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STRATIGRAPHIC RELATIONSHIPS IN MESOZOIC BASEMENT ROCKS AT THE DESERT PEAK EAST EGS AREA, NEVADA

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ABSTRACT

Several plutonic units within Mesozoic basement rocks of the east Desert Peak area are potential EGS reservoirs. Sill-like Jurassic diorites and Cretaceous granodiorite intrusives occur at temperatures exceeding 400ºF (204ºC) within the basement. Geologic studies are being conducted to determine the lateral and vertical distribution of the basement lithologies, the nature of contacts (depositional, fault, or intrusive) with surrounding schistose metasedimentary rocks, and the character and mineralogy of natural fractures and veins in the rocks to identify suitable targets for stimulation in subsequent phases of this enhanced geothermal system (EGS) project.

Dioritic intrusives in the Jurassic section are tentatively correlated to the Humboldt mafic complex; a sequence of gabbroic to intermediate composition intrusives and comagmatic basaltic volcanics that are closely associated with shallow marine metasediments (quartz arenite of the Boyer Ranch Formation; gypsum and carbonate of the Lovelock Formation), and which host the high-temperature Dixie Valley geothermal system 75 km to the east. In the Desert Peak geothermal area, a thick (100 m) quartz monzodiorite sill within the Jurassic section can be correlated across the EGS project site (drillholes DP 23-1 and 35-13 TCH) and to outcrops near the Desert Queen mine (about 6 km NE of the EGS area). However, complicated structural and stratigraphic relationships with surrounding Jurassic intrusive and metasedimentary units and the presence of both Cretaceous and Miocene dikes in the monzodiorite suggest variable physical and mechanical properties and possible unpredictable behavior as a result of well stimulation procedures. A better lithologic target for future wellbore stimulation may be the Cretaceous-aged granodiorite that intrudes the Jurassic section. The homogeneous Cretaceous granodiorite is a more massive intrusive body (at least 750 m thick) and below a sericitized roof, is generally weakly altered with only a few discrete fracture/fault zones.

Introduction

The Desert Peak East Enhanced Geothermal System Project (DPEEP) is a DOE-Industry cost-shared site located within the Hot Springs Mountains, northwestern Churchill County, approximately 50 miles (80.5 km) northeast of Reno, Nevada. This study is part of DOE Contract DE-FC36-02ID14406, awarded to ORMAT Nevada, Inc. and its partner GeothermEx, Inc.

As defined by ORMAT (2002) and Schochet and others (2002), the DPEEP area is in Sections 13, 14 and 23, T22N and R27E, located between the Rhyolite Ridge Fault to the west and the Desert Queen Fault to the east (Figure 1). The focus of the DPEEP research is the pre-Tertiary metamorphic and granitic rocks that have temperatures up to 400ºF (204ºC) in the study area.

Petrographic and mineralogic analyses of rock material from two drill holes within the DPEEP area were performed in order to identify the lithologies and the stratigraphic relationships between the various rock types. A total of 52 thin sections were examined and 30 X-ray diffraction (XRD) analyses were completed on rock samples from these two wells (Lutz, 2003). Exploration well DP 23-1 was drilled to a depth of 9,641 feet (2,939 m) in 1979, and drill cuttings from the deep test have been stored in the Energy and Geoscience Institute's Geothermal Sample Library since the early 1980s. Core hole 35-15 TCH was core drilled to a depth of 4,230 feet (1,289 m) in 1992 and the core has been stored on site near the Desert Peak power plant since that time. Both the DP 23-1 and 35-13 TCH wells have commercial temperatures (300 to 410ºF; 149 to 210ºC) and penetrate potential reservoir rock;

however, both encountered non-commercial permeability.

A general stratigraphic framework for the east Desert Peak EGS area is presented in Lutz and others, 2003. In this paper, we discuss in more detail the stratigraphy of the Mesozoic basement rocks and regional relationships between the different lithologies in the Jurassic rocks. The objective is to understand the lateral and vertical distribution of potential EGS reservoir lithologies, and/or clay-rich fault or breccia zones and other lithologic units, such as phyllites, that may be detrimental to either the well bore stability or the well bore stimulation program.

Geologic Framework of the East Desert Peak Area

The Hot Springs Mountains rise to a maximum elevation of about 5,400 feet (1,646 m) above sea level and are veneered by Quaternary and Tertiary volcanic and metasedimentary rocks. Adjacent ranges consist of various Mesozoic sedimentary, volcanic and granitic rocks overlain by Tertiary volcanic formations similar to those found in the Hot Springs Mountains (Willden and Speed, 1974; Benoit and others, 1982). Extensive drilling in the Desert Peak geothermal area has shown that the northern Hot Springs Mountains are underlain by Mesozoic metamorphic and granitic rocks (Benoit and others, 1982; Lutz and others, 2003). These crystalline rocks are the subject of the current EGS study.

Mesozoic Lithologies in the Study Drill Holes

Three packages of rock constitute the Mesozoic basement in the east Desert Peak area: an upper package of fine-grained, weakly metamorphosed marine metasediments; an intermediate group of dioritic intrusives with minor intercalated schists and phyllites; and a thick granodiorite unit at depth. A downhole plot of the lithologies, secondary and hydrothermal alteration minerals, and measured subsurface temperatures for well DP 23-1 is shown in Figure 2. Although there are no radiometric dates for these packages of rock, the muscovite-biotite granodiorite is similar to Cretaceous two-mica granites typical of the Sierra Nevada batholith found to the west in Nevada and California. Diorites in the package of rock overlying the granodiorite are similar to Jurassic-aged diorites mapped at the Desert Queen Mine (Willden and Speed, 1974), located about 4 miles (6.5 km) northeast of the DPEEP area (Fig. 1).

The upper metasedimentary package is labeled as pT1 (Pre-Tertiary unit 1) in Figure 2 and subsequent figures. The pT1 package is a sequence of fine-grained pelites, shales, graywackes, tephra deposits, dolomitic mudstones, and minor siltstones, rhyolite conglomerates and volcaniclastics. This sequence has undergone low-grade regional greenschist metamorphism and the rocks are generally non-foliated.

Pre-Tertiary Unit 2 (pT2) underlies pT1 in the DPEEP area, and consists of intercalated dioritic rocks and foliated metasedimentary rocks. The metasedimentary rocks consist of chlorite-muscovite slates, phyllites, biotite schists, and a few thin marbles. A distinctive black phyllite is present at 5,500 feet (1,676 m) in DP 23-1 and at 3,047 feet (929 m) in 35-13 TCH (Fig. 3).

The dioritic rocks of pT2 include rocks with compositions between quartz monzonite, quartz monzodiorite, and hornblende diorite. The dominant composition in both DP 23-1 and in 35-13 TCH is a quartz monzodiorite with 7-10 wt % quartz, 40-45 wt % plagioclase, 10-15 wt % potassium feldspar and 1-4 wt % sphene. The quartz monzodiorite is a laterally extensive plutonic unit within the pT2 package. In 35-13 TCH, it is 351 feet (107 m) thick. In well DP 23-1, quartz monzodiorite in a similar stratigraphic position is about 320 feet (98 m) thick. The quartz monzonite may represent a tabular to sill-like body that is semi-concordant with adjacent sedimentary units (Fig. 3).

In DP 23-1, a clinopyroxene and hornblende-bearing diorite directly overlies the main granodiorite intrusive body (Fig. 2). The diorite is medium crystalline and contains primary hornblende phenocrysts with cores of clinopyroxene. The diorite is strongly propylitically altered to epidote, chlorite, pyrite and calcite, is moderately sericitized, and has also been thermally metamorphosed by the underlying granodiorite intrusive. A 60-foot (18 m) thick granitic dike cuts the diorite from 6,860 to 6,920 feet (2,091 to 2,109 m).

The biotite-muscovite granodiorite is present below 7,020 feet (2,140 m) in well DP 23-1. The granodiorite is equigranular, medium to coarsely crystalline, and contains primary biotite and muscovite, microcline and orthoclase, and large quartz crystals. X-ray diffraction mineralogy indicates that the granodiorite contains 22-28 wt % quartz, 37-42 wt % plagioclase, 14-19 wt % potassium feldspar and 3 to 5 wt % mica. There are some associated late-stage tourmaline-bearing aplite dikes and pegmatitic veins containing muscovite and biotite that extend from the granodiorite into the overlying diorite and metasedimentary rocks. Similar tourmaline-bearing dikes occur in the quartz monzodiorite in 35-13 TCH (Fig. 3), and imply that the granodiorite may be present beneath the bottom of this relatively shallow core hole.

The granodiorite appears to have intruded into and partially altered the pT2 sequence in both DP 23-1 and 35-13 TCH. Hornfelsic-type alteration (quartzamphibole-pyroxene-biotite-tourmaline-epidote-pyrite) and recrystallization of the metamorphic rocks is evident at the contacts between this intrusive unit and the surrounding rocks. The distribution of these contact metamorphic minerals and other secondary minerals is indicated in Figure 2.

From an EGS perspective, there are three favorable (i.e., competent) crystalline rock units in the Mesozoic basement- the two Jurassic-aged diorites in the pT2 section, and the deep Cretaceous granodiorite. The first Jurassic unit is the quartz monzodiorite extending from 5,060 to 5,380 feet (1,542 to 1,640 m) in well DP 23-1, which is also found in 35-13 TCH from 3,123 feet to 3,484 feet (952 to 1,062 m). The second is the hornblende diorite unit extending from 6,800 feet to 7,020 feet (2,073 and 2,140 m) in well DP 23-1. Beneath these units is the granodiorite that is less altered, less veined and more massive than the two intrusive units above. In DP 23-1, the granodiorite is about 775 meters thick.

Local and Regional Stratigraphic Relationships

The Mesozoic basement lithologies and stratigraphic sequences found in wells DP 23-1 and 35-13 TCH can generally be traced throughout the DPEEP area and across the northern Hot Springs Mountains. The pre-Tertiary section, although over 1,000 feet (300 m) shallower in 35-13 TCH than in DP 23-1, can be correlated across the DPEEP area. Using the work of Benoit and others (1982), Figure 4 illustrates general stratigraphic correlations across the northern Hot Springs Mountains and the EGS project site.

The shallow core hole 35-13 TCH was not apparently deep enough to intersect either the pT2 hornblende diorite or the granodiorite observed in well DP 23-1. However, the presence of granitic dikes and tourmaline-bearing veins in 35-13 TCH suggest that the main granodiorite intrusive body is within 500 meters of the base of 35-13. Hornblende-bearing rocks and hornblende diorite have been described from both subsurface samples in the Desert Peak field, and at the Desert Queen Mine (Willden and Speed, 1974), located about 4 miles (6.5 km) NE of the DPEEP site (Fig. 1). Willden and Speed mapped the Desert Queen intrusive as a mid-Jurassic diorite. The hornblende diorite in DP 23-1 may also correlate to the “hornblendite” reported in Desert Peak well B29-1 by Benoit and others (1982). Well B29-1 is located about 3.5 miles (5.6 km) southwest of the DPEEP area (Fig. 1).

The pT1 and pT2 sequences are similar to weakly metamorphosed Jurassic rocks that overlie metavolcanic and metasedimentary Triassic-Jurassic rocks found to the northeast in the Stillwater Range and within the Dixie Valley geothermal reservoir (Willden and Speed, 1974, Lutz and others, 1997; Plank, 1997), and to other Mesozoic formations in northwestern Nevada described by other workers (Garside, 1998; Oldow and others, 1990). The hornblende diorites and quartz monzodiorites of the pT2 metamorphic package are generally similar to intrusives of the Jurassic-age Humboldt mafic complex (Dilek and Moores, 1995; Johnson and Barton, 2000; Lutz and Hulen, 2001). We tentatively correlate the hornblende-bearing quartz monzodiorite in 35-13 TCH and DP 23-1, the hornblende diorite in DP 23-1, the “hornblendite” noted in well B29-1, and the propylitically-altered hornblende diorite outcrops at the Desert Queen Mine, and suggest that these hornblende-bearing plutonic rocks represent deeper portions of the Jurassic Humboldt complex.

“Greenstones” described from wells B21-1 and B21-2 (Benoit and others, 1982) may represent propylitically-altered metavolcanics from the upper part of the Humboldt complex. Quartzites and limestones or marbles described from wells B21-1 and B29-1 and from Stratigraphic Test No. 3 (labeled ST-3 in Figure 4) may represent portions of the Boyer Ranch Formation, and the Lovelock and/or Muttlebury Formations, respectively. These mid-Jurassic metasedimentary formations are closely associated with the Humboldt complex in the Stillwater Range and in the Mopung Hills at the southern end of the West Humboldt Range (Willden and Speed, 1974). This interpretation places the Desert Peak geothermal area at the southwestern edge of this Jurassic back-arc basin, while the Dixie Valley geothermal field lies at its northeastern edge. In both geothermal areas, fractured Jurassic-age dioritic rocks may serve as important reservoir rocks, and permeability pathways or conduits for present-day geothermal fluids.

The widespread occurrence of greenstones and diorites in the pT2 metamorphic package suggests that Jurassic basement rocks underlie much of the northern Hot Springs Mountains. Individual units within the metasedimentary packages (pT1 and pT2) are more difficult to correlate over the area, or to assign to a specific formation or age. The pT1 sequence appears to be discontinuous; it was not recognized in most of the wells in the Desert Peak field, but is clearly present in both DP 23-1 and 35-13 TCH (see Figures 3 and 4). A metaignimbrite bed can be used as a marker bed for correlation within the pT1 unit. As illustrated in Figure 3, the upper two subunits of pT1 are missing in 35-13 TCH and may have been eroded off before deposition of the overlying Oligocene-age tuffaceous units. Hence, the topographic high in the Mesozoic basement in the area east of the Desert Peak EGS area (see Figures 3 and 4) appears to have present since at least the early Oligocene.

The difference in metamorphic grade between pT1 and pT2 suggests a fault contact between these two units, but the nature and age of this fault is unknown. If the diorites are middle Jurassic in age, the intercalated black phyllites of the pT2 subunit are likely late Triassic to early Jurassic rocks. The overlying pT1 metasediments and metavolcanics may represent middle to late Jurassic strata, age equivalents of the Jurassic Gardnerville or Peavine Peak Formations described from the Talapoosa and Olinghouse mining districts in the Virginia and the Pah Rah Ranges, respectively (Garside, 1998; John and others, 1999). A detailed stratigraphic/structural analysis of the subsurface Triassic-Jurassic rocks in the Hot Spring Mountains has not yet been conducted. Further research on well cuttings and core material from the other geothermal wells could help resolve some of these issues, and could be combined with surface mapping, geophysical surveys and age dating of the plutonic units (Faulds and others, 2003) to more fully interpret the stratigraphy of the Mesozoic basement.

Summary

There are three major intrusive bodies in the pre-Tertiary section that are good candidates for future hydraulic stimulation, and all three appear to be present across the Desert Peak East EGS project area. Two of these are strongly altered, strongly veined, sill-like Jurassic diorites that are up to 100 meters thick. Both of these dioritic plutons are cut by granitic dikes that are up to 20 meters thick. The abundant carbonate alteration and veining in the quartz monzodiorite may be amenable to chemical stimulation, but complicated stratigraphic relationships with surrounding incompetent metasedimentary rocks such as the phyllite suggest unpredictable mechanical properties.

On the basis of petrographic and mineralogical studies and stratigraphic correlations, the most attractive EGS target in the project area is the two-mica granodiorite (Lutz and others, 2003; Robertson-Tait and Morris, 2003). Analysis of a well bore imaging log and the results of initial injection testing of well DP 23-1 have been used to evaluate *in-situ* stresses, and the orientations and apertures of natural fractures; these characteristics are being used to discriminate between possible EGS target zones in the well (Robertson-Tait and others, 2004).

Acknowledgments

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REFERENCES

Benoit, W.R., J.E. Hiner, and R.T Forest, 1982, Discovery and Geology of the Desert Peak Geothermal Field: A Case History, Nevada Bureau of Mines and Geology Bulletin 97, 82p.

Dilek, Y., and E.M. Moores, 1995, Geology of the Humboldt igneous complex, Nevada and tectonic implications for the Jurassic magmatism in the Cordilleran orogen: in Miller, D.M., and Busby, C., Jurassic Magmatism and Tectonics of the North American Cordillera: Geological Society of America, Special Paper 299, p. 229-248.

Faulds, J.E., Garside, L., and Opplinger, G., 2003, Structural analysis of the Desert Peak-Brady geothermal field, western Nevada: implications for understanding linkages between NE-trending structures and geothermal anomalies in the Humboldt structural zone: Geothermal Resources Council Transactions, v. 27, p. 859-864.

Garside, L.J., 1998, Mesozoic Metavolcanic and Metasedimentary Rocks of the Reno- Carson City Area Nevada and Adjacent California, NBMG, Report 49, 30 p.

John, D.A., Garside, L.J., and Wallace, A.R., 1999, Magmatic and tectonic setting of late Eocene epithermal gold-silver deposits in northern Nevada, with an example on the Pah Rah and Virginia Ranges and the northern Nevada rift: Geological Society of Nevada Spring 1999 Field Trip Guidebook, Special Publication 29, Low-sulfidation Gold Deposits in Northern Nevada, p. 65-158.

Johnson, D.A., and Barton, M.D., 2000, Time-space development of an external brine-dominated, igneous-driven hydrothermal system: Humboldt Mafic Complex, Western Nevada: Part 1. Contrasting Styles of Intrusion-associated Hydrothermal Systems, Dilles, Barton, Johnson, Proffett, Einauldi, eds., Society of Economic Geologists Guidebook Series, Volume 32, p. 127-143.

Lutz, S.J., Moore, J.N., and Benoit, D., 1997, Geologic framework of Jurassic reservoir rocks in the Dixie Valley Geothermal Field, Nevada: Implications from hydrothermal alteration and stratigraphy, 22nd Stanford Workshop on Geothermal Reservoir Engineering, SGP-TR-155, January 27-29, 1997, p. 131 - 139.

Lutz, S.J., and J.B. Hulen, 2002, Geologic setting and alteration mineralogy of the Nickel mine and Bolivia region, Jurassic Humboldt mafic complex and Boyer Ranch Formation, northern Stillwater Range, Nevada: Geological Society of Nevada Spring 2002 Field Trip Guidebook, Special Publication No. 35, Jurassic Magmatism and Metal Deposits in Western Nevada, p. 117-133.

Lutz, S.J., 2003, Petrographic and X-Ray diffraction analyses of samples from corehole 35-13TCH and drillhole B23-1, Desert Peak Geothermal Field, Nevada: Report prepared for ORMAT Nevada Inc. under DOE Contract DE-FC07-02ID14406.

Lutz, S.J., Schriener, A., Jr., Schochet, D., and Robertson-Tait, A., 2003, Geologic characterization of Pre-Tertiary rocks at the Desert Peak East EGS Project Site, Churchill County, Nevada: Geothermal Resources Council Transactions, v. 27, p. 865-870.

ORMAT Nevada, Inc, 2002, Application to US Department of Energy Idaho Operations Office for Financial Assistance for Enhanced Geothermal Systems Project Development at Desert Peak East, Churchill County, Nevada, submitted by ORMAT and GeothermEx to DOE, April 2002.

Oldow, J.S., Bartel, R.L., and Gelber, A.W., 1990, Depositional setting and regional relationships of basinal assemblages: Pershing Ridge Group and Fencemaker Canyon sequence in northwestern Nevada: Geological Society of America Bulletin, v. 102, p. 193-222.

Plank, G.L., 1997, Structure, stratigraphy, and tectonics of a part of the Stillwater Escarpment and implications for the Dixie Valley geothermal system: M.S. thesis draft, University of Nevada- Reno, 153p.

Robertson-Tait, A., S.J. Lutz, J. Sheridan and C. Morris, 2004. Selection of an interval for massive hydraulic stimulation in well DP 23-1, Desert Peak East EGS Project, Nevada. Proceedings, 29th Stanford Workshop on Geothermal Reservoir Engineering (this volume).

Robertson-Tait, A., and Morris, C., 2003, Progress and future plans at the Desert Peak East EGS Project: Geothermal Resources Council Transactions, v. 27, p. 871-877.

Sanyal, S.K., Lovekin, J.W., Henneberger, R.C., Robertson-Tait, A., Brown, P.J., Morris, C.L., and Schochet, D., 2003, Injection testing for an enhanced geothermal system project at Desert Peak, Nevada: Geothermal Resources Council Transactions, v. 27, p. 885-891.

Schochet, D., Robertson-Tait, A., and Schriener Jr., A., 2002, Desert Peak East, Nevada: A step toward EGS commercialization in the Basin and Range: Geothermal Resources Council Transactions, v. 26, p 251-254.

Willden, R. and Speed, R.C., 1974, Geology and Mineral Deposits of Churchill County, Nevada, Nevada Bureau of Mines and Geology Bulletin 83, 95 p.

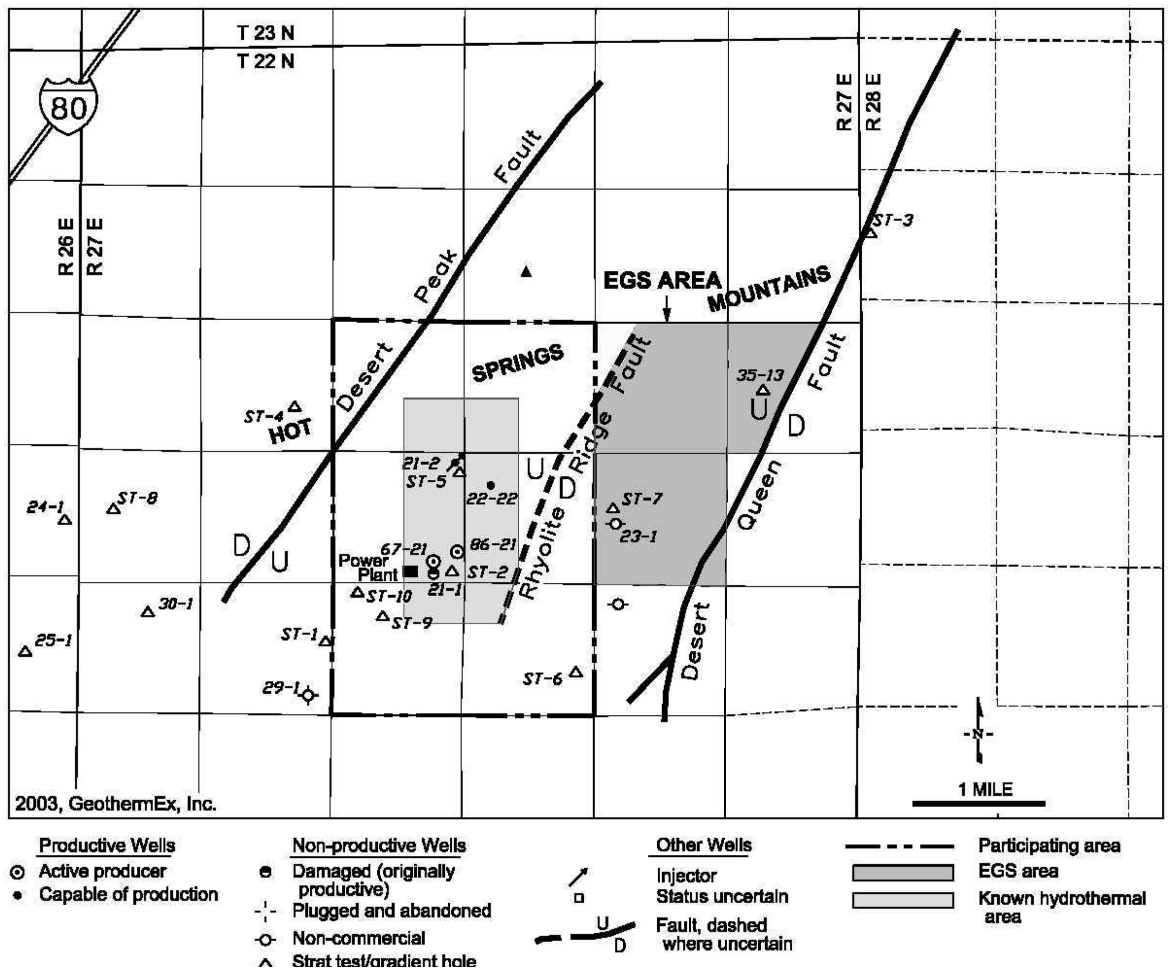

Figure 1. Well and fault location map, Desert Peak East EGS project site (faults from Benoit and others, 1982).

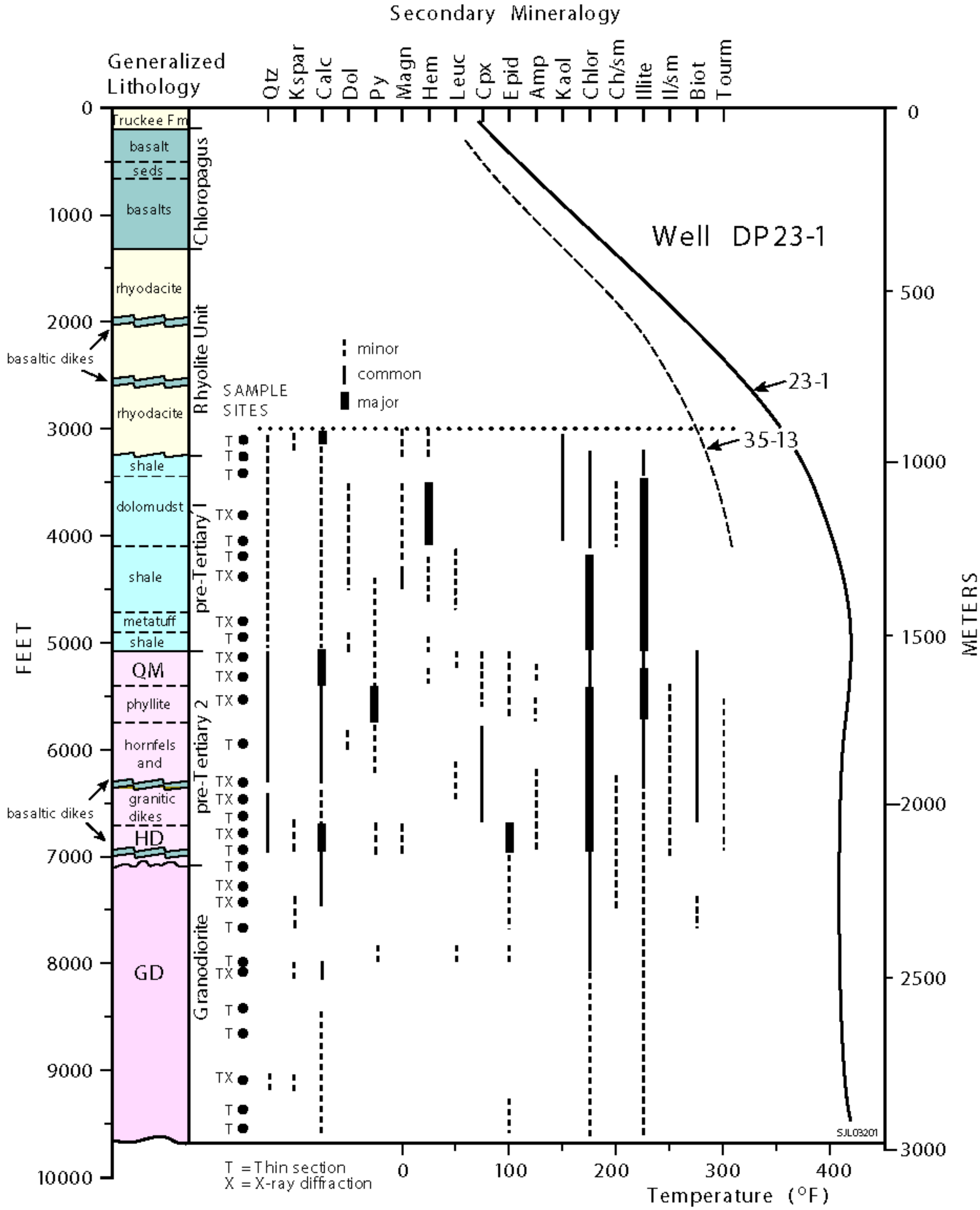

Figure 2: Lithologic column, distribution of secondary and hydrothermal alteration minerals in the pre-Tertiary section, and measured wellbore temperatures for well DP 23-1. Measured temperatures for core hole 35-13 TCH are also shown.

Explanation - Mineral abundances: Major = 15-5-%; Common = 5-15%; Minor = 1-5%. Mesozoic intrusives: QM = Jurassic quartz monzodiorite; HB = Jurassic hornblende diorite; GD = Cretaceous granodiorite.

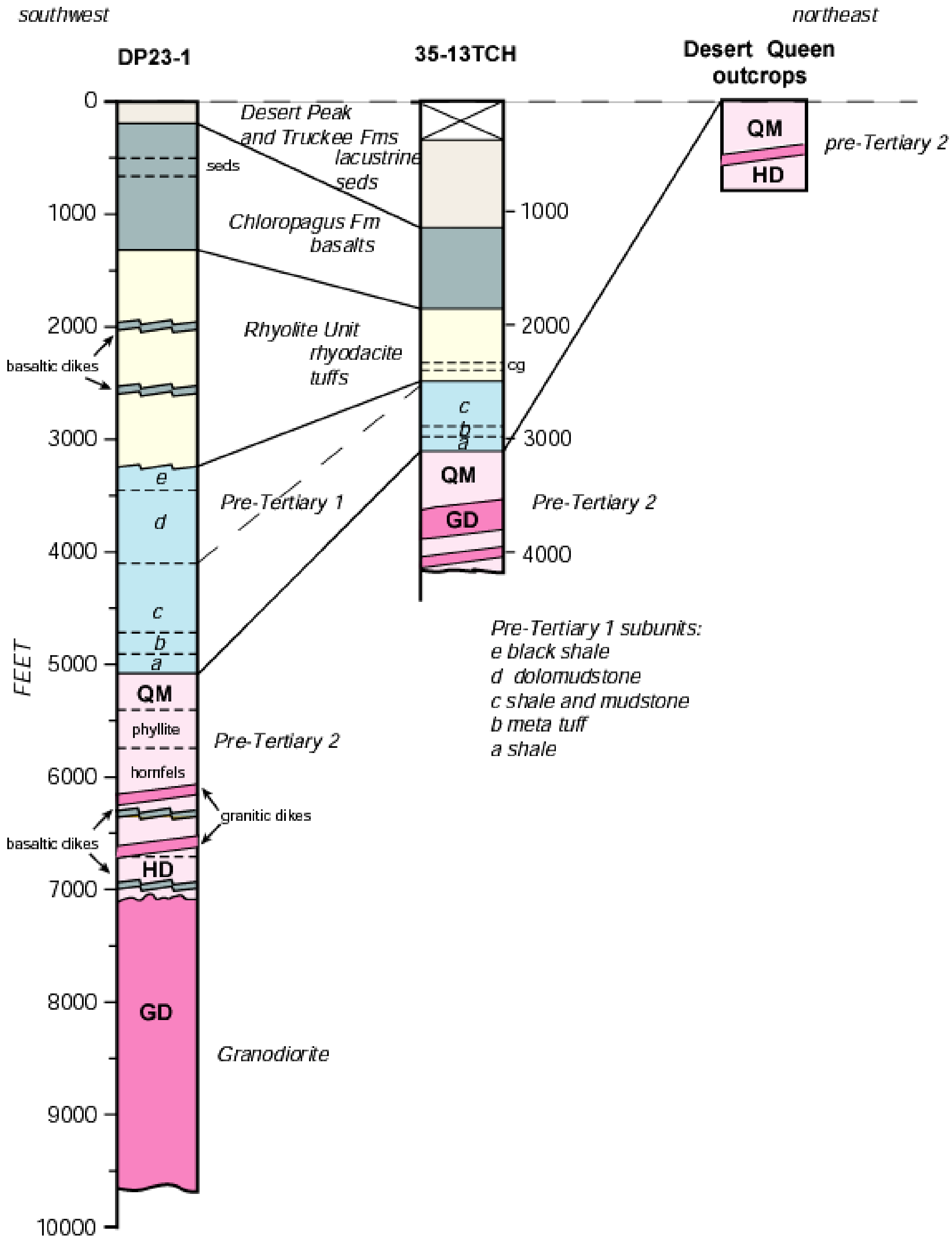

Figure 3: Detailed stratigraphic correlations of Desert Peak East wells DP 23-1 and 35-13 TCH and outcrops at the Desert Queen mine area (not to horizontal scale).

Mesozoic intrusives: QM = Jurassic quartz monzodiorite; HB = Jurassic hornblende diorite; GD = Cretaceous granodiorite.

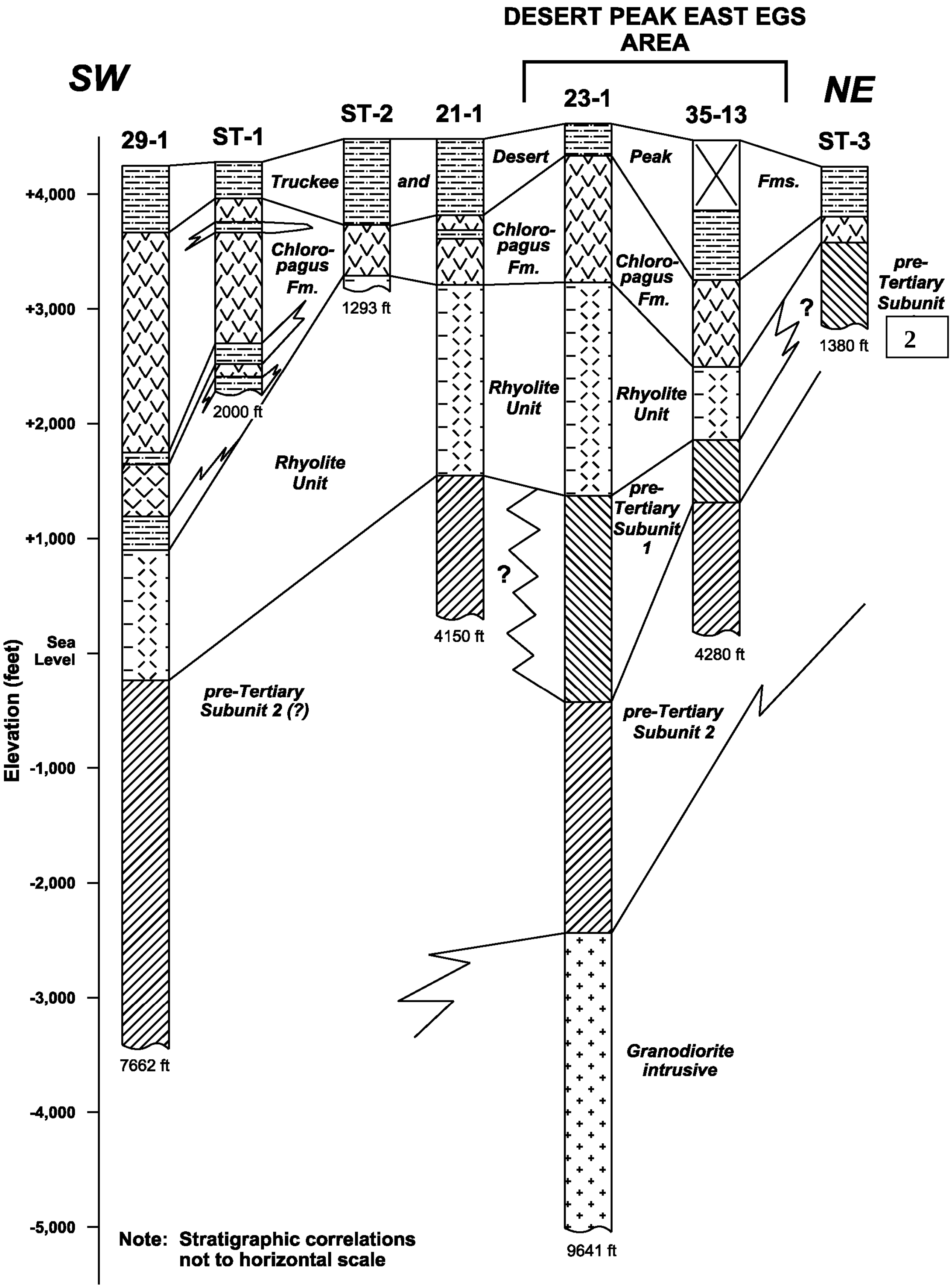

Figure 4: General stratigraphic correlations across the Hot Springs Mountains and the Desert Peak East EGS project area (stratigraphy of wells within the hydrothermal portion of the Desert Peak field from Benoit and others, 1982). Structural interpretations have not been attempted nor are implied.