Geophysical determination of fault locations across pediments of western Bull Mountain, Jefferson Valley, Montana

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INTRODUCTION

Bull Mountain is surrounded by Precambrian metasedimentary rocks overlain by mid to late Tertiary-age mudstones and paraconglomerates. These rocks are covered by a Quaternary pediment that has been dissected by northeast-trending streams. These streams likely follow fracture patterns resulting from a period of faulting in the late Precambrian (Coppinger, 1995). Post-Miocene uplift created north-striking faults visible on the western edge of St. Paul's Gulch and in gullies located west of the gulch (Figure 1). Although field evidence strongly suggests the direction of fault strike, it does not account for specific location of the faults through the pediment. The purpose of this study is to use seismic refraction and gravity methods to determine the location of these faults and shed some light on their geometry.

The Precambrian section consists of a 1600-700Ma partially-metamorphosed sandstone interbedded with black argillites. The Tertiary section consists of an Oligocene Chadronian-age mudstone (37-34Ma) and a Miocene Barstovian-age paraconglomerate (16-10Ma). Popcorn weathering defines the Chadronian mudstone. Grussy sandstones and coarse channel pebble conglomerates also occur within the Chadronian-age rocks. Barstovian exposures include brown gravels, pebbly mudstones, and matrix-supported debris flow deposits. All sections are easily distinguished by lithology and color in the field.

Field evidence reveals that the north-striking faults juxtapose Tertiary against Precambrian and Tertiary against Tertiary. Because of distinct lithology, seismic velocity and density should clearly delineate the sections. However, extensive weathering, particularly of the Precambrian, may add ambiguity to the data and mask the contact between the layers

METHODS

Mapping. Following Coppinger (1995), a geologic map was prepared on a 1"=500' topographic base map in order to clarify the geology of the area and reassess the locations of the faults (Figures 1 and 2). Formation mapping had a high degree of certainty based on the unique characteristics of each section, but some fault zones within the Precambrian were less certain due to the similar appearance of northeast-striking joints and north-striking faults. Seismic and gravity data should confirm or disprove the assessments.

Seismic. Two seismic refraction lines were laid out along the large pediment surface in order to define the location of the faults across the surface (see Figure 1). Data were collected using a BISON series 9024 digital refraction seismometer. Seismic lines were laid out alternately such that geophone 13 of the first spread became geophone 1 of the second. Twenty-four 40 Hz geophones were attached to takeouts located at five meter intervals. Each was surveyed with the total station in order to provide elevation control for the data. Shot points were located five meters off each end of the spread and in between phones 12 and 13 for seismic line 1000. The first spread of seismic line 2000 followed the same pattern, but the rest included additional shot points between phones 6 and 7 and between phones 18 and 19. This alteration helped to more clearly define the fault locations. Nine or more hits were made with a sixteen pound sledge hammer at each shot point in order to emphasize the first arrivals. Seismic data were processed using the SIP program. First arrivals were noted according to the first major drop in the seismic record. Seismic velocity was calculated based on the slopes within the travel time curves. Depth models were created in order to assist in the analysis of these data.

Gravity. Gravity surveys were conducted in order to define the fault locations based on density contrast between Tertiary and Precambrian rocks. One line followed the trace of seismic line 2000 so as to clarify the seismic data. The second line paralleled the access road above Whitehall, Montana in order to clarify the existence of northern extensions of the St. Paul's Gulch faults. Gravity stations on both of these lines were placed 100 feet apart and were surveyed using a total station in order to provide elevation data for the gravity corrections. A third line connected the southwest ends of seismic lines 2000 and 1000 in order to provide density control for the corrections. Readings were taken every ten feet along this line. Using the Lacoste Romberg gravity meter, all readings were taken in loops lasting approximately one hour. Each new loop began with the next to last station of the previous loop to account for drift. Data was then corrected by loop for elevation, drift, latitude, and the Bouguer anomaly basin margin has been evaluated as a fault, which most likely connects the London Hills and Cherry Creek faults. If the model represented onlap associated with a paleovalley, the subsurface geometries would be closer to the diagram in Figure 3d. A negative 5-8 mGal Bouguer anomaly was found on the southern section of the 1000 series line and could represent a series of smaller, associated faults.

The current gravity model for the 1000-2000 series line, has not been constrained by seismic refraction data, simply because the amount of noise present is great and determining a first break is difficult. However, preliminary analysis of seismic data near the center of this line could produce a depth constraint on the gravity model.

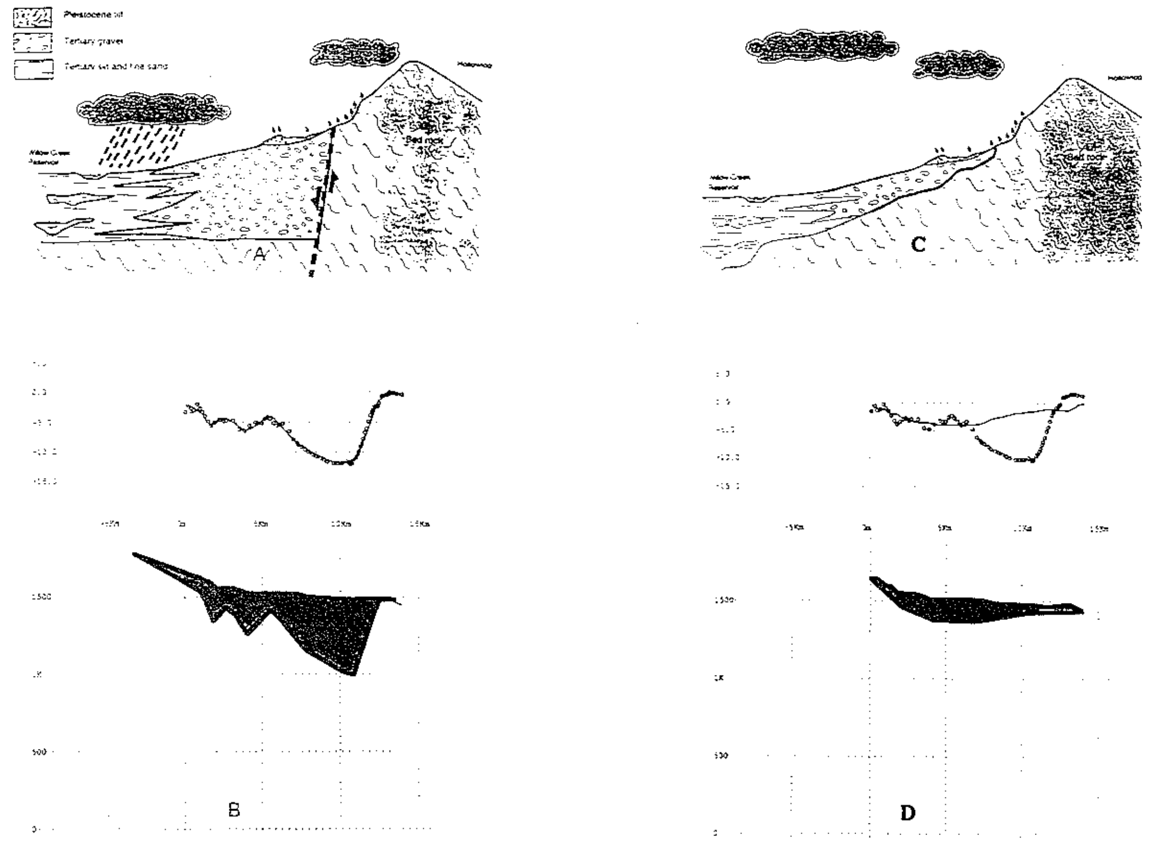

Figure 3. Cross sections and appropriate subsurface gravity models illustrating two hypotheses relating the Tertiary basin fill and the Archean bedrock, (a) a fault bounded basin and (b) its Bouguer gravity profile, or (c) a thin segment of sediments over bedrock and (d) its Bouguer gravity profile. Gravity profiles are vertically exaggerated by 10.

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using a spreadsheet. Tidal and topographical corrections were considered unnecessary as the topography difference was little from one end of the line to the other and tidal effects were thought to be minimal.

RESULTS

Seismic. Data indicate the presence of five distinct layers with the following velocities (m/sec): 350-450, 500-700, 800-1000, 1450-1700, and greater than 2000. The travel time plots reveal the presence of two main faults occurring at 210 meters and 332 meters along seismic line 1000 and at 242 meters and 400 meters along seismic line 2000 (Figure 2). Smaller faults exist along seismic line 2000 at locations 165 meters and 225 meters.

Gravity. Data indicate an increase in gravity with distance traveled NE. Plotted values show breaks in gravity occurring near stations 2011, 2005, 4022, 4012, and 4006. These correspond to locations 244 meters, 427 meters, 305 meters, 610 meters, and 792 meters respectively (Figure 2).

DISCUSSION

Seismic records reveal the presence of five layers with velocities given above. The first refers to the air blast generated during data collection and not to a rock unit. The second appears to correspond to the Quaternary deposits composed of various sediments and textures. The third corresponds to the coarse Barstovian-age debris flow deposit and the fourth to the finer-grained Chadronian mudstone. The high velocity fifth layer corresponds to the Precambrian rocks. In some cases, the Precambrian did not show up on seismic records. Extensive weathering of the Precambrian and resulting decreases in seismic velocity to that of the Chadronian could possibly account for this error, but it is equally likely that first arrivals were not identified properly. Excess noise in the seismic record can easily disguise the accurate first arrival times.

Both gravity and seismic data reveal the presence of two main faults trending N/S across the pediment as shown in Figure 2. These extend from St. Paul's Gulch northward to the northwest edge of the large pediment where the western fault splits into two branches. The western branch appears to continue northwestward toward the access road where a fault has been mapped between Barstovian-age and Precambrian rocks and where gravity data confirm the presence of a fault. The eastern branch continues northward either toward the location where Precambrian is faulted against Chadronian or toward the location southwest of the mapped fault where gravity data suggest a fault. Because data could not be collected between the large pediment and the roadside, the true location of this fault is unknown.

Two ambiguities can not be resolved with the geophysical data; the appearance of the fault at 165 meters on seismic line 2000 and the suggestion, based on seismic interpretation, that the northeasternmost fault juxtaposes Chadronian against Chadronian instead of Precambrian against Precambrian as field observations reveal. The first inconsistency may be the result of either poor identification of first arrival times, or it may be the southern continuation of the NW fault juxtaposing Barstovian-age rocks against Precambrian rocks. Because this fault did not show up on seismic line 1000, I assume it is an artifact of the method of analysis. The second ambiguity may be the result of misinterpretation of layers according to seismic velocity, because velocity varies with degree of induration. Because this fault has been mapped in St. Paul's Gulch as Precambrian against Precambrian, it will be interpreted as such. Although the presence of this fault is supported by both gravity and seismic data, the northern extension of it remains unknown because data were not collected on the middle pediment (Figure 1). In short, seismic and gravity data confirm the location of one branching and one unbranching N/S trending fault extending from St. Paul's Gulch northwestward across the pediment. Data were insufficient to contribute information on their geometry.

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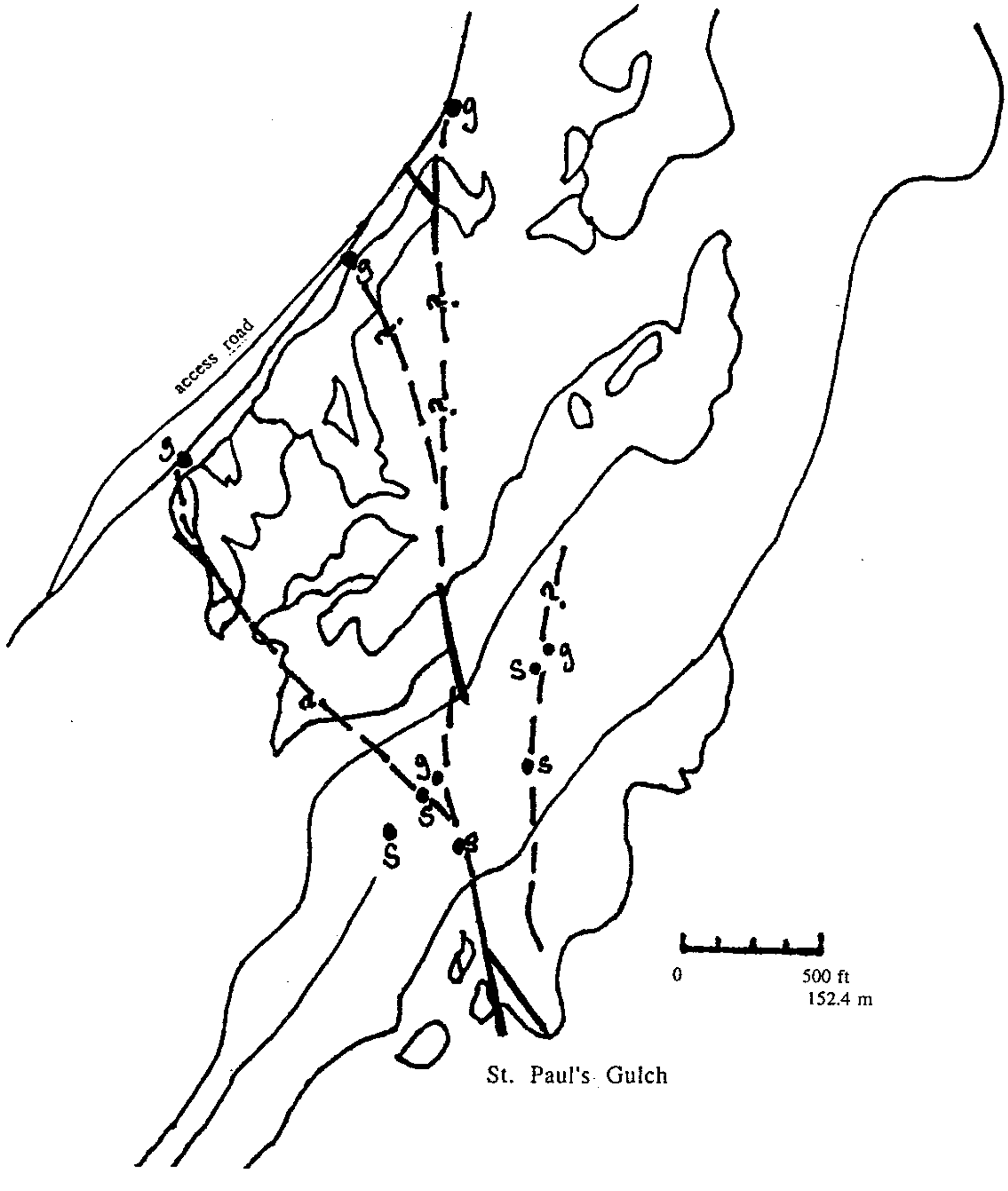

Figure 2 Location of faults interpreted from seismic and gravity data, which are denoted by dots on the pediment and along the access road (s=seismic, g=gravity).

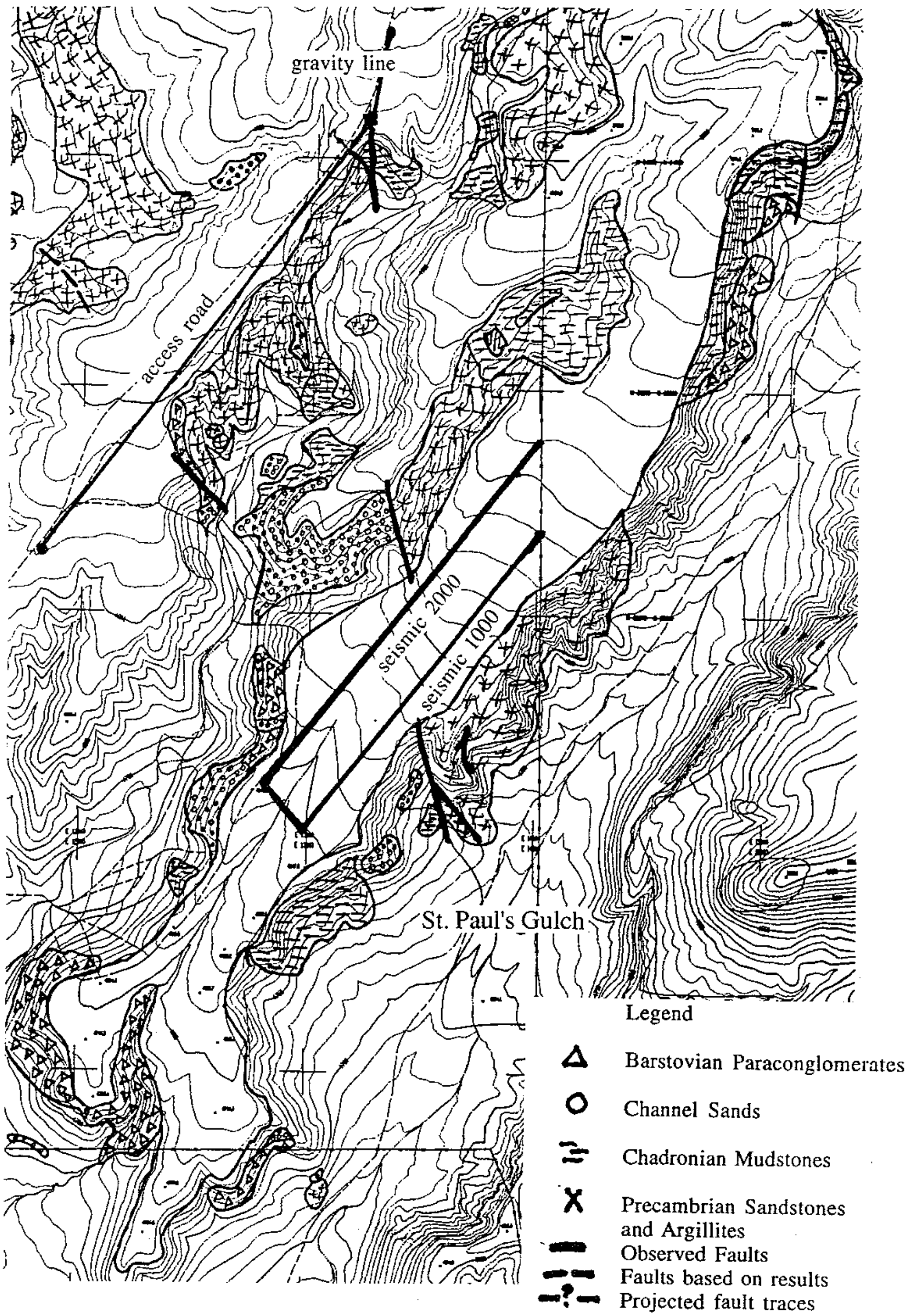

Figure 1 Location of seismic and gravity lines relative to location of the faults. Distances are measured SW to NE along each line. Contour interval=10m

Correlation of shallow 2-D seismic reflection data with lithologic well logs and cross-section, Rocker Operable Unit, Montana

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INTRODUCTION

The Rocker Timber Framing and Treating Plant Operable Unit exists within the Silver Bow Creek/Butte Area Superfund site, which is centered around the town of Butte, Montana. The site is very flat and consists of a railway switching yard and several buildings and piles of debris. The soil and debris contain high concentrations of arsenic, which has created a pollution plume in the local shallow aquifer. Remedial actions have been decided upon by the Environmental Protection Agency (EPA) based on subsurface cross sections created from lithologic well logs. Shallow two dimensional (2-D) seismic reflection can offer a subsurface image depicting lithologic boundaries, which can be checked by well log data to provide a more accurate picture of the geometry beneath the Rocker site.

Geology. The uppermost deposits of the Rocker site have been entirely disturbed by human activity. Originally, the construction of the rail yard and timber treating plant required "a large fill" (ARCO, 1995). More recently, approximately 1,000 cubic yards of arsenic-bearing wood chips and soil were removed from two areas of the site, and approximately 8,800 cubic yards of soil cover were placed to a depth of at least 12 inches in some areas (ARCO, 1995). One local contractor estimated that the upper 5 to 6 feet of the subsurface consists of at least 25 percent debris.

Underlying the fill is undisturbed Quaternary alluvium, consisting of poorly compacted sands, gravels, and silts representing meandering channel and overbank deposits. In the Butte area these deposits range up to several hundred feet thick, although the maximum thickness reported in lithologic well logs from the Rocker site is about 80 to 90 feet (ARCO, 1995).

Below the Quaternary deposits are undivided Tertiary sediments, which are believed to underlie the entire site. These consist of dense, partially cemented silt and fine to medium sand-size particles, which are irregularly bedded to massive. Occasional thin layers of highly fragmented, well-cemented silt and sand grains occur, as well as hard, well-cemented, angular, fine grained to aphanitic gravels.

Cretaceous age granitic rocks regionally identified as the Butte Quartz Monzonite underlie the Tertiary deposits at the site and in the surrounding area. Unconformably overlying and intruding these granitic rocks, and underlying the Tertiary fluvial deposits, is a highly variable suite of Tertiary volcanic rocks referred to as the Lowland Creek Volcanics. The units of the suite range from extrusive dacites and tuffs to intrusive rhyolites. The geometry of the volcanic and granitic rocks under the Rocker site remains unresolved, as all of the wells on site finish within the Tertiary fluvial sediments. Based on surface mapping, however, it appears that these Tertiary sediments are in direct contact with Cretaceous granitics just to the east of the Rocker site.

History of the Rocker Site. The Rocker Timber Framing and Treating Plant was operated by the Anaconda Company from approximately 1907 to 1957. During its years of operation, the plant milled and treated timbers for use as supports in the mines in and around Butte, as well as poles for Montana power. Both dipping and pressure treating were used to apply arsenic to the timbers, and creosote to the poles. When the plant was closed in 1957, the equipment and buildings were dismantled, and the debris disposed of on site.

In the 1970's, the Atlantic Richfield Company (ARCO) purchased the Anaconda Company and all of its inholdings. On September 8, 1983, the Silver Bow Creek Superfund site was listed on the National Priorities List (NPL), including the Rocker Operable Unit. This listing was revised on July 22, 1987 to include large areas around the town of Butte, Montana. In all cases, the Anaconda Company, and therefore ARCO, was found to be the liable party. While all decisions for the ensuing cleanup are made by the EPA, the research and cleanup of each site is being funded by ARCO and carried out by local environmental contractors.

Previous Investigations. The initial site evaluation was conducted in 1987 and 1988 for ARCO by Hydrometrics, Inc. In response to a 1989 Phase II investigation, ARCO was ordered to perform soil tests for arsenic, and remove soils which had an arsenic content of higher than 10,000 mg/kg (ARCO, 1995).

Observation wells were dug on site, and lithologic logs were obtained from the drilling, as well as samples and core samples (ARCO, 1995). From these logs, several subsurface cross sections along well lines were drawn (ARCO, 1995). In addition, geophysical logs were made of five wells by Century Geophysics. These logs consist