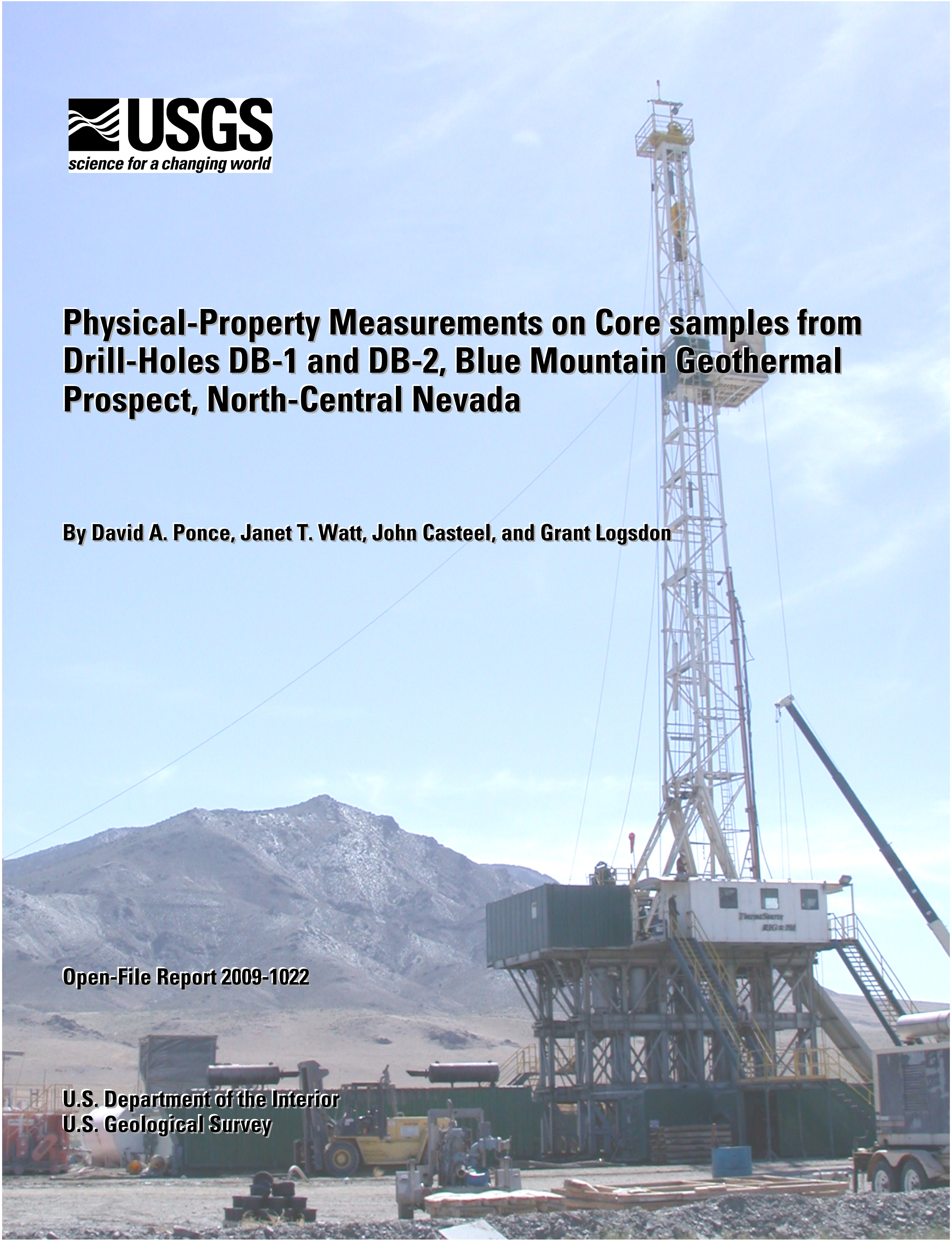

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Physical-Property Measurements on Core samples from Drill-Holes DB-1 and DB-2, Blue Mountain Geothermal Prospect, North-Central Nevada

By David A. Ponce, Janet T. Watt, John Casteel, and Grant Logsdon

Open-File Report 2009-1022

U.S. Department of the Interior
U.S. Geological Survey

Cover: View looking eastward toward Blue Mountain, north-central Nevada (Photograph by J.T. Watt).

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Contents

Figures

Tables

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Physical-Property Measurements on Core Samples from Drill-Holes DB-1 and DB-2, Blue Mountain Geothermal Prospect, North-Central Nevada

By David A. Ponce[1], Janet T. Watt[1], John Casteel[2], and Grant Logsdon[2]

Introduction

From May to June 2008, the U.S. Geological Survey (USGS) collected and measured physical properties on 36 core samples from drill-hole Deep Blue No. 1 (DB-1) and 46 samples from drill-hole Deep Blue No. 2 (DB-2) along the west side of Blue Mountain about 40 km west of Winnemucca, Nev. (fig. 1). These data were collected as part of an effort to determine the geophysical setting of the Blue Mountain geothermal prospect as an aid to understanding the geologic framework of geothermal systems throughout the Great Basin. The physical properties of these rocks and other rock types in the area create a distinguishable pattern of gravity and magnetic anomalies that can be used to infer their subsurface geologic structure.

Drill-holes DB-1 and DB-2 were spudded in alluvium on the western flank of Blue Mountain in 2002 and 2004, respectively, and are about 1 km apart (fig. 1). Drill-hole DB-1 is at a ground elevation of 1,325 m and was drilled to a depth of 672 m and drill-hole DB-2 is at a ground elevation of 1,392 m and was drilled to a depth of 1522 m. Diameter of the core samples is 6.4 cm. These drill holes penetrate Jurassic and Triassic metasedimentary rocks predominantly consisting of argillite, mudstone, and sandstone; Tertiary diorite and gabbro; and younger Tertiary felsic dikes.

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Physical-Property Data

Core samples were collected about every 15 m in drill-hole DB-1 and about every 30 m in drill-hole DB-2, where possible. Cores were stored in standard drill-core boxes that were subject to dry conditions for 4 to 6 years. Physical-property measurements were also made from surface samples of the Blue Mountain diorite and the Winnemucca Mountain diorite in the eastern Krum Hills (fig. 1).

Densities were determined using the buoyancy method (for example, Johnson and Olhoeft, 1984) using a Sartorius® electronic balance, and magnetic-susceptibility measurements (for example, Carmichael, 1984) were made using a Kappameter® KT-5. Grain, saturated-bulk, and dry-bulk densities were computed for each sample by weighing the dry sample in air (Wa), saturated and submerged in water (Ww), and saturated and weighed in air (Was) using the following formulas, where weights were measured in grams:

Grain density = 1,000 kg/m^3 * Wa/(Wa-Ww),

Saturated-bulk density = 1,000 kg/m^3 * Was/(Was-Ww), and

Dry-bulk density = 1,000 kg/m^3 * Wa/(Was-Ww).

Samples were saturated with water for at least 24 hours prior to measuring their weight in water and then towel dried to remove surface water prior to measuring their saturated weight in air. Note that samples were not oven dried prior to measuring their weight in air, and although the effect is small, it may result in too high a dry weight for some samples having high porosity and water content.

Porosity, or the relative volume of pore spaces, can be derived from the grain and dry-bulk density using the following relationship (for example, Johnson and Olhoeft, 1984):

Porosity (%) = (1 - (dry-bulk density)/(grain density))*100.

Average physical properties by rock type are listed in table 1, and the entire digital dataset is provided in table 2 as an Excel file. Generalized stratigraphic columns derived from lithologic logs (modified from Fairbank Engineering, Ltd., written commun., 2002-2005) of each drill hole are shown in figure 2, density and magnetic susceptibility versus depth are shown in figure 3, porosity versus depth is shown in figure 4, and photographs of the samples are shown in figure 5. In figure 5, photographs of samples are shown in numerical sequence except for 08DB1-1098 which is the first core sample in the upper-left corner of figure 5C. Core sample 08DB-0750 dissolved and is shown in figure 5A beforehand. Arrows on each sample indicate direction toward the bottom of the drill hole.

Discussion

In general, a moderate density and low magnetic susceptibility remains fairly constant within the argillite rocks, and there is a direct correlation of high density and high magnetic susceptibility with mafic intrusive rocks (fig. 3). Rock-type designations are primarily from those listed in the core logs (Fairbank Engineering Ltd., written commun., 2002-2005; Fairbank Engineering Ltd., 2004). All reported core-sample depths are from those listed on the core boxes themselves, and the delineation of boundaries or zones within each drill hole are limited by the approximate 15- and 30-m sample spacing in drill-holes DB-1 and DB-2, respectively.

Within the upper parts of the argillite unit in drill-hole DB-1, a prominent zone of high porosity occurs from depths of 250 m to 392 m. This high-porosity zone is expressed as the difference between the grain and dry-bulk density (fig. 3A) or in the porosity versus depth illustration (fig. 4); porosity values reach up to 13.7 percent in this zone. The high porosity indicates that the rocks in this zone may be highly fractured and thus have high permeability as well. Although magnetic susceptibility is variable in most of the argillitic rocks, it is relatively flat throughout this zone which suggests that these rocks have been altered, possibly from circulating hydrothermal fluids. Alternatively, this could be due to a small but constant magnetite mineralization in this zone. This zone is also apparent, but not as prominent, in drill-hole DB-2 from similar depths of 212 to 363 m (figs. 3B and 4), where porosity values reach up to 5.8 percent. The upper boundary of these zones is near a prominent change in the gradient of the temperature-pressure curves for drill-holes DB-1 and DB-2 (GeothermEx, Inc., 2008) and could represent one of the north-south striking basin and range normal faults that serve as part of the plumbing system for the geothermal system (Parr and Percival, 1991). However, Noramax Corporation (2003) indicates that the West fault, for example, penetrated drill-hole DB-1 at a much shallower depth of 98 to 187 m than the high-porosity zone.

Mafic intrusive rocks occur in drill-hole DB-1 from 500 to 550 m. Three diorite/granodiorite core samples have an average saturated bulk density of 2,780 kg/m^3, with a range of 2,739 to 2,814 kg/m^3 and an average magnetic susceptibility of 1.20 x 10^{-3} SI, with a range of 0.48 to 1.58 x 10^{-3}

SI. These rocks in drill-hole DB-1 are of lower density and much lower susceptibility than mafic intrusive rocks in drill-hole DB-2. Felsic intrusive rocks have moderate densities and are weakly magnetic in both drill-holes DB-1 and DB-2 (table 1).

In drill-hole DB-2, mafic intrusive rocks occur throughout the bottom-half of the drill hole from 764 to 1,522 m and have similar high densities and magnetic susceptibilities, suggesting that they are from the same source. Nine gabbro core samples have an average saturated bulk density of 2,901 kg/m^3, with a range of 2,744 to 2,963 kg/m^3 and an average magnetic susceptibility of 20.0 x 10^{-3} SI, with a range of 0.26 to 27.5 x 10^{-3} SI. If the magnetic mineral is magnetite, this amounts to as much as about 0.8 percent magnetite. Mafic rocks also occur at the surface along the southwest flank of Blue Mountain (fig. 1) that were originally mapped as a Jurassic diorite pluton (Wilden, 1964; Stewart and Carlson, 1978), but are now thought to be mafic dikes (diorite to gabbro) possibly of late Tertiary age (Wyld, 2002). This change in geology leads to the possibility that these north-striking mafic dikes could in fact be related to one of the northern Nevada rifts (fig. 1) that formed about 16 Ma as the Yellowstone Hotspot emerged along the Oregon-Idaho border (Ponce and Glen, 2002; 2008). These surface samples have similar appearance and susceptibility (but lower density) as the core samples, suggesting these mafic rocks are probably related (table 1). In addition, an aeromagnetic anomaly is associated with the exposed diorite dikes at Blue Mountain, and an examination of the horizontal extent of the source inferred from aeromagnetic data (Kucks and others, 2006) indicates these rocks extend westward across the geothermal prospect area.

Surface-rock samples were also collected from a mafic pluton due east of Blue Mountain, the Winnemucca Mountain diorite, along the southeast edge of the Krum Hills (fig.1). These rocks have a much lower density and are weakly magnetized compared to the Blue Mountain diorite, with an average saturated bulk density of 2,639 kg/m^3 and a magnetic susceptibility of 0.66 x 10^{-3} SI, and are probably not related to the Blue Mountain diorite. In addition, because of its very low magnetization, the Winnemucca Mountain diorite is not expressed in the aeromagnetic map of Nevada (Kucks and others, 2006).

Acknowledgments

We thank Glenn Melosh and Kim Niggemann of Nevada Geothermal Power, Inc. for granting access to the core samples from the Blue Mountain geothermal prospect. We also thank Colin Williams and Steve Hickman of the USGS for their support. Chris Mesic of the USGS assisted in making the physical-property measurements on the surface samples from the Blue Mountain diorite and the Winnemucca Mountain diorite.

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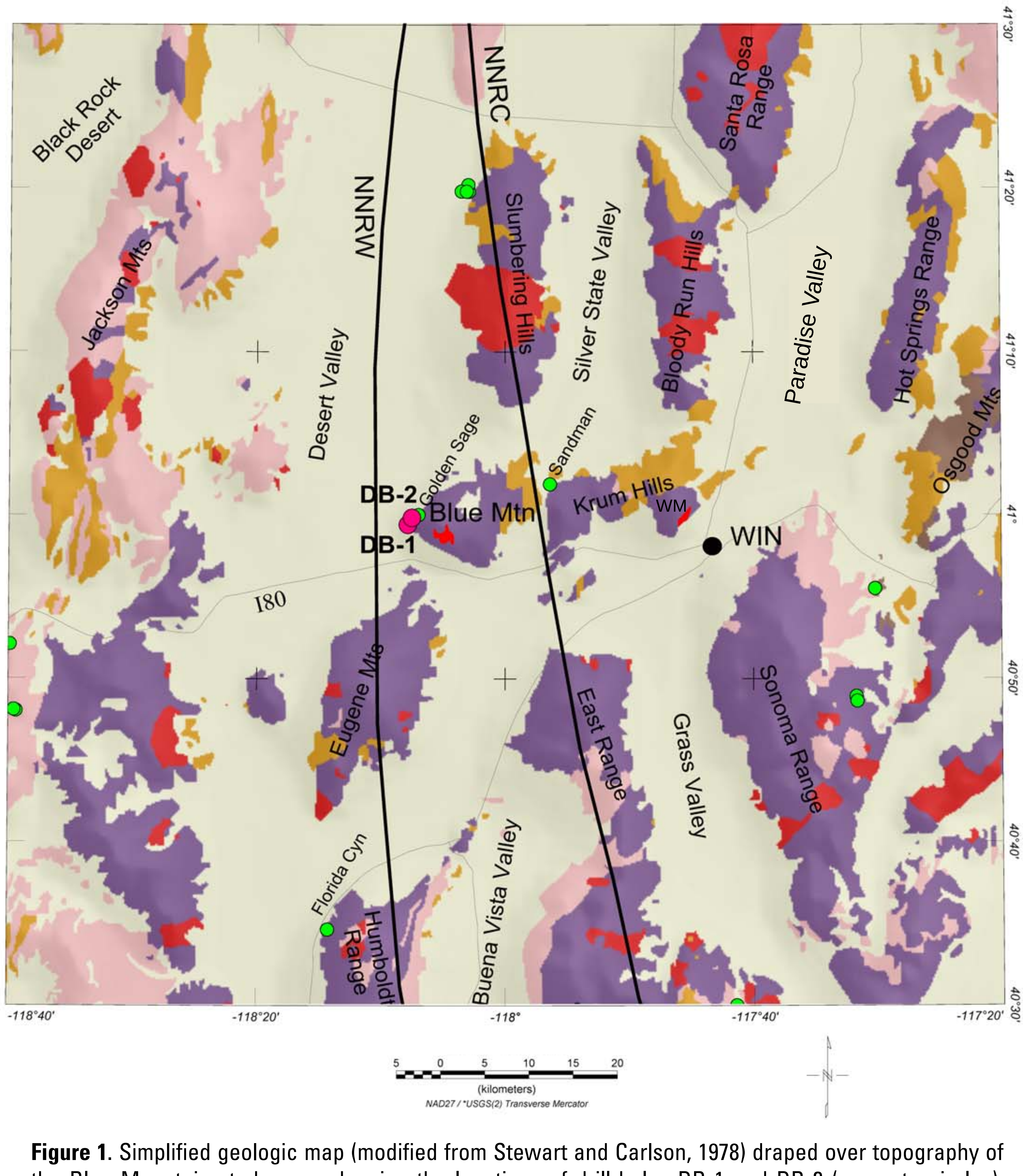


Figure 1. Simplified geologic map (modified from Stewart and Carlson, 1978) draped over topography of the Blue Mountain study area showing the locations of drill-holes DB-1 and DB-2 (magenta circles). Green circles, epithermal gold deposits (from Wallace and others, 2004); NNRC and NNRW, central and western northern Nevada rifts inferred from aeromagnetic data (Ponce and Glen, 2002); WIN, Winnemucca; WM, Winnemucca Mountain. Geology: Yellow, Quaternary alluvium; pink, Tertiary volcanic rocks; orange, Tertiary basaltic rocks; purple, pre-Cenozoic rocks; red, plutonic rocks.

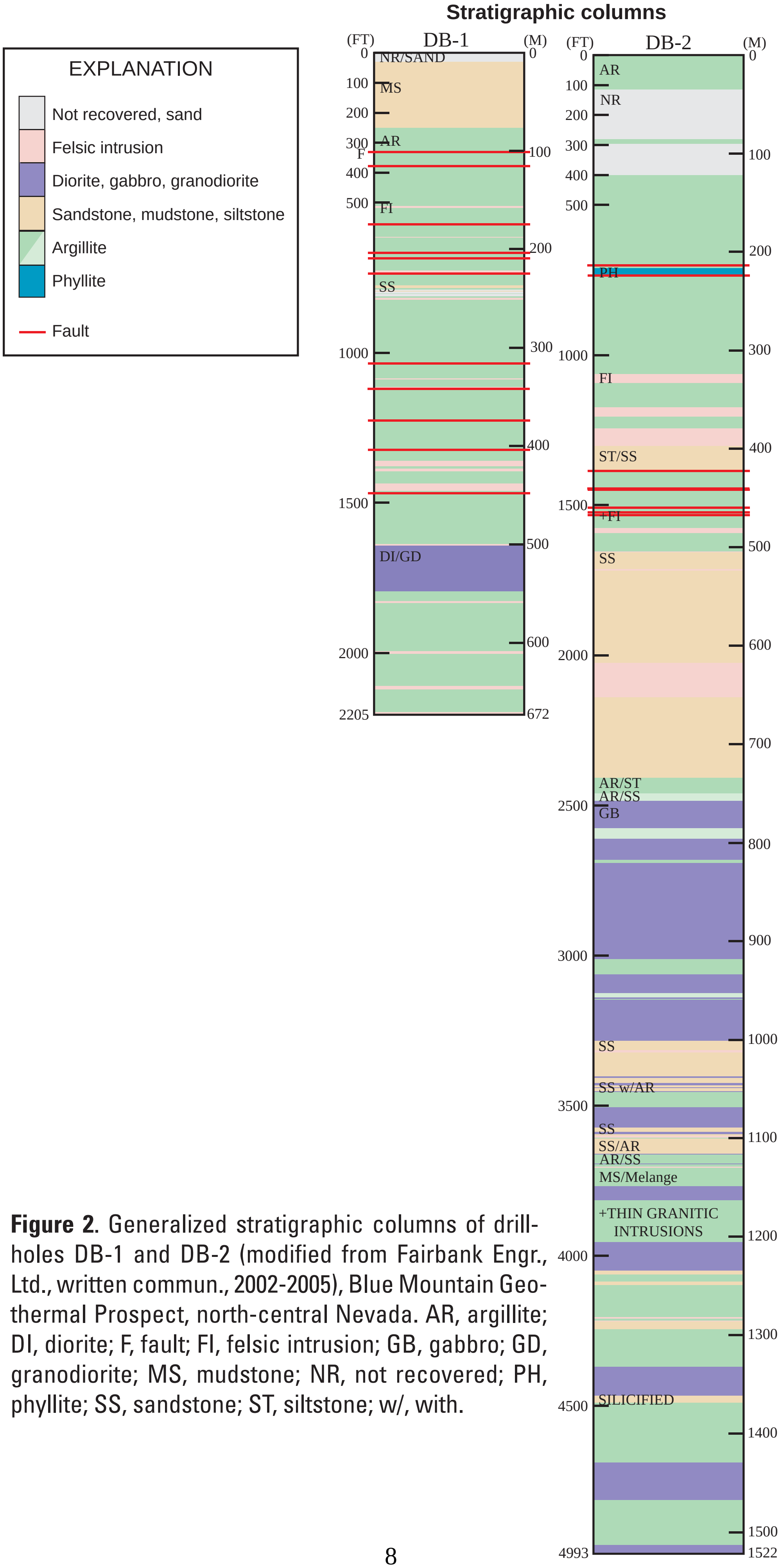


Figure 2. Generalized stratigraphic columns of drill-holes DB-1 and DB-2 (modified from Fairbank Engr., Ltd., written commun., 2002-2005), Blue Mountain Geothermal Prospect, north-central Nevada. AR, argillite; DI, diorite; F, fault; FI, felsic intrusion; GB, gabbro; GD, granodiorite; MS, mudstone; NR, not recovered; PH, phyllite; SS, sandstone; ST, siltstone; w/, with.

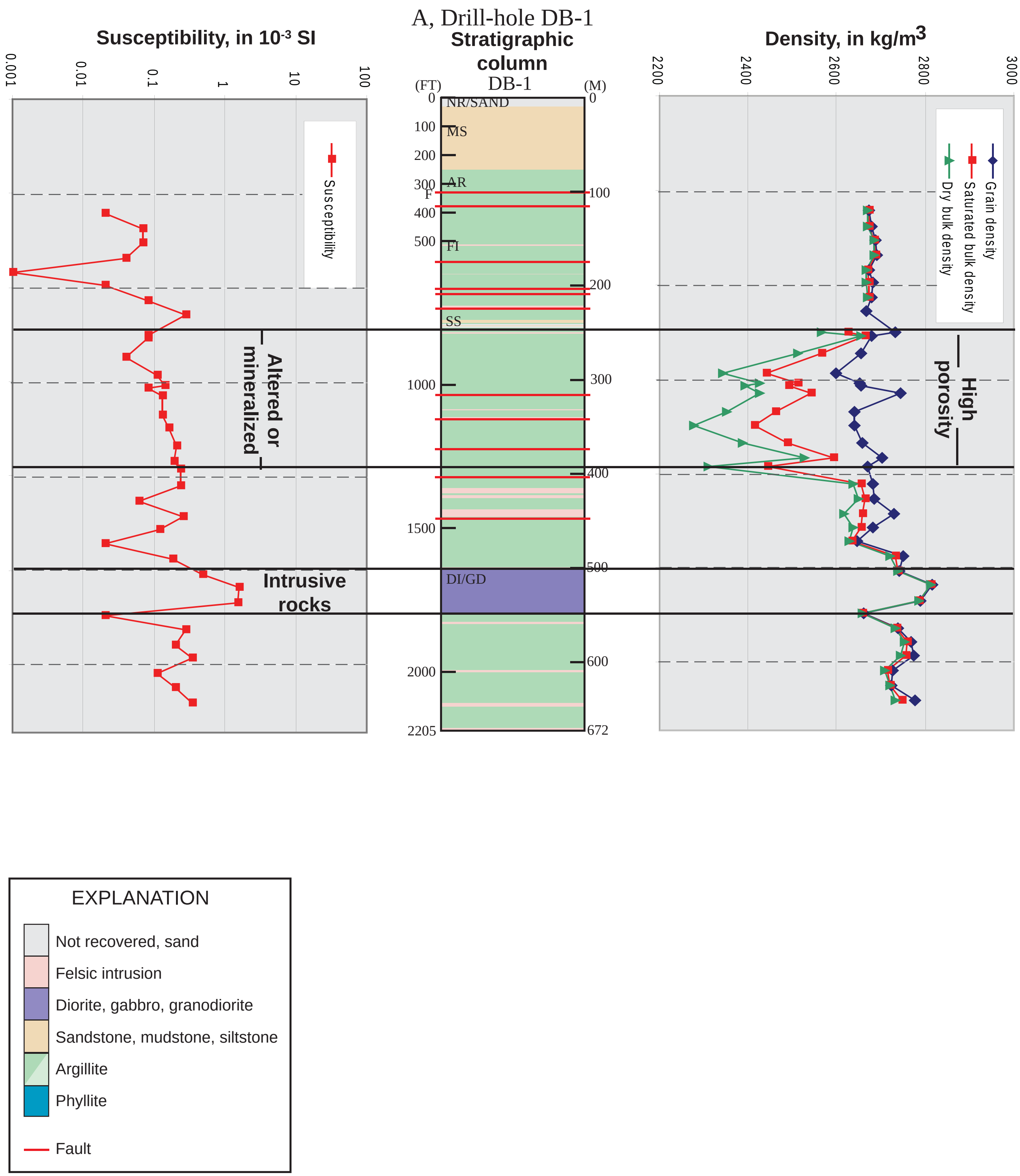
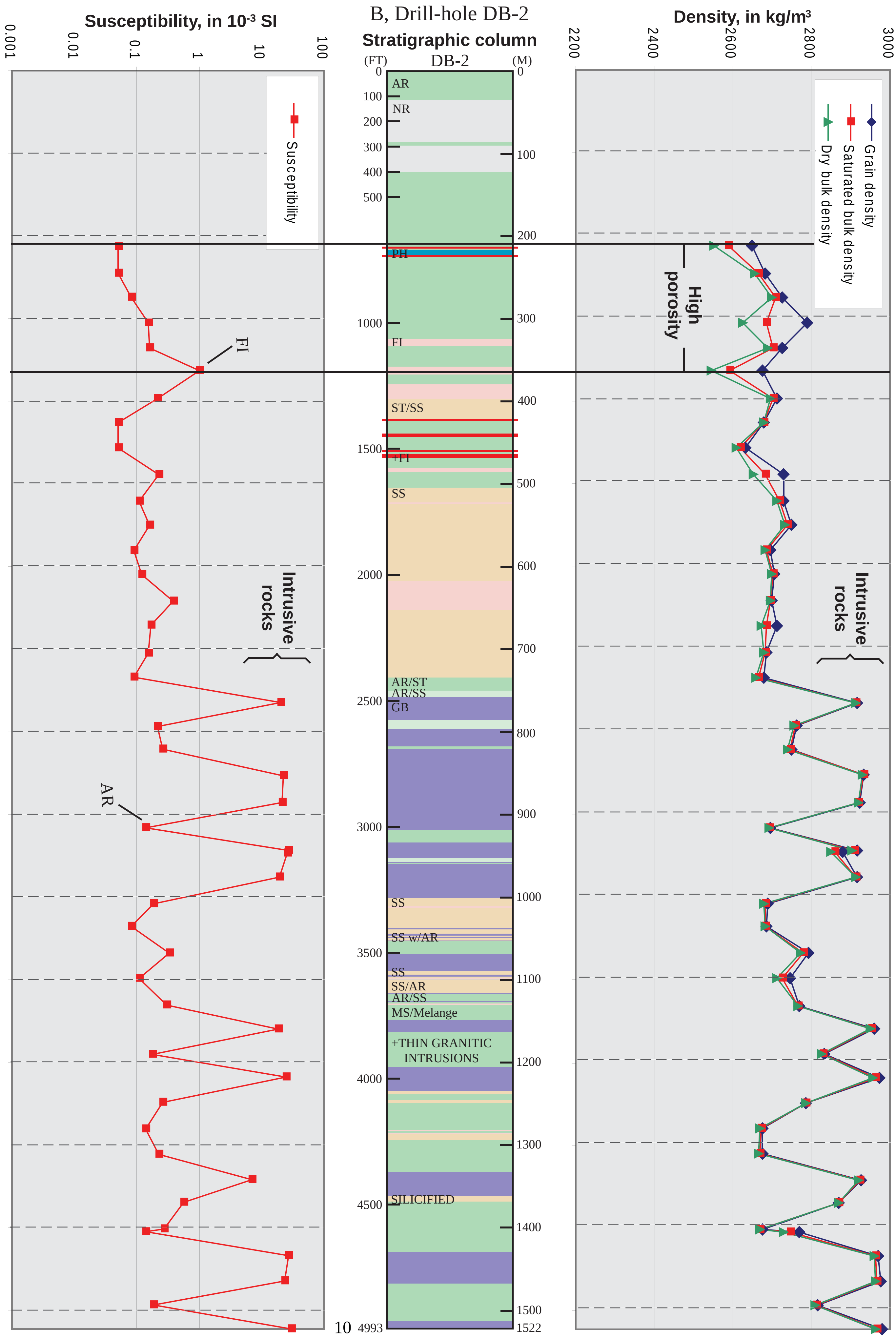


Figure 3. *A*, Density and susceptibility versus depth in drill-hole DB-1, and *B*, drill-hole DB-2, Blue Mountain Geothermal Prospect, north-central Nevada. See figure 2 for explanation.


B, Drill-hole DB-2
Stratigraphic column
DB-2
(FT)
(M)
Susceptibility, in 10⁻³ SI
0.001
0.01
0.1
1
10
100
Susceptibility
FI
AR
Intrusive rocks
Density, in kg/m³
2200
2400
2600
2800
3000
Grain density
Saturated bulk density
Dry bulk density
High porosity
Intrusive rocks
AR
NR
PH
FI
ST/SS
+FI
SS
AR/ST
AR/SS
GB
SS
SS w/AR
SS
SS/AR
AR/SS
MS/Melange
+THIN GRANITIC INTRUSIONS
SILICIFIED
4993
1522
10

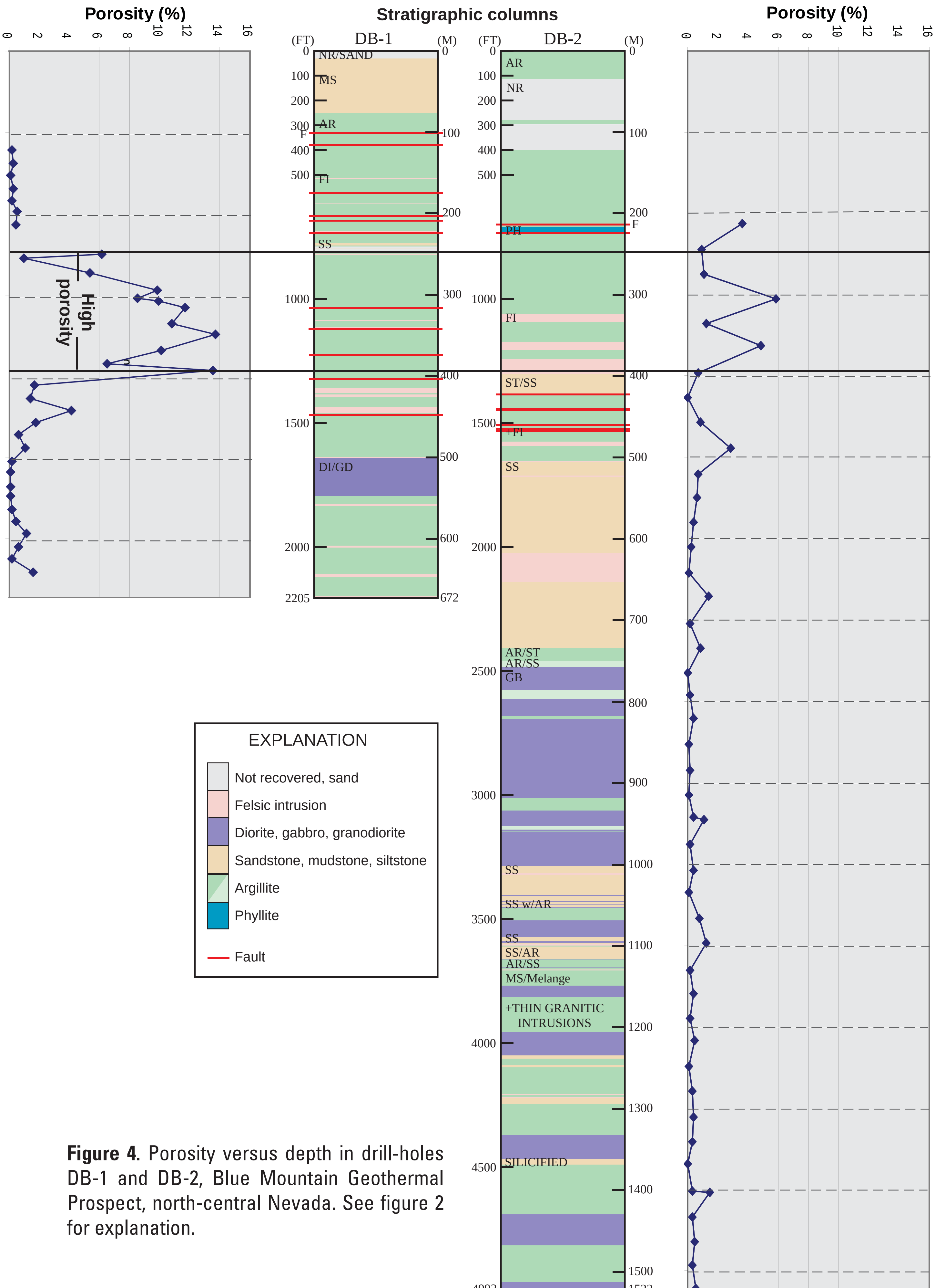


Figure 4. Porosity versus depth in drill-holes DB-1 and DB-2, Blue Mountain Geothermal Prospect, north-central Nevada. See figure 2 for explanation.

A

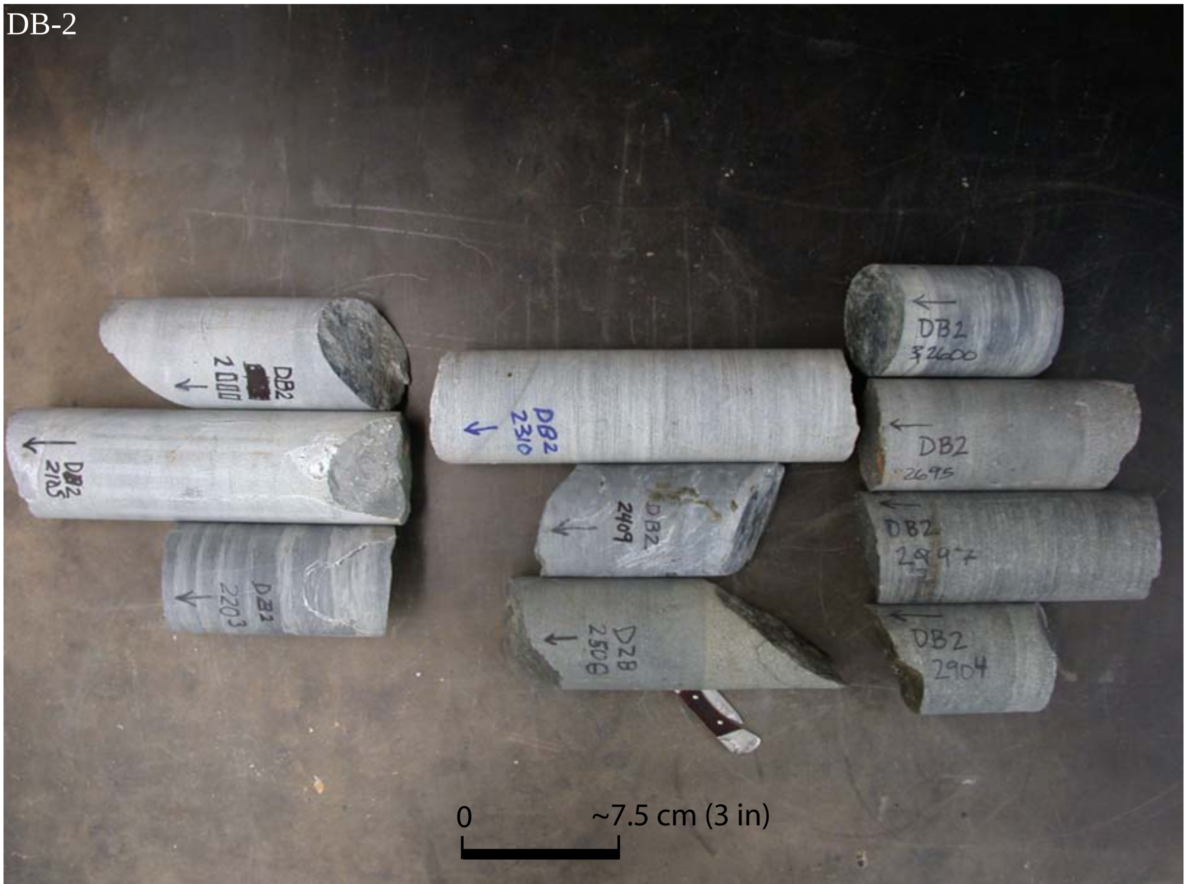
B

Figure 5. *A-F*, Core-sample photographs. *G*, Photos of surface samples from the Blue Mountain diorite on the southwest face of Blue Mountain. *H*, Photos of surface samples from the Winnemucca Mountain diorite along the southeast margin of Krum Hills.

C

D

E



F

G Blue Mountain Diorite

H Winnemucca Mountain Diorite

Table 1. Physical-property data by rock type, Blue Mountain Geothermal Prospect, north-central Nevada.

Rock type	Number of samples	Grain density kg/m^3	Range	Saturated-bulk density kg/m^3	Range	Dry-bulk density kg/m^3	Range	Magnetic susceptibility x10^{-3} SI	Range
DB-1									
Argillite	26	2,688	2,598 - 2,775	2,621	2,441 - 2,759	2,581	2,309 - 2,754	0.12	0.00 - 0.35
Diorite	3	2,782	2,742 - 2,815	2,780	2,739 - 2,814	2,778	2,737 - 2,813	1.20	0.48 - 1.58
Felsic rocks	1	2,729	-- --	2,658	-- --	2,617	-- --	0.26	-- --
Mudstone	4-5	2,709	2,639 - 2,776	2,654	2,414 - 2,747	2,615	2,277 - 2,733	0.25	0.16 - 0.34
Quartz vein	1	2,645	-- --	2,634	-- --	2,628	-- --	0.02	-- --
DB-2									
Argillite	21	2,720	2,631 - 2,827	2,704	2,587 - 2,870	2,694	2,551 - 2,870	0.17	0.05 - 0.56
Diorite	4	2,963	2,927 - 2,979	2,955	2,922 - 2,968	2,951	2,919 - 2,963	21.8	6.90 - 29.6
Felsic rocks	3	2,706	2,674 - 2,730	2,658	2,593 - 2,701	2,631	2,545 - 2,695	0.49	0.21 - 1.02
Gabbro	9	2,907	2,750 - 2,972	2,901	2,744 - 2,963	2,897	2,740 - 2,958	20.0	0.26 - 27.5
Mudstone	2	2,823	2,816 - 2,831	2,819	2,811 - 2,828	2,817	2,808 - 2,826	0.18	0.18 - 0.19
Sandstone	6	2,721	2,684 - 2,770	2,711	2,683 - 2,745	2,706	2,682 - 2,733	0.16	0.08 - 0.39
Siltstone	1	2,675	-- --	2,670	-- --	2,667	-- --	0.27	-- --
DB-1 and DB-2									
Argillite	47	2,702	2,598 - 2,871	2,658	2,441 - 2,870	2,632	2,309 - 2,870	0.14	0.00 - 0.56
Diorite	7	2,885	2,742 - 2,979	2,880	2,739 - 2,968	2,877	2,737 - 2,963	13.0	0.48 - 29.6
Felsic rocks	4	2,712	2,674 - 2,730	2,658	2,593 - 2,701	2,628	2,545 - 2,695	0.43	0.02 - 1.02
Gabbro	9	2,907	2,750 - 2,972	2,901	2,744 - 2,963	2,897	2,740 - 2,958	20.0	0.26 - 27.5
Mudstone	6-7	2,742	2,639 - 2,831	2,709	2,414 - 2,828	2,682	2,277 - 2,826	0.23	0.16 - 0.34
Sandstone	6	2,721	2,684 - 2,770	2,711	2,683 - 2,745	2,706	2,682 - 2,733	0.16	0.08 - 0.39
Siltstone	1	2,675	-- --	2,670	-- --	2,667	-- --	0.27	-- --
Quartz vein	1	2,645	-- --	2,634	-- --	2,628	-- --	0.02	-- --
Surface samples--Blue Mtn Diorite									
Diorite	10	2,827	2,810 - 2,837	2,788	2,775 - 2,804	2,766	2,746 - 2,791	15.6	15.0 - 24.8
Surface samples--Winnemucca Mtn Diorite (eastern Krum Hills)									
Diorite	10	2,670	2,613 - 2,704	2,643	2,568 - 2,688	2,627	2,540 - 2,682	0.70	0.23 - 1.93