**INTERPRETATION OF DRILL CUTTINGS
FROM GEOTHERMAL WELLS**

by

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CONTENTS

	Page
PREFACE.	1
INTRODUCTION	2
IDENTIFICATION OF LITHOLOGY FROM DRILL CUTTINGS.	2
RECOGNITION OF FAULTS AND FRACTURES FROM DRILL CUTTINGS.	7
INTERPRETATION OF HYDROTHERMAL ALTERATION IN DRILL CUTTINGS.	9
GEOCHEMISTRY OF DRILL CUTTINGS	11
SAMPLE COLLECTION.	15
PREPARATION OF SAMPLES FOR EXAMINATION	16
EXAMINATION OF SAMPLES	17
SAMPLE STORAGE	18
ACKNOWLEDGEMENTS	18
REFERENCES	19

ILLUSTRATIONS

Figure 1. Mineralogic composition of a muscovite-biotite quartz diorite as whole rock and as corresponding air-drilled cuttings.	5
Figure 2. Lead geochemistry of cuttings compared with diagrammatic casing and cementing record, upper portion of Well Utah State 14-2, Roosevelt Hot Springs KGRA, Utah. . . .	14
Table I. Mineralogic compositions of various size fractions of sieved, laboratory air-drilled quartz diorite cuttings. . . .	6

PREFACE

Drill cuttings, which by comparison with core are relatively inexpensive and easy to obtain, are the samples typically collected from geothermal wells. They are the principal source of the direct downhole geologic information essential for a successful subsurface investigation.

Cuttings, however, can be far more difficult to interpret than core. They are finely ground and mixed, commonly contaminated samples of formerly more or less coherent rock, and therefore can present special interpretation problems. These problems, and methods to help solve them, are discussed in this outline, which is also published as part of Geothermal Resources Council Technical Training Course No. 7, "Introduction to Geothermal Log Interpretation" (Hulen and Sibbett, 1981).

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I. INTRODUCTION

- A. Interpretation of drill cuttings (and core, if available) uniquely provides direct subsurface geologic information essential for successful investigation of a geothermal reservoir. Effective use of this approach, however, requires a full understanding of its strengths and limitations.
- B. Procedures and problems of cuttings interpretation may be significantly different for geothermal and petroleum wells.
  - 1. Petroleum wells are typically drilled in relatively unfractured and unaltered rocks.
  - 2. Geothermal wells are more likely to be drilled in fractured, altered, igneous and metamorphic rocks. Identification of faults, fractures and igneous and metamorphic rock types can be difficult from drill cuttings.
  - 3. Contamination of cuttings is more likely in geothermal wells.
    - a. Caving, lost-circulation and abnormally high drill string and drill bit wear are common in the hot, highly abrasive geothermal environment (Nicholson, 1980; Wolke, 1980).
    - b. Contamination may lead to misinterpretation of subsurface geology and may bias geochemical and physical analyses of cuttings samples relative to corresponding undrilled rock.

II. IDENTIFICATION OF LITHOLOGY FROM DRILL CUTTINGS

- A. Logging of sediments and sedimentary rock is adequately covered by petroleum-oriented literature (Low, 1977; Maher, 1964; Hills, 1949). Identification and differentiation of igneous and meta-

morphic rock are emphasized for this outline.

B. Accurate rock type identification, crucial for stratigraphic and structural interpretation, is also important because certain rocks are more likely than others to develop and sustain fault and fracture permeability. Two examples from the Roosevelt Hot Springs KGRA, Utah:

1. Thick (up to 4 m [13.1 ft]) mylonite zones in massive granitic rocks commonly disappear along strike when they enter adjacent well-foliated biotite-rich gneisses (Nielson et al., 1978).
2. Fine-grained granite dikes and plugs within the KGRA are commonly faulted and fractured even though their host rocks may remain unbroken (Nielson et al., 1978; Sibbett and Nielson, 1980).

C. Many rock types which are readily identified in outcrop or core may be difficult to differentiate when reduced to drill cuttings.

1. Larger-scale diagnostic features such as the following can be obliterated by the drilling process: segregation banding in gneisses and schists, relict bedding, small intrusive bodies such as dikes and sills, xenoliths, phenocrysts, pumice lapilli, lithic fragments, etc.
2. Cuttings may be smaller than the grain size of the rock penetrated, so that characteristic intergrain relationships are destroyed.

D. The composition of a cuttings sample may not accurately reflect the actual rock penetrated.

1. Uncompensated lag (time required for samples to reach the surface) may produce interpretation errors.
  2. Previously drilled units may cave into the hole or otherwise be incorporated into a sample.
  3. Lost-circulation materials or other foreign debris may contaminate samples.
  4. Cuttings may become segregated by specific gravity differentiation in transit to and at the sample collection point.
  5. Clay- and fine silt-size components of a rock are readily removed from a sample, either with drilling fluid at the collection point or during washing.
  6. Selective pulverization by drilling of softer, more brittle, more readily cleaved, or finer grained minerals may result in their depletion in a sample during collection or washing. Cuttings collected from biotite quartz diorite used for air-drilling experiments at Terratek, Salt Lake City, are apparently enriched in quartz, plagioclase, opaques and epidote and depleted in biotite, chlorite, orthoclase, sphene and calcite relative to corresponding undrilled rock (Figures 1 and 2).
- E. Simulated drill cuttings of representative surface rock types are useful for recognition of downhole lithologies (as well as faulting and hydrothermal alteration) in actual cuttings samples.
- F. Certain minerals and/or textures observable even at the small scale of cuttings may be diagnostic of a particular rock or group of rocks.

FIGURE 1.
MINERALOGIC COMPOSITION
OF A MUSCOVITE-BIOTITE
QUARTZ DIORITE AS WHOLE
ROCK AND AS CORRESPONDING
AIR-DRILLED CUTTINGS

MINERAL	VOL. PERCENT %:	
	WHOLE ROCK	AIR DRILLED CUTTINGS
PLAGIOCLASE (PLAG.)	51.6	52.4
QUARTZ (QTE.)	23.6	27.1
ORTHOCLASE (ORTH.)	9.4	7.9
BIOTITE (BTE.)	7.1	4.6
MUSCOVITE (MUSC.)	3.3	3.0
EPIDOTE (EPID.)	2.9	3.0
CHLORITE (CHL.)	0.9	0.8
DARK OPAQUES (OPAQ.)	0.3	0.4
CALCITE (CAL.)	0.3	0.1
SPHENE (SPH.)	0.1	0.1
APATITE & ZIRCON	0.1	0.1

TABLE I

Mineralogic Compositions of Various Size Fractions
of Sieved, Laboratory Air-Drilled
Quartz Diorite Cuttings

Mineral	Volume Percent In:							
	Whole Rock	Unsieved Cuttings	Sieved Cuttings, Size Range in mm					
			>2	<2, >1	<1, >1/2	<1/2, >1/4	<1/4, >1/8	<1/8
Quartz	23.6	27.1	23.7	20.4	22.6	27.4	29.5	30.0
Plagioclase	51.6	52.4	52.9	58.0	52.4	52.0	53.3	50.5
Orthoclase	9.4	7.9	11.9	6.2	7.4	6.7	7.2	7.3
Biotite	7.1	4.6	3.7	5.3	6.5	4.6	3.0	5.0
Muscovite	3.3	3.3	3.4	3.0	3.4	3.6	3.2	3.0
Chlorite	0.9	0.8	0.6	1.2	1.0	0.8	0.8	0.9
Epidote	2.9	3.0	2.6	5.2	5.1	3.9	2.2	2.2
Calcite	0.5	0.3	0.5	0.1	0.5	0.5	Tr.	0.1
Opaque Minerals	0.3	0.4	0.6	0.3	0.7	0.4	0.4	0.2
Sphene	0.3	0.2	0.1	0.3	0.3	0.1	0.4	0.3
Apatite	0.1	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.
Zircon	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.

1. Indicative of metamorphic origin:
  - a. Metamorphic minerals such as sillimanite and cordierite
  - b. Foliation, mortar texture, and strain shadows and kink-banding (thin-section only), all of which, however, can also be produced by late-stage movement of a partially crystallized magma
  - c. Mosaic texture and grain boundaries (if observable) bearing no relationship to crystallographic axes or cleavage traces.
2. Indicative of igneous origin: euhedral feldspars or other minerals low in the metamorphic crystalloblastic series (ranking of minerals by tendency to develop euhedral boundaries during metamorphism - thin-section only)

III. RECOGNITION OF FAULTS AND FRACTURES FROM DRILL CUTTINGS

- A. Faults can be recognized in cuttings by the presence of gouge, microbreccia, cataclasite or mylonite, slickensiding, and hydrothermal alteration.
- B. Cuttings provide little or no evidence for certain faults.
  1. Many faults, for example, have produced abundant fine loose gouge and microbreccia. This material is easily disaggregated by drilling and subsequently lost from the sample, either with drilling fluid during collection or later when the sample is washed.
  2. Not all faulting is accompanied by production of gouge or other physical evidence of movement. Faults of this type, however, can commonly be recognized by their responses on appropriate

geophysical well logs.

- C. Fractures, along which no movement has occurred, cannot be directly detected in cuttings by visual examination. Anomalously large cuttings, however, may indicate fracturing.
  - 1. In Well Utah State 14-2 at Roosevelt Hot Springs KGRA, for example, within a fractured hot-water entry zone between 487.7 and 548.6 m (1600 and 1800 ft), average chip size is three to five times as large as in surrounding unfractured rock.
  - 2. These larger cuttings may reflect the relative ease with which fractured rock is dislodged by the drill bit.
- D. Drilling produces artificial gouge, microbreccia and slickensides which can be confused with their natural counterparts.
  - 1. Artificial gouge and microbreccia, however, are invariably friable, whereas natural material may be well indurated and resistant to crumbling.
  - 2. Only natural gouge and microbreccia can be hydrothermally altered, although such alteration can be simulated by crushing and streaking of rock-forming or alteration minerals in the rock penetrated.
  - 3. Pseudo-slickensides commonly show obvious concave surfaces, but never convex surfaces.
  - 4. Dark metallic streaks are common on pseudo-slickensides.
  - 5. Natural slickensides may be heavily furrowed or striated and irregular even in drill cuttings, whereas drill-produced slickensides are generally smooth.

IV. INTERPRETATION OF HYDROTHERMAL ALTERATION IN DRILL CUTTINGS

- A. Alteration can help define three-dimensional geometry of a geothermal system and can help locate thermal fluid entry zones within the system (Elders et al., 1979; Browne, 1978; Browne and Ellis, 1970; Steiner, 1968).
- B. Alteration textures and paragenetic relationships may be obscured or obliterated in cuttings.
  - 1. All but the smallest veins and veinlets and their cross-cutting relationships are destroyed.
  - 2. Interpretation becomes more difficult as drill chip size decreases.
  - 3. Artificial cuttings of representative hydrothermally altered surface rocks and a knowledge of surface alteration paragenesis are useful for interpretation of alteration in actual cuttings.
- C. Softer alteration (and rock-forming) minerals, such as montmorillonite, chlorite and calcite, are readily disaggregated by drilling and therefore may be depleted in cuttings relative to corresponding undrilled rock (see also this outline, section II-D-6).
- D. Fossil or paleohydrothermal alteration can be indistinguishable from alteration produced by a presently active geothermal system.
  - 1. Even fossil alteration zones are of interest, as they typically occupy zones of structural weakness which are easily refractured, providing channels for renewed thermal fluid flow. At Roosevelt Hot Springs KGRA, for example, refracturing of dense silicified Tertiary mylonite zones is believed to be responsible

for much of the geothermal reservoir's present permeability (Nielson et al., 1978; Sibbett and Nielson, 1980).

- E. Alteration mineralogy relative to depth of occurrence can provide clues to the age of alteration relative to present geothermal activity. Minerals which typically form at high temperatures and/or pressures and occur at shallow levels in active systems (such as near-surface epidote at Roosevelt Hot Springs KGRA, Utah [Bamford et al., 1980; Glenn and Hulen, 1980]) are probably of fossil derivation.
- F. Certain alteration minerals (and some rock-forming minerals to a lesser extent) can effect responses on geophysical well logs, which may lead to erroneous conclusions about a geothermal reservoir. Micas, chlorites and clays, for example, contain abundant bound water, which in igneous and metamorphic rocks can account for most or all of the response of the neutron porosity logging tool (Nelson and Glenn, 1975).
- G. Various contaminants in cuttings may strongly resemble natural alteration minerals encountered in a geothermal well. Many of these can be removed from the cuttings by careful sample preparation (this outline, section VII).
  - 1. Drilling muds
    - a. Bentonite (montmorillonite)
    - b. Attapulgite
  - 2. Lost-circulation materials
    - a. Muscovite

- b. Cellophane flakes and plastic foil (may resemble muscovite or sericite if very finely ground)
- 3. Mud weighting agents
  - a. Hematite
  - b. Barite
  - c. Calcite
- 4. Rust derived from drill steel may resemble limonite.
  - a. Rust may form discrete flakes, grains and lumps as well as cement binding several chips or grains.
  - b. It commonly contains relict magnetic steel, which will distinguish it from natural limonite.

V. GEOCHEMISTRY OF DRILL CUTTINGS

- A. Multi-element geochemistry, like alteration, is useful in estimating the size and configuration of a geothermal reservoir and in locating or predicting approach to thermal fluid entries (Christensen, 1980; Bamford et al, 1980; Bamford, 1978; Ewers and Keays, 1977).
- B. Geochemistry of cuttings may be different than that of corresponding undrilled rock.
  - 1. Clays, sulfides, limonites and other minerals in which diagnostic trace elements are commonly concentrated (Levinson, 1974) may be enriched or depleted in cuttings (this outline, sections II-D-6 and IV-C).
  - 2. Contaminants in a cuttings sample may dilute a potentially useful geochemical indicator beneath its detection limit.
  - 3. Metallic contaminants in cuttings may produce confusing

geochemical signatures (Bamford et al., 1980).

C. Sources of metallic contaminants in drill cuttings:

1. Abrasion and corrosion of drillpipe, bottom-hole assemblies (particularly bits) and casing

a. This is particularly troublesome when air drilling (Nicholson, 1980; Wolke, 1980).

b. Drill steels, or rust derived therefrom, commonly contain, in addition to iron, the following elements in major concentration: chromium, molybdenum, nickel, vanadium and manganese (U.S. Steel, 1964).

c. Threads on tool joints may be lightly plated with copper (for example Hughes, 1980-1981).

d. Tungsten carbide is commonly used as a wear-resistant component of bits, stabilizers and reamers, drill collars and tool joints (Scott, 1980; Hendrikson et al., 1980; Sutton, 1980; and, for example, Hughes, 1980-1981, and Reed Rock Bit Company, 1980-1981).

e. Monel drill collars, such as commonly used at The Geysers geothermal field (Scott, 1980) may yield nickel and copper to the cuttings (Chemical Rubber Company, 1976-1977).

2. Drilling through downhole cement placement assemblies

a. Cementing collars, float and guide shoes and stabilizers are generally made of drillable metal such as aluminum or cast iron (see, for example, Halliburton, 1980-1981; Smith, 1974).

- b. Drillable cores of cementing plugs, drop balls and ball components are now generally made of aluminum (see, for example, Halliburton, 1980-1981). In the past, however, they have also been made of lead (Bamford et al., 1980, pers. communication with D. Bristol of Halliburton Mfg.). In Well Utah State 14-2 at Roosevelt Hot Springs KGRA, highest lead values in cuttings are recorded at and below two of three cementing locations (Figure 3).
- 3. Thread and tool joint compounds, particularly those used for high-temperature/high-pressure applications (see, for example, Jet-Lube, 1980-1981; Bestolife, 1980-1981; Oil Center Research Inc. (Liquid-O-Ring) 1980-1981; Standco, 1980-1981), may contain, in various combinations, lead, zinc, copper and molybdenum.
- 4. Paints contain a wide variety of metallic coloring agents (Chemical Rubber Company, 1976-1977), the most common of which include:
  - a. lead, zinc and titanium (white)
  - b. chromium (green)
  - c. copper (blue and green)
  - d. tin (blue)
  - e. cobalt (blue, violet)
  - f. cadmium (red, orange, yellow)
  - g. manganese (blue, violet)
- 5. Various mud weighting agents may contribute to metallic

FIGURE 2
LEAD GEOCHEMISTRY OF CUTTINGS COMPARED
WITH DIAGRAMMATIC CASING AND CEMENTING RECORD
UPPER PORTION OF WELL, UTAH STATE 14-2, ROOSE-
VELT HOT SPRINGS AREA, UTAH.

DATA FROM BAMFORD ET AL. (1980) AND GLENN AND HULEN (1979)

contamination of cuttings.

- a. galena (lead)
- b. hematite (iron)
- c. barite (barium)

VI. SAMPLE COLLECTION

A. Samples should be collected at relatively short intervals.

1. Lithology, alteration and fault/fracture intensity in geothermal systems can be very complex and can change abruptly over small distances.
2. Ten-foot intervals should be the maximum for routine sampling. If particularly complex geology is anticipated, shorter intervals might be more appropriate.

B. Samples should be as representative as possible of the entire drilled interval. Samples taken continuously are preferable to "grab" samples taken at the end of an interval, but the former may be impractical to collect.

C. Sample collection from mud-drilled wells with solids removal equipment: openings in shaker screens should be as small as practical to reduce loss of finer material.

1. This finer material, if removed from the mud by desilters, desanders and decanting centrifuges, can be collected and considered with corresponding coarser cuttings if necessary.
2. Some clay and/or clay-sized material from the drilled rock will inevitably be removed from the sample with the mud.

D. Sample collection from mud-drilled wells without solids removal

equipment: cuttings can be collected either complete with mud or in a very fine-mesh sieve.

E. Sample collection from air-drilled wells:

1. Cuttings can be collected directly from the muffler outlet. Representative samples may sometimes be difficult to obtain because of temporary retention of cuttings within the muffler.
2. Clay- and silt-size material may be lost to the atmosphere as dust if wetting or foaming agents are not used.

VII. PREPARATION OF SAMPLES FOR EXAMINATION

A. Mud-drilled samples:

1. Samples should be carefully washed to remove remaining drilling mud as well as low-density lost-circulation materials.
  - a. Washing through a fine sieve, which results in loss of natural fines with drilling mud, is nonetheless one of the best compromise procedures for obtaining a useful clean sample.
  - b. If natural fines are crucial to planned studies, samples should be washed by adding water, agitating and decanting, then repeating the process until the water remains clear. Even this procedure, however, will remove some natural clays and other fine-crystalline sheet silicates from samples.
2. Larger pieces of high-density lost-circulation material and other contaminants remaining after washing can be hand-picked. Unless extraordinary and generally impractical measures are taken, smaller particles of these contaminants will remain in

the sample.

3. Drill steel can be magnetically separated, but this procedure will also remove some natural magnetite as well as any mineral with which it is intergrown.
- B. Air-drilled samples: No washing is required unless foaming agents are used for drilling, otherwise sample preparation is the same as for mud-drilled samples.
- C. Cuttings can be mounted on chip-boards at an appropriate scale to allow observation of subtle downhole changes that might otherwise escape detection.
- D. Grain-mount thin-sections of selected samples may be necessary for accurate characterization of lithology and alteration. The small amount of material used to prepare such a thin-section, however, may not be completely representative of the rock penetrated. This is particularly true when cuttings are smaller than the average grain size of the rock.

VIII. EXAMINATION OF SAMPLES

- A. Binocular microscopic examination of cuttings at 5-50X is adequate for routine preliminary geologic logging.
- B. A fairly large portion (at least 10 g) of each sample should be examined. Although chip-boards are a valuable logging aid, the small amount of sample used in their preparation may not be completely representative of the rock penetrated.
- C. Frequent reference to simulated cuttings of representative surface rocks is very useful (this outline, sections II-E and IV-B-3).

- D. Wetting the sample may enhance the visibility of certain features in the cuttings, such as finely disseminated sulfides.

IX. SAMPLE STORAGE

- A. For deferred study, samples should be dried and stored in a moisture-free environment.

1. Drill steel, a common contaminant in cuttings, readily rusts when moist. The rust may resemble limonite, as it does in cuttings from certain shallow heat flow holes at the Roosevelt Hot Springs KGRA (Hulen, 1978). By contrast with steel, rust cannot be magnetically removed from a sample.

2. Clays may hydrate if kept moist, and therefore may be readily dissociated and removed from cuttings during subsequent washing.

- B. Samples likely to be analyzed for mobile elements such as mercury should be stored in air-tight glass bottles to minimize the possibility of cross-contamination.

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