RESEARCH NOTE

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Spectral gamma logging in crystalline basement rocks

Francis G. West, A. William Laughlin
Los Alamos Scientific Laboratory, University of California, Los Alamos, New Mexico 87545

Abstract

Spectral gamma logging in the crystalline basement rocks of two deep holes of the Los Alamos Scientific Laboratory's Dry Hot Rock Geothermal Project indicates that this type of log is useful for determining rock types, detecting fracture zones, and examining mobility of the heat-producing elements U, Th, and K.

Introduction

Although geophysical logging is a routine procedure during the drilling of oil and gas wells in sedimentary rocks, little information is available on the response of various logging tools run through crystalline basement rocks. Because of the current interest in deep continental drilling and geothermal energy extraction, it appears likely that in the future many drill holes will penetrate crystalline rocks. To maximize the information obtained from such drill holes, geophysical logging techniques will need to be modified and evaluated for use in this new environment. Reported here are some of our results with the spectragamma log, one of the potentially more useful logs in crystalline rocks.

This log has proven to be valuable for determining the lithology of crystalline rocks, for making lithologic correlations between drill holes, for detecting fracture zones, and for examining the mobility of the radioactive elements U, Th, and K.

Setting

As part of its Dry Hot Rock Geothermal Energy Project, the Los Alamos Scientific Laboratory (LASL) has drilled three holes into Precambrian crystalline rocks in northern New Mexico. All three holes lie on the western flank of the Valles Caldera, about 32 km west of Los Alamos. The first hole, GT-1 in Barley Canyon, reached a total depth of 0.79 km and penetrated 143 m of Precambrian rocks. Holes GT-2 and EE-1 are located about 77 m apart on Fenton Hill and have total depths of 2.93 and 3.06 km, respectively. Precambrian rocks were encountered at a depth of about 0.73 km in GT-2 and EE-1. The Precambrian rocks at the Fenton Hill site consist of a complex sequence of banded gneisses and mafic schists intruded by dikes of monzogranite and a large biotite granodiorite body (Laughlin and Eddy, 1976).

Method

The commercially available Spectralog (Dresser-Atlas Division, Dresser Industries) was used for the logging of both holes. This tool yields four continuous calibrated records (Wichmann and others, 1975): one for the total gamma activity and one each for K, a radioactive ^{238}U daughter (^{214}Bi), and a radioactive ^{232}Th daughter (^{208}Tl). The last two values are *then* converted to equivalent amounts of U and Th by assuming secular equilibrium between parents and daughters. The 2.62-MeV gamma peak of ^{208}Tl at the high end of the spectrum is recorded directly for the Th determination. Stripping techniques are applied first to the 1.76-MeV gamma peak of ^{214}Bi for the U content and then to the 1.46-MeV peak for the ^{40}K content. The validity of the assumption of secular equilibrium of the respective decay chains has not yet been proven for the rocks of GT-2 and EE-1. Although we are not overly dependent upon the absolute values because our applications to date are based on relative changes, U and Th contents of the cores and cuttings are being measured to test this assumption. A good test of the accuracy of the K results was obtained in the interval from 2,591 to 2,928 m (8,500 to 9,607 ft) in GT-2. Five K_2O determinations from three cores from this interval indicate that the rock is homogeneous and has a mean K_2O content of 4.18 percent. The homogeneity is confirmed by the spectral gamma log, and the mean K_2O content calculated from the log is 4.05 percent.

Twenty-three cores taken from the Precambrian section of GT-2 and EE-1 are being used to calibrate our use of the spectral gamma log. Cuttings collected at 1.6-m (5-ft) intervals through the entire depth of GT-2 are also being used for this purpose, but because of lag time in reaching the surface and mixing of cuttings, less reliance is placed on the use of the cuttings for calibration. Another problem is that any intergranular U in the rock may preferentially be lost during drilling, biasing the results from the cuttings.

Discussion

Certain rock types encountered yield distinctive patterns on the logs, and these patterns have been used to identify the rocks, to estimate proportions of these rocks in the boreholes, and to correlate between drill holes. For example, two cores from the 1,295-m (4,250-ft) to 1,312-m (4,305-ft) interval of GT-2 encountered hornblende-biotite schists characterized by a rock chemistry similar to that of a basaltic andesite. This rock type is identified on the log by a relatively low total gamma activity and low individual U, Th, and K values (Fig. 1). Sharp peaks within this interval that appear on all four traces have been correlated with short intervals of biotite-rich granitic or granodioritic gneiss that were recovered in core samples. From this distinctive pattern, it has been determined that about 8 percent of the Precambrian rocks in GT-2 are biotite schists.

An example of correlation between drill holes is illustrated in Figures 2 and 3, which show the signature of a felsic dike approxi-

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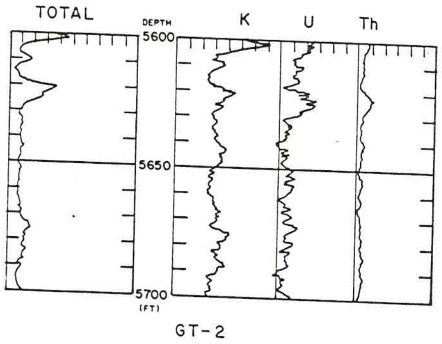

Figure 1. Spectral gamma log of biotite-schist zone in GT-2. Small peak at 5,620 ft is produced by a felsic zone within the schist.

mately 15.2 m (50 ft) thick. The dike was cored in GT-2, and samples were available for calibration purposes. The rock is a medium-grained leucocratic monzogranite with a composition distinct from surrounding rocks. Although different scales were used on the two logs (Figs. 2, 3), both show similar patterns for the dike. The upper and lower contacts are marked by abrupt increases in the total gamma activity and in the concentrations of U, Th, and K.

Figure 2 also shows another relationship that was found to be common in the logs of GT-2 and EE-1: the coincidence of U peaks with fracture zones. Other geophysical logs, such as the full-wave sonic and electrical, indicate that there is an unhealed fracture zone at approximately 1,291 m (4,237 ft). The peak of U with no corresponding Th or K peaks suggests that the more mobile U or its daughters (such as ^{226}Ra) have moved into the fractures. We have seen such correlations between U peaks and fracture zones at several other places in the logs. For example, in Figure 4 we show the log of GT-2 from 2,774 to 2,804 m (9,100 to 9,200 ft). This section is part of a long interval from 2,591 to 2,928 m (8,500 to 9,607 ft), where the rock is inferred from cuttings, coring, and logging to be a rather homogeneous biotite granodiorite. Within this homogeneous zone are several U peaks that are unaccompanied by Th or K peaks. These peaks are interpreted as sealed fractures because corroborative evidence for open fractures is generally lacking on the other logs.

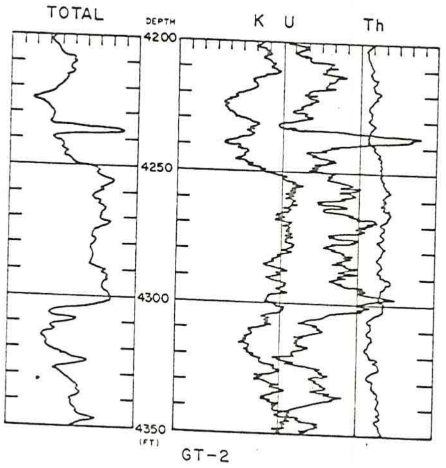

Figure 2. Spectral gamma signature of a leucocratic monzogranite dike extending from 4,250 to 4,305 ft in GT-2.

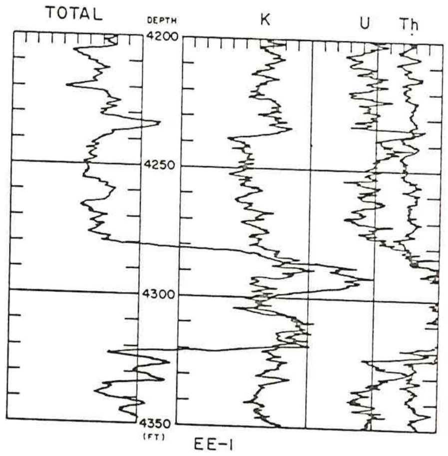

Figure 3. Dike shown in Figure 2 can be distinguished in this log from EE-1, although a slightly different scale was used for recording.

Another example of the mobility of the heat-producing elements is shown in Figure 5. This part of the log of EE-1 shows the upper 29.6 m (97 ft) of the Precambrian basement rock and the lower 1 m (3 ft) of the overlying Mississippian Sandia Formation.

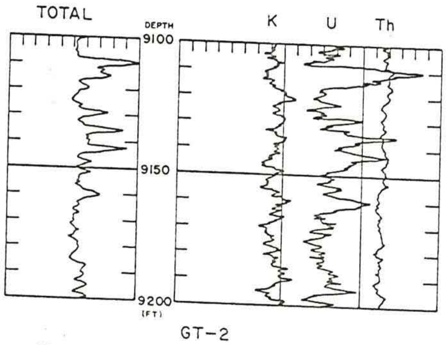

Figure 4. Homogeneous biotite granodiorite in GT-2 is cut by sealed fractures that are enriched in U.

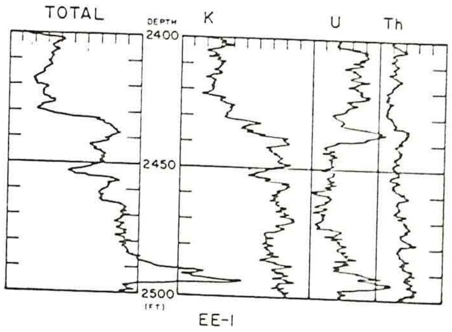

Figure 5. This portion of log of EE-1 shows upper 97 ft of Precambrian basement rock; unconformity occurs at a depth of 2,403 ft. No loss of uranium is exhibited below unconformity. Loss of potassium has apparently occurred within upper 50 ft of Precambrian rocks.

Because of the high mobility of uranium in an oxidizing environment, it might be expected that uranium would have been leached for some depth below the unconformity. This is not true in this case, since the uranium values generally decrease with depth. Potassium, however, has apparently been partly removed from the upper 15 m (50 ft) of the crystalline rocks and increases gradually through the 732.4- to 746.8-m (2,403- to 2,450-ft) interval.

Preliminary results from spectral gamma logging in crystalline rocks indicate that rock types may be inferred from the relative concentrations of K, U, and Th. Use of the log may also provide insight into the nature of uranium mobility at depth. Definition of the limits of the spectral gamma log due to the assumption of secular equilibrium or to the measuring technique itself will evolve with continued field use.

References Cited

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Acknowledgments

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