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30 June 2011
Project 770604001

Mr. Will Osborn
AltaRock Energy, Inc.
2320 Marinship Way, Suite 200
Sausalito, California 94965

Subject: Geotechnical Consultation
Newberry EGS Demonstration
Newberry, Oregon

Dear Mr. Osborn:

This letter presents a summary of our observations and our geotechnical conclusions regarding stability issues associated with low levels of seismicity that could be generated as part of the Newberry Volcano Enhanced Geothermal Systems (EGS) Demonstration. An EGS reservoir is created by inducing "hydroshearing", defined as shear slip on existing fractures by injecting water at high pressure into a rock formation. This process is known to generate seismic vibrations, or "induced seismicity". Specifically we were requested to provide conclusions regarding the stability of Paulina Lake dam, a talus slope on the south side of Paulina Peak, which Roadway 500 crosses, and two slopes along the north sides of Paulina and East lakes under various levels of ground shaking.

Background

For this study we reviewed the following documents:

- report titled "Evaluations of Induced Seismicity/Seismic Hazards and Risk for the Newberry Volcano EGS Demonstration," prepared by URS, dated 24 November 2010
- report titled "Development of Scenario Ground Shaking Maps and Evaluations of the Impacts of Ground Shaking on Local Buildings, Avalanches, and the Lava River Cave, Newberry Volcano EGS Demonstration," prepared by URS, dated 28 January 2011
- report titled "Hydroshearing Controls and Mitigation of Induced Seismicity at the Newberry EGS Demonstration," prepared by AltaRock Energy, dated 4 April 2011
- Memorandum titled "Impact of EGS-Induced Seismicity on Paulina Lake Dam; Newberry EGS Demonstration Project," prepared by URS, dated 5 April 2011
- report titled "M_{max} Assessment for the Newberry EGS Demonstration at the Davenport 55-29 Site," prepared by Fugro Consultants, Inc., dated 6 May 2011

These studies indicated hydroshearing could generate earthquakes up to about Magnitude 3.5. Although a magnitude earthquake of 3.5 is possible, the probability of such an earthquake is low. A map presenting median peak ground acceleration (PGA) for a magnitude 3.5 earthquake generated near the well head was developed for the project (URS, 2011). This map presents a contour of median PGA values ranging from 0.06 to 0.10g. The well is about 3.4 kilometers (km) from the western side of Paulina Lake. Because the dam is shown near the edge of contour and ground shaking typically decrease with distance, the estimate median PGA near the western edge of Paulina Lake is about 0.06 to 0.08g.

Observations

On 9 June 2011, one of the undersigned, John Gouchon, visited Paulina Lake and observed Paulina Dam which is near the southwest corner of the Lake. The dam is connected to a concrete bridge. We understand the dam was constructed in 1946 and the concrete bridge was built 1951. The bridge consists of two arches separated by a rectangular box culvert (see Figures 1a and 1b). A concrete wall spans across the two arches and box along the backside of the bridge (see Figure 2). The wall is about 3 to 4 feet high and 12 to 14 inches thick. The bases of the concrete bridge as well as the abutments appear to be keyed into and bottomed in bedrock, consisting of andesitic tuff deposited during various volcanic eruptions. We observed a crack along the top of the concrete arches. It appears that "tell tales" (crack monitoring instruments) had been placed to monitor the crack. The crack may have developed from freeze-thawing cycles; however, because it is above the water level in the lake, it does not appear to be a conduit for water seepage. We did not observe evidence of seepage or significant erosion at the abutments or foundations. A new steel bridge was recently constructed directly above the original bridge, but not relying on it for support, to carry vehicular loads.

Figures 1a and 1b. Paulina Lake Bridge and Dam (Downstream)

Figure 2. Concrete dam on upstream side of bridge; steel channels used to support timber lagging (not in place when this picture was taken) to raise height of dam

Because the road to Paulina Peak and the talus slope were snow covered, we were not able to observe the talus slope. The approximate location of the talus slope (Designated as "C") and the local geology are shown on Figure 3. Figure 3 indicates the geologic unit for the talus slope is rock mapped as Felsic/Intermediate Dome. Figure 4 presents slope inclination for the Newberry Crater area and indicates the Talus slope generally has slope inclinations ranging from 25 to 40 degrees or flatter except for some areas in the northern portion of Area C north of the roadway and Paulina Peak where inclination appears to be greater than 55 degrees. These very steep faces slope to the northwest and north, and likely represent the evacuated headscarp for the large landslide that extends to the north and northwest. Additionally, there are isolated areas near Roadway 500 where the inclinations are about 40 to 55 degrees and are likely cuts for the roadway.

Subsequent to our visit, we were requested to provide commentary regarding the stability of two other slope areas (designated as areas "A" and "B"); the locations these slopes are shown on Figures 3 and 4, along with the respective geology and slope inclination. During our site visit we did not observe these areas; however, we have reviewed the geologic and slope inclination information pertaining to these sites and a summary is provided in Table 1.

TABLE 1

Summary of Geology and Slope Inclinations for Areas A and B

Area	Geologic Formation	Slope Inclination
A	Q_c – Cinder Cone	25 to 40 deg. or flatter
	Q_r – Rhyolite Obsidian	25 to 40 deg. near lake with an isolated area at 40 to 55 deg; less than 25 deg. away from the lake
	Q_{yc} – Younger Cinder Cone/Fissure	25 to 40 deg.
	Q_{cw} – Wall Rock (undifferentiated)	25 to 40 deg.
	Q_{yt} – Rhyolite Tephra	25 to 40 deg. or flatter
B	Q_c – Cinder Cone	25 to 40 deg. or flatter with very small isolated areas of 40 to 55 degrees

CONCLUSIONS

We were requested to provide an assessment of the likelihood and degree of damage at Paulina Dam and slope failures for the talus slope and the other four slopes for PGA values of 0.014, 0.028, 0.05 and 0.10g. Table 2 presents a comparison of ground shaking in terms of PGA and perceived shaking and the potential for damage. For a PGA of 0.014g the perceived shaking is weak and potential for damage is none. For a PGA value of 0.028 and 0.05g the perceived shaking is light and moderate, respectively and the potential for damage is none and very light. A PGA value of 0.10g is considered strong and potential for damage is light.

TABLE 2

Comparison of Quantitative and Qualitative Measures of Ground Shaking[1]

MMI[2]	Ground Acceleration (g)	Perceived Shaking	Potential Damage
I	< 0.0017	Not Felt	None
II-III	0.0017 - 0.014	Weak	None
IV	0.014 - 0.039	Light	None
V	0.039 - 0.092	Moderate	Very light
VI	0.092 - 0.18	Strong	Light
VII	0.18 - 0.34	Very Strong	Moderate

The remaining sections present our conclusions regarding the dam and slopes.

Paulina Dam

According to USGS intensity and corresponding PGA, for estimated ground shaking for PGA's of 0.014 and 0.028 the perceived shaking will be light and the potential for damage none. For a PGA of less than about 0.1 g's, the perceived shaking is moderate and the potential for damage is very light. Furthermore, according to the *Federal Guidelines for Dam Safety: Earthquake Analyses and Design of Dams* (May 2005) no major concrete dam is known to have failed as a result of earthquake-induced ground motion. According to study by the United States Committee on Large Dams (USCOLD 1999) approximately 100 concrete dams have been significantly shaken by earthquake of which 15 have experienced PGA's greater than 0.20g.

For example, the Crystal Springs dam in San Mateo County, California is a 154-foot-high gravity-arch dam, which is adjacent to the San Andreas Fault and was subjected to an approximate magnitude 8 earthquake (1906 San Francisco Earthquake); no apparent damage was observed. The Pacoima Dam, which is a 372 foot high arch dam, survived the magnitude 6.6 San Fernando Earthquake without evidence of distress despite experiencing estimated foundation accelerations of 0.6 to 0.8g. Therefore because of the relatively low estimated earthquake magnitude (less than or equal to 3.5) and low estimated PGA's (less than 0.1g), we conclude the likelihood of damage is none for PGA values of 0.014 and 0.028g and only very light to light damage, which could consist of minor cracking for PGA values of 0.05 and 0.10g. Considering these low levels of acceleration and the previous performance of concrete dams, we conclude the probability of additional damage to the dam is low and the probability of failure of the dam is extremely remote.

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1 USGS Intensity and Corresponding PGA

2 Modified Mercalli Intensity Scale

Considering the age of the bridge and dam structure, it is possible that the some cracking may occur during an earthquake. We suggest that the bridge/dam be monitored if PGA's are measured above a triggering limit. Crack monitoring gauges (tell–tales) may be placed on the existing crack above the arch of the bridge to observe any changes in the crack width.

Talus Slope (Area C)

Although we were not able to observe the talus slope, it is likely that the very steep portions of the slope (greater than 55 degrees) have low safety factors against raveling of the slope. We used the rock mass classification for geomorphic purposes (Selby, 1980) and the basic rock mass ratings predicted from slope angles of natural rock outcrops (Banks, 2004) methods to determine the average stable slope angles for the different bedrock units. Rock strength, weathering, jointing characteristics, and water seepage amounts were assumed for each rock type based on standardized geologic criteria and geologic assumptions.

As previously discussed the talus slope is underlain by mostly Felsic/Intermediate Dome formation. The characteristic of this formation is that slopes up to about 70 degrees are stable under static conditions. On the basis of our discussions with the Forest Service, we understand that rocks occasional tumble down the slope on to the roadway. We conclude minor earthquakes with PGA's of 0.014 and 0.028g could cause some rocks/boulders to fall onto the roadway. However, because the duration of magnitude 3.5 earthquakes is short, the estimate PGA is less than 0.1g and the geologic properties, the probability of a deep seated landslide is low.

Furthermore a review of historical United States earthquakes from 1958 to 1977 indicates that of the 300 earthquakes which are in the database for that time period, 62 had a magnitude less than 4.0. Of these 62 earthquakes only 1 report of a landslide (associated with a magnitude 3.5 earthquake) was found in the database and was judged of questionable validity by the compilers of the data[3]. The paper also discussed the relation between earthquake magnitude and distance from the epicenter and the distribution of landslides. The paper concludes that for a landslide to occur during a magnitude 4 earthquake, the epicentral distance would need to be less than 0.2 km. The distance to the well head is about 3.5 km, which further supports the conclusion that the probability of a deep seated landslide is low.

During the injection process, we suggest that that a piece of grading equipment such as a dozer or back-hoe be present, which can remove any boulders which could fall onto the road.

Slope Areas A and B

The slope areas designated A and B are underlain by different types of volcanic rock as described above in Table 1. Table 3 summarizes the average maximum stable slope angles under static loading for each of the volcanic rock types, as determined by the rock mass classification systems described above for Area C.

[3] Keefer, D.K., 1984, *Landslides caused by earthquakes: Geological Society of America Bulletin*, v. 95, p. 406-421

TABLE 3

Summary of Geology and Maximum Stable Slope Inclinations for Areas A and B

Area	Geologic Formation	Average Maximum Stable Slope Inclination[4]
A	Q_c – Cinder Cone	68 to 69 degrees
	Q_r – Rhyolite Obsidian	90 degrees
	Q_{yc} – Younger Cinder Cone/Fissure	74 to 75 degrees
	Q_{cw} – Wall Rock (undifferentiated)	43 to 50 degrees
	Q_{yt} – Rhyolite Tephra	60 to 63 degrees
B	Q_c – Cinder Cone	68 to 69 degrees

On the basis of the above analyses, the existing slope inclinations in each rock type are much flatter than the calculated average maximum stable slope inclinations for all areas except for the areas of Area A within the geologic unit Q_{cw} (wall rock). For this unit, the calculated maximum average stable slope inclination is 43 to 50 degrees. We discussed the slopes in this area with Mr. Trenton Cladouhos, a Senior Geologist with AltaRock Energy, Inc., who provided us with refined LIDAR data that indicates the slope inclinations in this formation range from 30 to 35 degrees. Consequently, we conclude that the subject slopes in all geologic units have a low to very low risk of deep seated landsliding during static and minor earthquake loading with PGA's up to 0.1g. However, these slopes could experience localized rockfalls, topples, or shallow landsliding during minor earthquakes based on localized discontinuities in the rock. We anticipate that these landslides will be relatively small and should not create a seiche hazard in the lakes. If you have any questions, please call.

Sincerely yours,
TREADWELL & ROLLO, A LANGAN COMPANY

John Gouchon, G.E. #2282
Senior Associate

Richard Rodgers, G.E. #732
Principal

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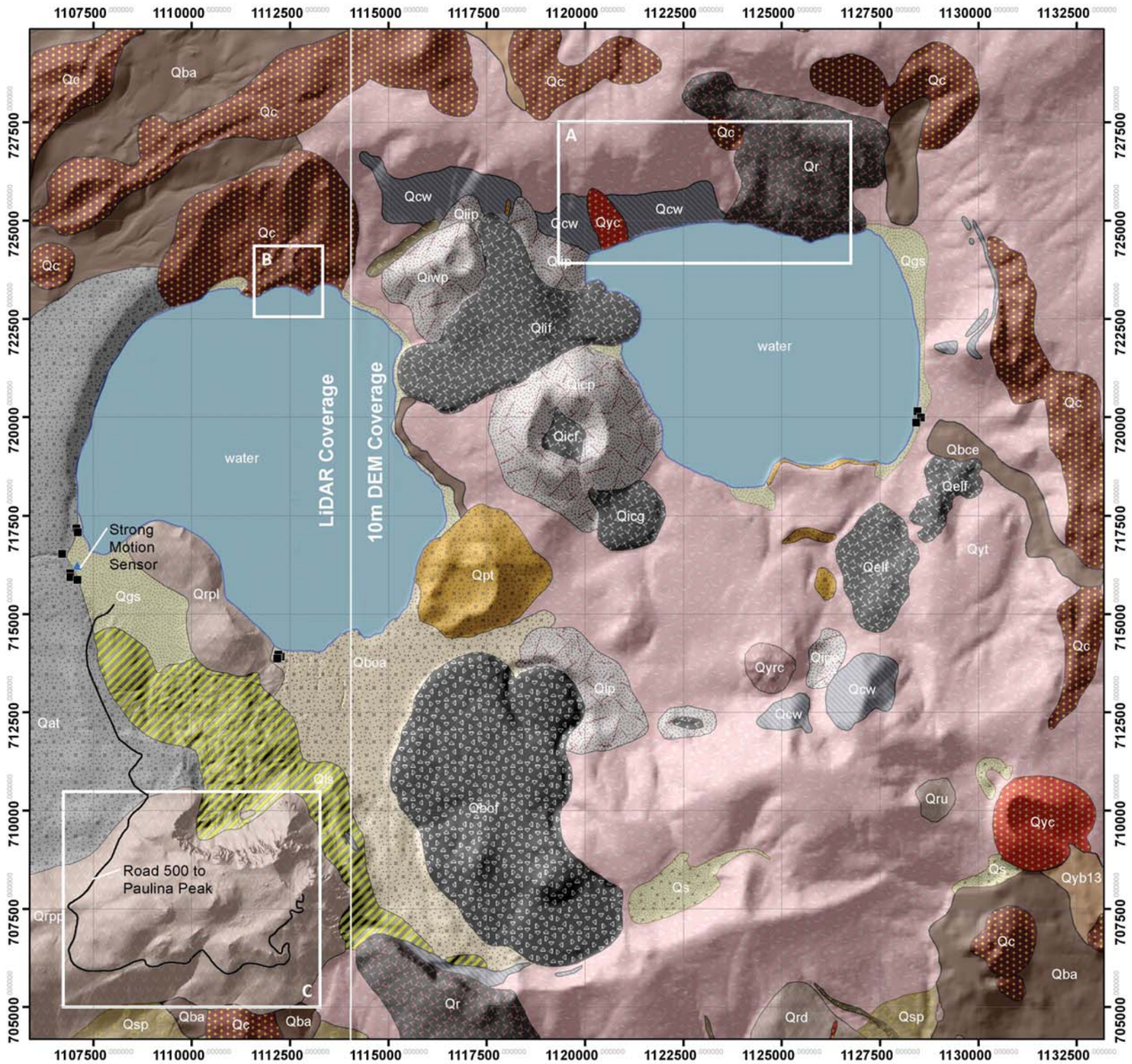
[4] Average maximum stable slope inclination estimated using the rock mass classification systems methods developed by Shelby (1980) and Banks (2004)



Geology at Newberry Crater

NAD1983 HARN Lambert Conformal Conic, ft

water	water
Qls	Landslide
Qcw	Wall rock (undiff)
Qgs	Gravel, sand of caldera
Qs	Sedimentary deposit
Qsp	Sedimentary and pyroclastic
Qypm	Pumiceous mudflow
Q--p	Pumice
Qbof	Big Obsidian Flow
Qelf, Qicg, Qlif	Obsidian
Qr	Rhyolite Obsidian
Qboa	Tuff
Qpt	Palagonite Tuff
Qat	Andesite Tuff
Qyt	Rhyolite Tephra
Qyrc	Young Rhyolite Flows
Qr--	Felsic/Intermediate Domes
Qyc	Young Cinder Cone/Fissure
Qc	Cinder Cone
Qyb	Young Basaltic Andesite
Qba, Qbce	Basaltic Andesite

A — Area of Interest

■ Surveyed Structure

O. Callahan
AltaRock Energy, 2011

NEWBERRY ENHANCED GEOTHERMAL SYSTEMS
Newberry, Oregon

GEOLOGY MAP

Date 06/27/11	Project No. 770604001	Figure 3

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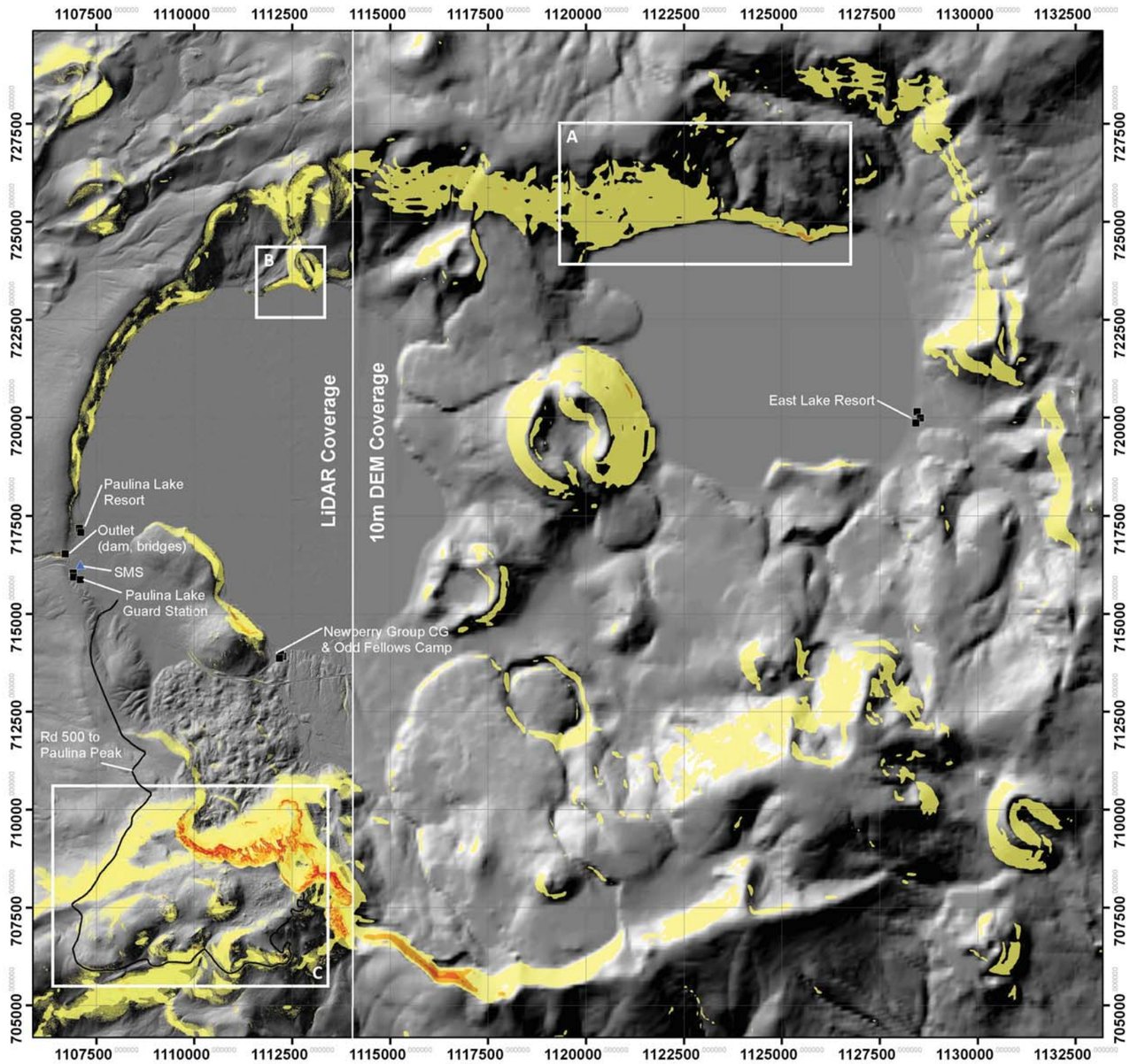
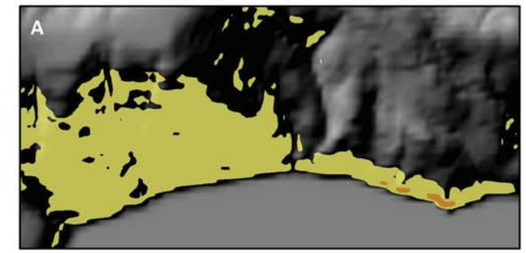


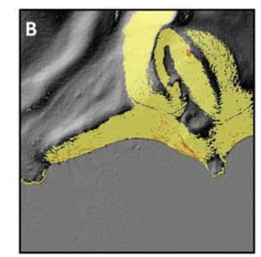
Slope Angles at Newberry Crater from LiDAR and 10m DEM

NAD1983 HARN Lambert Conformal Conic, ft

O. Callahan, AltaRock Energy, 2011

Areas of Interest



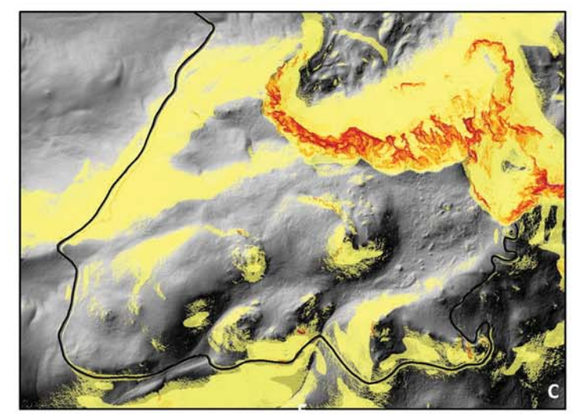


Slopes (Degrees)

- 0 - 25
- 25 - 40
- 40 - 55
- 55 - 65
- 65 - 75
- 75 - 80
- 80 - 85
- 85 - 90

Surveyed Structure

Strong Motion Sensor



NEWBERRY ENHANCED GEOTHERMAL SYSTEMS
Newberry, Oregon

LIDAR SLOPE INLCINATION MAP

Date 06/27/11	Project No. 770604001	Figure 4

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