Seismic reflection investigation to support or undermine the existence of a normal fault in Rocker, Montana

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INTRODUCTION

The miners that explored the areas surrounding Butte, Montana discovered in the late 1800s that the veins of gold, silver and copper could only be found up to a certain boundary on the West side of Butte—a north—south boundary that apparently ran through the town of Rocker. Mines dug to the West of Rocker were repeatedly unsuccessful and before long, all mining to the immediate west was discontinued. The old miners blamed the disappearance of the metals to a normal fault, extending perpendicular to the Silver Bow Creek and just east of Rocker, with the western side dropped. In time, this fault became known to the miners and locals as The Rocker Fault (Debra Hanneman, personal communication; ARCO, 1995).

The Rocker fault has found its way onto several maps of the region (ARCO, 1995) and the theory of its existence has been adopted by numerous consultants and geologists studying the area. Despite the fact that no previous investigation has been specifically designed to determine if the subsurface features of the area match a structural environment indicative of faulting through the Tertiary—aged sediments found there, many aspects of the area have been sampled and examined extensively. This study has combined previously gathered information with newly acquired geophysical and geologic data to visualize the features lying below the town of Rocker, in order to consider the feasibility of the Rocker Fault's existence.

BACKGROUND

The town of Rocker lies seven miles west of Butte along the Silver Bow Creek of southwestern Montana. Immediately south of the creek and the center of Rocker are the remains of the Rocker Timber Framing and Treating Plant, which operated from 1909 until 1957. When it was still in operation, the plant treated wood that was to be used in the underground mines with preserving chemicals such as creosote and arsenic solutions. After the facility closed down, these chemicals were improperly contained, and since then have been seeping into the ground and the Silver Bow Creek, creating environmental hazards in the immediate and surrounding areas. The Rocker Timber Framing and Treatment Plant has been identified as part of the Silver Bow Creek Superfund site since 1983 (ARCO, 1995). In the last fifteen years, ARCO, the current owners of the site, have financed a number of studies of the Rocker site that have included water testing and the drilling of wells.

All areas examined in this study lie in an east—west alluvial valley, within the Upper Silver Bow Creek drainage basin. The site itself is nearly flat. Late Cretaceous granitics, known as the Butte Quartz Monzonite (Derkey and Bartholomew, 1988; Smedes, 1964), crop out in the hills surrounding Rocker to the Northeast, Southeast, and West. The region is characterized by a complex system of volcanic intrusions and metamorphic zones, and hydrothermal activity and secondary mineralization, were responsible for the ore deposits appearing throughout the area. Tertiary sediments overlying the granitics are deposited in complicated sequences that include lake bed deposits, paleochannel deposits, mudstones, and volcanic tuffs. Above the Tertiary sediments and filling much of the Silver Bow Creek drainage basin, are Quaternary alluvial deposits. Some Quaternary deposits have cut down into the Tertiary material. Conclusive studies of the stratigraphy beneath the Rocker site do not exist. Core samples taken from the site by ARCO (1995) suggest that the Quaternary—Tertiary contact below the surface becomes more shallow to the West, and domestic wells dug within a kilometer to the south of Rocker reach granitic material at their maximum depths.

Proponents of the Rocker Fault generally place it along Canada Creek, which flows into the Silver Bow Creek about half a mile east of the Rocker site. Previous studies (ARCO, 1995; Derkey and Bartholomew, 1988; Smedes, 1964) identified faults in the region resulting from late Cretaceous west—east extension as well as later faulting sequences that have offset both the Cretaceous and Tertiary deposits (Constenius, 1996). If the Rocker Fault existed, it would probably resemble the sequences of normal faults identified in the granitics elsewhere in the region (Constenius, 1996). These faults are almost exclusively listric in character, and the Tertiary sediments above the levels. These wells can be used to calibrate the model to observed head values. The third layer was the Tertiary layer that was modeled as 300 to 500 feet thick based on the seismic profiles.

An initial steady state model was created using MODFLOW (McDonald and Harbaugh, 1988) a three dimensional finite difference groundwater flow model. Sources and sinks used in the model included Silver Bow Creek and an average precipitation rate of 12 inches/year. The resulting model, although simple was sufficient to evaluate the conceptual model. The computed flow gradient (0.0026) is very close to the gradient derived from observed water levels in the monitoring wells on the site (0.0025) and model head values are within five percent of observed values, with a small model flow budget discrepancy.(ARCO, 1995)

Discussion

Modeling the site without an estimate of Tertiary thickness would not have provided a reliable model of groundwater flow through the site. The seismic profile provided an estimate of the thickness Tertiary aquifer without the expense of drilling to depths of over 600 feet. By combining this new estimate with the previously estimated hydraulic parameters. (Hydrometrics Inc.1988)

Further seismic work at the site could include some higher resolution reflection profiles designed to image shallower in the subsurface. This could help in possibly locating Tertiary age channels which being more transmissive could serve to channelize groundwater flow.

Acknowledgments

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granitics would either be offset as synextensional basin—fill strata (Constenius, 1996) or as a ductile unit within the hanging block. In their Remedial Investigation Report, ARCO described four faults appearing within five miles of Rocker, two to the South and two to the North, that would pass through the site if they were projected. One of the faults, appearing roughly a mile and a half northeast of Rocker, trending northeast—southwest, west—side dropped, would pass through the confluence of Canada Creek and the Silver Bow Creek if extended.

METHODS

Seismic reflection data made up the bulk of the data I used in this study. Jon Conaway of Montana Tech, Erika Hammar—Klose of Smith College, James Sneeringer of Beloit College and I, with help from Dr. Debra Hanneman, ran four lines on the Rocker Operable Unit: three roughly parallel to the Silver Bow Creek and one tie—line that crossed two of the first three. We chose the particular location for each line according to how well it avoided obvious obstructions, covered areas of the site that the other lines did not, and over—lapped with well—drilling locations for elevation control and core sample correlation. We ran line 1 the furthest to the West of the lines, touching the Silver Bow Creek on its east end and extending westward to parallel the meandering Silver Bow creek at a distance of about 30 meters. The tie—line crossed roughly perpendicular to the Silver Bow Creek through the eastern end of line 1 and the western end of line 2. We ran line 2 approximately 70 meters south of the Silver Bow Creek and line 3 further to the East and South, trending northwest—southeast, 200 meters from the Creek.

A Bison Series 9024 stacking seismograph was used to acquire the reflection data. We set up groups of three 40 Hz geophones at each take—out in a linear arrangement and 24 take—outs for each shot point. Samples were collected at 1.00 samples per millisecond and recorded with a digital high—cut filter of 250 Hz and a digital low—cut filter of 32 Hz. Sampling time was half a second (500 samples per channel). Take—outs were spaced five meters apart. The use of a roll—along box ensured that for each shot point 24 consecutive take—outs would be recording, starting with the take—out located five meters up the line from the source. The source consisted of a 16—pound sledge hammer and a metal striking plate.

I processed the data using WinSeis, a program put out by Kansas Geological Survey, designed specifically to view and manipulate seismic reflection and refraction data. The following steps were taken to process the Rocker data: 1) I applied AGC (Auto Gain Control) to the data; 2) removed noisy and dead or ringing traces; 3) surgically muted out first arrivals and the air blast, ground roll, and the portions of the traces that arrived thereafter; 4) sorted the traces for geometry; 5) applied static corrections (including elevation corrections) to the data; 6) resorted the traces into Common Depth Point gathers (CDP's); 7) picked velocities for Normal Move—Out (NMO) corrections; 8) applied NMO corrections for the CDP's and stacked them. I did experiment with some filters, primarily frequency band—pass filters and F—K filters to remove first arrival energy, but exaggerated muting without filtering seemed to yield the best results.

Other methods included surveying to obtain elevations for the static corrections, geologic mapping of the area and examining core samples taken from well—drillings on the Rocker Site. We examined the core samples to see if we agreed with ARCO's interpretation of them.

RESULTS

Stacked sections for each of the four lines in the seismic reflection survey were processed using the elevation corrections obtained from the site (see fig. 1).

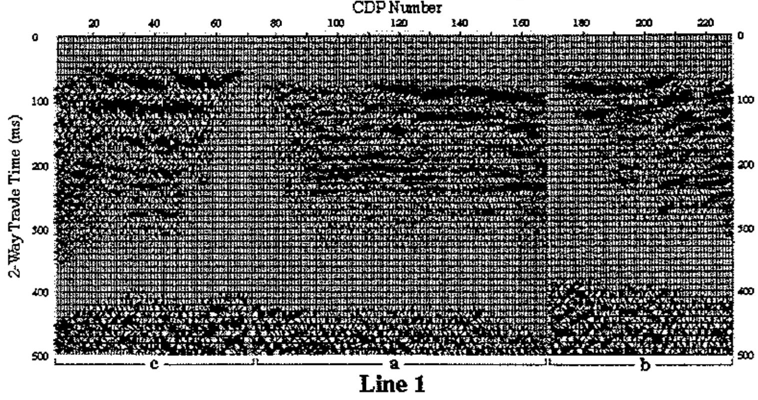
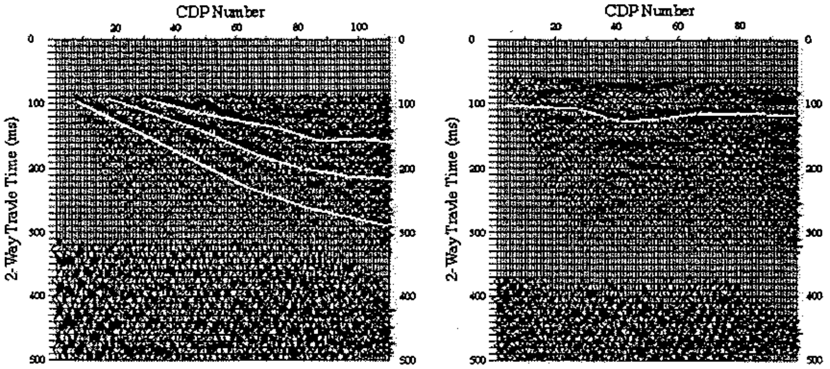


Figure 1: Results for three of the four seismic profiles. Line 1 was shot in three sections, a) a central section shot from east to west, and two continuation lines, b) one extending the line further to the West, shot east to west, c) the other extending the line further to the East, shot from west to east.



Line 2 **Line 3**

Figure 1 (continued): Lines 2 and 3. Important features have been outlined in white. In line 2, the lowermost reflector probably represents the boundary between the Tertiary and basement rock.

Examination of the actual core samples obtained by the ARCO contractors, revealed that certain portions of the samples were misidentified and not included in the original report as members of the Tertiary material as they should have been. In most cases these mistaken samples were classified as Quaternary deposits, though they closely resembled Tertiary mudstones seen elsewhere in the region.

DISCUSSION

The results of this study do not support the existence of a Rocker Fault that has offset the Tertiary sediments, for three reasons: 1) the Quaternary—Tertiary boundary does not closely resemble the western edge of a fault—block system, as was originally thought; 2) the contact between the Tertiary sediments and the basement rock is not indicative of a Tertiary—aged fault block basin; and 3) the age of the particular Tertiary sediments obtained from the Rocker site are inconsistent with the ages that might be expected in a listric fault zone.

Before the recent observations made from well—core studies (ARCO, 1995), compelling evidence for the Rocker Fault did not exist. The first models created for the subsurface of the Rocker site depended heavily upon the data obtained from well drillings, and in large part these preliminary models were responsible for legitimizing the possible existence of the Rocker Fault and sparking interest in the structural history of the site. However, examination of the well—drillings led to an adjustment of the model for the Quaternary—Tertiary boundary, and the realization that the shape of the actual boundary is not so suggestive of a fault—block system after all (see fig. 2).

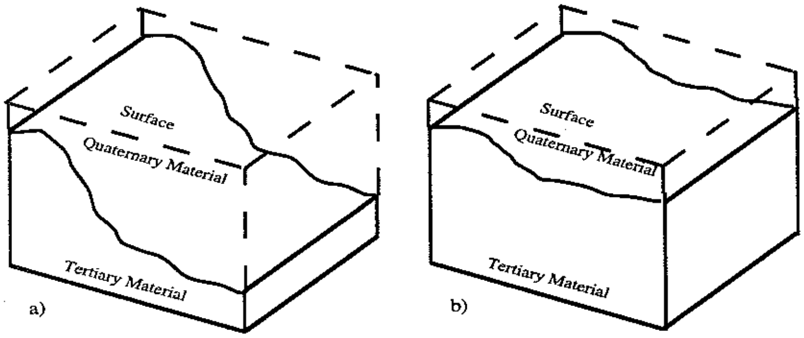
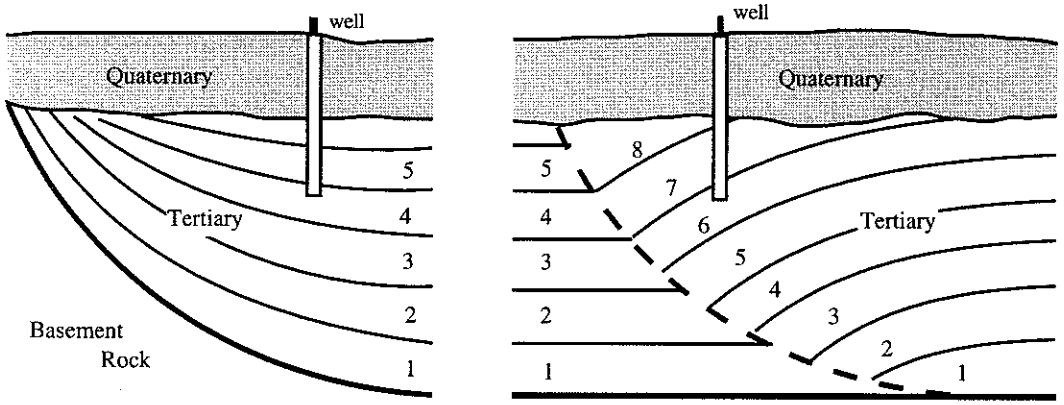


Figure 2: a) The model for the subsurface contact between the Tertiary and Quaternary units originally proposed by ARCO (1995) based upon well—drilling samples.
b) The adjusted model for the Tertiary—Quaternary boundary after examination of the well—cores.
(Assume the scale is the same for a and b.)

The form of the basement rock, as suggested by the reflection survey, lies at an even depth of approximately 180 meters below the surface along line 1. Further to the East the basement rock nears the surface and creates a concave contact with the Tertiary sediments seen in line 2. Processing of line 3 revealed the appearance of high velocity (2000 m/s) reflectors at shallow depths—a probable indicator that the granitic basement rock is much closer to the surface in this area than in the other lines. There are a few reflectors that appear within the Tertiary in line 2, above the contact to the granitics, and it appears that the bedding is typical for a basin—fill sequence. The reflectors visible within the Tertiary along line 1 appear relatively undisturbed and horizontal. Features associated with faulted sedimentary basins (Anders and Schlische, 1994; Doutsos and Piper, 1990) include tilted bedding toward the footwall within the hanging wall and offsets in the hanging wall away from the fault. Some or all of these features would have been apparent if there was a major fault east of line 1.

Finally, the age distribution for the Tertiary deposits seen in and around Rocker are not consistent with what would be expected in a listric fault system. A normal fault in the Tertiary deposits would likely be listric, as is nearly every fault in the region associated with the extensional episodes of the middle Eocene to early Miocene (Constenius, 1996). In a listric fault system, bedding within the hanging wall are dipped down toward the footwall as the hanging wall subsides—which in the case of Rocker would mean a down—dipping to the East of the younger Tertiary—aged sediments. With the presence of a listric fault just east of Rocker, younger—aged Tertiary material should have appeared in the well—drillings below the Quaternary sediments (fig. 3). The Tertiary material taken from the core samples in Rocker are Eocene in age—older than the Tertiary deposits outcropping to the West and in the foothills surrounding the site (Debra Hanneman, 1997, personal communication).

Figure 3: (Tertiary Sediments labelled oldest to youngest 1 - 8)



a) In the case that the Tertiary sediments represent undisturbed basin-fill deposits, well-cores will reach only the older sediments that have not been down-cut by the Quaternary.

b) In the case that the Tertiary sediments have been offset by listric faulting, sediments of younger age should appear within the well-logs. On the Rocker site they do not — indicating that listric faulting has probably not occured.

CONCLUSION

Though it is impossible to say with certainty that the Rocker Fault does not exist with the information available, data acquired in this study suggests that it does not. Given the well—log data, seismic reflection evidence for structurally undisturbed basin—fill sediments above the basement rock, and sediment age distributions inconsistent with a listric faulting zone, it seems unlikely that the Tertiary sediments have been offset by a major fault.

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Structural and environmental controls on groundwater flow and the potential for contamination: Warm Springs Creek Valley, Anaconda, Montana.

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INTRODUCTION

Southwestern Montana has a rich history of orogenic activity and related sedimentation events. Most notably, this area was recently affected by Laramide tectonism. As a result of the mountain building events, there are a series of ridges and valleys that, though not necessarily parallel or orderly, have a certain homogeneity about them. The valleys have a commonality that arises from the widespread deposition of Tertiary sands and gravels, while the mountains' similarities are erosional features from Pleistocene glaciation. Nestled between gaciated peaks in one of these Tertiary-fill valleys lies the city of Anaconda, Montana.

Surficial Hydrology. In the Anaconda area, the Warm Springs and Silver Bow Creeks come together to form the Clarks Fork River. Warm Springs Creek flows east from the Georgetown Lake area, through downtown Anaconda, and northeast toward the town of Warm Springs. The Silver Bow Creek flows west through Butte and Rocker, MT, and joins the Warm Springs Creek ten miles east of Anaconda in Warm Springs, MT (figure 1). The Warm Springs Creek watershed covers 425 square kilometers and receives approximately 25 cm of rainfall annually. Total vertical relief in the watershed is over 1.5 km, approximately half of which lies within the lowest tenth.

Purpose. Locally, the city of Anaconda is known for its former glory days in the mining industry, the most prominent of which was the operation of a smelting facility that processed the rock excavated from the Berkeley Pit in neighboring Butte, Montana. Mine and smelter wastes still piled on the valley floor threaten local surface and groundwater quality. A four square-mile area on the north bank of Warm Springs Creek, northeast of downtown Anaconda, was studied to: 1.) determine the extent to which local sedimentary structure controls the flow of groundwater in the valley, 2.) characterize the soils in order to make assessments of infiltration and percolation rates, and 3.) evaluate the potential for contamination of local water resources resulting from the presence of the mine and smelter waste.

GEOLOGIC UNITS

The land surrounding the lower half of Warm Springs Creek is geologically diverse and raises some important and difficult questions about the emplacement and deposition history. The volcanic, metamorphic, and sedimentary units in the region are all noticeably deformed: there is evidence of folding, faulting and tilting in each unit. Because of the diversity of the geologic units, the contacts are distinct, yet because of the short time span for their emplacement and deposition, the processes involved in their deformation are somewhat difficult to interpret.

There are six distinct units in this area (figure 2). The southern half of the watershed is composed of massive fine- to medium-grained Tertiary sandstones. These units are considered to be part of the Bozeman Group–Renova Formation's fine-grained strata deposited in low-energy flood plain and pond environments (Kuenzi & Fields, 1971) and are early- to mid-Oligocene in age (37 Ma). The beds are tilted and have an average NE 040 strike and dip 25°SE. The units range in thickness from 3 to 45 m. There is evidence of faulting on this southern slope of the watershed, including offset beds and modern hydrothermal activity. Two steep-sided travertine domes appear on this southern slope of the watershed and stand 3-4 m taller than the ground around them. The more northerly of the two is still overflowing with lukewarm water, while the other has a water level approximately 1.5 m below the rim of the dome. Further south and past the watershed boundary lie two more domes, one fairly new (little build up of dome sides) while another is quite a bit older: railroad tracks were cut through the dome approximately 80 years ago and there has been no more recent evidence of hydrothermal activity at this locale.

The next unit overlying the Tertiary beds is a massive volcanic breccia unit, and is part of the Lowland Creek Volcaniclastic series. This light to medium grey rock has a fine-grained matrix that supports a pebble- to cobble-sized angular breccia of similar composition. There are rims of mineralogic alteration around the edges of the breccia.