Innovate Geothermal Ltd.

104-445 West 2nd Ave.
Vancouver, BC
V5Y 0E8 Canada
(604) 349-8040

To: Fallon FORGE project team
From: Jeff Witter
Re: Summary of rock density measurements
Date: December 5, 2017

Dear Fallon FORGE project team,

This memo is a brief synopsis of rock density measurements which were made in Nov.-Dec. 2017 as part of the Fallon FORGE project. Researchers from University of Nevada, Reno measured rock density on core samples obtained from three different wells: 51-20 (~6 km SE of the FORGE site), FOH2 (within the FORGE area), and BCH-3 (at the Bradys geothermal area ~40 km NW of the FORGE site). The subsurface geology at these three wells is similar and consists of Quaternary sediments (QTs) on top, overlying mafic Tertiary volcanic rocks (Tba) which, in turn, overlie a variety of Mesozoic basement rocks (Mz). In the BCH-3 well, a layer of Oligocene-age rhyolitic ignimbrite (Ttr) is sandwiched in between the Tba and Mz rocks. UNR researchers measured grain density, saturated bulk density, and dry bulk density on the core samples from these wells (although in this memo, only saturated bulk density is reported).

Densities were measured on the following major rock types encountered in each well:
51-20 → only Tba (n = 33)
FOH-2 → only Tba (n = 172)
BCH-3 → Tba, Ttr, and Mz (n = 120)

The Tba rock type (i.e. mega-unit) has been divided into subordinate rock units (i.e. sub-units) according to Table 1. The percent abundance of each rock sub-unit has been estimated by UNR researchers according to the geology well logs.

Mega-Unit abbr.	Sub-Unit abbr.	Sub-Unit Name	Percent abundance	Normalized
Tba	Tba	Basaltic andesite	40%	0.42
Tba	Tbav	Vesicular basaltic andesite	30%	0.32
Tba	Tbab	Basaltic andesite auto-breccia	15%	0.16
Tba	Ttu	Lithic tuff, non-welded tuff, welded tuff	3%	0.03
Tba	Tss	Volcanic sandstone	3%	0.03
Tba	Tbr/Tsb	Basaltic sedimentary breccia	3%	0.03
Tba	Td	Dacite lavas	1%	0.01
		Sum	95%	1.0000

Table 1. Rock sub-units within the Tba mega-unit.

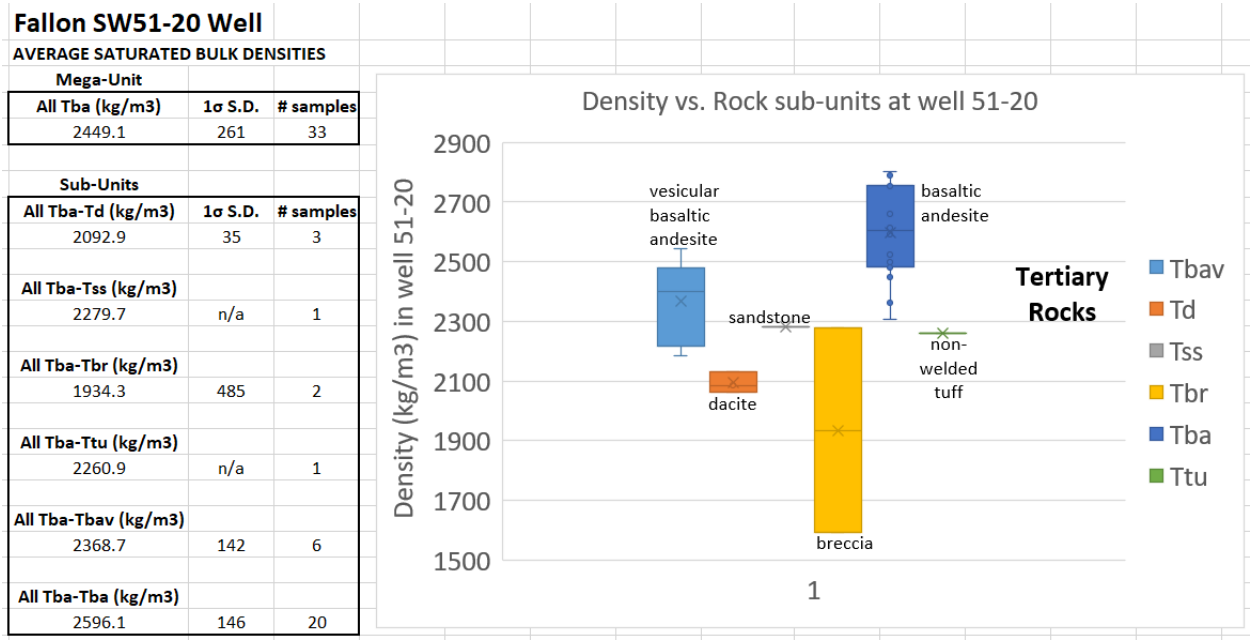
Mesozoic basement rocks have also been sub-divided into mega-units according to Table 2. The Oligocene-age rhyolitic ignimbrite (Ttr) is not divided into sub-units.

Mega-Unit abbr.	Sub-Unit abbr.	Sub-Unit Name	Percent abundance	Normalized
Mzu	--	Undistinguished metamorphics	6%	0.060
Mzm	--	Marble	1%	0.0050
Mzq	--	Quartzite	22%	0.219
Mzgr	--	Granite	5%	0.050
Mzt	--	Ignimbrite/ash-flow tuffs	39%	0.388
Mzaba	--	Altered basaltic andesite	26%	0.259
Mzs	--	Slate	2%	0.020
		Sum	101%	1.0000

Table 2. Rock mega-units in the Mesozoic basement.

Rock Densities Measured in well 51-20

Saturated bulk density values from well 51-20 for the entire Tba mega-unit as well as the individual sub-units are shown in Figure 1.



Fallon SW51-20 Well

AVERAGE SATURATED BULK DENSITIES

Mega-Unit		
All Tba (kg/m3)	1σ S.D.	# samples
2449.1	261	33

Sub-Units		
All Tba-Td (kg/m3)	1σ S.D.	# samples
2092.9	35	3
All Tba-Tss (kg/m3)		
2279.7	n/a	1
All Tba-Tbr (kg/m3)		
1934.3	485	2
All Tba-Ttu (kg/m3)		
2260.9	n/a	1
All Tba-Tbav (kg/m3)		
2368.7	142	6
All Tba-Tba (kg/m3)		
2596.1	146	20

Figure 1. Left: Average saturated bulk densities of Tba mega-unit and sub-units in well 51-20. Right: Box and whisker plot of the saturated bulk density of each sub-unit.

An alternate approach to estimate the density of the Tba mega-unit is to calculate a weighted sum using the densities of the individual sub-units and the estimated proportion of each sub-unit (Figure 2).

		Bulk Density of Tba Mega-Unit based upon well 51-20			
	Sub-Unit abbr.	Density	Proportion	Density contribution	
Measured	Tba	2596.1	42%	1093.1	
Measured	Tbav	2368.7	32%	748.0	
Assumed from FOH-2	Tbab	2226	16%	351	
Measured	Ttu	2260.9	3%	71.4	
Measured	Tss	2279.7	3%	72.0	
Measured	Tbr/Tsb	1934.3	3%	61.1	
Measured	Td	2092.9	1%	22.0	
			100%	**2419**	**Bulk Density (kg/m3)**

Figure 2. Saturated bulk density of the Tba mega-unit in well 51-20 weighted by the proportions of each rock sub-unit. Note: sub-unit Tbab does not occur in well 51-20 so a density value from well FOH-2 has been used.

Rock Densities Measured in well FOH-2

Saturated bulk density values from well FOH-2 for the entire Tba mega-unit as well as the individual sub-units are shown in Figure 3.

Well FOH-2

AVERAGE SATURATED BULK DENSITIES

Mega-Unit		
All Tba (kg/m3)	**1σ S.D.**	**# samples**
2417.8	181.4	172
Sub-Unit		
All Tba-Td (kg/m3)	**1σ S.D.**	**# samples**
n/a	n/a	0
All Tba-Tss (kg/m3)		
2121.4	104	3
All Tba-Tsb (kg/m3)		
2495.2	11	2
All Tba-Ttu (kg/m3)		
n/a	n/a	0
All Tba-Tbav (kg/m3)		
2385.7	176	88
All Tba-Tba (kg/m3)		
2532.7	124	61
All Tba-Tbab (kg/m3)		
2225.7	99	18

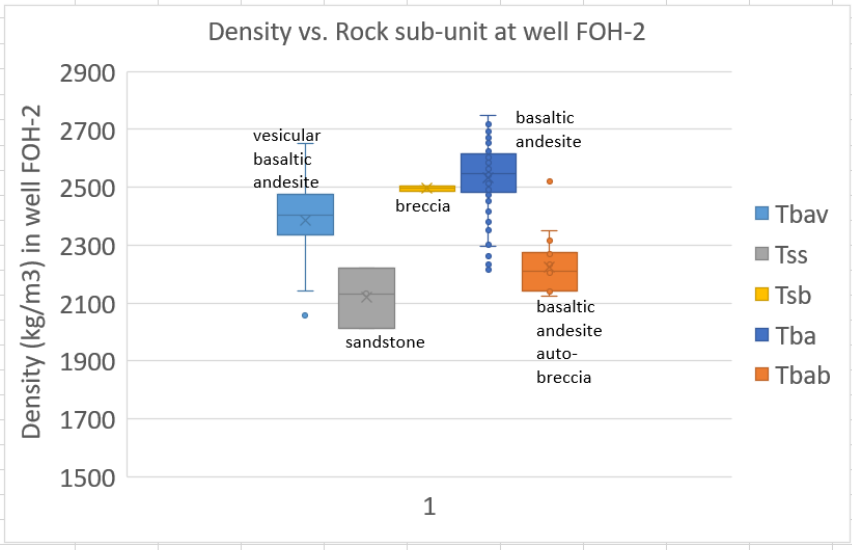


Figure 3. Left: Average saturated bulk densities of Tba mega-unit and sub-units in well FOH-2. Right: Box and whisker plot of the saturated bulk density of each sub-unit.

Bulk Density of Tba Mega-Unit based upon well FOH-2					
	Sub-Unit abbr.	Density	Proportion	Density contribution	
Measured	Tba	2532.7	42%	1066.4	
Measured	Tbav	2385.7	32%	753.4	
Measured	Tbab	2225.7	16%	351	
Assumed from 51-20	Ttu	2261	3%	71.4	
Measured	Tss	2121.4	3%	67.0	
Measured	Tbr/Tsb	2495.2	3%	78.8	
Assumed from 51-20	Td	2093	1%	22.0	
			100%	**2410**	**Bulk Density (kg/m3)**

Figure 4. Saturated bulk density of the Tba mega-unit in well FOH-2 weighted by the proportions of each rock sub-unit. Note: sub-units Ttu and Td do not occur in well FOH-2 so density values from well 51-20 have been used.

Densities in well BCH-3

Saturated bulk density values from well BCH-3 for the Tba, Ttr and Mesozic mega-units as well as the individual sub-units are shown in Figure 5.

AVERAGES Mega-Units	Bradys BCH-3 Sub-Units	1σ S.D.	# samples
All Tba (kg/m3) 2317.3	All Tba-Tbav (kg/m3) 2478.2	135	6
	All Tba-Tba (kg/m3) 2419.0	137	16
All Ttr (kg/m3) 2447.7	All Tba-Ttu Lithic Tuff (kg/m3) 2215.1	96	7
All Mz (kg/m3) 2703.1	All Tba-Ttu NW&W Tuff (kg/m3) 2128.3	45	5
	All Tba-Td (kg/m3) 2257.2	61	4
	All Tba-Tss (kg/m3) 2223.7	147	10
	All Tba-Tbr (kg/m3) 2357.9	78	6
	All Mzaba-Mzba (kg/m3) 2697.3	44	30
	All Mzaba-Mzbbr (kg/m3) 2725.7	25	10
	All Mzs-Mzs (kg/m3) 2678.1	11	2

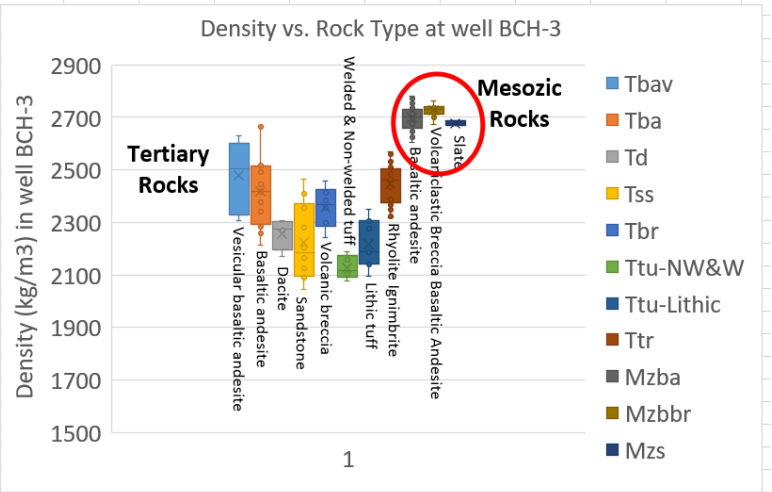


Figure 5. Left: Average saturated bulk densities of mega-units and sub-units in well BCH-3. Right: Box and whisker plot of the saturated bulk density of each sub-unit.

		Bulk Density of Tba Mega-Unit based upon well BCH-3				
	Sub-Unit abbr.		Density	Proportion	Density contribution	
	Measured	Tba	2419.0	42%	1018.5	
	Measured	Tbav	2478.2	32%	782.6	
Assumed from FOH-2		Tbab	2226	16%	351	
	Measured	Ttu	2178.9	3%	68.8	
	Measured	Tss	2223.7	3%	70.2	
	Measured	Tbr/Tsb	2357.9	3%	74.5	
	Measured	Td	2257.2	1%	23.8	
				100%	**2390**	**Bulk Density (kg/m3)**
		Bulk Density Ttr Mega-Unit based upon well BCH-3				
		2447.7	**Bulk Density**			
		Bulk Density of Mesozoic Basement based upon well BCH-3				
	Mega-unit abbr.		Density	Proportion	Density contribution	
	Assumed	Mzu	2600	0.060	155.2	Undistinguished metamorphics
	Assumed	Mzm	2800	0.005	13.9	Marble
	Assumed	Mzq	2600	0.219	569.2	Quartzite
	Assumed	Mzgr	2600	0.050	129.4	Granite
	Assumed	Mzt	2600	0.388	1009.0	Ignimbrite/ash-flow tuffs
	Measured	Mzaba	2704.4	0.259	699.6	Altered basaltic andesite
	Measured	Mzs	2678.1	0.020	53.3	Slate
				1.000	**2630**	**Bulk Density (kg/m3)**

Figure 6. Top: Saturated bulk density of the Tba mega-unit in well BCH-3 weighted by the proportions of each rock sub-unit. Note that sub-unit Tbab does not occur in well BCH-3 so a density value from well FOH-2 has been used. Middle: Saturated bulk density of the Ttr mega-unit in well BCH-3 (n=24). Bottom: Saturated bulk density of the Mesozoic basement rocks in well BCH-3 weighted by the proportions of each rock unit. Note that several rock units observed in the basement do not occur in well BCH-3 so assumed density values have been used.

Summary

The average saturated bulk density of the mafic Tertiary volcanics (rock mega-unit Tba) in the three wells 51-20, FOH-2, and BCH-3 is 2449, 2418, and 2317 kg/m^3, respectively. These values are straight averages of the measured data and do not take into account the relative abundance of the different rock sub-units.

When weighted by the proportions of the different rock sub-units, the saturated bulk density of rock mega-unit Tba is 2419, 2410, and 2390 kg/m^3 in wells 51-20, FOH-2, and BCH-3,

respectively. Using this approach, the density estimate for the Tba mega-unit is quite consistent from one well to the next with a value of ~2400 kg/m^3.

The average saturated bulk density of the Oligocene ignimbrite (rock mega-unit Ttr) in well BCH-3 is 2448 kg/m^3. This is only slightly denser than the overlying Tba unit.

The average saturated bulk density of the Mesozoic basement rocks found in well BCH-3 is 2703 kg/m^3. This value doesn't take into account the relative abundance of the different rock types in the Mesozic basement. When weighted by the proportions of the different rock types, the saturated bulk density of basement is 2630 kg/m^3 in well BCH-3. However, this value may not be accurate as it assumes literature values for the densities of 5 out of the 7 rock types that occur in the basement.

Density measurements of the Quaternary sedimentary cover (QTs) were not performed.