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

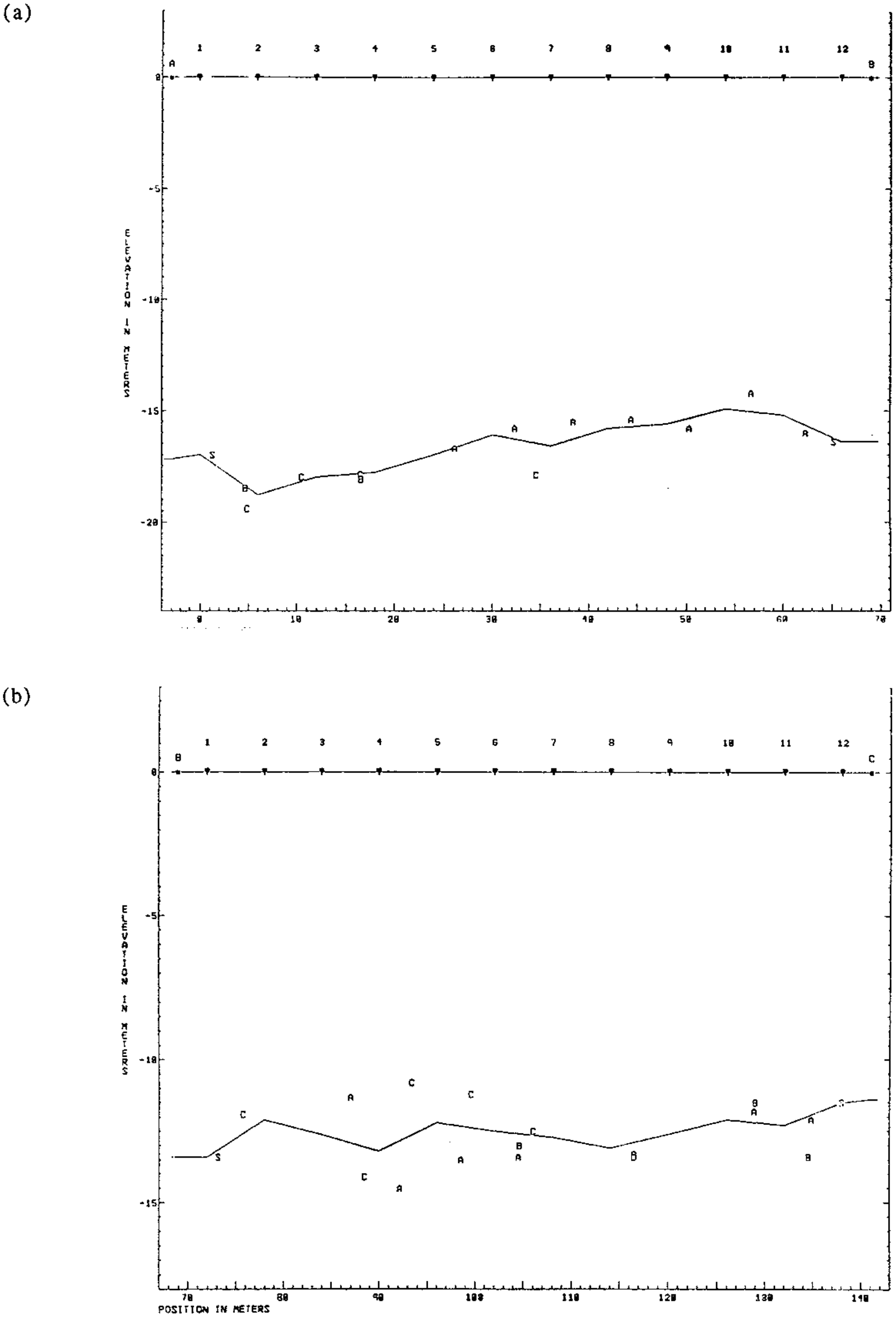
The slump was surveyed with a total station and a data collector. Surveys were chosen with the goal of documenting the 0.46 m of movement per week observed by Druyvestein, Johnson & Anderson Surveyors (DJA) during the spring of 1996 (beginning on April 15, 1996). Two base stations, one below the slide (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.

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.



The topography of the site area is hilly, with slopes averaging approximately 20 degrees. The hills are cut by numerous drainages that feed into Warm Springs Creek, a tributary to the Clark Fork River that runs the length of Deer Lodge Valley.

Hydrology. The climate of the Deer Lodge Valley is semi-arid, with an average of 350 mm of precipitation annually over the last 14 yeas (data from 1983-1996) (National Climatic Data Center, 1996). Most of the precipitation is received in the spring and summer months (April-August). The vegetation in the area is sparse, ranging from grasses, small shrubs, and small willows near drainages and seeps to grass or nothing in dryer areas. Runoff is relatively high because the slopes are somewhat steep and the vegetation is sparse. At the same time, however, the till has enough permeability to allow some infiltration of precipitation.

A perched water table exists because of impermeable local clay layers and the clay content of the till. An air photo taken before the failure shows springs emerging from the hillside and running into local drainages, as indicated by vegetation patterns.

GEOMORPHOLOGY OF THE FAILURE

The landslide occurs in the Old Works Diamicton on the east facing slope of East Knob (Figure 1). Based on the mass wasting classification by Varnes (1958), the area of failure is a slump-earthflow combination. The upper portion of the slump failed in coherent blocks, which rotated in places, and retained the lag pavement cover. As the upper portion failed, the lower portion most likely turned into an earthflow, as indicated by lack of coherence in the material and severe disturbance of the lag pavement. The exact toe is indistinguishable due to the removal and reworking of material. The area of the slide is approximately 57,000 m^2 (0.057 km^2). The volume of the slide is unknown, as no known detachment surface was observed. The main head scarp averages 5 m in height.

The earthflow portion is characterized by a traditional hummocky surface, full of crevasses and small scarps. Extensional and compressional features are common throughout the landslide. Extensional features include crevasses, uphill scarps, depressions, and what looks like a mini-rift valley opening up between two blocks moving apart. Sag ponds fed by seeps occur in the hummocky depressions. Compressional type features include upheaval of material, and thrusting of moving material over the stable slope on the northern edge.

Two main generations of failure can be seen in the slump. An older more eroded scarp (elevation 5410 feet) exists downslope from the current head scarp (elevation 5470 feet). Initial failure occurred at the older scarp sometime in August 1995 (M.P., ARCO, oral communication, January 15, 1997). This failure decreased lateral support for the slope above, and as more material was borrowed from below, the slope failed again at the present head scarp. Large blocks continue to break off, continually changing the morphology of the scarp. No evidence for potential failure occurs above the scarp.

A clay layer provides a local secondary failure surface for two blocks near the head scarp. Slickensides formed as the blocks slid over the wet clay, providing general directions of movement. The most pronounced slickensides occur near the top of the slide on the scarp wall, and underneath a moving block. Fresh slickensides occurred after rainfall, indicating localized movement of blocks. The only observed movement occurred during a 15 day period, during which 9.1 mm of precipitation fell resulting in 16 cm of movement.

Dynamics of the failure. Surveys taken from July 30 through August 12, 1996 show the slump-earthflow moved an average of 0.3 m. Stations 100, 102, 104-107, and 1010 showed movement (Figure 1), ranging from 0.2 to 0.4 m. This movement correlates well with the DJA survey data taken near the same time. Stations located on the flow and slump show no significant differences in amounts of movement. Station 103, however, shows no evidence of movement. Since 103 lies near the high pit, its lack of movement is most likely explained by the termination of excavation in the high pit because of safety reasons. Station 1010 does lie near the high pit, on a small tributary flow lobe. Movement of 0.4 m was recorded, most likely due to saturation. As expected, survey points located outside of the failed area show no evidence of activity, supporting field evidence that the slope outside the landslide is currently stable. The survey data is also supported by small changes in bearings from the nails sets put near cracks. In general, the landslide in moving southeast.

Precipitation and rates of movement. Survey data from DJA along with mine demonstrates that movement of the landslide is closely tied with the amount of precipitation received. During the three week survey period, 5.3 mm of precipitation fell, as compared to the 67 mm that fell during May and June (National Climatic Data Center, 1996). August was an unusually dry month, and as a result, the landslide moved less. May and June show the most activity, which would be expected since these two months had the most precipitation. Once it began raining more (in late August and September) the landslide began moving more, as documented by DJA. Average velocities calculated from DJA surveys (April through September) range from 18 to 30 cm per week, with the landslide moving an average of 0.21 m per week.

In conclusion, the 0.46 m per week of movement observed by DJA is closely tied to the high precipitation levels. When there was less precipitation, movement decreased, as evidenced by my survey data. One would expect less movement during such a dry time, but ARCO began borrowing again in the lower pit at the end of July, further decreasing lateral support. Obviously, borrowing and amounts of precipitation are both critical factors.

DISCUSSION

Causes of failure. Initial failure of the slope was caused primarily by removal of the toe, which decreased lateral support, and blockage of a natural drainage, which increased saturation of the hill. During removal of material, a natural drainage on the southeast end of the slide area was blocked with waste material. In the lower pit, flow material at the toe of the slide built up, along with the waste material from borrowing. These two altered runoff patterns, coupled with the already perched water table and clay content, resulted in saturation of the slope. Once enough lateral support was removed, failure occurred. Both causes continue to have an effect on movement, as supported by survey, precipitation, and excavation information from July and August.

Mitigation efforts. Two main attempts have been made at slowing movement of the failed slope: lowering the water level and changing excavation methods. After the slope began to fail, ARCO continued to borrow from the upper pit until the following spring when the pit became unworkable. To slow removal of the toe and reduce reduction of lateral support, ARCO cut from the upper slope and down (toward the toe). The excavation backslope is kept at a maximum of 18 degrees to increase stability (M.P., ARCO, oral communication, January 15, 1997).

More importantly, ARCO excavated a dewatering ditch in the lower pit for the purpose of draining water from the failed slope (Figure 1). The ditch, dug in June 1996, starts at the approximate toe of the slide, near the end of the lower pit. The ditch seems to drain the slope fairly well, as it contained standing water and was well saturated during dry months. Survey data from DJA shows that after the first of July, rates of motion decreased. In the period before the ditch was excavated (78 days), 86 mm of rain fell, while after the excavation (85 days), 73 mm of rain fell. So, it can be said that the decrease in rates of motion was from less precipitation and/or draining of the saturated slope. Recently the dewatering ditch had to be cleaned, however, as material began flowing into it (M.P., ARCO, oral communication, January 15, 1997). In conclusion, these efforts have helped, but they have not resulted in complete stabilization of the landslide.

REFERENCES CITED

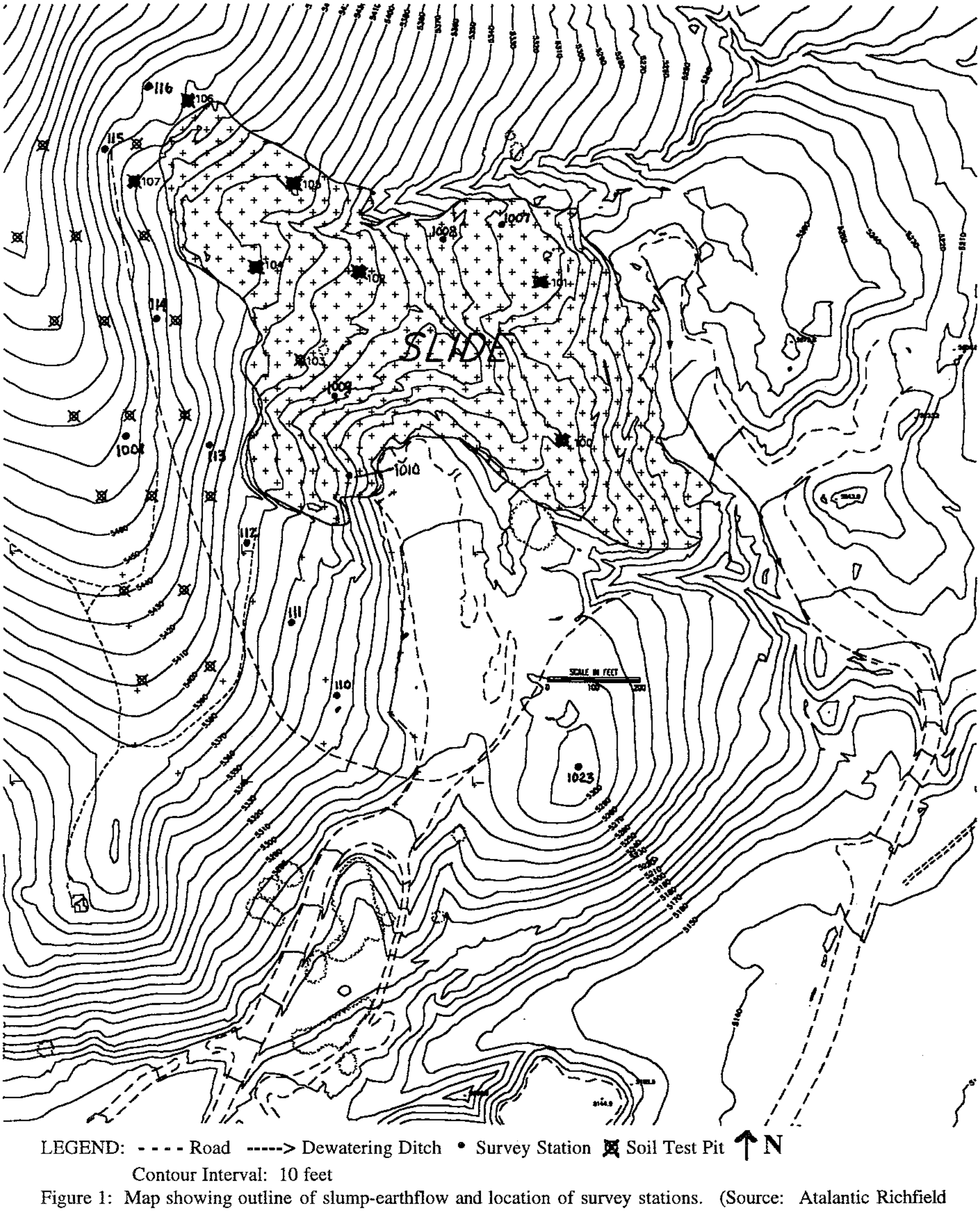
ESA Consultants Inc., 1996, Anaconda Smelter NPL site Old Works/East Anaconda development area operable unit remedial action work plan/final design report: Bozeman, 31p.

Hanneman, D.L., and C.J. Wideman, 1991, Sequence stratigraphy of Cenozoic continental rocks, southwestern Montana: Geologic Society of America Bulletin, v. 103, p. 1335-1345.

National Climatic Data Center, 1996, U.S. monthly precipitation for cooperative and NWS sites: http://www.ncdc.noaa.gov/coop-precip.html.

Smedes, H.W., 1962, Lowland Creek volcanics, an upper Oligocene formation near Butte, Montana: Journal of Geology, v. 7, p. 255-266.

Varnes, D.J., 1958, Landslide types and processes, in E.B. Eckel, ed., Landslides and engineering practice: Highway research board special report 29 (NAS-NRC), Washington, D.C., p. 20-47.



LEGEND: - - - - Road -----> Dewatering Ditch • Survey Station ⊠ Soil Test Pit ↑ N

Contour Interval: 10 feet

Figure 1: Map showing outline of slump-earthflow and location of survey stations. (Source: Atalantic Richfield Company, 1996)

Gravity and seismic refraction survey of Cenozoic deposits in the Willow Creek watershed and the region surrounding Harrison, southwest Montana

Sarah Peugh
Department of Geology, The Colorado College, 902 N. Cascade Ave., Colorado Springs, CO 80946
Faculty Sponsors: Jeffrey Noblett, The Colorado College; Glenn Kroeger, Trinity University

INTRODUCTION

The Willow Creek Watershed lies on the eastern slope of the Tobacco Root mountains in Madison County, Montana (Figure 1). The Cenozoic basin of this study surrounds the town of Harrison, Montana and consists of Quaternary Alluvium lying on top Tertiary fill which overlies a metamorphosed Archean basement. The basin may have developed in one of three ways: 1) the valley is simply a paleovalley and the basin margins are associated with onlap; 2) the basin represents the edge of either the Three Forks basin to the north or the Madison basin to the south; or 3) the basin is a separate, fault bounded basin. The purpose of this research is to use gravity data, constrained by seismic refraction, to delineate the subsurface geometry and the nature of these deposits and the associated basin. Gravity work shows the density contrasts of the underlying rocks and therefore tells us if tectonism has occurred. Seismic data determine the depth to bedrock along the basin boundaries and thus provides one less variable in modeling the gravity profile.

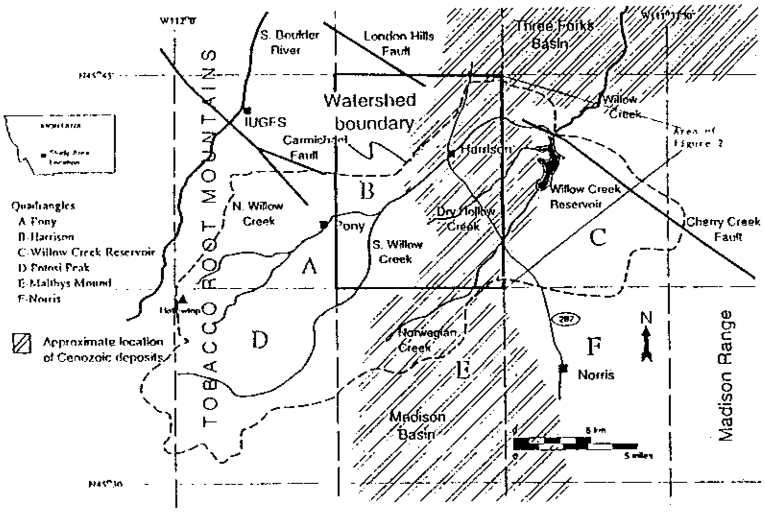


Figure 1. Map of Willow Creek watershed showing watershed boundary, quadrangles, Cenozoic deposits and structural features.

BACKGROUND GEOLOGY

The southwest Montana transverse zone (SWMTZ) separates the Cordilleran fold and thrust belt to the north from structural features related to the basement-cored uplift of the Rocky Mountain foreland to the south (Schmidt and O'Neill, 1986). The zone is east-trending and covers 120 kilometers, stretching from the Highland Mountains on the west to the Bridger Range on the east (Schmidt and O'Neill, 1982). The area of study for this investigation lies in the south-central region of this zone (N45°37'30"-N45°45' latitude, W111°45'-W111°52'30" longitude) and is greatly influenced by Rocky Mountain foreland structures. The foreland is characterized by northwest-trending faults along which uplift occurred during the Laramide orogeny in late Cretaceous and Paleocene time (ca. 95-55 Ma) (Schmidt and O'Neill, 1982). The Carmichael, London Hills, and Cherry Creek faults (Figure 1), which are part of this northwest trending fault system, extend from the SWMTZ to the southeast for several kilometers and intersect the basin of interest. As can be determined from Figure 1, it is possible that the London Hills fault and the Cherry Creek fault are in fact connected, but covered by Cenozoic deposits.