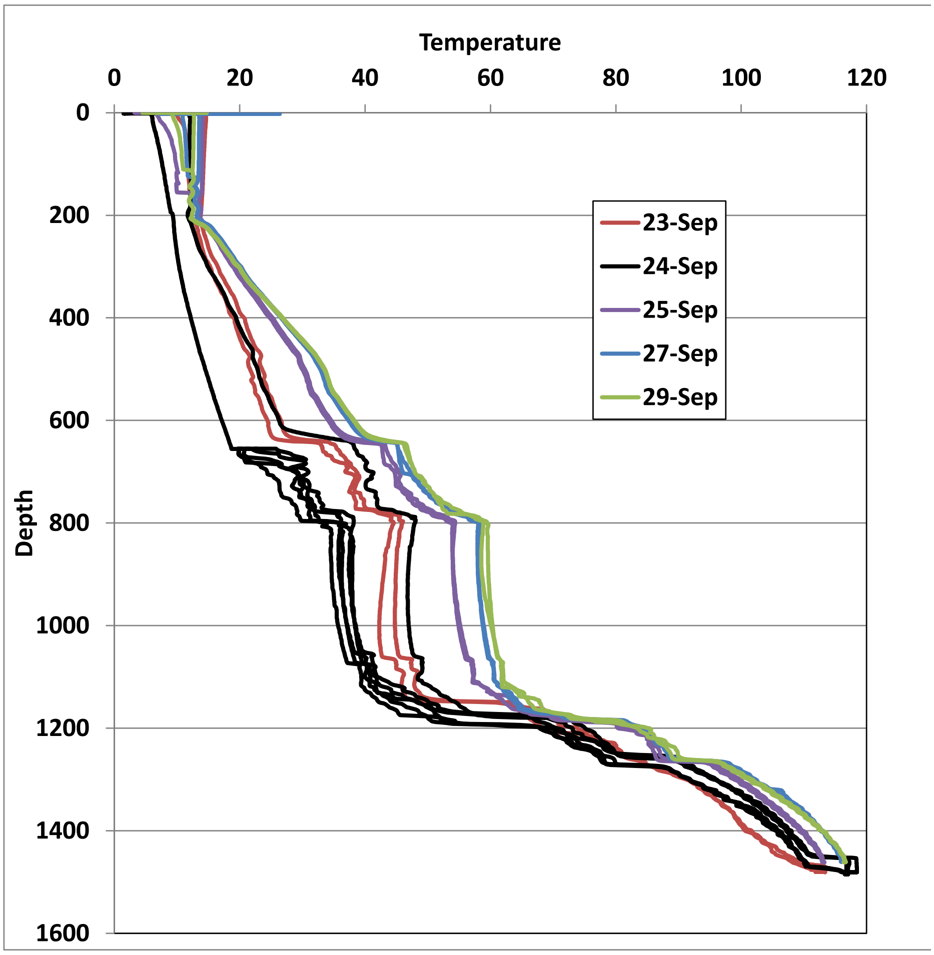

Figure 1: Downhole Temperatures measured in B1, {Temperature (degC), Depth (m)}

The table below summarizes the feed zones encountered during drilling and interpreted from the well testing.

Table 6: Summary of well B-1 feed zones.

Depth (m CFH)	Type of Feed Zone	Temperature (°C)
2-240	Shallow groundwater aquifer	~20
555-560	Total Losses in tuffs	~30-40
795-1075	Main zone, H_2S at ~850 m	~60-90
1195	Total Losses, top of fault zone (?)	~90-100
1263	Total Losses, (bottom of fault zone (?)	~100-110

CHF = Casing Head Flange

The maximum static pressures were logged during the fifth static survey (5 day survey) with ~130 bar measured at ~1460 m. This corresponds to a static water level at a depth of ~113 m. The static water levels have progressively shallowed between the five static surveys, indicating the well is filling with fluid. This rise in water level is also partially due to the thermal expansion of the water in the wellbore as it heats up. Figure 2 below shows these static pressure runs.

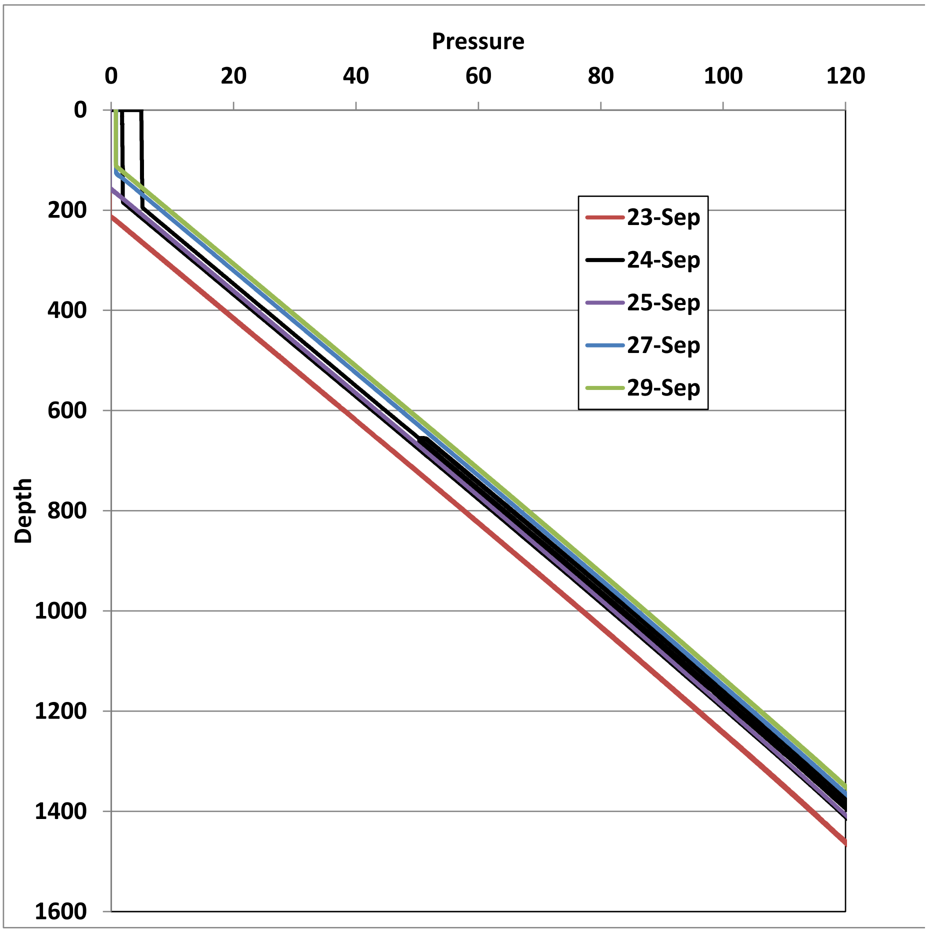

Figure 2: Downhole pressures measured in B1, {Pressure (bara), Depth (m)}

ii. Permeability

The completion test produced a good pressure falloff test (PFO), shown in Figure 3. There is a pressure drop of 2.6 bar when the pump is shut from a flow of 320 lpm, giving an injectivity of 2 l/s.b, or 7 t/h.b. This is considered to be low permeability by conventional geothermal steam production standards. The PFO shows a slight rebound at the end of the test. This is very common in wells with internal flows, and reflects the changing hydrostatic gradient within the well. It can be seen in Figure 1 that downhole temperatures were still changing during the test on 24 Sep.

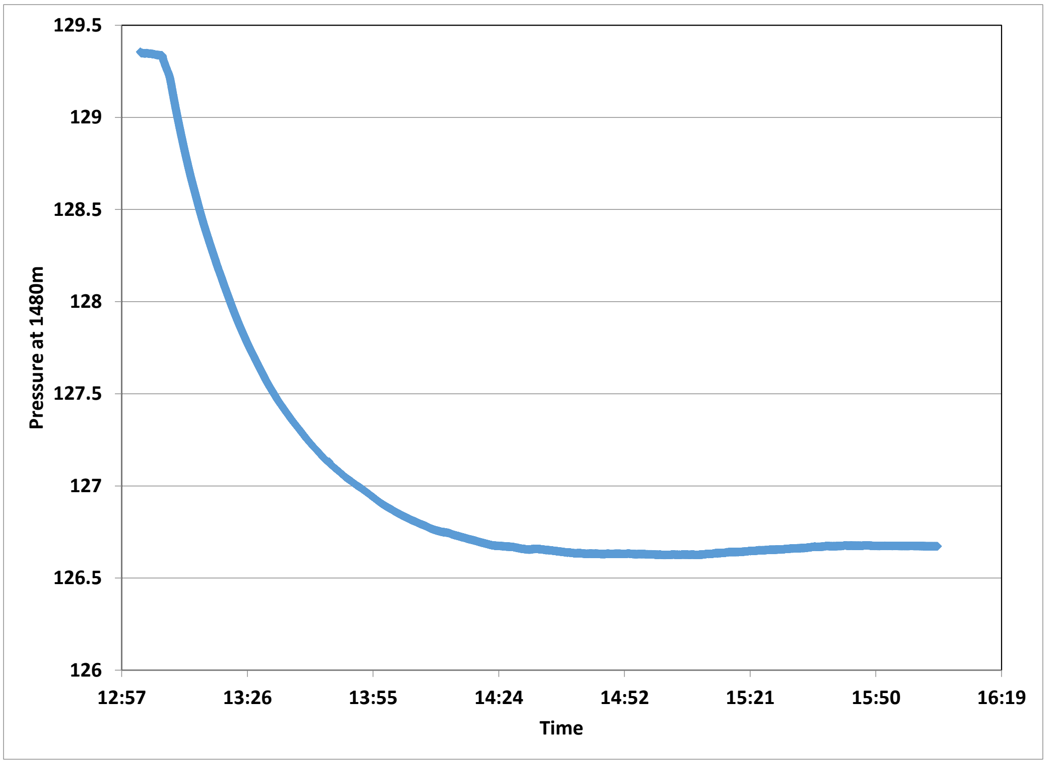

Figure 3: Pressure falloff {Pressure (bara), Time (hh:mm)}.

Three (3) out of the five (5) downhole runs had usable spinner data and are displayed in the figures below. Runs 1 & 2 did not produce usable spinner data due to low well permeability and a malfunctioning winch unit in Run1 and the spinner was clogged with wellbore debris in Run2. The subsequent three runs all produced quality data and provided very similar results.

Analysis of the spinner logs and temperature transients allows identification of permeable intervals. In all five runs, there is an internal flow within the well, with water inflowing at an upper zone extending from just below the casing shoe, at around 700m to 815m. The dominant entry appears to be the zone at ~795 m where spinner data indicates the well is inflowing with intra-wellbore flow down the well to an outflow zone at ~1075 m. The flow is around 80 litres per minute (lpm). Although the spinner data was inadequate in the first two runs, the temperature profile in these runs agrees with the subsequent three flow profiles. This dominant feed zone appears to be less than 90°C (and probably closer to 70°C) and is not the zone of interest for geothermal electricity production; although it could be utilized in a direct use/district heating application.

Secondary feed zones appear to exist at 1195 m and 1263 m. This correlates with lithology changes around the granite body and a package of meta-sediments including dolomitic marble, greywacke and ophiolites. These lithologies may be in place or they may represent an exotic block of rock moved to this location by fault displacement. Permeability is often encountered in along extensional fault planes or adjacent to fault planes in a fractured damage zone. The spinner data indicate that fluid may be flowing up the wellbore from 1263 m and exiting at 1195 m. The temperature of these two feed zones may be ~100°C.

The bottom of the well below 1263 m appears to be completely impermeable. However, the rapid heating at 1470 m between surveys suggest there may be some dynamic cooling effect associated with minor permeability at the bottom of the well that is reducing over time

Temperature of the inflow at the upper zone is nearly 60°C in the last profile. Temperature of the formation at the lower zone is obscured by the flow within the well, but based upon the temperatures below it would be around 90°C. If the well is discharged it will produce a mixture of fluid from the upper and lower zones, presumably around 75°C.

Spinner results are shown in the following three figures. Spinner data was analysed using the method of Grant, M. A., & Bixley, P. F., "An improved algorithm for spinner profile analysis". There was one pass up and down, and so a linear spinner model was used. There were biases in the results and they were adjusted to give zero flow in the casing. In all three cases there was circulation at the liner top, with upward flow within the liner and downward flow in the annulus between liner and casing. Such circulation is very common and should be ignored. Spinner analysis is plotted sowing the standard error on the calculated velocity.

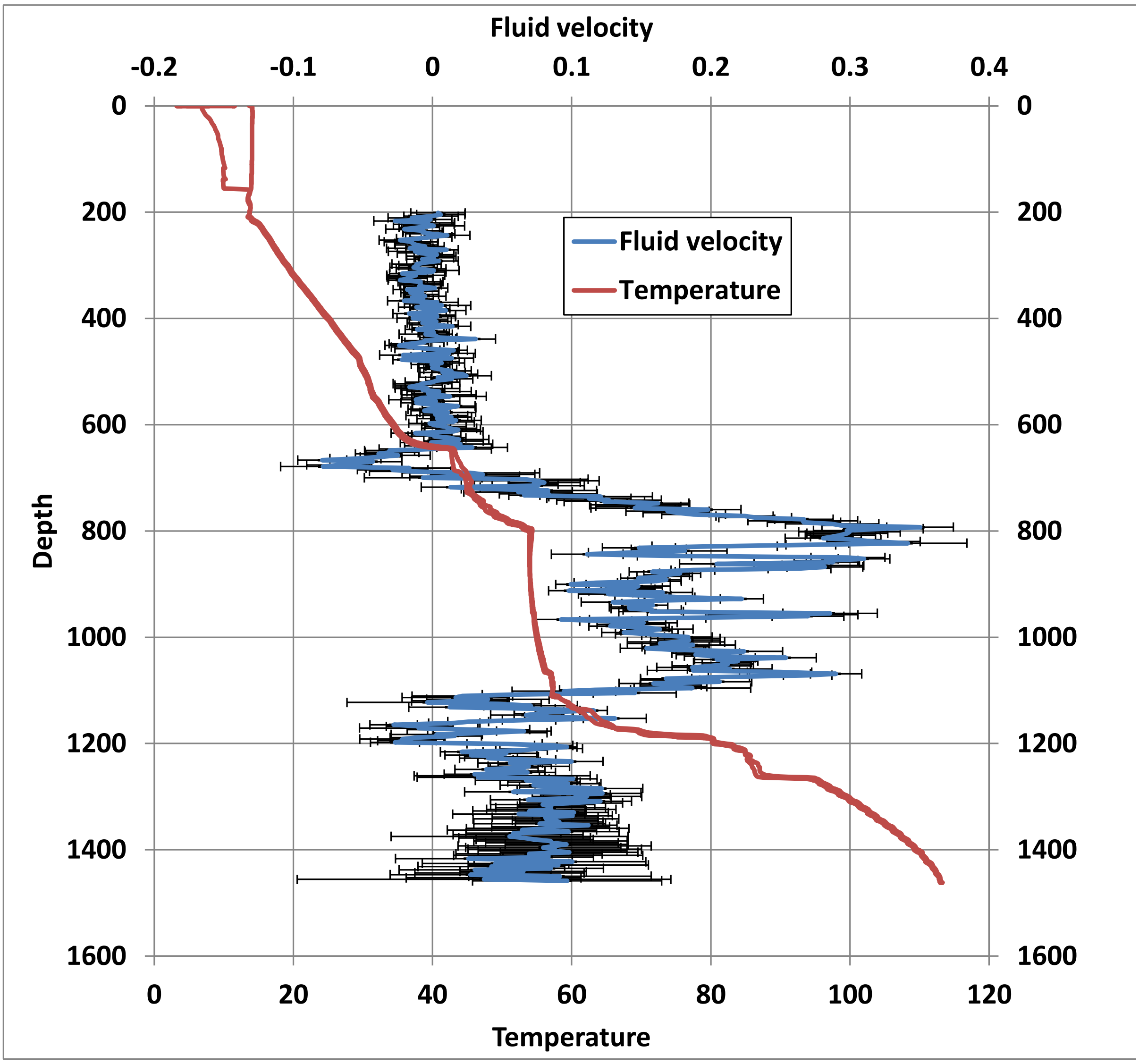

Figure 4: Temperature (degC) and spinner data (m/s) VS Depth(m), Run 3, 25 Sep-16

The data observed in Figure 4 above is an inflow over the interval 720-810m, and an outflow over 1065-1120m. Flow between the zones is 0.16 m/s, which corresponds to a flow of about 75 lpm.

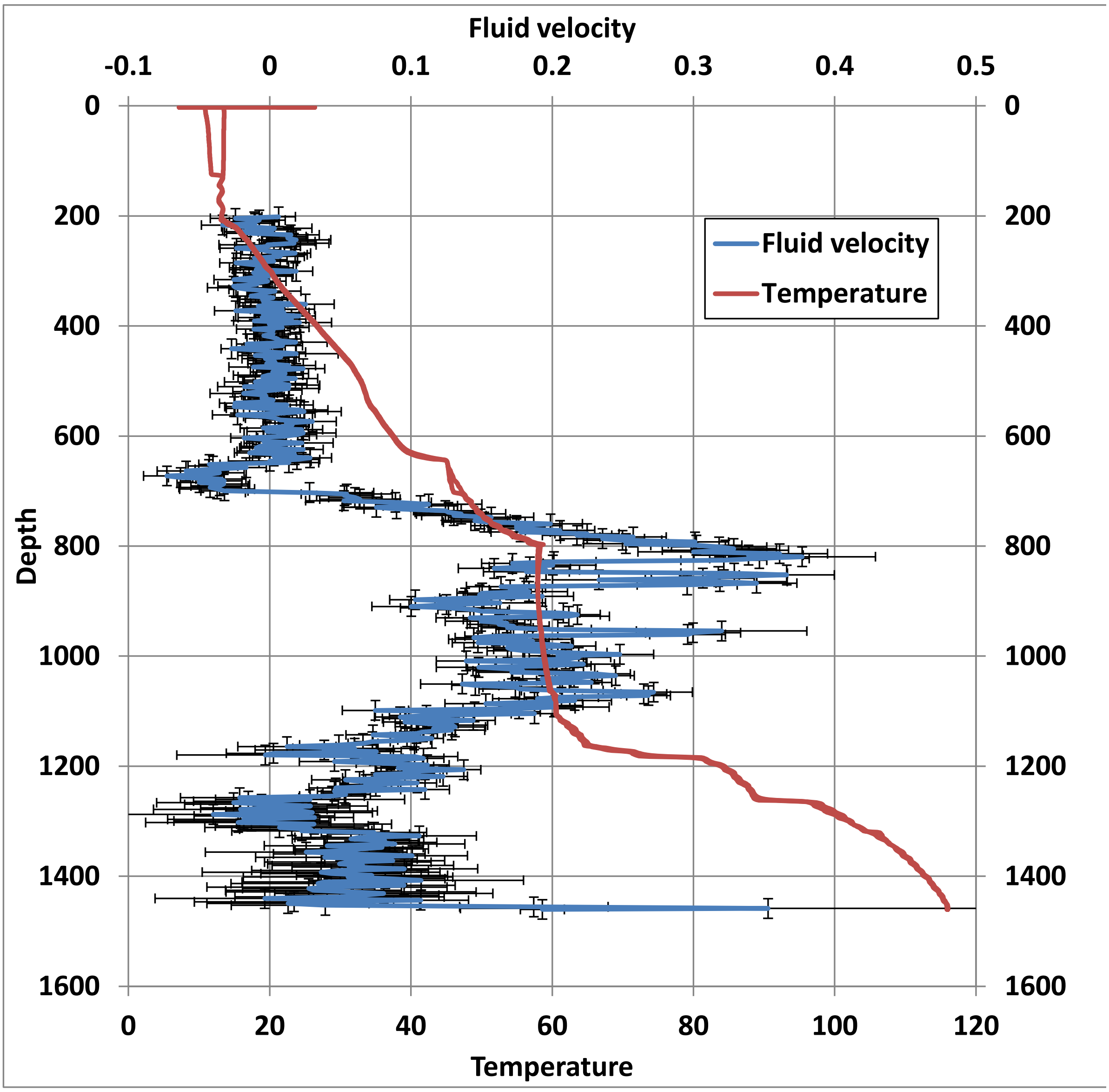

Figure 5: Temperature (degC) and spinner data (m/s) VS Depth(m), Run 4, 27 Sep-16

The data displayed in Figure 5 shows there is an inflow over the interval 700-815m, and an outflow over 1080-1260m, with most of the outflow within 1080-1150m, and the balance over 1200-1260m. Flow between the zones is 0.18 m/s, which corresponds to a flow of about 85 lpm.

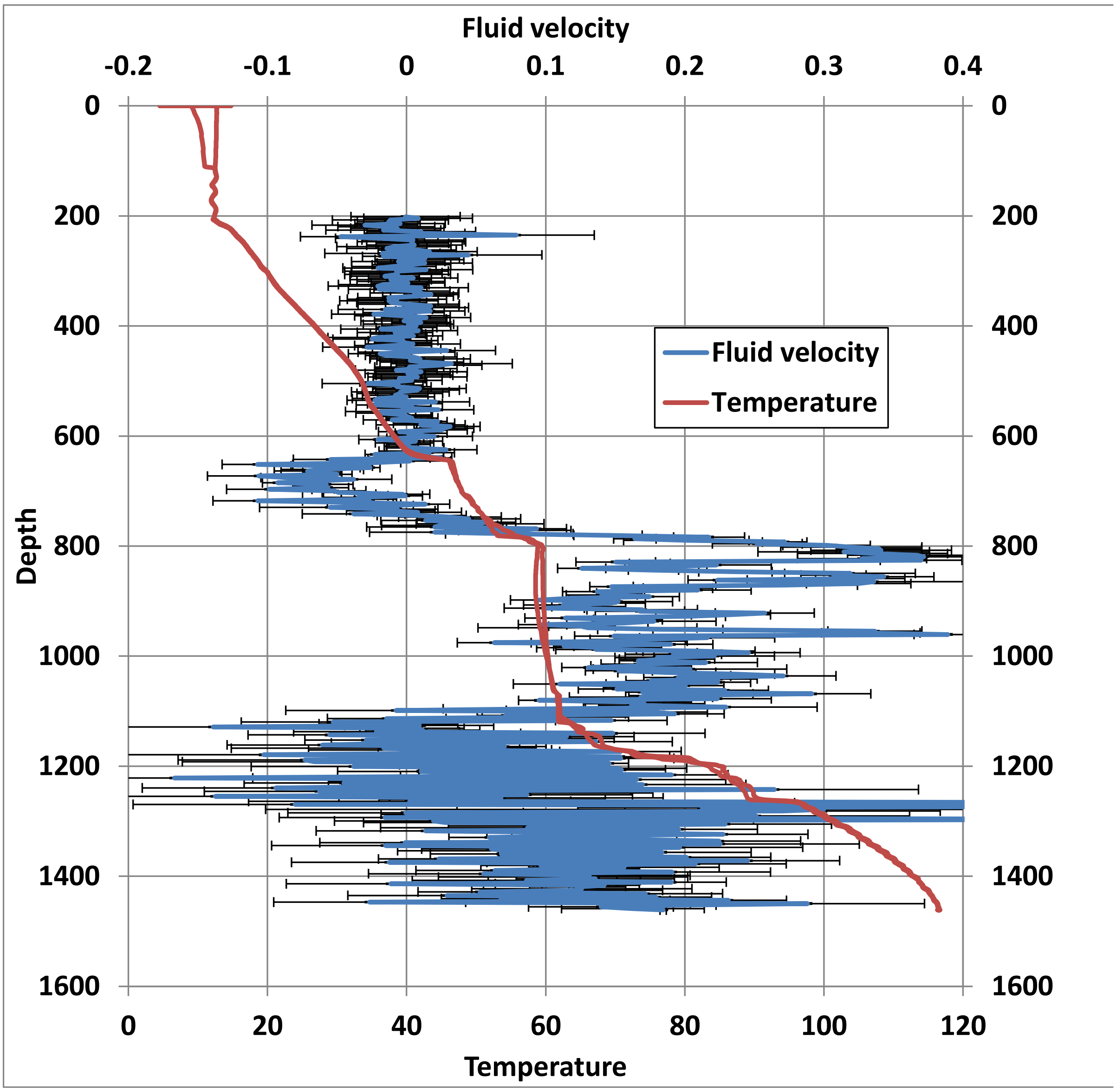

Figure 6: Temperature (degC) and spinner data (m/s) VS Depth(m), Run 4, 27 Sep-16

The data shown in Figure 6 shows there is an inflow over the interval 730-815m, and an outflow over 1100-1120m. Flow between the zones is 0.18 m/s, which corresponds to a flow of about 85 lpm.

V. UPDATED CONCEPTUAL MODEL

The conceptual model of the Karkar Geothermal Field, presented in a resource assessment report by Georisk (2012) and revised by ISOR (2012), has been revised and updated based on review of the available resource reports, original re-interpretation of the data sets, and integration of data acquired from B-1. Cross sections illustrating the conceptual model have been prepared and are presented in Figure 8 and Figure 9. Cross Section AA' runs WSW to ENE approximately perpendicular to the mapped N-S extensional fault zone and includes the Jermaghbyur Hot Spring, well B-4, and the basin containing well B-1 and proposed well B-2. Cross Section BB' runs from NNW to SSE approximately parallel to the mapped N-S extensional fault zone, through the volcanic domes on either side of the basin and wells B-1 and B-2, and approximately perpendicular to the E-W strike slip fault interpreted by Erdogan Olmez (Olmez, personal communication).

The preferred conceptual model involves a heat source at unknown depth related to volcanic intrusives and/or high regional heat flow. The location of this heat source may be below the intersection of the E-W strike slip fault and the N-S extensional fault zone. Hot buoyant fluids ascending from depth along the extension faults utilize permeable marble zones in the basement rocks and fracture networks between the faults to circulate with a geothermal reservoir at depths of approximately 2000-3000 m and at temperatures above 160°C. The intersection of the fault trends allows an upward flow of geothermal fluid to reach the permeable contact between the Paleozoic basement rocks and the overlying fractured Quaternary volcanic rocks. Geothermal fluid outflows along the basement contact in all directions at temperatures less than 100°C and mixes with cold meteoric groundwater which downflows along the fractured throats of the volcanic domes and within the fractured basin. The geothermal outflows were previously hotter for a relatively short period of time; when fluids 50-100°C circulated within the basin and hydrothermally altered the naturally low-resistivity tuffs to even lower low-resistivity smectite-zeolite clays.

Meteoric water within the pull-apart basin recharges the reservoir along extensional faults on the margins of the basin.

An outflow at >30°C flows west along the basement contact and surfaces along a minor N-S fault at the Jermaghybur Hot Spring, along with CO_2 derived from buried organic and/or deep crustal sources.

i. Karkar: Well B-2

Well B-2 is the second exploration slim well in the current drilling program. The location of this well has previously been selected by R2E2 and the drilling is currently underway ~400 m southwest of well B-1.

Well B-2 should be drilled deeper to prove higher temperatures than have been found in well B-1 and to test the conceptual model of a permeable upflow along the intersection of the E-W strike slip fault and the N-S extensional fault zone. The location of B-2 previously chosen by R2E2 and shown in Figure 7 is reasonable for encountering these higher temperatures and higher permeability than B-1. This is due to its location at the edge of the basin near the intersection of the dominant fault trends and away from cold waters circulating within the basin. Additionally, the B-2 location is marginally closer to the higher temperature gradient measured in well B-4.

Discovering high temperatures is the primary goal of well B-2. Well B-2 should be drilled to the maximum capability of the rig, reportedly 2000 m. At this depth a conductive temperature gradient similar to well B-4 could prove temperatures >180°C and indicate the potential for a high-temperature geothermal field with wells capable of self-discharging. This type of resource is much more likely to be economically developed and feasible.

The secondary goal of well B-2 is discovering permeability at commercial temperatures. Commercial permeability at commercial temperatures may be discovered in B-2 due to its location at the intersection of dominant fault trends.

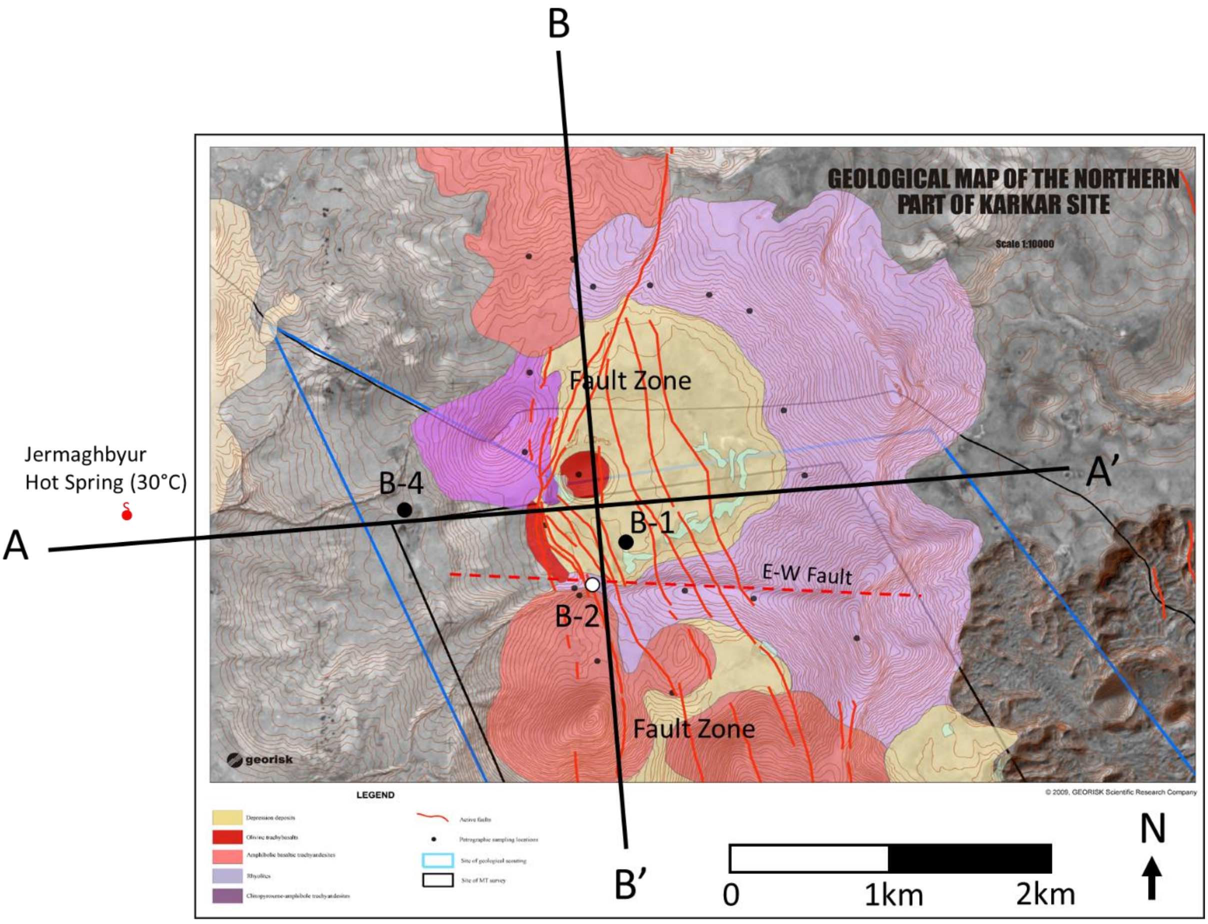

Figure 7: Map of the Karkar Geothermal Field. Base geology map is after Georisk (2009).

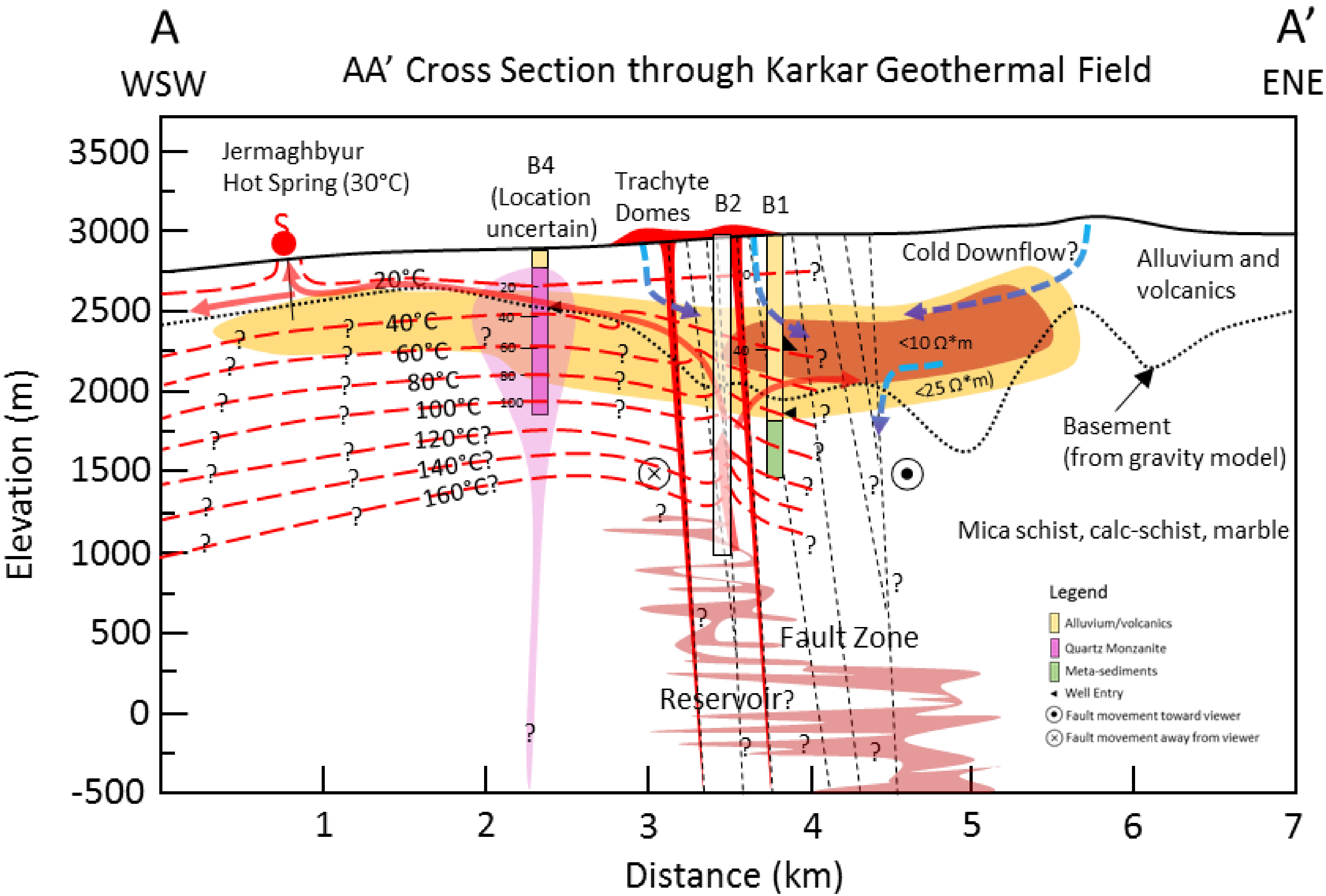

Figure 8: Cross Section AA' illustrating the conceptual model of the Karkar geothermal Field.

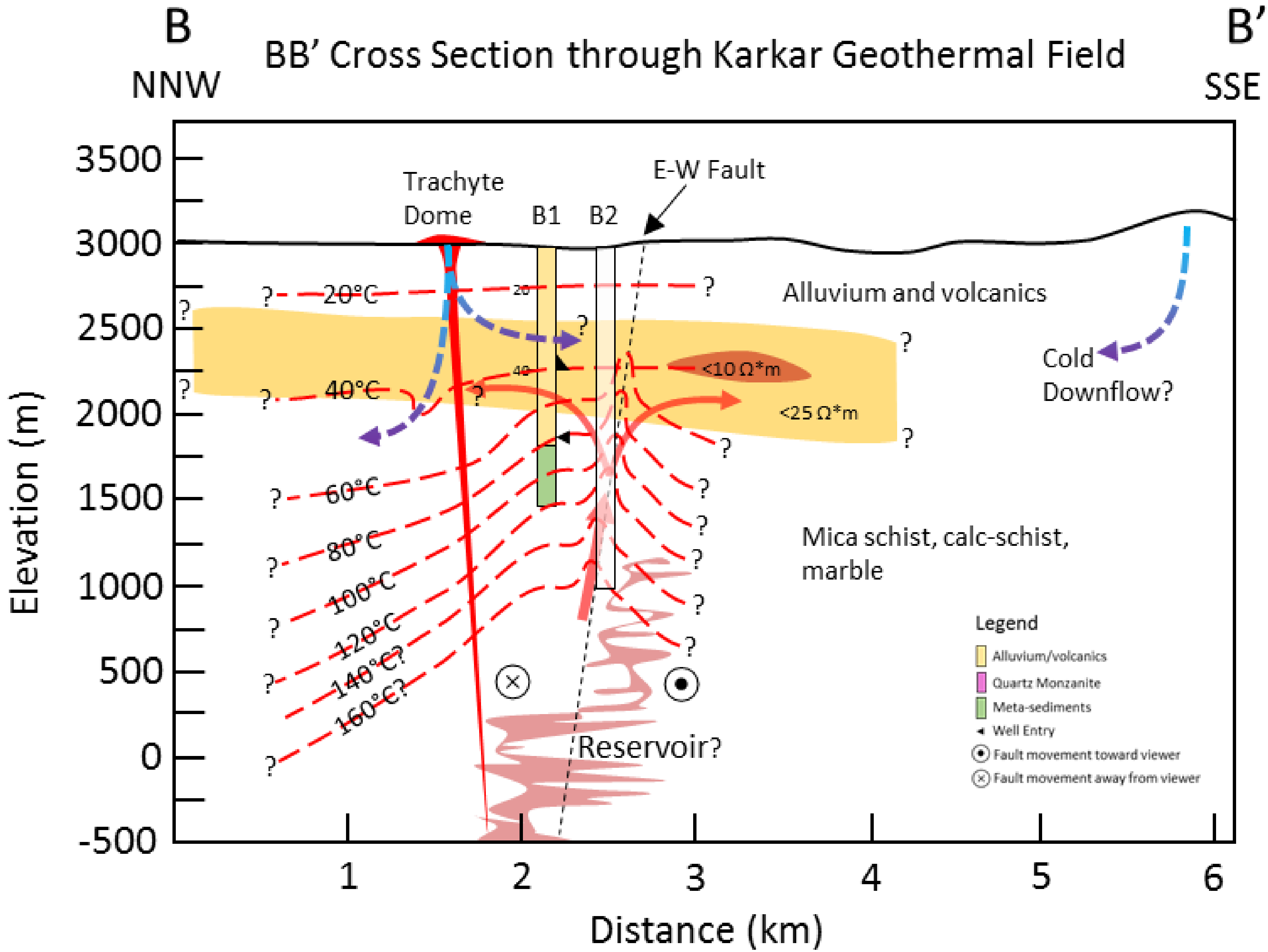

Figure 9: Cross Section BB' illustrating the conceptual model of the Karkar geothermal Field.

VI. CONCLUSIONS

Well B-1 supports the high temperature gradients and elevated temperatures of the Karkar Geothermal Field first discovered in well B-4. While the precise location of B-4 is unconfirmed (to within several hundred meters), well B-1 extends the area of this heat anomaly at least ~1.5 km east from the reported location of B-4 into the pull-apart basin. The elevated conductive gradient at the bottom of B-1 has proven temperatures >110°C at less than 2000 m, and possibly as high as 160°C at depths of 2000 m, or >200°C at 3000 m. At these depths similar temperatures and permeability are encountered in similar basement rocks underlying commercially successful geothermal energy developments in western Anatolia and in the Basin and Range Province of the western United States.

The following other conclusion also apply:

- The main feed zone of well B-1 has a temperature <100°C. Therefore, it is not the zone of interest for commercial geothermal energy production. However, it may be useful for a direct use/district heating project.
- The bottom of well B-1 is >110°C, however there are no definitive feed zones at this temperature and therefore, cannot be utilized in B-1 production. If B-1 were deepened to 2000-3000 m, it may encounter permeable zones at higher temperature within the basement rocks. This situation would be analogous to commercial geothermal fields in western Anatolia and in the western United States.
- The basement contact is permeable but contains a mixture of hot outflowing and cold downflowing waters. It is not the zone of interest for geothermal production but could be useful for injection or direct use.
- The low-resistivity anomaly is possibly the product of previously higher temperatures within the basin but is not currently associated with in situ high-temperature fluid. However, it’s geometry may still inform well targeting.
- The lateral extents of the Karkar Geothermal Field are unbounded in all directions. Deep temperatures in the basement rocks may fall of rapidly to the east of well B-1, but the upflow and hottest part of the system has not been located yet.
- The temperatures and geothermometry of the Jermaghbyur Hot Spring are consistent with outflow of a geothermal system located to the east near wells B-1 and B-2.

i. Recommendations

B-2 should be drilled to at least 2000 m at the current location chosen by R2E2 in order to prove higher temperatures and permeability associated with a possible upward flow at the intersection of the dominant fault trends.

The following other recommendations also apply:

- Cuttings from B-1 and B-2 should be analysed at an appropriate laboratory for petrographic mineral identification, alteration clays by shortwave infrared (SWIR) and/or x-ray diffraction (XRD), and possibly fluid inclusion temperature analysis. Appropriate laboratories include ISOR in Iceland and GNS Science in New Zealand.
- Gas from the Jermaghbyur Hot Spring should be sampled and analyzed at one of the above laboratories in order to calculate geothermometers and identify the source of the CO_2 gas.
- Well B-1 should be deepened at a later date to a depth of 2000-3000m. Commercial temperatures and permeability may be encountered at these depths by analogy to similar geological settings around the world that host commercial geothermal fields.

VII. Works Cited

Georisk (2009), Geological field works, Magneto-Telluric (MT) sounding of the Gridzor and Karkar geothermal fields, *Unpublished report.*

Georisk (2012), Independent interpretation of the results of the 3D MT, gravity and CO2 surveys conducted at the Karkar Site, *Unpublished report.*

Grant, M. A., & Bixley, P. F., 1995 "An improved algorithm for spinner profile analysis" Proc., NZ Geothermal Workshop, Auckland University

ISOR (2012), Memorandum, dated 3-August-2012. *Unpublished memo.*

ISOR (2013a), Armenia World Bank Energy Mission September 5 – September 10, 2013, ISOR MEMO, *Unpublished report*.

ISOR (2013b), Memo: Regarding deep resistivity profiles in Karkar area, Armenia. *Unpublished report*.

White, J.T., Karakhaniand, A., Connor, C.B., Connor, L., Hughes, J.D., Malservisi, R., Wetmore, P., (2015), Coupling geophysical investigation with hydrothermal modeling to constrain the enthalpy classification of a potential geothermal resource, *Journal of Volcanology and Geothermal Research* 298, pp. 59–70, http://dx.doi.org/10.1016/j.jvolgeores.2015.03.020

APPENDIX A: Test Summary

Table 7: Well Test Summary

Time Start	Time Stop	Comment
22Sep		
0200	1400	Issues with HD winch and also with well as it was 'tight'. Max injection into well was 2000 l/min. This caused the pressure to build up till it flattened at 28.5bg. This process repeated 3 times. The flow could only be sustained for about 40 minutes as tanks ran out of water. This process was carried out 3 more times that evening.
1630	1800	Run drift tool. Issues with winch – eventually sorted out. MCD tagged at 1494m chf
23 Sep		
1907	2100	Undertake shut PTS run – zero flow into well. Max T = 113.7 degC
24 Sep		
		Pump rate set at minimum flow of 320 l/min. This flow was maintained till a steady whp of between 4.3 – 5.5bg was maintained.
1130	1300	Kuster tool run in hole for spinnering runs
1300	1600	Tool set at PFO depth 0f 1480m. Pumps shut. When the tool was pulled to surface the spinner was totally full of cuttings – and a piece of rope. It was noticed in the data that the spinner stopped when set at the PFO depth.
25 Sep		
		Drift Run to 1470mcd
1130	1350	Shut PTS run to 1460m. Max T = 113.2 degC
27 Sep		
		Drift Run - Hobo temperature logger run inside weight bar to allow it to penetrate bottom hole fill. MCD determined to be 1465m. Hobo run to 1470m. Max T = 122 degC
1345	1600	Shut PTS undertaken. Tool logging depth 1460m Max T = 116 decC
29 Sep		
		Drift Run - Hobo logger run inside weight bar. MCD ≈ 1465m. Hobo set at this depth – max T = 122.2 degC
1230	1415	Shut PTS to 1460m. Max T = 116 degC

APPENDIX B: Summary Plot

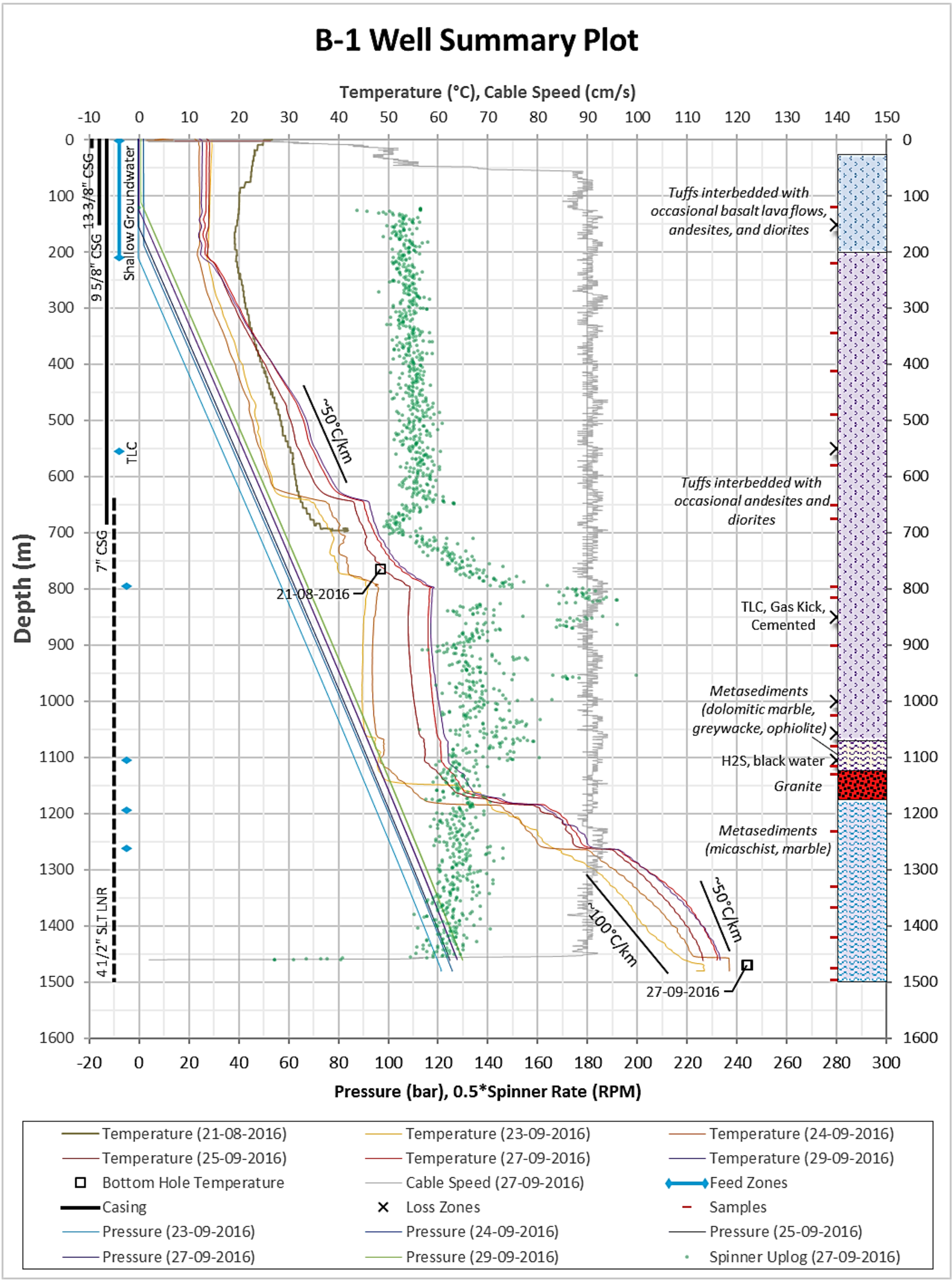

Figure 10: Well Test Summary Plot

APPENDIX C: Acknowledgements

There were many different companies that helped with the completion of this project and analysis of the data. We would like to acknowledge the following people and their respective companies:

Malcolm A. Grant
Director/Senior Geothermal Reservoir Engineer
MAGAK

Maxwell Wilmarth
Senior Project Geologist
Geologica Geothermal Group, Inc

Andrew Austin
Senior Geothermal Well Test Engineer
JRG Energy Consultants Ltd.

Dr. Mert Eker
Operational Manager
HD Energy Limited

APPENDIX D: Comments and Retort

After initial review from the World Bank and technical advisors to the project, ISOR, the following questions and comments were made:

From: Tamara Babayan [mailto:tamara.babayan@gmail.com]
Sent: Friday, 28 October 2016 4:19 a.m.
To: John Gilliland <john@jrgenergy.com>
Cc: Artur Grigoryan <ArturGrigoryan@raed.am>
Subject: Fwd: JRG Energy_Well Test Report_Karkar-B1 - World Bank comments

Dear John,

I am forwarding the comments received from the World Bank regarding the well logging and testing report.

Please send us your responses or questions if any. Also please let me know if you need to discuss the points with the geothermal team of WB, i.e. IZOR consultants.

Regards,

Tamara

Tamara Babayan
Director, R2E2 Fund
32, Proshyan str. 1st lane, Yerevan 0019, Armenia
Phone: +374 10 588011
Mobile: +374 93 930030
Web: www.r2e2.am

Dear Tamara,

Below are our comments to JRG's well logging and testing report, prepared by ISOR. In addition, the attached marked-up version of the report includes some additional comments from Thrainn that would serve to improve the document.

Please, let me know if the JRG team would like to discuss any of the points below and we can organize a call with ISOR.

Best regards,

Almudena

ISOR's comments to JRG's well logging and testing report

ÍSOR received the logging and well testing report from JRG Energy. After reading through the report, ISOR found that there are some discrepancies in some of the tables and text regarding the circulation losses and the formations recognized. Also there is a suggestion that the very low resistivity in the tuffs could be somewhat due to an older hydrothermal alteration, even though no indications are apparent in the cuttings on this alteration. In general there are also minor issues regarding the reporting and interpretation of the permeability and temperatures in well B1.

Information on the bottom hole temperature, geothermal gradient, very low permeability and the occurrence of metamorphic rocks seems to be solid.

The geothermal gradient in well B1 is high (that is after entering the metamorphic rocks), compared to the average continental geothermal gradient, or roughly 3 times higher. This is an indication of high heat flow, possibly related to volcanic activity or radioactivity of decaying plutonic rocks like granite. This may be the source of heat for a geothermal system.

Care should, however, be taken when extending a geothermal gradient to great depths, since it is usually not certain that it will extend unchanged.

1. If a reservoir (permeability) is reached, the gradient will most likely change due to convection and a uniform temperature is expected over hundreds of meters. This might happen within the next few hundred meters of drilling within in a reservoir with low to intermediate temperatures or if it is encountered deeper than that, may reach a reservoir with higher temperature.

2. If the gradient will stay roughly the same to greater depths, it might indicate that little or no permeability can be expected. Permeability will disrupt the gradient. In this case the high temperatures may be reached but no reservoir. This may then be a candidate for Hot Dry Rock (HDR) development. In general metamorphic rocks are impermeable, but analogues can be found around the world that they may host geothermal reservoirs, especially in carbonate rocks.

3. The high geothermal gradient observed just below the contact between the volcanic tuffs and the metamorphic rocks may be overestimated and can "bend off" at deeper levels (indications of this can be seen in the temperature profiles, below 1,250m). This can be due to the formations at about 1,250 m have not fully thermally recovered while they have deeper (giving a flatter temperature profile). This may also be due to heat mining form the basement just below the somewhat permeable tuffs so the temperature of the metamorphic rocks rises faster with depth in top of the basement than at deeper levels.

The high gradient indicates possibilities of the existence of a geothermal reservoir in Karkar. However, we have no solid proof of permeability at depth creating such reservoir. This reduces somewhat the hope that an exploitable geothermal system is present, at least for the intermediate to high temperature. The only surface manifestation, the Jermaghbyur Hot Spring some 2-3 km away, is not very conclusive and indicates reservoir temperatures in the region of 70-180°C (Georisk, 2012).

The conceptual model presented in the report is optimistic but does not seem impossible even though there is lack of indicative data, except for elevated geothermal gradient. A crucial point in this model is the interpretation of the low resistivity layer as a slightly hydrothermally altered layer. The cutting analysis did not confirm this, but additional XRD may clarify this point. If no trace of hydrothermal alteration is found, the conceptual model has to be revised.

Drilling of well B2 will test the conceptual model since it is aimed at the proposed up flow within faults and fractures. Therefore drilling as deep as possible is important (2000 m).

Hopefully the drilling of well B2 will give us some more indications on the situation and we sincerely hope that it will strengthen the likelihood of a commercially viable reservoir in Karkar.

JRG Energy's Comments and Retort

JRG Energy reviewed the comments and questions posed from the World Bank and ISOR. Most of the comments were simply observations or and/or a difference in professional opinion of a relatively subjective matter. JRG Energy openly accepts these comments and feels that no alterations to the initial report will need to be made at this time. Most of the questionable assessments will be proven, disproven, or otherwise left subjective upon completion of the second well; therefore, we intend on using this information for further speculation or conclusive arguments during the final Karkar well test report. Some comments and answers to question asked are below:

1. *Permeability of the well is considered low by traditional Geothermal Reservoir criteria, but there is a possibility it is obstructed with debris.* Cuttings? (Section 1.0, Paragraph 3, pg 4)

   Yes. It was observed through depth and tension data along with spinner data from the PTS that the well was being filled with debris (also interpreted as cuttings)

2. *Do you have examples of commercially viable resources where this sort of temperature gradient is observed in basement rocks?* (Section 1.0, Paragraph 3, pg 4)

   Yes. Both in Turkey and in the Geysers Basin and Range. Most of this data is proprietary, however a report comparing Karkar with specific examples can be compiled upon completion of the well test.

3. *Did the JRG team check the cuttings or is this based on the information from the mud loggers? (Section 2.2, Title, pg 5)*

   The JRG team did analyze some of the cuttings using the mudloggers equipment at the wellsite. For the most part, we generally agreed with the mudloggers's interpretation, but this was not within JGR's Scope of Work to perform proper cutting analysis.

4. *What kind of sediment is ophiolite? (Section 2.2, Table 2, pg 6)*

   Ophiolite is of course dominantly an igneous rock assemblage, but is highly stratified and the term often includes the marine sediments which cover the extrusive. Ophiolites also contains sedimentary deposits chemically precipitated from mineral-rich hydrothermal fluid encountering cold seawater.

5. *The geothermal outflows were previously hotter for a relatively short period of time; when fluids 50-100°C circulated within the basin and hydrothermally altered the naturally low-resistivity tuffs to even lower low-resistivity smectite-zeolite clays. I am not fully comfortable with this statement. The cuttings did not show any significant alteration so it can not be argued that the low resistivity zone, observed in the MT data, is due to fossil hydrothermal activity. It does not add up. … (Section 5.0, Paragraph 2, pg 17)*

Alteration is logged in the cuttings throughout the well, in the form of pyrite, smectite and others, albeit at low intensity. Alteration products, especially smectite, can sometimes be preferentially lost to the mud circulation system so it is possible there was more smectite in situ than what was logged. The degree of alteration logged to 1500 m in B-2 is consistent with a low temperature outflow from a moderate temperature resource.

Currently, fluids in well B-1 within the drilled basin (above the metamorphic basement) are <70°C. However the cuttings from within the basin, beginning at ~650 m, have logged alteration including smectite. Smectite can occur alone as an alteration clay mineral from low temperature up to ~70°C, above which it begins to interlayer with illite (Harvey, 2013). This interlayered smectite/illite alteration is best identified with laboratory XRD methods. JRG's conceptual model for the Karkar reservoir allows for higher temperature geothermal fluid (up to ~100°C) to have previously circulated in the basin above the metamorphic basement, but this is not required by the data. XRD analysis of the cuttings samples sent to ISOR will help to determine if higher temperature alteration minerals, such as illite, are present in the cuttings, which would indicate previously higher temperatures.

Reference: Harvey, C., (2013), *Water-Rock Interaction, Alteration Minerals and Mineral Geothermometry*, IGA Academy Report 0111-2013.

6. *At this depth a conductive temperature gradient similar to well B-4 could prove temperatures >180°C and indicate the potential for a high-temperature geothermal field with wells capable of self-discharging. This type of resource is much more likely to be economically developed and feasible. As compared to what? (Section 5.1, Paragraph 2, pg 18)*

A resource with temperatures >180°C is much more likely to be economically developed and feasible for **power generation** than the resource at ~120°C discovered in B-2. This is taken from the global percentage of economically developed geothermal power stations created from known geothermal resources with temperature >180°C compared to the global percentage of economically developed geothermal power stations created from known geothermal resources with temperature ~120°C.


JRG Energy