U. S. DEPARTMENT OF THE INTERIOR

U. S. GEOLOGICAL SURVEY

Schlumberger DC Resistivity Soundings in the Boulder Watershed, Jefferson and Lewis and Clark Counties, Montana

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[1]Schlumberger DC Resistivity Soundings in the Boulder Watershed, Jefferson

[1] *Use of particular band names does not directly or indirectly constitute endorsement by the U. S. Geological Survey*

and Lewis and Clark Counties, Montana

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INTRODUCTION

During July, 1997, twenty four Schlumberger dc resistivity soundings were made in the Boulder watershed and adjacent areas (fig. 1). The objective of geophysical studies in the watershed is to map subsurface lithologic, structural and hydrologic features important in controlling possible ground water contamination from mining activities and for design of remediation efforts. These studies are part of an abandoned mine land study (http://amli.usgs.gov/amli/) of the Boulder Basin mining district (http://www.deq.state.mt.us/mtmines2/linkdocs/techdocs/73tech.html).

The Boulder Basin mining district is located in the Northeast part of the Cretaceous Boulder Batholith. Geologic mapping in the area has been done by Becraft and others, 1963, and Ruppel, 1963. A more recent summary of the geologic setting is given by O'Neill and others (2000) The majority of the batholith is a muti-textured granitoid which include different plutons. In the Boulder watershed the batholith is overlain by cogenetic Elkhorn Mountains Volcanics which are predominatly quartz latite to andesite in composition

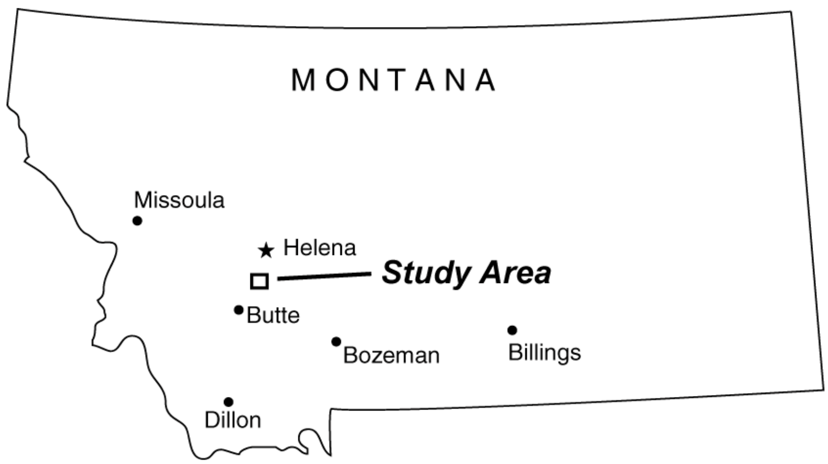

Figure 1 Index map for the study area

The Boulder Batholith is extensively jointed particularly in this study area which is in the upper part of the Batholith. The batholithic rocks are cut by numerous faults which trend northeast or east. The mineralization follows the east-trending faults or shear zones.

Pleistocene glacial till is present on some of the upland surfaces. Till is present in many of the flat areas in the valleys. Till is present in many of the flat areas in the valleys and lateral moraines are present along some of the larger valleys. Tertiary unconsolidated gravels mantle the uplands. Holocene fluvial-alluvial and minor pond and bog deposits have accumulated along some parts of the drainages.

The first geophysical work in the area by the USGS was a helicopter airborne geophysical survey carried out in 1996 using electromagnetic (EM) and magnetic survey systems (Smith et al., 2000). EM survey measurements are used to map variations in subsurface resistivity or its reciprocal conductivity. The dc resistivity survey was done as a follow-up of the airborne survey and to address smaller scale subsurface mapping issues.

An electronic version of this open-file report can be found in the abandoned mine lands web site given above and in http://greenwood.cr.usgs.gov/. The digital version includes plot files and digital data files for the dc resistivity soundings.

METHOD

The dc resistivity method involves the observation of electrical fields caused by current introduced into the ground (Sheriff, 1988). In dc soundings, the electrical fields are observed as a function of expanding current electrodes. By expanding the current electrodes, the apparent resistivity of the subsurface can be calculated as a function of vertical depth. Detailed description of various dc sounding methods can be found in standard geophysical texts such as Telford, and others (1990). A very good general reference is Zhody and others (1974). There are a number of world wide web sites that have information about dc sounding methods. The University of British Columbia maintains a web site (http://www.geop.ubc.ca/ubcgif/tutorials/resip/resip.html) which has an introductory geophysical section on resistivity methods. Another good introductory site is maintained by the Colorado School of mines (http://magma.Mines.EDU/fs_home/tboyd/GP311/). The Environmental Engineering Geophysical Society (EEGS) also has an excellent web site (http://www.eegs.org) that has numerous links to geophysical topics including dc resistivity methods.

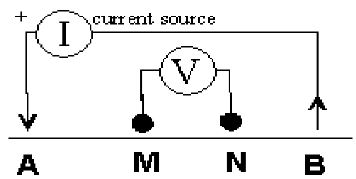

Figure 2 DC resistivity array where AB are current electrodes and MN are voltage electrodes.

SURVEY

In this survey an ABEM SAS[1] (http://www.abem.se/)dc resistivity system was used in a Schlumberger electrode arry (fig. 2). Current electrode spacing began with .91m and ended with 61 m (3ft to 200ft). The maximum electrode spacing was determined by instrumental and operational considerations which were primarily power and portability. The voltage (potential) electrode spacing was maintained at less the 1/3 the current electrode spacing and increased once per decade spacing. When the voltage electrode spacing was changed, two repeat measurements were made at the previous and new MN spacings. In general the maximum depth of investigation for the survey is about 30 meters. A total of twenty soundings were made in the Boulder Basin watershed (fig. 3) which are designated MTAMLxx where xx is the sounding number. Four additional soundings were made in the Ten Mile drainage to the north of the Boulder Basin (MTAML 20-24). Location information for all soundings is given in Table 1.

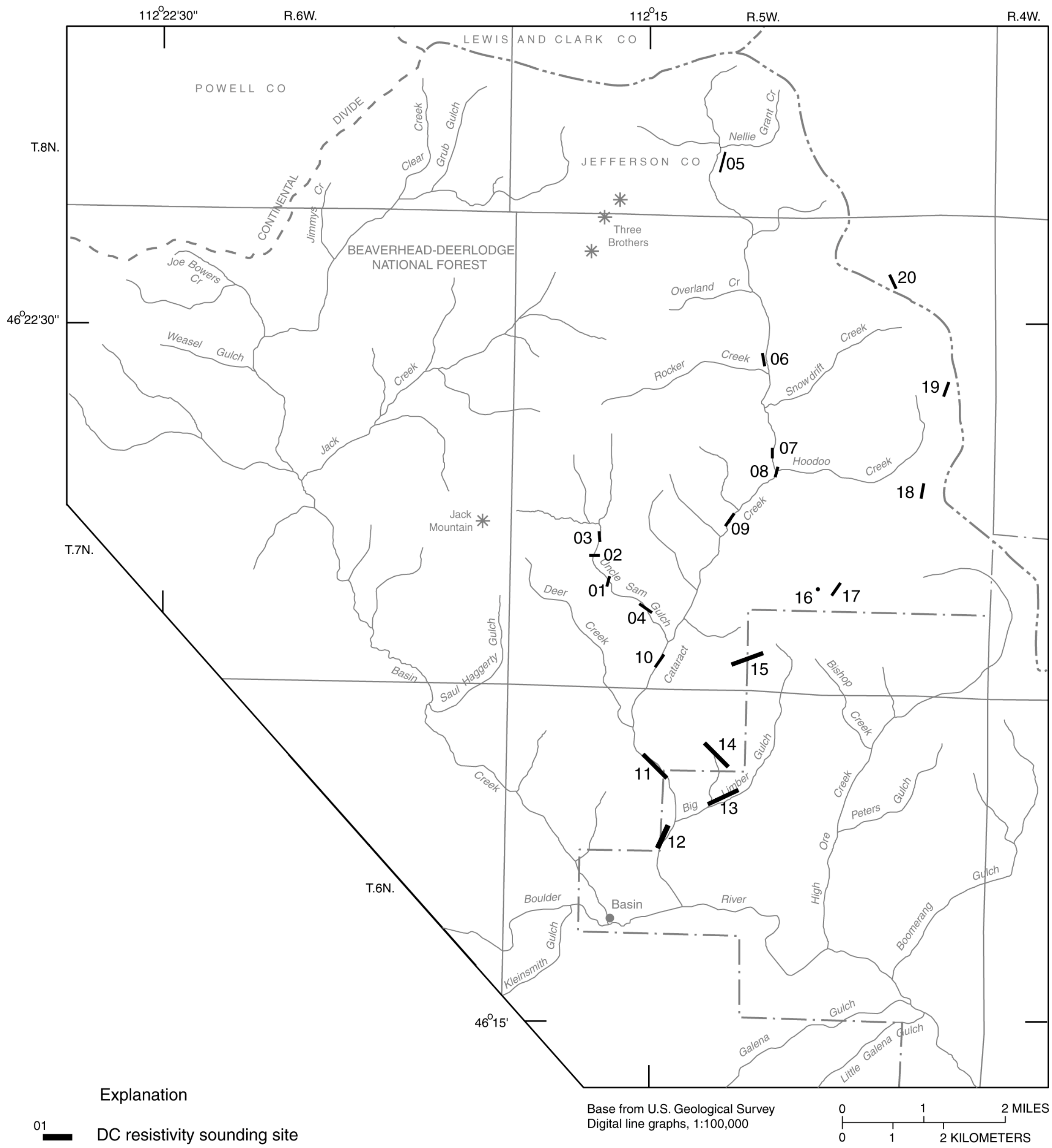

Figure 3. DC resistivity sounding locations in the Boulder Basin watershed

Table 1. *DC sounding locations in geographic coordinates. The latitude and longitude are referenced to WGS84.*

UTM coordinates are referenced to NAD27, zone 12 (-111 degrees west).

BOULDER BASIN 1997 SCHLUMBERGER SOUNDING LOCATIONS					
SOUNDING NUMBER	**LATITUDE**	**LONGITUDE**	**UTM EASTING (Kilometers)**	**UTM NORTHING (Kilometers)**	**ELEVATION (feet)**
MTAML01	46^0 20.63'	112^0 15.65'	402.977606	5133.023297	7160
MTAML02	46^0 21.045'	112^0 15.977'	402.570517	5133.798517	8000
MTAML03	46^0 21.177'	112^0 15.974'	402.578274	5134.042903	8000
MTAML04	46^0 19.471'	112^0 15.034'	403.733737	5130.864451	6680
MTAML05	46^0 24.19'	112^0 13.70'	405.580819	5139.576690	7160
MTAML06	46^0 22.00'	112^0 13.0'	406.415242	5135.507198	6800
MTAML07	46^0 21.00'	112^0 12.90'	406.515017	5133.653351	6690
MTAML08	46^0 20.70'	112^0 13.2'	406.121747	5133.103704	6480
MTAML09	46^0 19.90'	112^0 14.0'	405.046736	5129.971421	6440
MTAML10	46^0 18.9'	112^0 14.8'	404.017307	5129.802303	6200
MTAML11	46^0 15.0'	112^0 17.8'	400.049610	5122.641875	5920
MTAML12	46^0 17.0'	112^0 13.9'	405.117481	5126.265705	5440
MTAML13	46^0 17.3'	112^0 17.3'	400.761177	5126.890657	5600
MTAML14	46^0 17.9'	112^0 14.1'	404.886669	5127.936372	6120
MTAML15	46^0 19'	112^0 13.4'	405.816622	5129.959483	7160
MTAML16	46^0 19.8'	112^0 12.4'	407.122335	5131.421297	7560
MTAML17	46^0 18.9'	112^0 14.8'	404.017307	5129.802303	7640
MTAML18	46^0 20.7'	112^0 10.8'	409.199702	5133.057057	7240
MTAML19	46^0 22.0'	112^0 10.3'	409.876574	5135.454977	7480
MTAML20	46^0 23.0'	112^0 11.7'	408.109772	5137.333693	7480
MTAML21	46^0 28.7'	112^0 14.6'	404.559172	5147.946786	6150
MTAML22	46^0 27.7'	112^0 14.9'	404.146107	5146.100926	6350
MTAML23	46^0 26.3'	112^0 14.2'	405.001366	5143.494173	6740
MTAML24	46^0 25.5'	112^0 15.0'	403.953707	5142.028761	6780

DISCUSSION

Data collected in the field were entered into the INTERPEX[1] program RESIX-IP™ (version 2.0). Using this program, a “smooth” layered earth model was computed for each sounding. The smooth model is an inversion process which produces a layer and resistivity for each observation point. Details of the program are given in the manual (Interpex, 1993) and additional information can be found on their web site (www.interpex.com). Field data, interpreted smooth model, and plot is given for each sounding in Appendix A.

The apparent resistivities estimated in the airborne electromagnetic survey (Smith and others, 2000) average on the order of low hundreds of ohm-meters through much of the depth range of the measurements. In some areas, deeper estimated resistivities are a few tens of ohm-meters. This is rather surprising considering that the resistivity of fresh volcanic and batholithic rocks such as characteristic of the Boulder Batholith are commonly in the 1,000's of ohm-meters (Telford and others, 1990).

DC resistivity sounding, MTAML01F, was made near the head of the Uncle Sam Gulch drainage (fig. 3) and is shown in Figure 4 as well as in Appendix A. This part of Uncle Sam Gulch has a north - south trending zone of low estimated subsurface resistivity and magnetization from the airborne survey. A drill hole 1 km to the south of this sounding reached a depth of 16.5m (50 feet). McDougal (written communication) describes the upper half of the drill hole as altered with the fresher rocks at the bottom of the hole. However the fresher intrusive rock is fractured with probable low temperature hydrothermal alteration along the fractures. It is not possible to tell with the present data whether the more surficial alteration is weathering or low temperature hydrothermal alteration. At least

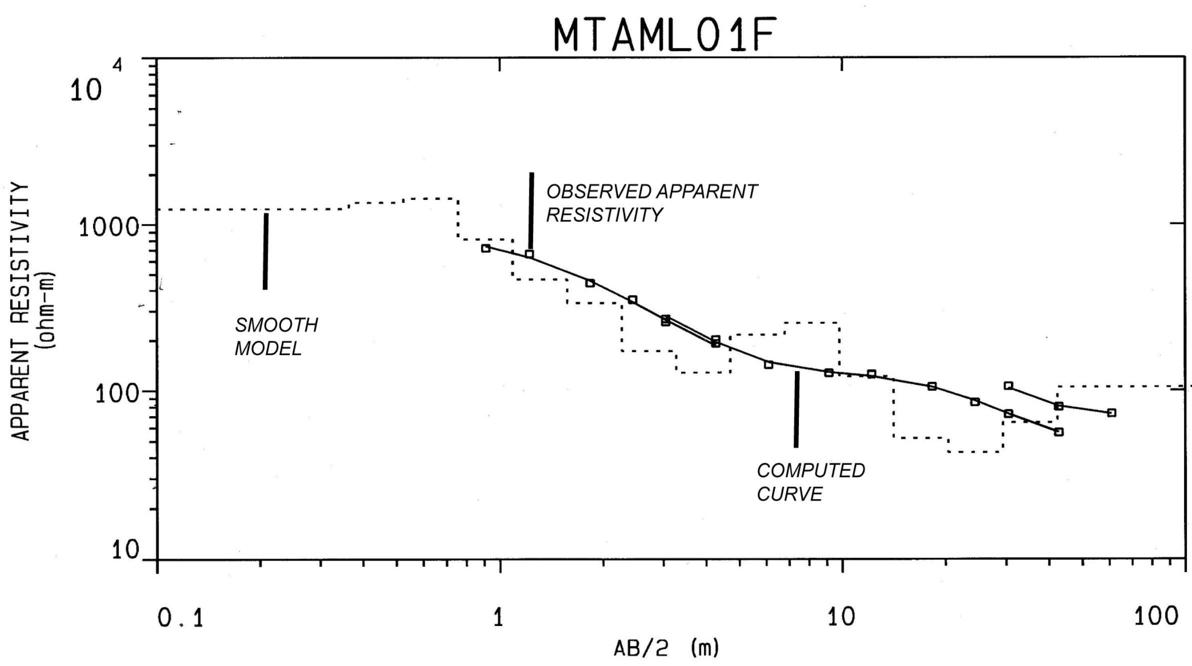

Figure 4 DC resistivity sounding at the head of Uncle Sam Gulch. The x-axis is electrode spacing (AB/2) and depth of smooth model. The y-axis is the measured apparent resistivity and the interpreted smooth layer model resistivity.

in this general area ground truth suggests that batholith rocks are not as resistive as was expected.

In general the lower than expected estimated resistivities from the airborne survey are on the same order of magnitude as ground survey. The implication of this observation is that the volcanic and batholithic rocks, within 60m of the surface, are fractured and altered. A consequence of this hypothesis is that while a large portion of the groundwater flow is in the near surface there is probably also a vertical flow component.

REFERENCES

Becraft, G.E., Pinckney, D.M., and Rosenblum, S., 1963, Geology and mineral deposits of the Jefferson City quadrangle, Jefferson and Lewis and Clark Counties, Montana: U.S. Geological Survey Professional Paper 428, 101 p.

INTERPEX, 1993, RESIX-IP v 2.0 Users Manual, Interpex Limited, Golden Colorado, 150p.

O'Niell, J.M., Lund, K., Van Gosen, B.S., Desborough, G., DeWitt, E., and Sole, T., 2000, Geologic framework of the Boulder abandoned mine lands study area, Powell, Jefferson, and Lewis and Clark Counties, Montana, Open-file-report, ofr-00-????,(in review) 62p.

Ruppel, E.T., 1963, Geology of the Basin quadrangle, Jefferson, Lewis and Clark, and Powell Counties, Montana: U.S. Geological Survey Bulletin 1151, 121 p.

Smith, B. D., McCafferty, A. E., and McDougal, R. R., 2000, Utilization of Airborne Magnetic, Electromagnetic, and Radiometric Data in Abandoned Mine Land Investigations, in, Proceedings of ICARD 2000, Society of Mining Engineers meeting, Denver, CO., 8p.

Telford, W. M., L. P. Geldart, and R. E. Sheriff, 1990, Applied Geophysics, 2nd ed., Cambridge University Press, 875p.

Zohdy, A. A. R., Eaton, G.P., and Mabey, D.R., 1974, Application of surface geophysics to ground water investigations: Techniques of water-resources investigations of the United States Geological Survey, Book 2, Chapter D1, 116p.