U.S. DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

FIELD AND PHOTOGRAMMETRIC METHODS FOR MAPPING NUCLEAR INDUCED SURFACE EFFECTS AT THE NEVADA TEST SITE, NYE COUNTY NEVADA

By

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SECTION I

1.1 ACKNOWLEDGMENTS

This paper documents surface effects mapping procedures established by the U.S. Geological Survey in 1965 and adopted by the Los Alamos and Lawrence Livermore National Laboratories. These procedures have stayed relatively consistent throughout the years but the accuracy of documenting the surface effects has been improved by advancements in photography and photogrammetric methods. Surface effects mapping itself is a time consuming and tedious task, but one that has been completed with considerable attention to detail. Surface effects documentation was pioneered by F.A. McKeown and F.N. Houser in the early 1960's. Many other USGS geologists have been involved in the process including F.M. Byers Jr., H.R. Covington, D.D. Dickey, G.L. Dixon, M.N. Garcia, E.C. Jenkins, Florian Maldonado, P.P. Orkild, T.L. Prather, R.P. Snyder, R.R. Spengler, and Susan Steele Wier. Geologists from the National Laboratories have included Brian Allen, Anne Cavazos, Sigmund Drellack, Jose Gonzales, Ward Hawkins, Richard McArthur, Lawrence McKague, William McKinnis, Lance Prothro, William Davies, Casey Schmidt, and Margaret Townsend. Their combined mapping efforts and reports have documented surface effects at the Nevada Test Site for the past 40 plus years.

1.2 INTRODUCTION

Underground nuclear testing began at the Nevada Test Site (NTS) in 1951 with the detonation of the UNCLE event. Since that time over 827 more tests have been conducted underground (DOE, 1994). From 1951 to 1992 the tests were concentrated in three major testing areas, Yucca Flat, Pahute Mesa, and Rainier Mesa (fig 1.). Detailed descriptions of the test areas can be found in Allen and others, 1997. DIVIDER was the last underground nuclear event detonated at the NTS in 1992. Later that year, President William J. Clinton signed a moratorium on U.S. nuclear testing banning testing in the United States. The multilateral Comprehensive Test Ban Treaty signed between the United States, Britain, France, and Russia that banned nuclear testing by these countries followed the moratorium in 1996.

The U.S. Geological Survey became involved with the testing program at the NTS in 1957 as part of an aggressive effort to map the geology of the entire NTS at 1:24,000 scale. The mapping effort not only provided the first detailed geologic maps of the area; it also provided scientists with the opportunity to experiment with the geology at the NTS to see if the geologic environment influenced the containment of the nuclear tests. The early days of testing, documented in Carothers and others, 1995, discusses how the geologic environment became a testing parameter for nuclear testing. Events were sited near faults and at the boundary of geologic units to test various containment scenarios. These early experiments demonstrated that geology and hydrology played a critical role in siting and understanding the geologic nature of the Test Site. The USGS, supported by the Atomic Energy Commission and the Department of Energy began an extensive program of applied and basic research to evaluate the geophysical, hydrologic, and geologic environment of the NTS. Part of these studies focused on the surface effects formed following detonation of a nuclear test.

Surface effects can be grouped into three main categories: Geologic and hydrologic effects, Ecological effects, and Cultural-feature effects (Allen and others, 1997). This paper deals largely with geological effects, i.e. collapse sinks, surface cracks, fractures, faults, block chatter, spall, and pressure ridges. Detailed descriptions of these effects can be found in Allen and others, 1997. Surface effects mapping was initiated by the USGS in 1959 and continued by the testing organizations Los Alamos and Lawrence Livermore National Laboratories and the Defense Nuclear Agency (now the Defense Special Weapons Agency, DSWA), in 1977, 1980, and 1982, respectively. Throughout its history, surface effects mapping has been accomplished with varying degrees of quality. To standardize mapping techniques the USGS conducted a pilot program in 1982 to determine if the Kern PG-2 photogrammetric stereo plotter (Pillmore, 1979), utilizing precision optics, electronic instrumentation, and post-test photography could supplement field mapping. The pilot program (Van de Werken, 1983) recognized that surface effects mapping could be completed with a greater degree of accuracy photogrammetrically, but recognized the continued need for field mapping as a way of providing visual descriptions of the surface effects that photography could not. Additionally, the pilot program recognized that mapping surface effects on the plotter permitted access into areas off limits to field geologists because of safety concerns. The results of the pilot program produced a joint mapping program between the testing organizations conducting field mapping studies and the USGS conducting photogrammetric studies. Although subsurface nuclear testing is no longer conducted at the NTS, this manual has been written to provide written documentation of past procedures and to support ongoing readiness efforts by the Nevada Operations Office of the Department of Energy.

SECTION 2
FIELD MAPPING PROCEDURES

2.1 Time Frame in which events are mapped

Surface effects are mapped as soon as entry into the area is permitted allowing or weather and operational considerations. Early mobilization prevents obliteration of fractures from construction and weather.

2.2 Feature to be mapped

For completeness, all surface effects produced by the event should be mapped. The formation of geologic surface effects is dependent upon many factors including the lithology of the surface material, the yield of the event, and the depth of burial (DOB) of the device. Accordingly, a smaller yield event detonated in alluvium will produce fewer surface effects than a larger yield event in the same medium and at the same DOB. Quite often, the extent of fracturing produced by larger yield events makes it logistically difficult to map all surface effects data (Fig. 2).

2.3 Materials used in the field

Pre-test photographs as opposed to post-test photos are used to mapped surface effects in the field. Commonly, processing time for post-test photographs is 2 weeks, if surface effects mapping is delayed until post-test photography becomes available some of the effects may become obliterated by weather or construction. The USGS maintains pre- and post-test photography for all tests at the Data Center and Core Library in Mercury, Nevada. Requests regarding NTS test-related photography should be directed to the Core Library Manager, P.O. Box 327, Mercury, NV. 89023. Additionally, information on availability of pre- and post-test photography can be viewed over the Internet at

<http://wwwnv.wr.usgs.gov>.

NTS pre- and post-test aerial photographs are vertically flown at scales ranging from 1:2,400 to 1:6,000 feet. Each set typically consists of 9 photographs divided into 3 flight lines (figure 3). Due to the extent of surface effects, some photo sets of Pahute Mesa have 15 photographs (figure 3). There is about 60% overlap of photographs on the same flight line and 30% side overlap to adjacent flight lines. The overlap creates a three-dimensional or stereo image of the ground. In theory, a precisely vertical photograph is as accurate in scale and direction as the best map. Unfortunately, the scales of most aerial photographs are slightly distorted due to uneven ground surfaces and a slight amount of camera tilt introduced when the photographs were taken. The amount of distortion varies and is relatively negligible for our purposes. For a more detailed explanation on the effects of tilt and distortion, see Compton, 1962 and Ray, 1960.

To minimize distortion, field geologists should mark surface effects on photographs maximizing use of the stereo image. When pre-test coverage is inadequate, field geologists can obtain stereo coverage by using pre- and post-test coverage from recent nearby events or by using 1:6,000 feet extended coverage photography for Yucca Flat and Pahute Mesa. As a last resort, the surface effects can be mapped directly onto a USGS topographic or geologic quadrangle map. To assure accuracy, a scale of 1:12,000 feet or larger is recommended. For information on obtaining USGS publications see Appendix A.

The photographs should be carried into the field in a map folder large enough to adequately protect them. It is advisable to carry a pocket stereoscope into the field. Only fine-tipped writing instruments should be used to mark the photographs. Field geologists need to keep in mind that surface effects mapped on the photo will be compiled photogrammetrically. To aid the photogrammetric process, care should be taken to concentrate marking surface effects on the central flight line first, moving to adjacent flight lines as needed. Suggested symbols and colors for the features are shown in Table 1.

2.4 Radius of the field mapped area

The radius of the mapped area is a function of the event size, predicted ground motion, spall radius, and sink formation. In order to assure that all features have been documented, a grid needs to be walked around the site, beginning as close as possible to ground zero and extended outward until no more surface effects are detected. Additionally, the field geologist needs to check to see if nearby faults and surface effects from nearby events have been reactivated. A detailed field report is then compiled containing:

- The date(s) field mapping was completed
- Members of the field party
- The extent of fracturing
- Observation of new surface faults
- Approximation of sink size and any sink abnormalities (i.e. offset sink)
- Reactivation of known faults and fractures in the vicinity and to what extent
- Fracture abnormalities

SECTION 3
PHOTOGRAMMETRIC MAPPING PROCEDURES

The Kern PG-2 plotter was designed for topographic mapping (Pillmore, 1979). The plotter (Fig. 4) has been used to map surface effects because it is capable of creating a nearly distortion free stereoscopic model of the ground from which data can be transferred to a base map. Aerial photographs are mounted on two plates that can be moved and rotated so that the photographs effectively capture the orientation of the camera in the airplane at the time of exposure. The photography is observed orthogonally, such that projecting lines are perpendicular to the plane of projection. A geologist can easily view the photographs three-dimensionally and magnify portions of the photographs as needed. Data is transferred from the photographs onto a stable map base by way of a polar pantographic arm that follows the movement of the geologist as the stereoscopic image is viewed. The PG-2 plotters are maintained within the USGS Photogrammetic Plotter Laboratory in Denver, Colorado. For information on the availability of the laboratory and associated costs write to:

U.S. Geological Survey
National Cooperative Geologic Mapping Team
P.O. Box 25046, MS 913
Denver, CO. 80225
Attn: Chief Scientist

3.1 Time frame in which events are mapped

Surface effects are mapped when field mapping is received from the field geologists and post-test photography is received.

3.2 Features to be mapped

All surface effects are mapped.

3.3 Materials used for mapping on aerial photographs

To take advantage of the plotter's high-quality viewing and illumination systems post-test photo transparencies should be used whenever possible as transparencies provide a higher resolution of ground features. If transparencies are unavailable, paper prints are used. Typically, post-test photography is flown at 1:4,800 feet. This scale is large enough to provide adequate control points when orienting the photographs on the PG-2 plotter and small enough that surface effects are easily seen. Photo scales smaller than 1:6,000 can be used but are not recommended because it is difficult to ascertain new from reactivated fractures and natural from unnatural features.

3.4 Alternatives when photo coverage is insufficient

In some cases, surface effects may extend beyond stereoscopic coverage. When this occurs, surface effects need to be traced onto photography from adjacent sites, remounted onto the PG-2, and transferred onto the map generated using the post-test photography. If stereoscopic coverage cannot be found at scales larger than 1:6,000, smaller scaled photos can be used. Keep in mind that error is introduced when data is transferred.

SECTION 4

4.1 Methods for data compilation and reduction

A minimum of three control points is needed to properly orient the surface effects data onto a stable base map. Recommended control points include nearby expended sites, exploratory drill holes, and post-shot drill holes. Coordinates for these drill holes are available through the Drilling and Mining Summary (Fenix and Scisson, 1989). Additionally, surveyed crosses located due north, south, east, and west of surface ground zero (SGZ) may exist for some sites and make reasonable control points. Bechtel Nevada maintains the surveyed distances of the crosses. If drill holes and surveyed crosses are unavailable, road intersections, SGZ of nearby sites, drainage identified on topographic maps, and/or other prominent visual features can be used but introduce scaling error.

4.2– Reduction of data

Once field data and post-test photography are received, reduction of the data begins. A stereo pair of field marked photographs or a model is mounted onto a PG-2 Plotter and surface effects transferred onto a stable scale base with gray lead. Other cultural features are added in various colors including control points (orange), roads (green), drainage (blue), and other prominent visual features (orange). Once mapping on the model is completed, new control points are established to properly scale and orient the next model and mapping continues. The process continues until all field data has been transferred onto a base map.

Post-test photography is then mounted onto the PG-2 plotter. A meticulous grid is constructed that covers the entire photograph. All surface effects are mapped and questionable features are noted. If possible, control points are identical to those used to transfer field data. The preliminary map combines field and photogrammetric data and includes a title, north arrow, scale and is dated. The field geologist makes a final check of the data, appropriate changes are made and a final map is compiled. Surface effects data files are maintained by the U.S. Geological Survey in Denver, Colorado.

5.1 REFERENCES

Allen, B.M., Drellack, S.L., Jr., Townsend, M.J., 1997, Surface Effects of Underground Nuclear Explosions: U.S. Department of Energy Report DOE/NV/11718-122, 147 p.

Carothers, J.E., 1995, Caging the Dragon - The containment of underground explosions: U.S. Department of Energy Report DOE/NV/11718-388, 726 p.

Compton, R.R., 1962, Manual of field geology: John Wiley and Sons, New York, New York, 378 p.

Drellack, S.L., Jr., 1988, Fenix and Scisson Field Mapping Procedures, Fenix and Scisson Memo GEO-0451.

Fenix and Scisson, 1989, NTS Drilling and Mining Summary, Prepared under contract for the Department of Energy, DE-AC08-76NV00038, For official use only.

Houser, F.N., 1970, A summary of information and ideas regarding sinks and collapse, Nevada Test Site: U.S. Geological Survey report USGS-474-41, 30 p.; Available only from U.S. Department of Commerce, National Technical Information Service, Springfield, Virginia, 22161.

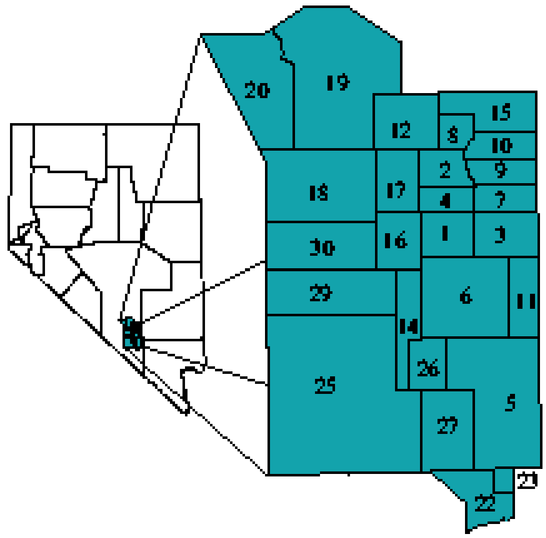
Pillmore, 1979, The history and function of the U.S. Geological Survey photogrammetric laboratory for geologic studies: American Society of Photogrammetry 45th Annual Meeting, March 1979, Proceedings, p. 465-468

Ray, R.G., 1960, Aerial photographs in geologic interpretation and mapping: U.S. Geological Survey Professional Paper 373, 230 p.

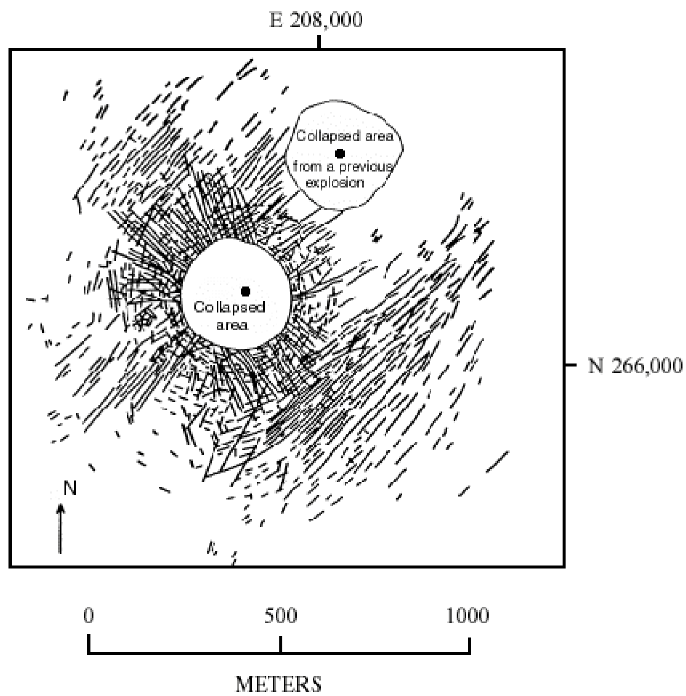
U. S. Department of Energy, 1994, United States Nuclear Tests, July 1945 through September 1992, DOE/NV, Revision 14; Available only from U.S. Department of Commerce, National Technical Information Service, Springfield, Virginia, 22161.

Van de Werken, M.G., 1983, The PG-2 photogrammetric plotter—A rapid and accurate means of mapping surface effects produced by subsurface nuclear testing at the Nevada Test Site, Nevada in Proceedings of the second symposium on Containment of Underground Nuclear Explosions, v.1: Lawrence Livermore National Laboratory Report CONF-830882, p. 393-410.

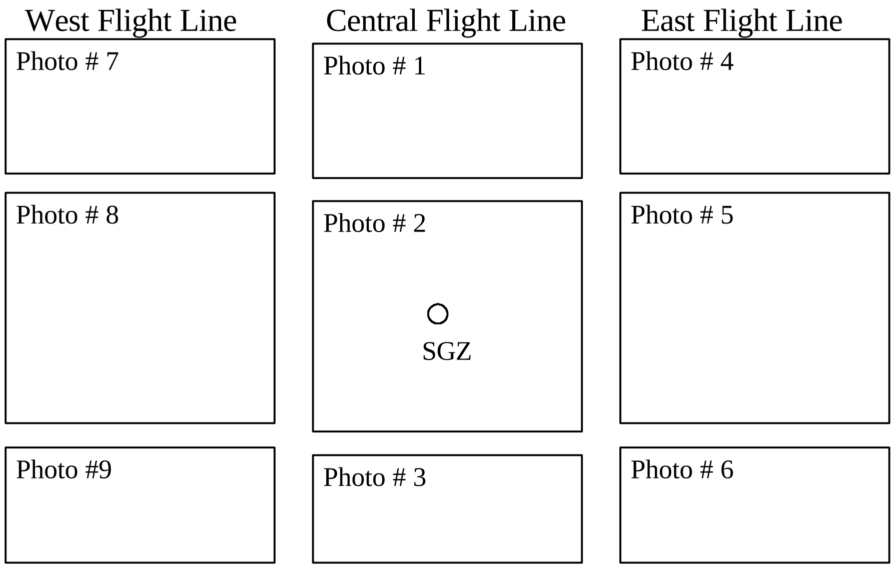
5.2 -- Figure 1. - - Main underground nuclear testing areas at the Nevada Test Site.

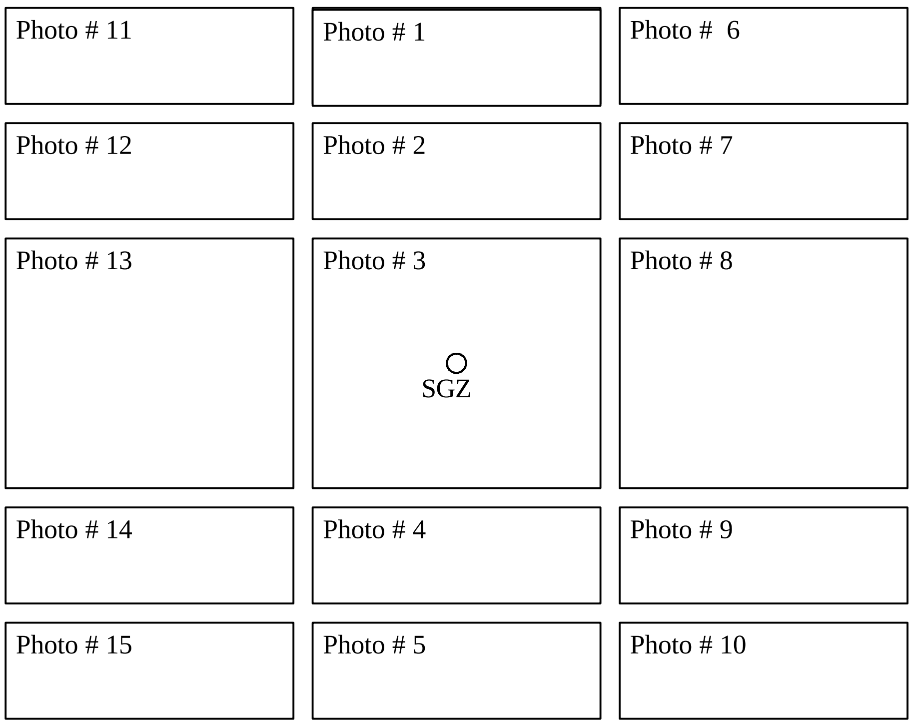


5.2 -- Figure 2. - - Surface effects produced above an underground nuclear explosion, Yucca Flat, Nevada. Mapped by T.L. Prather, USGS.



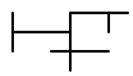
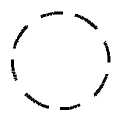
5.2 -- Figure 3. -- Layout of NTS pre- and post-test photography with 9 and 15 photographs (SGZ = Surface Ground Zero).





5.2 -- Figure 4. - - The Kern PG-2 Photogrammetric Plotter.

5.3 -- Table 1. Suggested Surface Effects Mapping Symbology

Feature	Symbol	Color
Fractures		black
Reactivated fractures		blue
Hairline fractures		red
Fractures with vertical displacement, ball and bar are on the downthrown side, displacement is in centimeters		black
Pressure Ridge		black
Block Chatter		blue
Sink		black
Spall	S	red
Perimeter and trailer park fence		green
Flags directing others to extended notes in an accompanying memo	A,B,C	green

5.4 -- GLOSSARY

This glossary contains definitions of common features observed at the Nevada Test Site. These definitions are from a variety of sources including Houser, 1970; Drellack, 1988; Allen and others, 1997; and Garcia, Drellack, and McKinnis, unpublished data.

Block Chatter: Small-scale movement of blocks from pre-existing joint systems I response to explosion-induced stresses. The results of these movements may be mosaics of cracks in brittle surface materials or dust trails in snow that match the underlying joint patterns. The term is often used to describe features that appear to be caused by this mechanism without real knowledge of the operating mechanism.

Concentric Fracture: Parting of the ground surface in a circular orientation around the surface ground zero of an underground explosion.

Fracture: A break in the ground surface material due to mechanical failure by stress. Fractures tend to have limited vertical extent below the surface.

Hairline fracture: A fracture with an aperture of less than 3 mm. Hairline fractures tend to form on prepared surfaces.

Linear fracture: A series of discontinuous, en echelon, parallel, or sub-parallel fractures in a line that form a trend.

Pressure Ridge: A compressional feature in which a narrow ridge is raised above the surrounding surface; typically straight to slightly curved or locally sinuous.

Radial fracture: Surface fractures oriented in a “spoke-like” pattern around surface ground zero.

Reactivated fracture: A pre-existing fracture on which failure recurs during ground motion from a subsequent event.

Sink: The topographic depression formed as a result of surface subsidence. Also known informally at the Nevada Test Site as craters.

Slump: The down sloe sliding of a mass of material.

Spall: The movement of rocks previously dislodged by joints from a cliff or wall.

Surface effects: A stress-induced feature formed following the detonation of a subsurface nuclear test.

5.5 -- SOURCES OF INFORMATION

Purchasing USGS publications

- **Anchorage, AK.**
  Anchorage-ESIC
  U.S. Geological Survey
  4230 University Drive, Rm. 101
  Anchorage, AK 99508-4664
  Toll Free Number: 1-800-USA-MAPS (from Alaska only)
  Telephone: (907) 786-7011
  FAX: (907) 786-7050
  Email: gfdurocher@usgs.gov

- **Denver, CO.**
  Denver-ESIC
  U.S. Geological Survey
  Box 25286, Building 810
  Denver Federal Center
  Denver, CO 80225
  Telephone: (303) 202-4200
  FAX: (303) 202-4188
  Email: infoservices@usgs.gov

  USGS Information Services (Map and Book Sales)
  Box 25286
  Denver Federal Center
  Denver, CO 80225
  Telephone: (303) 202-4700 or 1-800-HELP-MAP
  Fax: (303) 202-4693

  USGS Information Services (Open-File Report Sales)
  BOX 25286
  Denver Federal Center
  Denver, CO 80225
  Telephone: (303) 202-4200
  Fax: (303) 202-4695

- **Menlo Park, CA.**
  Menlo Park-ESIC
  U.S. Geological Survey
  Building 3, MS 532, Rm. 3128
  345 Middlefield Road
  Menlo Park, Ca 94025-3591
  Telephone: (650) 329-4309

FAX: (650) 329-5130
TDD: (650) 329-5092
Email: esic_west@usgs.gov

- **Reston, VA.**
  Reston-ESIC
  U.S. Geological Survey
  507 National Center
  Reston, VA 20192
  Toll Free Number: 1-800-USA-MAPS
  Telephone: (703) 648-6045
  FAX: (703) 648-5548
  TDD: (703) 648-4119
  Email: esicmail@usgs.gov

- **Rolla, MO.**
  Rolla-ESIC
  U.S. Geological Survey
  1400 Independence Road, MS 231
  Rolla, MO 65401-2602
  Telephone: (573) 308-3500
  FAX: (573) 308-3615
  Email: mcmcesic@usgs.gov

- **Salt Lake City, UT.**
  Salt Lake-ESIC
  U.S. Geological Survey
  2222 W 2300 S, 2nd Floor
  Salt Lake City, UT 84119
  Telephone: (801) 975-3742
  FAX: (801) 975-3740
  TDD: (801) 975-3744
  Email: slcesic@rmmc1.cr.usgs.gov

- **Sioux Falls, SD.**
  Sioux Falls-ESIC
  U.S. Geological Survey
  EROS Data Center
  Sioux Falls, SD 57198-0001
  Telephone: (605) 594-6151
  FAX: (605) 594-6589
  TDD: (605) 594-6933
  Email: custserv@edcmail.cr.usgs.gov

- **Spokane, WA.**
  Spokane-ESIC
  U.S. Geological Survey
  U.S. Post Office Building, Rm. 135
  904 West Riverside Avenue
  Spokane, WA 99201
  Telephone: (509) 353-2524
  FAX: (509) 353-2872
  TDD: (509) 353-3235
  Email: esnfic@mailmcan1.wr.usgs.gov

- **Washington, D.C.**
  Washington DC-ESIC
  U.S. Geological Survey
  U.S. Department of the Interior
  1849 C Street, NW, Rm. 2650
  Washington, D.C. 20240
  Telephone: (202) 208-4047
  Email: esicmail@usgs.gov