Gravity and seismic refraction survey of the contact between Cenozoic deposits and Archean bedrock in the Willow Creek watershed, Madison County, Montana

Kyle D. Kolodziejski
Department of Geology, Beloit College, 700 College St., Beloit, WI 53511-5595
Faculty sponsor: Richard C. Stenstrom, Beloit College

INTRODUCTION

The Willow Creek watershed lies on the eastern flank of the Northern Tobacco Root Mountain range in southwestern Montana. The general topography of the area consists of pediment downcut by small drainages, resulting in a landscape of rolling hills. Our main gravity line and seismic refraction survey runs north-south parallel to the basin margin of the Tobacco Root Mountains and has three branches extending westward, along primary and secondary roads. This gravity and seismic refraction survey will provide an insight to the subsurface geometries within the Willow Creek watershed. My area of focus is oriented east-west and perpendicular to the main north-south trending line. The site is located near a possible fault, as indicated by preliminary geologic maps of the area, and lies perpendicular to the contact between Cenozoic deposits and Archean bedrock. A gravity survey, constrained by data from seismic refraction lines, was used to delineate the subsurface geometries of these deposits.

Geology. The core of the Tobacco Root Mountains is the result of a domal uplift of southwestern Montana, and is composed of Precambrian metamorphic rocks of the Pony and Cherry Creek Series and the Late Cretaceous Tobacco Root batholith. Northeast of the Tobacco Root Mountains, early Precambrian rocks have been overlain by steeply dipping, undifferentiated sedimentary rocks (limestone, shale, siltstone, and sandstone) of Paleozoic to Mesozoic age. The region is cut by a series of northwest-southeast trending faults formed during Precambrian time (Vitaliano et al., 1979). Tertiary extensional tectonics reactivated these faults, producing intermontane basins which were filled by continental sediments. The break-up of basin and ranges associated with this extension caused recurrent movement along basement faults producing small northwest-trending half-grabens, which form the ridges of many local ranges. The Cenozoic deposits in the Willow Creek watershed may represent the edge of either the Madison basin to the south or the Three Forks basin to the north, paleovalley fill unrelated to either basin, or a separate basin (Hoh and Kroeger, 1997).

At the site late Pleistocene to Holocene pediment gravel, represented by stratified, sorted, angular to rounded gravel in a matrix of sand and silt, derived from sheetwash flow during the last interglacial period cover the Cenozoic deposits and Archean bedrock. The Tertiary sediments contain bedded to massive interbedded conglomerate, sandstone, siltstone, and mudstone which onlap the Archean bedrock. Locally, the Precambrian rocks are Archean in age consisting mainly of quartzofeldspathic gneisses intruded by orthoamphibolites and hornblende-plagioclase gneisses (Elliott, 1996).

Previous Studies. Previous geologic mapping projects in the Willow Creek watershed area focused primarily on the bedrock geology. Vitaliano and others (1979) produced a 1:62,500 scale geologic map of the southern Tobacco Root mountains including the Pony, Potosi Peak and parts of the Harrison and Maltbys Mound quadrangles. However, the geologic mapping of the Willow Creek watershed is meager and incomplete. Recently, Vuke and others (1995) released an open file report on the Bozeman 1:100,000 scale geologic map which encompasses the Willow Creek watershed. Unfortunately, the small scale of this map excludes pertinent information that may be useful to my detailed study.

METHODS

Although the Cenozoic-Archean contact is noticeable at the surface, the gravity survey was the primary method for subsurface exploration. My field site contains thirty-five gravity stations at 45-55 m intervals covering approximately 2 km. The relative horizontal and vertical coordinates of the gravity stations were accurately surveyed using a Lietz total geodetic station. To convert the relative elevations of each station to true elevations above sea level, two U. S. Geological Survey benchmarks were surveyed and tied into the data.

At each station the date, time, and dial reading of the LaCoste-Romberg gravity meter were recorded. This procedure was repeated in loops, where the first station of the running loop is remeasured every 60 to 90 minutes, to make sure the meter is stable and to account for any drift over time. After all the stations were measured, the data were reduced and graphed using Microsoft Excel (See Figure 1). Complete Bouguer gravity anomalies were constructed with the exception of terrain corrections. The Bouguer reduction density for the Cenozoic deposits were determined using Nettleton's method and applied the two dimensional gravity modeling program, Grav2D (Grant and West, 1965).

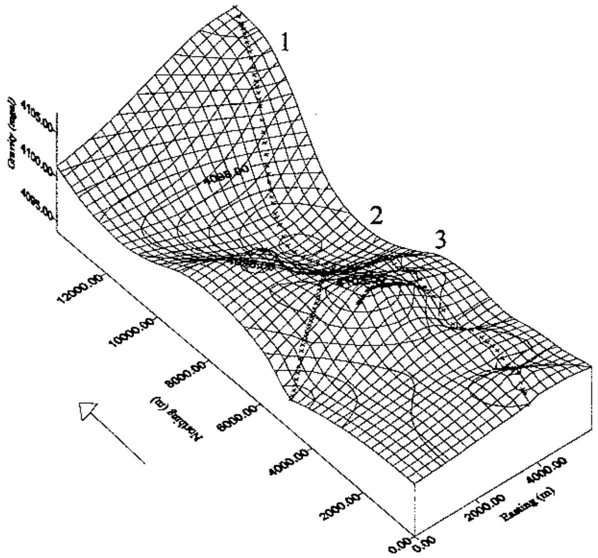

Figure 4: The gravity data are illustrated as a three-dimensional surface plot. The steep rise on the northeast corner is the site of the Elk Creek fault (1). The depression (2) is due to the deep Cenozoic sediment-filled graben. The smaller rise (3) is due to the Cherry Creek fault.

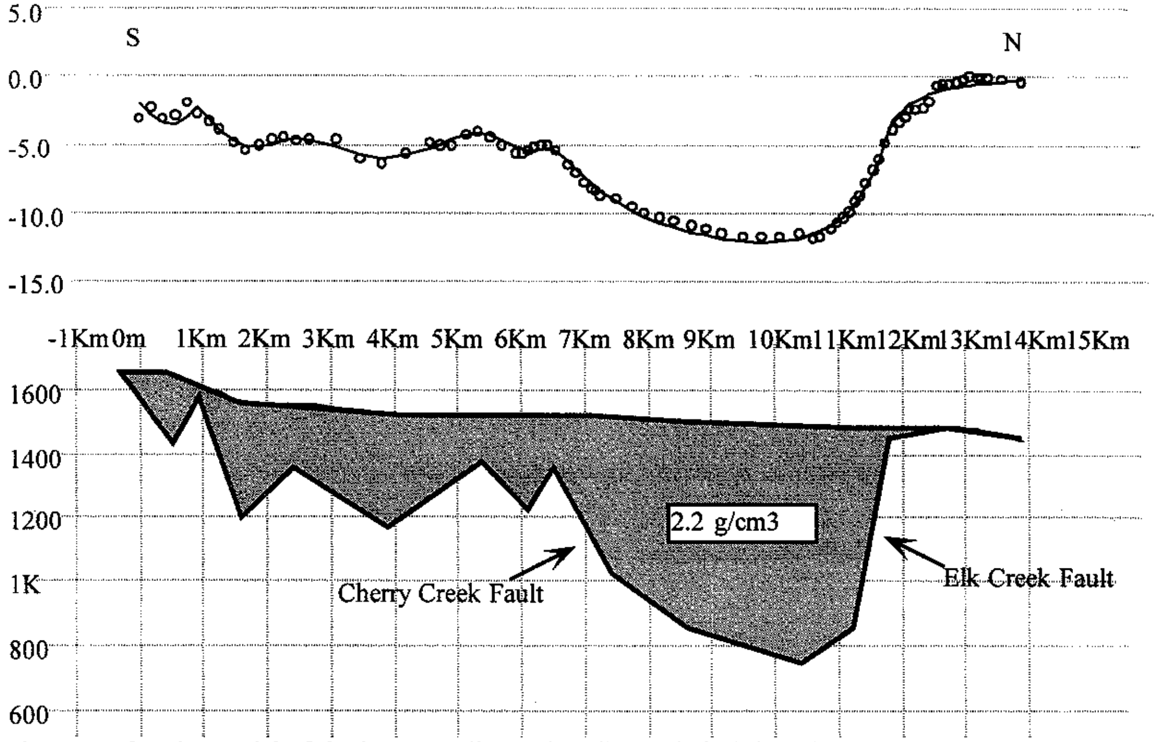

Figure 5: Gravity model of the long N-S line. The Elk Creek fault has about 750-1200 meters of throw. The Cherry Creek fault has about 400 meters of throw.

Seismic refraction lines were shot at locations along the gravity line near the contact between the Cenozoic deposits and Archean bedrock as indicated by primary gravity processing, well log data, and geologic maps of the area.

The seismic refraction survey consists of three lines covering about 630 m of terrain. This survey was conducted using a Geometrics 12 channel seismograph, with single 10 Hz geophones. A standard in-line geophone spread was used. Geophones were coupled firmly into the ground, at 6 m spacings, to prevent any noise caused by slight vibrations from irrelevant energy sources. The energy source, or shot point, was placed at a distance beyond the first geophone along the same line as the geophone cable. Reverse shots were placed at various distances beyond the twelfth geophone to pick up dipping beds.

All seismic records were computer processed using Rimrock Geophysics' seismic refraction program, SIP. The SIP program determines and models velocities and depths by using pre-determined first-break picks from the seismic waveform records. Velocities for layers 1 and 2 were computed using different methods. For layer 1, velocities were computed by dividing the direct distances from each shot point to each geophone by the corresponding arrival time. These individual velocities were averaged for each shot-point, and the weighted average for all spreads were computed. Refracted arrivals for layers below layer 1 were computed by two methods, 1) the regression method in which a straight line is fitted by least squares to the arrival times representing the velocity layer, and 2) the Hobson-Overton method (Scott, 1973), which is a least-squares adaptation of the plot of differences method (Redpath, 1973). SIP then used these velocities to formulate the depths of each layer.

RESULTS

The purpose of this gravity and seismic survey was to shed light on subsurface geometries existing at the Cenozoic-Archean contact along the basin margin. The complete Bouguer anomaly data for the area are graphed in Figure 2(a) and the geologic units are shown in Figure 2(b). Seismic data are available for most of the western half of the traverse and constrains depths and supports the gravity data. Tertiary deposits overlie the Archean metamorphic rocks that are exposed along the gravity line and yield good approximations of depth.

Figure 2 (a) and (b) illustrate one possible model that provides gravity values representative of the observed Bouguer anomaly. This model illustrates all known geologic and geophysical boundaries and provides a reasonable cross-section for the area. However, this model is not a unique solution and is subject to change when using other densities. According to Nettleton's method the Tertiary deposits yield densities of 2.1 g/cm^3, and for simplicity it was assumed that the Archean rocks have densities of 2.67 g/cm^3. These values fall within Burger's (1992) estimated ranges for metamorphic rocks and unconsolidated sediments, respectively.

Seismic data support the gravity by suggesting two layers are present within the section. The first layer, sand and gravel, give velocities between 900-1000 m/s and the second layer, metamorphic rocks, represent velocities ranging from 3900 to 4125 m/s. These velocities coincide with Burger's velocity ranges for common materials, including metamorphic rocks and unconsolidated sediments. Depth model plots of each line segment created by the seismic refraction processing program, give bedrock depths of 2-3 m near the Archean exposures and consistently decrease to depths of 18-19 m farther to the east. Sample depth plots of the eastern section of the gravity line are shown in Figure 3 (a) and (b).

It is concluded that the gravity and seismic data suggest similar depths and geometries of the subsurface. However, at this time no accurate conclusions can be made to determine if this structure is related to the graben bounded by the major northwest trending faults suggested by Elliott (1996).

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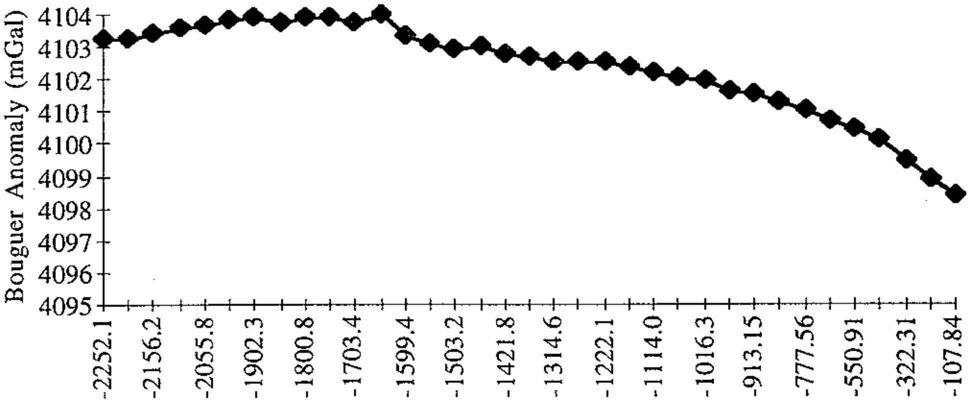


Figure 1. Bouguer gravity anomaly over distance.

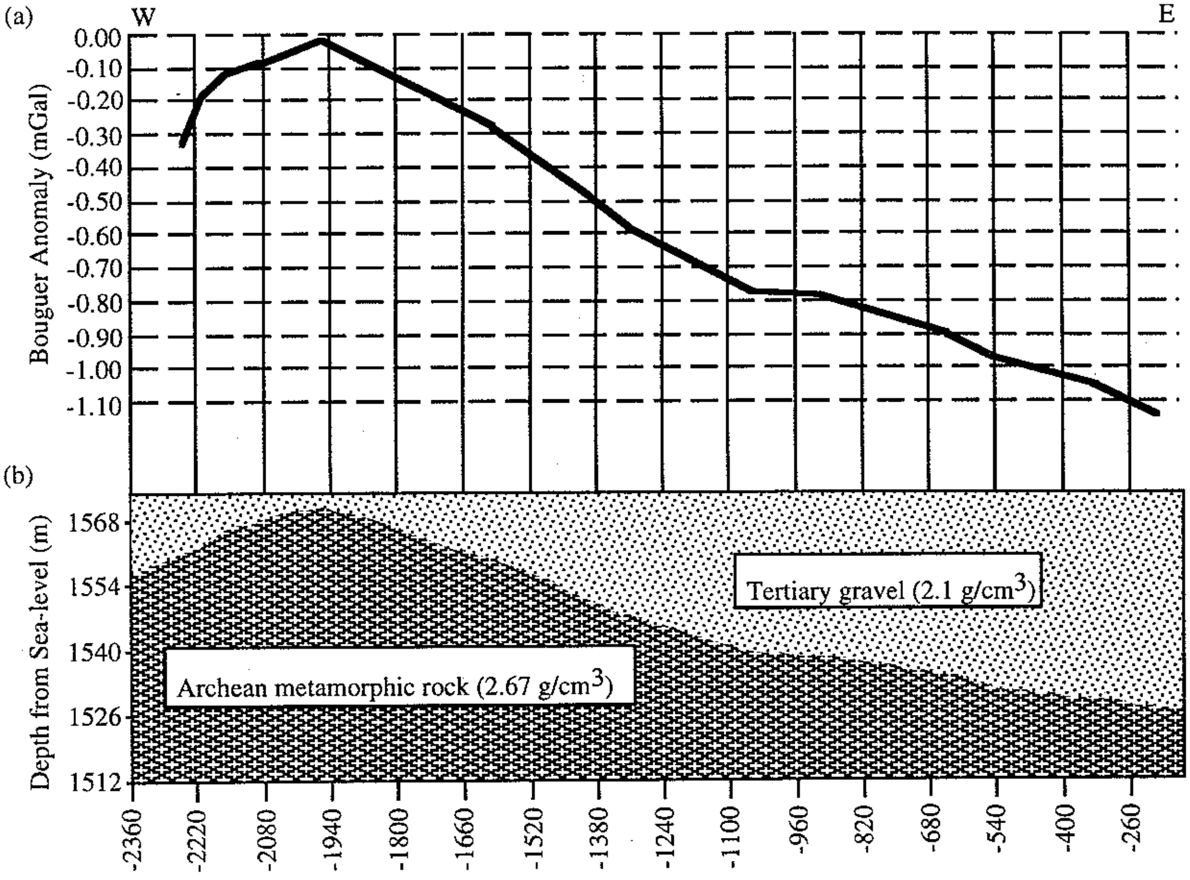
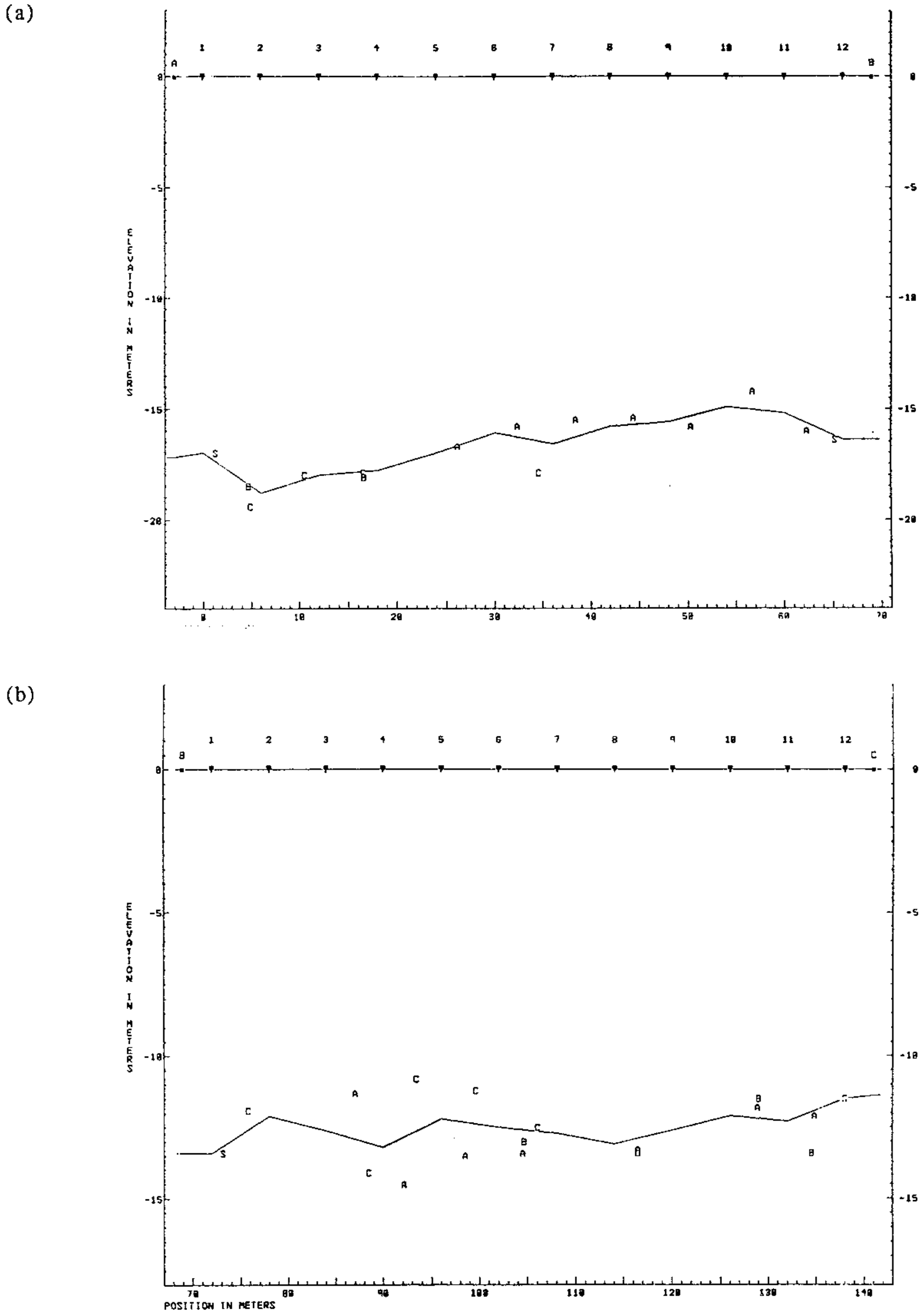


Figure 2. Bouguer anomaly and depth from sea-level along the gravity line. (a) Bouguer anomaly curve. (b) Bedrock surface derived from Bouguer gravity.

Figure 3. Depth model plots derived from seismic refraction processing program, SIP. Both are good examples of bedrock depth at approximately -1500 meters relative easting.



Slip slidin' away: slope failure at East Knob borrow pit, near Anaconda, Montana

Katie Lethenstrom
Department of Geology, Whitman College, Walla Walla, WA 99362
Faculty sponsors: Robert J. Carson, Whitman College

INTRODUCTION

Anaconda, Montana, located 43 km west of Butte in southwestern Montana, has a fascinating history marked by nearly a century of smelting mined copper ore. In 1983, parts of Anaconda and the surrounding area were declared a Superfund site due to the tremendous amount of pollutants in the soil, water, and air. Since then, the Atlantic Richfield Company (ARCO) and the Environmental Protection Agency (EPA) have worked to clean up the area, making it safe for humans and wildlife. As part of remediation, toxic smelter tailings must be capped with a suitable soil cover (ESA Consultants Inc., 1996). In an effort to be efficient, ARCO looked for a capping material nearby. East Knob qualified as a site for Type A soil cover required for the most toxic wastes. The soil cover cannot contain more than 45% cobbles, and soils that classify as loamy sand, sand, or clay are unsuitable (ESA Consultants Inc., 1996). Since the matrix meets Type A requirements, borrowing began, with about 628,000 m^3 of material removed to date (M.P., ARCO, oral communication, January 15, 1997). As borrowing progressed, the area above the borrow pits eventually failed.

The combined effects of the local geology, hydrologic conditions, and human action caused slope failure. Local clay layers act as an aquiclude, and during wetter months the slope becomes saturated. The natural slope remained stable until excavation began, decreasing lateral support. The failure is classified as a slump-earthflow combination, exhibiting features such as rotated slump blocks, crevasses, and earthflows. Surveying the slide leads to a better understanding of the movement, providing amounts of movement, mean velocities, and general direction of movement. Survey data also allows for correlation between rates of movement and amounts of precipitation.

ARCO made efforts at stopping movement, including trying to drain water from the slope, and changing excavating methods to minimize removal of lateral support. Survey data show that these efforts decreased movement somewhat but did not stop it.

METHODS

The slump was surveyed with a total station and a data collector. Surveys were chosen with the goal of documenting the 0.46 m of movement per week observed by Druyvestein, Johnson & Anderson Surveyors (DJA) during the spring of 1996 (beginning on April 15, 1996). Two base stations, one below the slide (1023) and the other above (1001), and tripod prisms were used for increased accuracy. In addition to the seven stations DJA established on the slide, I added four more stations to get a better understanding of the motion (Figure 1). At several places, nails were placed on either side of cracks in an effort to determine rates of movement and the relation between major blocks. The distance between nails, along with a bearing, were measured for each pair.

Survey data compiled over approximately a five month period by DJA was used to determine mean velocities and to look for a change in movement after the dewatering ditch was excavated. DJA survey data along with mine was used for correlation between amounts of precipitation and rates of movement, and to determine amounts of movement for stations, and the slide as a whole.

LOCAL GEOLOGY

Volcanics and sandstones comprise the various bedrock geologic units of the Anaconda area (Hanneman and Wideman, 1991; Smedes, 1962). The Lowland Creek Volcanics, early Tertiary in age, make up the youngest bedrock in the field area. The uppermost unit of the volcanics is a tuff layer, composed of white to light gray ash. Above the tuff lies a quartzite rich diamicton, Quaternary in age and believed to be fluvial in origin. The unit is informally named Old Works Diamicton by Karen Foster, and has a maximum thickness of 60 m. A well developed organic horizon and caliche layer comprise the upper half meter to meter of the diamicton. The unit is unconsolidated, unstratified, and matrix supported with well rounded clasts ranging in size from pebbles to boulders. The composition of the matrix, light tan in color, varies from place to place; some locations it is more sandy, while in others it has more clay. For the most part, the matrix is a sandy clay loam, containing local clay beds. Clast composition is mainly quartzites from the Precambrian Belt Supergroup, along with a few scattered volcanics. Years of fluvial erosion have removed the fine matrix leaving a lag gravel deposit, similar to a desert armor.