

ELECTRIC LOG ANALYSIS OF PRECAMBRIAN IGNEOUS AND METAMORPHIC ROCKS IN THE ST. FRANCOIS MOUNTAINS, MISSOURI

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Abstract

Electric log, core, and optical petrographic analysis of a metamorphosed and deformed Precambrian-aged rhyolite effusive event identified 2 litho-facies and effected characterization of the rock deformation. Single-point resistance (SPR) and spontaneous potential (SP) electric logs identified the ubiquitous clay seams and localized dikes. The igneous/metamorphic rocks had naturally elevated gamma emissions; consequently, natural gamma (NG) logging was useless in the identification of clay seams. However, NG logs proved useful in the identification of dikes, which had readings of less than 150 cps. The SPR/SP suite also identified intrusive black zones, characterized as martite by thin section analysis, within the rhyolite.

Acoustic televiewer (AT) logs identified a conjugate shear fracture set with the main fracture set bearing a strike of N35°W and dip 80°NW or SE. The minor fracture set trends N35°E and dips 80°NE or SW. Thirty percent of the fractures logged are horizontal suggesting a vertically upward stress relief consistent with granite emplacement.

Porous zones within the rhyolite porphyry and contiguous with fractures appear to be the result of subsurface potassium feldspar phenocryst weathering and erosion. These zones are invisible to SPR, SP, and NG tools. Much of the feldspars within the rhyolite porphyry show weathering to kaolinite. Erosion and mobilization of the kaolinite is putatively considered to be the causative agent for the deposition of clay in the horizontal fracture sets.

Introduction

The rehabilitation of a dam in the St Francois Mountains of south-central Missouri required a detailed subsurface analysis of the subsurface for a foundation design basis. The bedrock consists of fractured rhyolite porphyry overlying granite. Clay seams and igneous dikes within the rhyolite porphyry and granite have been reported throughout the footprint of the dam. The laterally extensive clay seams are interpreted as zones of weakness, and consequently, are considered to be a design-based issue. Local clay lenses are not interpreted as a design issue.

Over 100 NX cores (or equivalent) were completed within the footprint of the dam and contiguous property. These cores identified extensive subsurface fracturing, clay seams of up to 15 cm, and thick sequences of intrusive dikes.

Electric log suite consisting of caliper, flux-gate magnetometer (FGM), temperature (T), AT, SP, SPR, fluid resistivity (FR), and NG, were used, in conjunction with cores, to assess their potential for the prediction of subsurface conditions.

Geology

The Saint Francois Mountains are part of the Ozark Plateau geomorphic province and part of the Ozark Mountains. The Ozark Plateau province is located chiefly in southern Missouri and northern Arkansas, between the Arkansas and Missouri rivers. It is bordered on the south by the Ouachita physiographic province, on the south and east by the Coastal Plain province, on the east by the Interior Low Plateau province, and on the north and west by the Central Lowlands province. The province is small, with a total area of about 129,500 km². The Saint Francois Mountains are characteristically well-rounded, heavily eroded ridges or rolling upland with thin soils.

Geologic History

The Saint Francois Mountains are an approximately 1.5 billion years old Precambrian terrain of anorogenic granites and rhyolites. The granites intruded the volcanic units that overlay and surround them. These mountains are part of the continental shield. This type of lithologic succession of volcanic rock overlying related intrusive rock has been found in other shield areas. The area has been deeply eroded leaving rhyolitic knobs as high points and exposed granitic plutons. In Early Paleozoic times this area was central to the Ozark dome uplift and probably sub-aerially exposed as islands in the Cambrian seas that covered the area. During this time the Cambrian Lamotte Sandstone and overlying Bonne Terre Dolomite were deposited around the edges of the granitic and rhyolite highs. It is important to note that the younger Paleozoic units that now surround the Saint Francois Mountains are flat lying with minimal deformation. Presumably, these sediments overlaid the volcanic-igneous suite and protected it from erosion.

From youngest to oldest the formations include; Diabase dikes and sills; St. Francois Mountains Intrusive Suite, a subvolcanic alkali granite ring complex; and St. Francois Mountains Volcanic Supergroup consisting of chiefly alkali rhyolite ash-flow tuffs with minor trachyte.

Several geologic features distinguish the Ozark Plateau province as a region. The faulting in the Ozarks is generally normal with most faults displaying a downward displacement on the southern side. Gentle folds are present, but these are generally of low amplitude. Surface rocks are older than those exposed in surrounding areas.

This area of Missouri contains a wealth of lead and iron mineral resources. The rhyolites of the Saint Francois Mountains host several high-grade magmatic and hydrothermal hematite and magnetite iron deposits.

The structural position of this Precambrian (1.48 Ga) volcanic-plutonic complex relative to the rest of the surrounding basement is due to its position at the crest of the Ozark Dome. The Ozark Dome is a structural high in the continental basement bounded by normal faults and strike-slip faults. Late Precambrian to Early Cambrian (Braile, et al., 1986) continental breakup gave genesis to the Reelfoot Rift, an aulocogen or failed rift arm of a continental pull-apart basin to the southeast of the Ozark Dome. Late Pennsylvanian-Early Permian Alleghenian compressive stress uplifted the Ozark Dome and Saint Francois Mountains (Clendinen, et al., 1989). Basement subsidence southeast of the Ozark Dome due to crustal thinning and sediment loading ensued as the Reelfoot and associated basement faults were reactivated during Late Paleozoic continental rifting. This process has contributed to the position of Ozark Dome as a structural and topographic high. In addition, isostatic rebound of the Dome due to denudation has contributed to the structural offset of the Ozark Dome from the surrounding areas. The Mississippi Embayment currently flanks the Ozark Dome to the southeast. The Mississippi Embayment contains a thick sequence of Phanerozoic sediments of marine, fluvial, and aeolian affinity which overlie the faulted basement associated with the Reelfoot Rift and New Madrid Rift Complex.

The geologic structure of the Saint Francois Terrain is marked by brittle deformation. Very little ductile deformation or metamorphism is documented. Contact metamorphism exists along the contact

volcanic and intrusive units, but foliation and folding are not a significant part of the regional geology. Bedding due to debris, ash, and lava flow exists in the volcanic units and bedding structures are apparent in the Cambrian and Ordovician rocks.

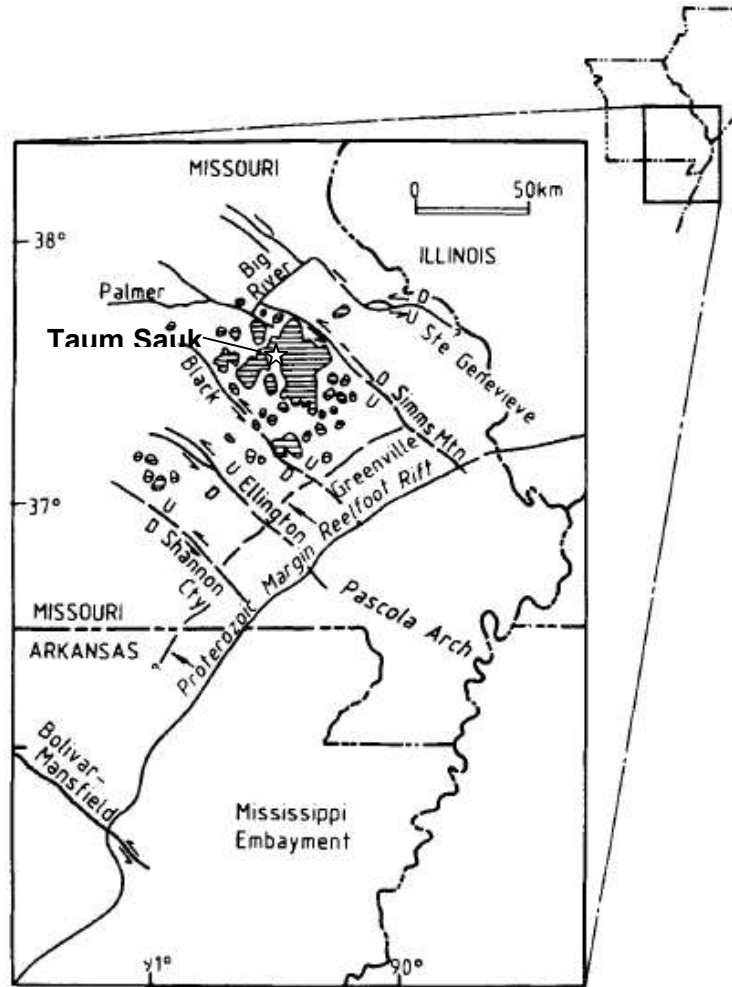


Figure 1.: Regional map showing relations of major faults in southeast Missouri and northeast Arkansas to Proterozoic margin of Reelfoot rift (from Clendinen, et al., 1989).

Lithology

Rhyolite porphyry is a high-compressive strength rock moderately- to intensely-jointed. Mostly dark red, purple, or gray aphanitic porphyry containing phenocrysts of pink or flesh-colored potassium feldspar, and with or without quartz phenocrysts, in a cryptocrystalline felsic groundmass. Optical petrography identified the rhyolite porphyry as consisting of potassium feldspar (0 – 12%); quartz phenocrysts (7 – 19%); aphanitic groundmass (75%); and rock fragments (7 – 8%).

The underlying granite porphyry is a massive hard rock with infrequent and tight joints. This unit was mapped by Pratt, et al., (1992) as a fine-grained hypabyssal gray amphibole-orthoclase granite, Slabtown-type, consisting of sodic amphibole and (or) biotite, orthoclase micropertite, and minor plagioclase with a medium silica content (70-73 percent). Optical petrographic analyses indicate the presence of potassium feldspar (62%), quartz (29%) plagioclase (3.5%) and biotite (5%; altered to chlorite).

Well Log Analysis

A suite of electric logs consisting of AT, FGM, caliper, FR, SP, SPR, T and NG, were collected from approximately 100 borings. Each electric log was compared to the cores retrieved from the borings to determine which log or log suite would best predict the occurrence of one of host rock, martite (impure hematite), diabase, kaolinitic clay and porous zones.

Host Rock

The host rock consisting of rhyolite nonconformably overlying granite exhibited an elevated NG signature but showed no other induced or measured responses to well logging. The log suite used within this survey was not successful in prediction of the subsurface occurrence of these host rocks.

Kaolinite

Kaolinitic clays, to a thickness of up to 25 cm, were found in nearly every boring. The presence of these clays suggested that there are potential zones of slippage in the subsurface, which represent a design issue for subsequent development.

Initially, NG logs were thought to be the most useful predictor of the occurrence of these thin clay seams; however, the elevated background gamma emissions from the host rocks masked these clays. SP, SPR and, to a lesser extent, caliper logs, accurately predicted the location and thickness of these clays in the subsurface (Figure 2).

None of these clay lenses had a lateral extent of greater than 30 feet, and thus are not considered to be a design-based issue.

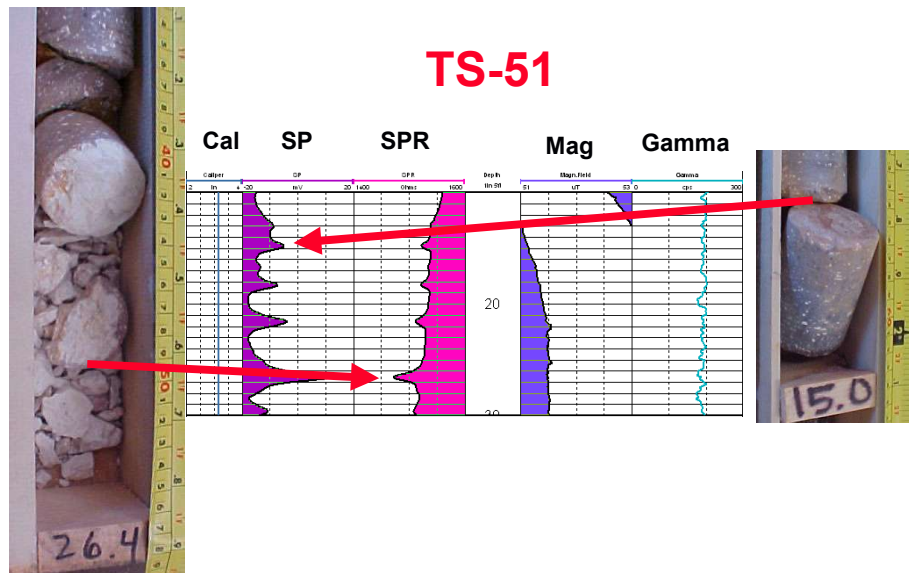


Figure 2.: Logging suite showing the SP and SPR response to the presence of clay TS-51 (from 15 feet and 26 feet below grade).

Diabase Dikes

Altered diabase dikes were noted in the subsurface from 2 areas of the site and the presence of these dikes warranted a design modification due to their perceived failure capability. The dikes were readily identified with the SP and SPR and to some extent with the FGM and NG (Figure 3). The variable concentration of magnetite (0 to 5%) in these dikes dictated the detection success. The NG

proved to be somewhat helpful in the prediction of the subsurface occurrence of diabase dikes due to the slightly lower gamma ray emission (<150 cps) from the dikes (Figure 3).

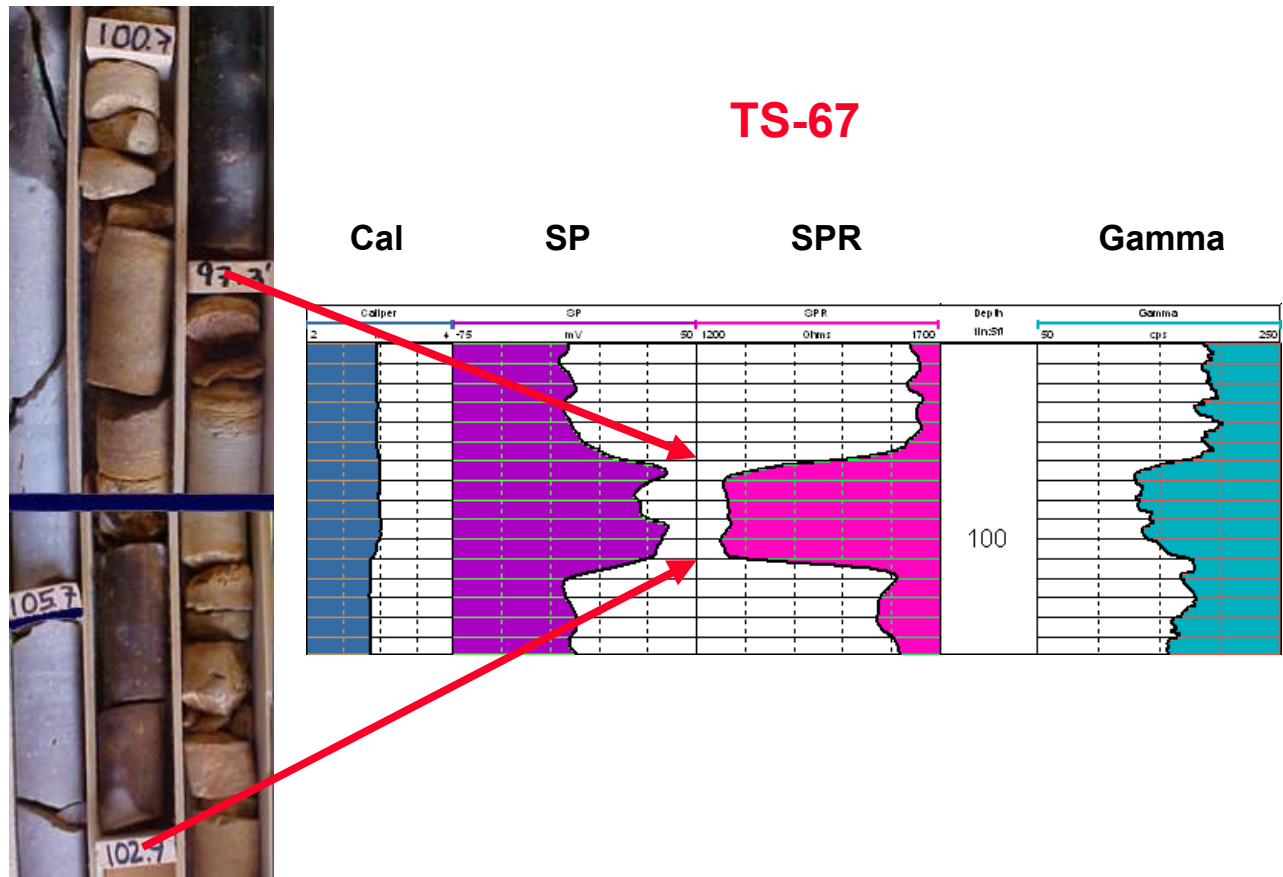


Figure 3.: Logging suite showing the SP, SPR and NG response to the diabase dike from boring TS-67 (97’ to 103’ feet below grade).

Martite

Martite (a hematite replacement of magnetite) is a secondary replacement fracture-fill mineral. This mineral was readily identified by the elevated SP, SPR, NG, and occasionally FGM signature (Figure 4). This dense mineral had a hardness of 6 (Mohs scale) and a specific gravity of 4.7 gm/cm. The presence of this mineral did not constitute a design-based issue.



TS-68

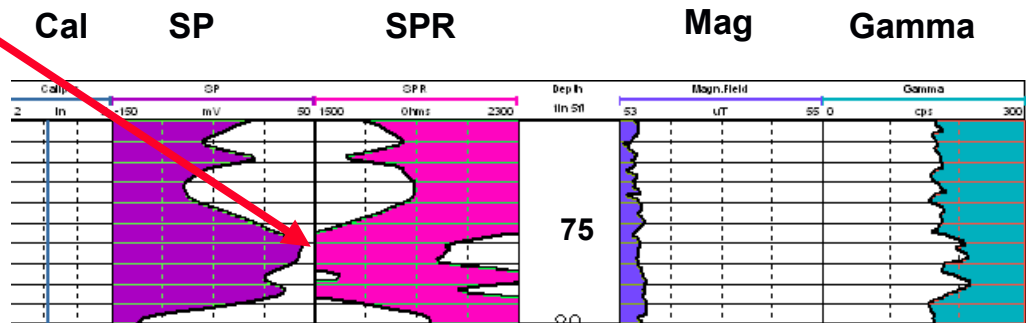


Figure 4.: Logging suite showing the SP, SPR and NG response to the occurrence of martite from boring TS-68 (76' to 79' feet below grade). Note the lack of response on the FGM log.

Host-Rock Porous Zones

Host rock porous zones were found locally through the rock section. These zones straddled fractures and the pores appeared to be “plucked” feldspar grains (Figure 5). The pores had no interconnection and did not extend from the fractures greater than 5 cm. These porous zones do not represent a design-based issue.



Figure 5.: Porous rhyolite porphyry from 81 ft below grade (TS-51).

Fracture Analysis

AT logs were collected from 40 borings. The fractures were readily identified and tabulated (Figures 6 and 7).

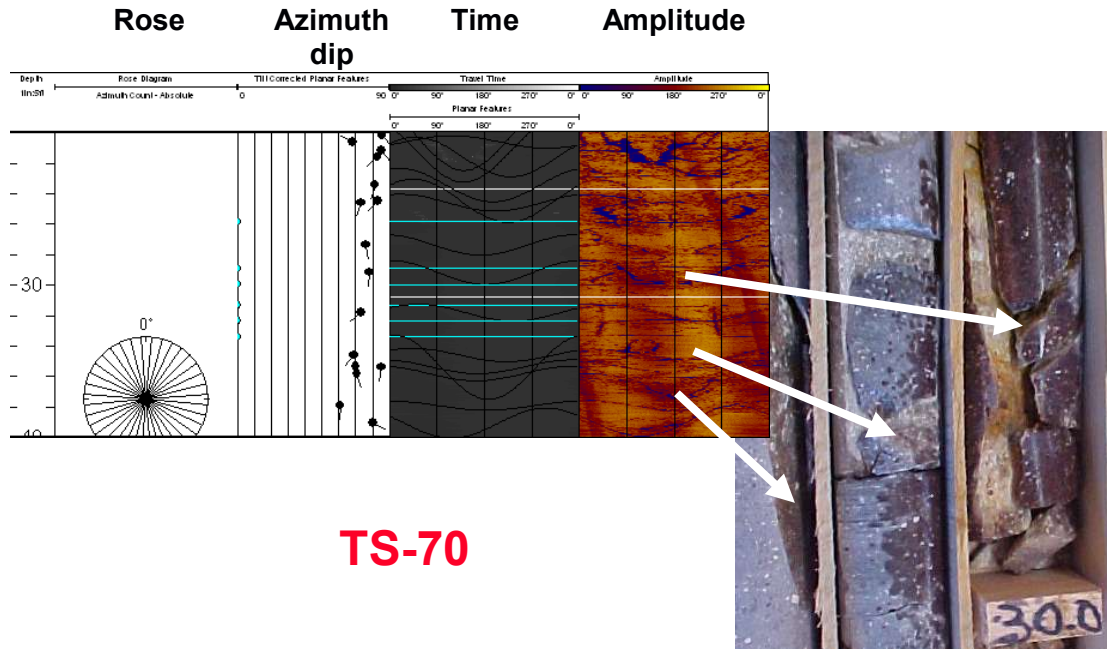


Figure 6.: Acoustic logging suite showing the occurrence of subsurface rock fractures from TS-70 (approximately 30 feet below grade).

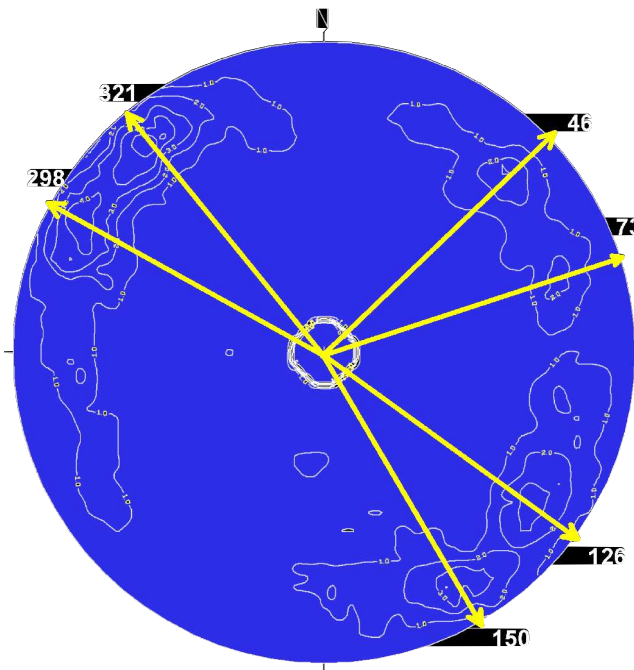


Figure 7.: Wulff stereonet showing the dip azimuths of approximately 700 AT log-identified fractures.

A conjugate shear fracture set was identified with the main set bearing a strike of N35°W and dip 80°NW or SE. The minor fracture set trends N35°E and dips 80°NE or SW. Thirty percent of the fractures logged are horizontal suggesting a vertically upward stress relief consistent with granite emplacement.

Conclusion

Core borings are an expensive strategy for determining design-based hazards and electric logs were deemed necessary to fully develop a subsurface understanding of a site in the St. Francois Mountains of Missouri. Electric log, core examination, and optical petrographic analysis of a metamorphosed and deformed PreCambrian-aged rhyolite effusive event identified subsurface kaolinitic clay lenses, diabase dikes, martite-rich zones, and rock deformation. SPR and SP electric logs were very useful with the identification of the ubiquitous clay seams and localized dikes. The igneous/metamorphic rocks had naturally elevated gamma emissions; consequently, NG logging was useless in the identification of clay seams. However, NG logs proved useful in the identification of dikes, which had readings of less than 150 cps. The SPR/SP suite also successfully identified secondary replacement zones of martite within the rhyolite.

Porous zones within the rhyolite porphyry and contiguous with fractures appear to be the result of subsurface potassium feldspar phenocryst weathering and erosion. The occurrence of these zones was not predicted by the electric log suite deployed. Erosion and mobilization of the kaolinite is putatively considered to be the causative agent for the deposition of clay in the horizontal fracture sets.

Acoustic televiewer (AT) logs identified a conjugate shear fracture set with the main fracture set bearing a strike of N35°W and dip 80°NW or SE. The minor fracture set trends N35°E and dips 80°NE or SW. Thirty percent of the fractures logged are horizontal suggesting a vertically upward stress relief consistent with granite emplacement.

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