Interpretation of a Tertiary-fill basin in southwestern Montana through the use of geophysical techniques

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INTRODUCTION

Willow Creek valley is located approximately 40 miles east-southeast of Butte, MT and surrounds the town of Harrison (Figure 1). Late Tertiary sediments overlaid by Quaternary alluvium fill the valley and rest unconformably against Archean basement rocks on the walls of the valley. Such an unconformity has two plausible interpretations: 1) The valley was originally a paleovalley and the basin margins are related to onlap processes, or 2) The valley is fault bounded. High density difference between Tertiary fill and Archean metamorphic rock (0.5-0.8 g/cc) is ideal for both gravity and seismic refraction investigation. The purpose of this investigation is to determine the nature of the unconformity using gravity methods constrained by seismic refraction data and to develop feasible models for the shallow subsurface geometry of the basin based on geophysical data.

BACKGROUND GEOLOGY

Willow Creek valley lies south of the Three Forks Basin and north of the Madison Basin in southwestern Montana (see Figure 1). Just to the north lies the southwest Montana transverse zone (SWMTZ), a major structural boundary marking the northern-most region of Archean basement rocks and the southern-most region of Paleozoic Belt Supergroup rocks in Montana (Schmidt and O'Neill, 1982). To the south of the SWMTZ lies Rocky Mountain foreland structures created during a period of uplift during Late Cretaceous and Paleocene time (ca. 95-55 Ma.) and exemplified by a set of northwest-trending faults. The valley of interest lies within this zone of NW-trending faults. The valley is also part of a regional intermontane basin system separating mountain ranges throughout western Montana and eastern Idaho (Fields, et al, 1985). Throughout its history, this system of valleys and mountains experienced similar orogenic developments to the traditional Basin and Range tectonics, including a distinct period of Cenozoic extension. Schmidt and Garihan (1986) suggested Neogene extension reactivated northwest-trending faults in the proximity of the Willow Creek watershed and produced half-graben structures that form the corners of several mountain ranges. Constenius (1996) related this Neogene event of normal faulting and basin-fill sedimentation to Basin and Range tectonism. However, Ruppel (1993) has argued that lateral motion along these faults created the existing basins.

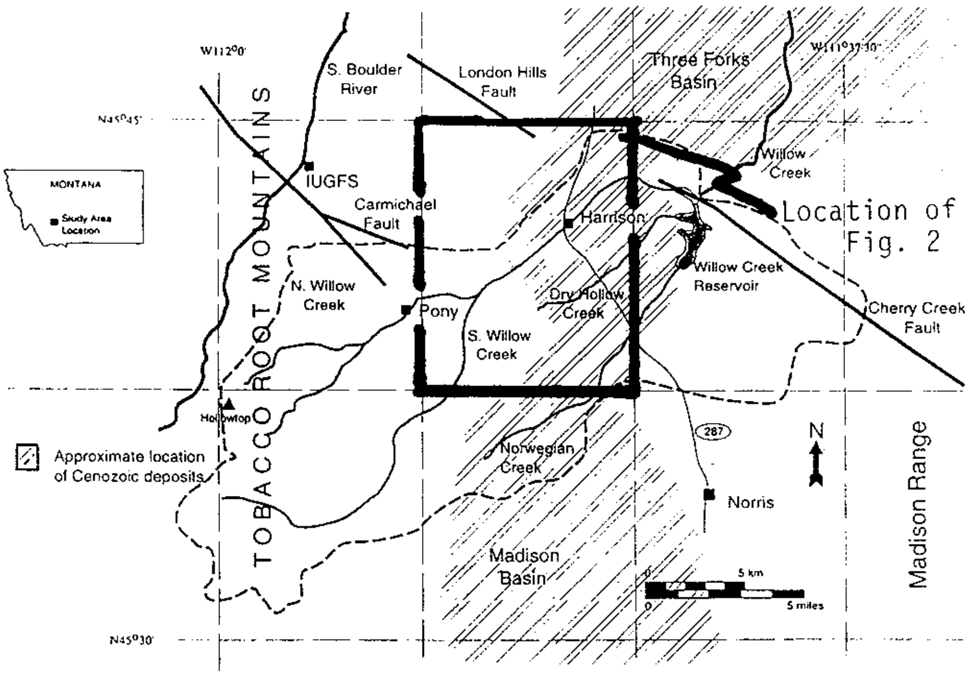

Figure 1. Map showing location of study area

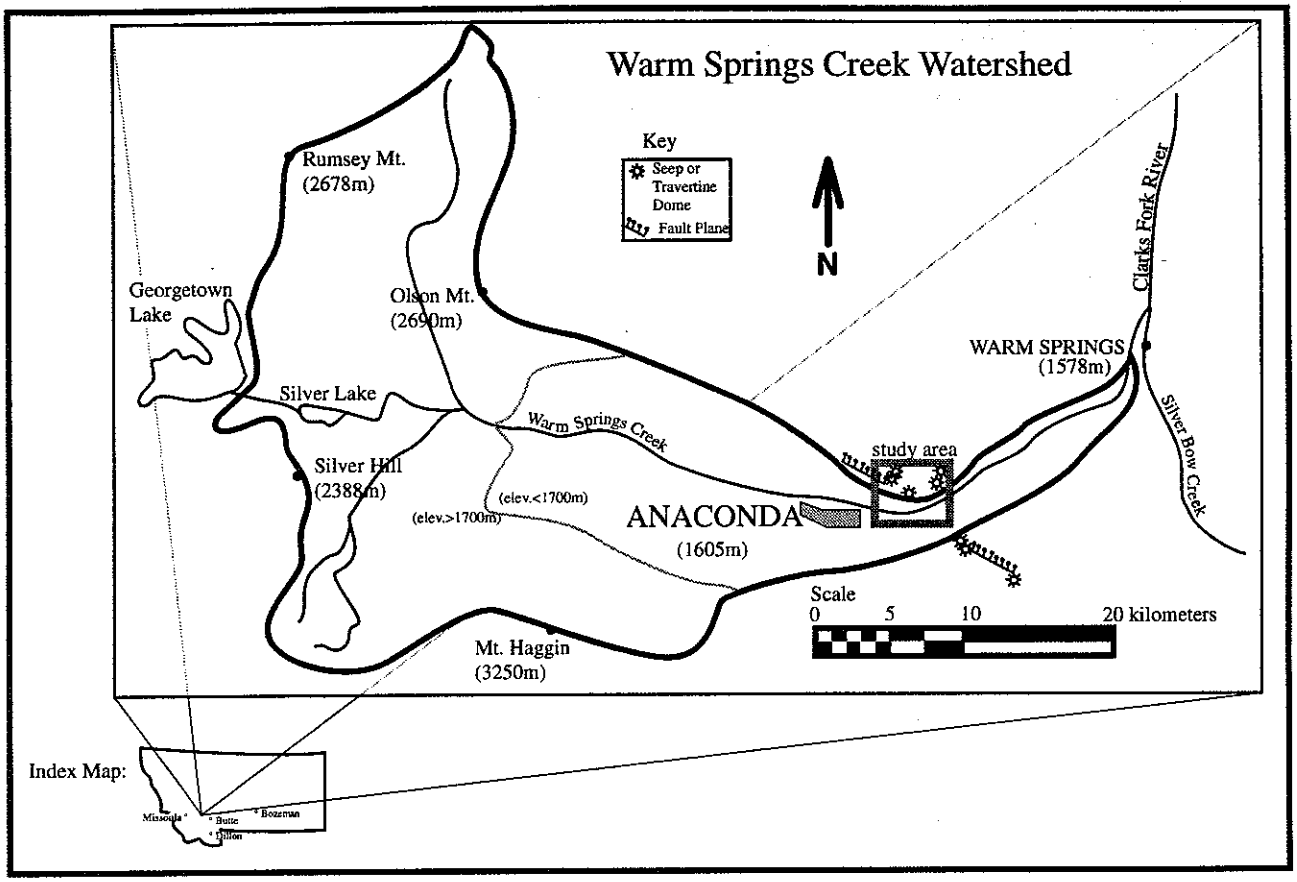

figure 1: map of study area

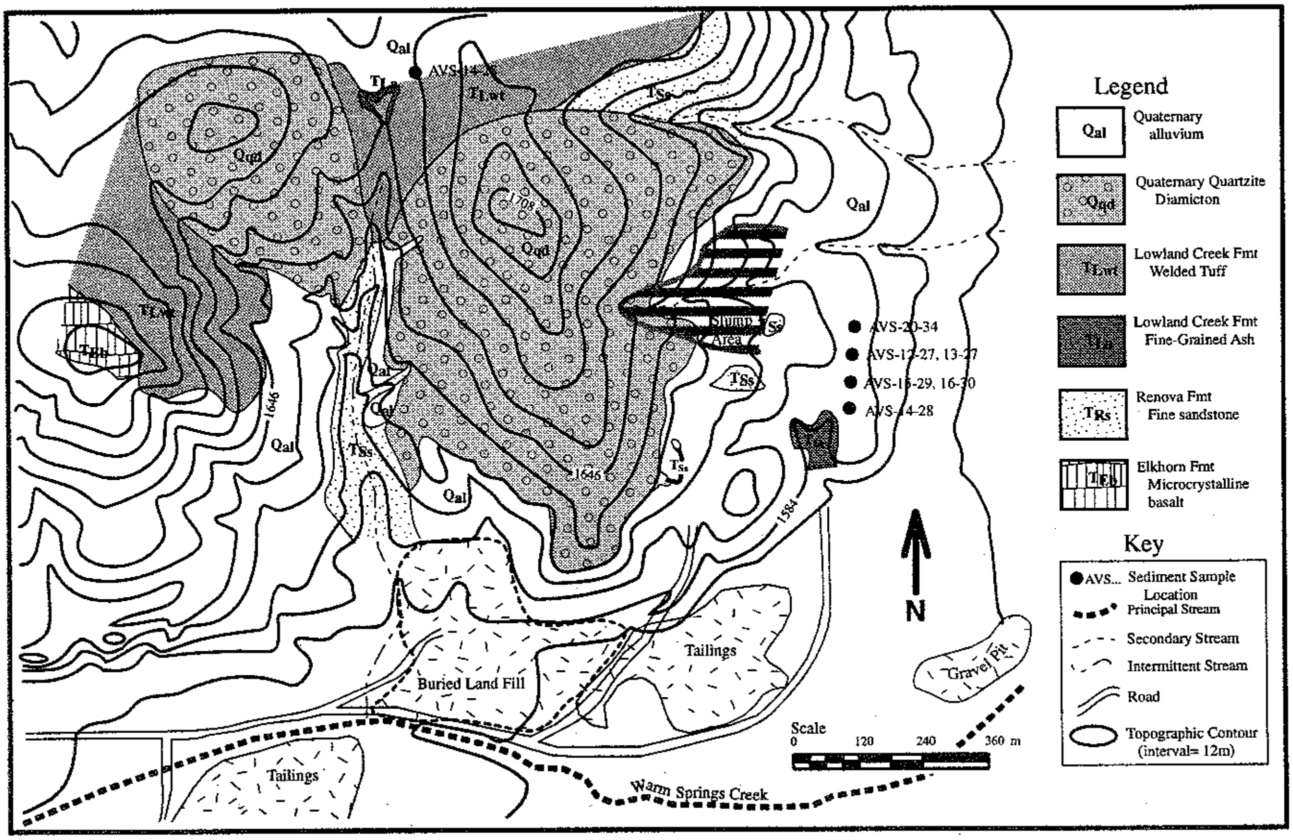

figure 2: geologic map of study area and sediment sample locations

Localized mapping of the study area has been unable to document to nature of the Tertiary-Archean contact within the basin. Two northwest-trending faults, the London Hills fault and the Cherry Creek fault, intersect the valley and are covered by Cenozoic sedimentary deposits. However, it is unclear whether these deposits simply bury the faults at depth or are affected by them. Geophysical data will provide a picture of the shallow (up to 10 km) subsurface of the basin. and will also determine whether the valley is indeed fault bounded and, if so, which style of movement occurred along the fault(s).

METHODS

Data Collection. A total of five gravity lines consisting of 213 gravity stations spaced between 50 and 250 meters apart over a total distance of 20 km were surveyed using a Sokia total station. Gravity lines were selected based on surface geological and topographical maps (Figure 2). The ideal location for a gravity line in Willow Creek valley is across basin margins where Tertiary fill is in contact with Archean gneiss. Seismic lines were set up with the same concept in mind and were referenced to the pre-existing gravity lines. Interpretation in the field of preliminary gravity data also determined where seismic lines were located: If there appeared to be a significant anomaly at a basin margin, then a seismic line would be shot there.

Gravity data were collected using a Lacoste-Romberg gravity meter in a series of "loops" containing 5-15 stations. Gravity at any particular station changes with time due to celestial attractions as well as inherent instrument drift, therefore it was necessary to measure certain "base stations" twice to account for such drift.

Tertiary-fill density measurements were derived from a special gravity line which ran across a slight topographic depression containing Tertiary sediments. Bouguer gravity was calculated using varying densities and plotted against distance and compared to the topographic profile. The Bouguer graph that neither resembled nor inverted the topography contained the most correct density.

Processing. All survey, gravity, and seismic refraction data were downloaded onto a computer at the Montana Technological Univ.

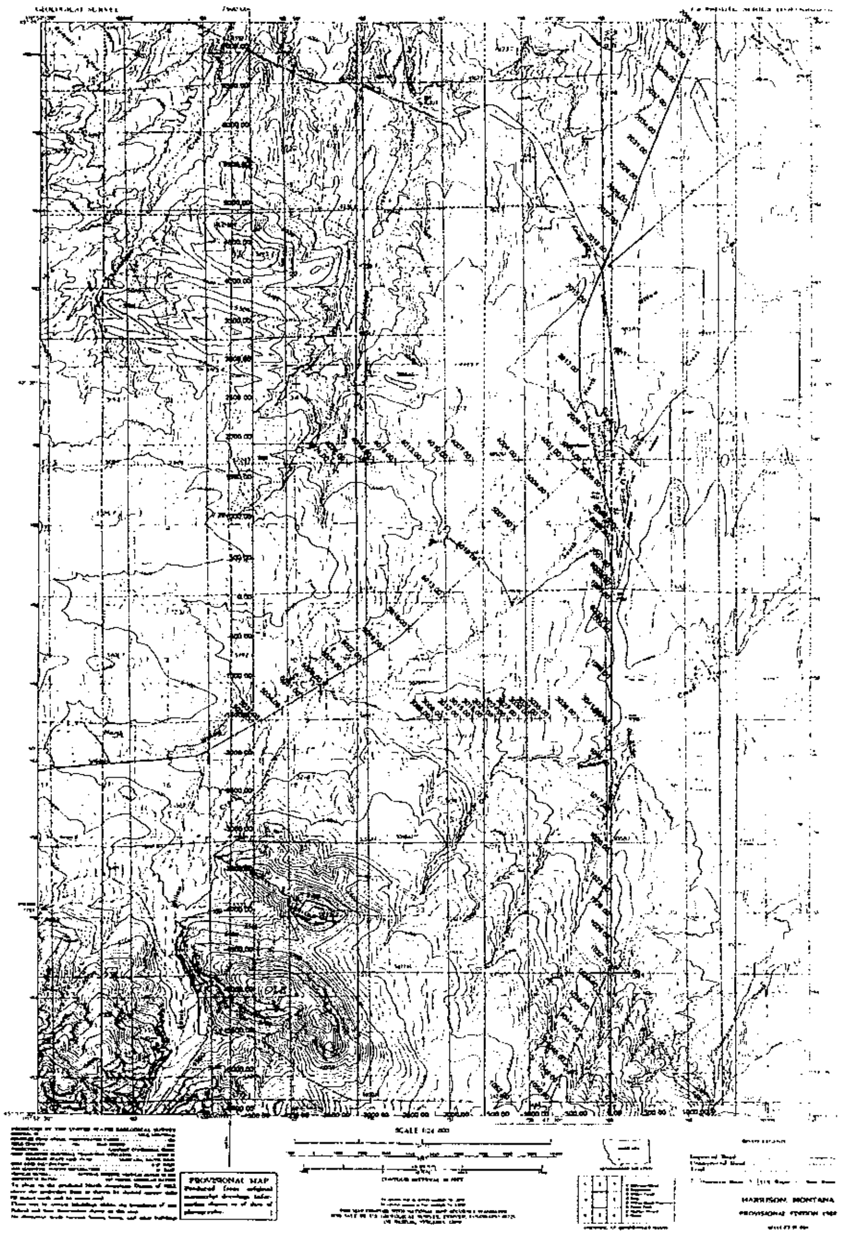

Figure 2. Topographic map (outlined in Fig 1) showing gravity stations.

in Butte and then copied onto several disks. Survey and gravity data were filed into an Excel spreadsheet while seismic refraction data was saved onto a PC-format disk.

Traditional methods were used to reduce gravity data. There are tens, perhaps hundreds of factors that affect gravity data, but only a few produce significant, unwanted changes in the data. Once all significant corrections are made, it is the geologist's job to interpret any anomalies in the data as some geologic feature, such as a fault boundary. The significant reductions include: drift and dial corrections, latitude, free air and Bouguer reductions. A regional gradient was also subtracted out of the Bouguer gravity data. Because we were in close proximity to the Tobacco Root Mountain uplift, Hammer chart terrain corrections were also necessary. Gravity reductions were performed at The Colorado College using Microsoft Excel 5.0 on Macintosh computers.

Modeling. I concentrated on modeling one Tertiary-Archean boundary correlating with the north end of the valley. The Macintosh formatted programs Grav2D and GravModel were both used to model subsurface terrain, the former being more user friendly. Both programs ask for field data including Bouguer gravity, elevation, and horizontal distance. These data sets can be directly loaded into Grav2D from an Excel spreadsheet; for GravModel, they must be entered manually. Both programs allow the user to create various cross-sections using polygonal shapes of infinite strike. A density of 2.1-2.2 g/cc (determined from the gravity line across a small depression) was assigned to the Tertiary fill, and a density of 2.7-2.9 g/cc (determined in the lab using water displacement techniques) was assigned to the Archean gneiss. Once densities were entered, a model curve was generated and compared to the user's curve. When densities were changed or polygons were edited, a new curve was generated. Feasable models were selected based on how close the field Bouguer curve aligned with the generated model curve.

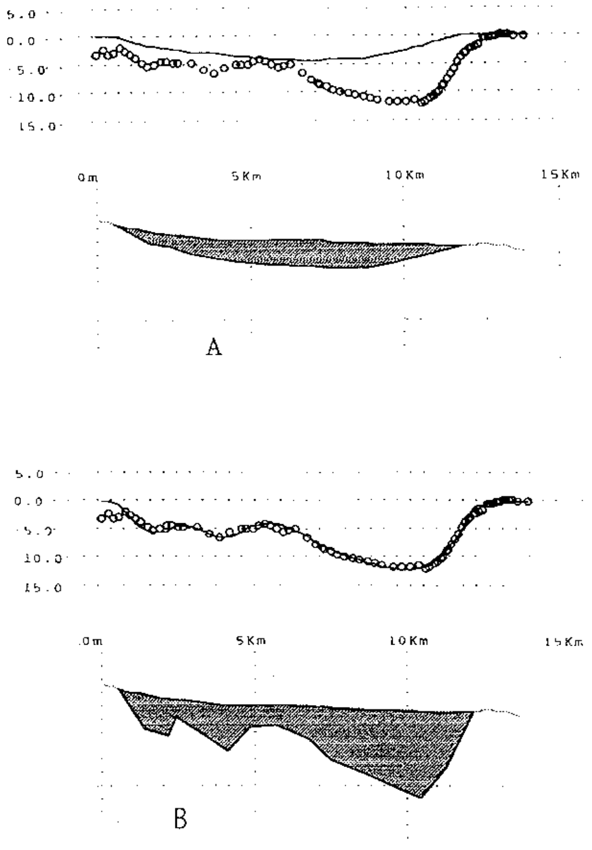

Figure 3. Grav2D charts showing field Bouguer curve (circles) and model Bouguer curves (solid line) for two basin geometries. A. Onlap/unconformity model; B. Fault/half-graben model. (Vertically exaggerated five times; gravity measured in mGals.)

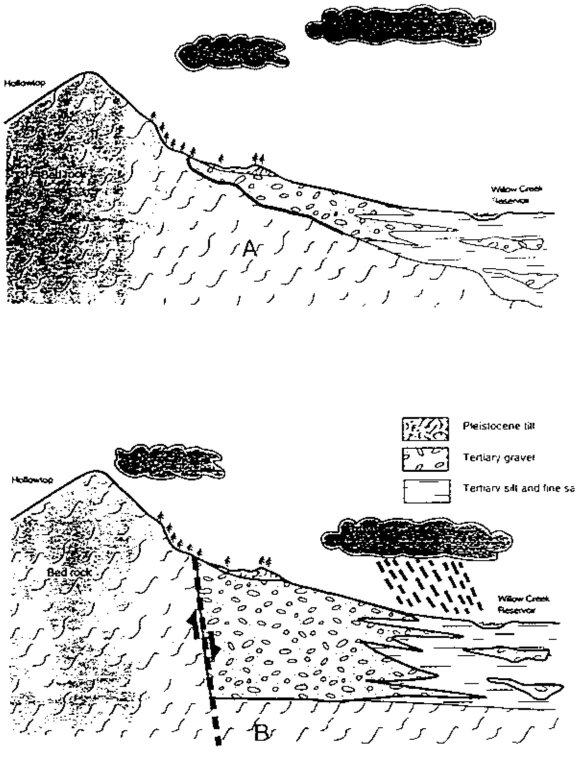

Figure 4. Cross-sections showing schematic interpretations of two basin geometries. A. Thin layer of sediment over older bedrock; B. A fault-bounded basin.

Seismic refraction data are being modeled using the DOS program SIP. Seismic lines, saved as data files on a disk or hard drive, are first opened and edited. The program allows the user to pick first breaks, set up line geometries, and model the data in two-dimensions. Seismic refraction data is currently in the processing stage but may provide information on depth to bedrock along the basin margins of the valley.

DISCUSSION AND CONCLUSIONS

A significant 10-15 mGal negative anomaly in Bouguer gravity exists on the northern end of line 2000 (north end of valley, Figure 3). This anomaly appears as a smooth, gradual dip that begins at about 7 km horizontal distance (Figure 3) and rises sharply approximately 12 mGals beginning at about 11 km horizontal distance before leveling off at about 12.5 km horizontal distance. Over 50 different subsurface models were created on Grav2D and GravModel, each varying in Tertiary depth and Tertiary/Archean angle of contact in proximity of the above anomaly. Several models account for such a relatively high anomaly. Grav2D generated a model curve similar to our field Bouguer gravity curve when Tertiary depth was between 400 and 500 meters. In addition, the Grav2D model curve matched our field Bouguer gravity curve when the angle of Tertiary/Archean contact was between 20° and 25°. Because of the significant "offset" of Archean rocks and rather high angle along the Tertiary/Archean contact, these models may be interpreted as half-grabens having been faulted on the north, correlating with the anomaly (Figure 4b). Erratic fluctuations in Bouguer gravity occur at the southern end of line 1000 that may be resultant of not-yet-determined terrain variations. Model depths can be tested through seismic refraction data which should also resolve the irregular nature in gravity of the southern end of this basin. Faulting to the north may suggest association with the northwest-trending London Hills or Cherry Creek fault. The half-graben structures created through the modeling programs also suggest a major component of normal movement along this fault.

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A high-resolution seismic reflection study of the Rocker Timber Treatment and Framing Plant Site, Rocker, Montana

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INTRODUCTION

The small town of Rocker lies seven miles east of Butte, Montana and is located in a relatively flat, east-west trending, alluvial valley flanked by highlands to the northeast and southeast. The Rocker Timber and Treating Plant operated from 1909 to 1957 to mill and preserve wood used in the underground mines in and around Butte. The treatment involved either dipping or pressure-treating the timber in a dissolved arsenic solution. Waste solution was handled poorly and was often left to leach into the ground. As a result of the mishandling, arsenic and other contaminants are now present in high concentrations in the soil and groundwater. The plant site was listed as a Superfund Site on the Environmental Protection Agency's National Priorities List in September of 1983 due to its close proximity to a residential area with numerous domestic wells.

The owner and primary responsible party for the Rocker site is the Atlantic Richfield Company (ARCO). Following the Superfund designation ARCO contracted Environmental Science and Engineering, Inc. (ESE) to investigate the surface soil, the subsurface soil, the geology, and the groundwater. ESE created a series of cross sections based on numerous test well logs and subsequent core data. The cross sections depict a distinct paleo-valley incised in the Cenozoic, basin-fill, sedimentary rocks. Following examination of original well logs and cores there is doubt as to the accuracy of the cross sections and the correlation made with the available information base. In addition, there is a question as to whether the pre-Cenozoic rocks are faulted or if the basin is erosional.

During the summer of 1996 a high resolution seismic reflection survey was conducted at the Rocker site by a group of students working on a Keck Consortium summer research project. Such a high resolution seismic reflection study has the power to image the subsurface and can help to confirm or negate a paleo-valley hypothesis and contribute to the knowledge of the geologic origin of the basin by defining the geometry of the subsurface reflectors. The goal of this project is to combine seismic reflection with core data and well logs in attempting to more completely determine the subsurface geology.

SITE DESCRIPTION

The Rocker Site is located in the Silver Bow Creek flood plain. The 16 acre site is relatively flat, but in general slopes north to the Silver Bow Creek. The creek itself has been diverted to create an area for a railroad siding which now occupies most of the present site. Railroad tracks bound the site to the south and run east-west through the center of the site. The entire site is littered with debris, such as timbers, metal scraps, and wire as well as containing some of the original buildings.

GEOLOGIC SETTING AND HISTORY

Rocker is located directly to the west of the Continental Divide near Butte, Montana in an intermontane basin and is part of the northern Rocky Mountains physiographic provence. The various stages of the Laramide orogeny in the late Cretaceous and early Tertiary largely shaped the geology of the area. Paleozoic and Mesozoic rocks were folded, uplifted, and faulted. In the late Cretaceous, between 78 and 68 Ma, the Boulder batholith crystallized at a depth of 3 - 4 km. The batholith intruded Paleozoic and Mesozoic sedimentary rocks as well as the Elkhorn Mountain Volcanics which formed at 78 to 73 Ma. The zone of maximum Laramide orogeny progressed from west to east and reached its culmination in the Butte area near the end of the Paleocene. The early Tertiary was a time of active erosion and deposition on the faulted blocks. Uplift and arching continued into the mid- to late-Tertiary when the area rose between 5,000 and 7,000 feet in elevation. This uplift caused extension which resulted in the local intermontane basins. The Eocene also saw the eruption of the Lowland Creek Volcanics, which overly the Boulder batholith. The sediments of late-Tertiary age are relatively undeformed (Hyndman, 1979).

Local bedrock is Butte Quartz Monzonite of Cretaceous age. The Lowland Creek Volcanics have an average thickness of 1500 feet. Tertiary sedimentary rocks overly the volcanic rocks. These sediments are well-indurated, and consist of "dense, partially cemented, brown, irregularly bedded to massive silt and fine to medium sand sized particles" (ARCO, 1995). Ribbon channels filled with gravel as a result of active channel deposition are present throughout the Tertiary sedimenetary rocks. These channels are interspersed with flood plain deposits, such as silts and sands. The main source rocks for the Tertiary sediments were the grussified Boulder batholith, the Lowland Creek Volcanics, and volcanic ash (tuffs).

Quaternary alluvium was deposited by Silver Bow Creek. The source for the Quaternary alluvium was mainly the batholith and the volcanic rocks, with the addition of reworked Tertiary sedimentary rocks. The