V. CASE STUDIES

The following summary covers a short-list of underground tests to illustrate some of the environments where test experience is documented and locations where follow-up studies have highlighted visual effects. While information on U.S. tests is emphasized in this present report and that done by Bechtel Nevada staff (Allen et al., 1997), an extensive literature research will be required to uncover experience at foreign localities. Future work should include a comprehensive review of testing experience with respect to geological, cultural, and floral/faunal effects, including characterization techniques.

1. Nevada Test Site

Underground testing at the NTS (U.S. Department of Energy, 1994b) has involved 828 nuclear explosions, dating from 1951, in 3 major areas: (1) Yucca Flat, (2) Pahute Mesa, and (3) Rainier Mesa. From the late 1950s until 1977, the U.S. Geological Survey documented surface effects of many underground tests, compiling composite surface effects maps for these different NTS areas. In addition to efforts by the U.S. Geological Survey, since 1977 responsibility for surface effects mapping has included the individual testing organizations.

A. Yucca Flat. Yucca Flat has been a principal site for underground nuclear tests. An intermontane basin and piedmont area, this area is underlain by alluvium reaching a thickness in excess of 600 m in the south-central part of the basin. Below the alluvium are Tertiary tuffs (~600 m thick), which rest on basement rock of Devonian to Cambrian carbonate rocks containing aquifers.

The surface of Yucca Flat is pockmarked by numerous collapse sinks ranging from 3 to 244 m in radius and 0.6 to 61 m in depth (Houser, 1970). Not all of the sinks are centered at SGZ, but most are well defined with a circular to elliptical shape, and for those tests conducted in the volcanic bedrock, sinks may be elongated.

Underground nuclear tests produce notable fractures in the overlying alluvium in radial and concentric patterns around test SGZ (Figure 3), but many of these fractures rarely extend to a depth beyond 30 m; most are usually widest at the surface and narrow with depth (Carr, 1965). Other fractures commonly align along preferential trends spatially related to the Yucca fault system or parallel bedrock joint patterns in bedrock adjacent to the valley, especially if the tests have been conducted in the bedrock below the alluvium (Barosh, 1968). These fractures in the soft Yucca Flat alluvium tend to fill with sediment relatively quickly. Where faults occur in Yucca Flat, they are subject to displacements up to 0.5

m by nearby underground tests within scaled distances of 150 to 300 m/kt$^{1/3}$ (Dickey, 1968). In these areas, fractures generally parallel the fault.

B. Pahute Mesa. Events in Pahute Mesa show surface effects generally including movement and extensions along previously known faults, movement on previously unknown faults, often ill-defined, generally asymmetric (with respect to SGZ) sinks, noticeably present radial and concentric fracture patterns, generally widespread cliff spall, and numerous and lengthy pressure ridges (Snyder, 1971; Maldonado, 1977). The high-yield (1.3 Mt) Boxcar event induced 1 m of horizontal and 0.1 m of vertical movement on a fault along which fractures were mapped for more than 6000 m from SGZ.

C. Rainier Mesa. Diamond Sculls was a low-yield (<20 kt) event detonated 424 m under Rainier Mesa in tunnel U-12t.02 in 1972. Surface effects mapping on aerial photographs at a scale of 1:4800 showed bedrock fracturing in areas where previous faults had been mapped (Snyder, 1972). Although no definite sink was apparent, fracture patterns north of SGZ might have indicated an incipient collapse structure. The event caused development of five major sets of fractures extending up to several hundred meters long with displacements of up to 0.3 m. Most of these fractures occurred within 500 m of SGZ.

D. Others. Other localities at the NTS that require more study with regards to surface effects are (1) Frenchman Flat, (2) Mine Mountain, (3) Buckboard Mesa, and (4) Climax mine.

2. Off-Site

A. Alaska (Amchitka Island). Long Shot, an 80-kt nuclear test detonated in October 1965 at a depth of 700 m on Amchitka Island, provided an experiment to record seismic wave arrivals and document the surface geologic, hydrologic, and tectonic (structural) effects of the explosion (McKeown et al.,1967). Extensive pre-shot documentation of existing geologic and hydrologic conditions characterized the site as a mildly undulating, swampy tableland, underlain to a depth of about 6 m by peat and to about 1200 m by the Banjo Point Formation of volcanic breccias and sediments. The site is bounded to the northwest and southeast by two major parallel normal faults, striking northeast and part of a larger tectonic framework of northeast-striking faults. The bedrock is saturated, and surface streams connect numerous small ponds and lakes.

The shot produced many surface effects, including ground cracks, movement of loose manmade/natural objects, rockfalls, slumping, building damage, and hydrologic effects, including mud geysers and tilting of ponds. Road cracks and movement of various materials extended to 2300 m south and 1130 m north of SGZ. The surface effects were sporadically distributed, and the most common ones were ground cracks, ranging from hairline to a few centimeters in width and a few centimeters to over 100 m in length up to 4000 m from SGZ, as discovered by the on-site inspection team. Occurring in relatively loose, unconsolidated ground, cracks generally formed a bread-crust-like pattern, but surface turf and peat concealed more than 90% of the ground within the fractured zone. Major ground cracks were parallel with the tectonic fabric, striking northeast, and showed as much as 15 cm of vertical displacement. Associated with these major ground cracks were pressure ridges, thought to have been produced by explosion-induced movement along the fault to the north of SGZ. Ground compaction and mud cracking was fairly conspicuous and produced up to 15 cm of settling around manmade structures. Rockfalls occurred within 1700 m of SGZ along the sea cliffs. Minor surface effects included slumping of the sides of trenches and banks of ponds as well as the movement of boulders and other objects for a distance of up to 30 cm over the turf in a direction generally away from SGZ. Hydrologic effects were also visible and included mud geysers, which coated grasses with mud near small bodies of surface water, and changes of pond and lake water levels.

Milrow (1 Mt), conducted on Amchitka in October 1969, was a much larger underground nuclear test than Long Shot. Detonated in lavas and breccias at a depth of 1218 m about 3 km south of Long Shot, visible geologic effects were few and of limited extent (U.S. Geological Survey, 1970). The visible effects were similar to those of Long Shot and included rockfalls, turf falls, slumping, cracking, and soil disturbances. The surface displacements were few and small (compared to those documented at the NTS), which is thought to be a result of the underlying peat formation, which flexed rather than broke in response to the explosion. Although several known faults existed near SGZ, there was no surface indication of induced cracking or displacement along them. The most obvious surface effects of Milrow were numerous rockfalls along the sea coast, several kilometers away from SGZ. Slumps, formed in areas of unconsolidated sand and gravel, especially on steep slopes near borrow pits, road beds, a runway (7 km from SGZ), and a lake, produced large, open, arcuate cracks up to 1.5 m deep. Soil disturbance included displacement of rocks within 2.5 km of SGZ and turf disruption, noted by randomly oriented cracks as much as 15 cm wide and 60 m long within 700 m of SGZ. About 36 hours after the test, chimney collapse formed a depression over SGZ 540 m wide and up to 6 m deep.

Cannikin event (< 5 Mt) surface effects have also been investigated (U.S. Geological Survey, 1972, 1974).

B. Colorado. Rulison was tested 70 km north of Grand Junction in 1969 at a depth of 2570 m in sandstone and shale. Designed to stimulate natural gas production, this 40-kt explosion increased the wellhead pressure by a factor of six for several months. A similar gas stimulation test (Rio Blanco) was conducted in 1973 at Rifle, Colorado, involving simultaneous firing of three 33-kt devices in a shaft.

C. New Mexico. Gasbuggy was conducted near Farmington, New Mexico, in 1967 to test the effectiveness of nuclear explosion for large-scale natural gas stimulation. Fired at a depth of 1300 m below the surface in sandstone, this 29-kt explosion produced no documented seismic damage. Gnome (3 kt) was fired in salt near Carlsbad, New Mexico, in 1961. It formed a cavity ~50 m in diameter and ~21 m high.

D. Mississippi. Salmon (5.3 kt) and Sterling (0.38 kt) were conducted near Hattiesburg, Mississippi, in 1966. Emplaced in a salt dome, Salmon was fired to make a cavity to test Sterling.

3. Foreign Test Sites

A. Russia. Reviewed by Adushkin and Spivak (1994), Russian nuclear tests have been conducted in two major areas. The Semipalatinsk Test Site was founded in 1948 with the first nuclear explosion tested in 1949 and the last in 1989. Of the 467 nuclear tests performed there, 345 were underground, the first of these underground experiments conducted in 1961. In the central hummocky, low-mountain topography of Central Kazakhstan, Semipalatinsk geology is dominated by its block structure and a wide range of crustal rock types: the Balapan area is underlain by a hard-rock basement of Paleozoic and Mesozoic age covered by a variable thickness up to 100 m of soft sediments, and the Degelen area is located in a granitic intrusive massif.

Novaya Zemlya, founded in 1954, is the site of 132 nuclear tests (until 1990) of which 45 were underground. The geology of the site is characterized by low epiplatform mountains developed in Upper Cambrian and Silurian sandstones, quartzites, shales, and limestones. Permafrost extends downward from the surface to an average depth of 480 m. Adushkin and Spivak emphasize that the effects of underground nuclear tests are dominated by the preexisting geologic structure, which for these Russian test sites is characterized as "block structure", individual pieces of the earth's crust bounded by tectonic faults and fractures. The spacing and orientation of faults and fractures dictate the size of the blocks. While much of the geologic deformation is transferred along these faults and structures, individual blocks can respond to an explosion in different ways depending on how they "filter" the signal produced by the explosion. As mentioned earlier in this report, the results of surface effects studies of Russian tests have been directed toward predictive capabilities in order to determine the types and degrees of rock damage with distance from the explosion as a function of yield.

B. France. France has tested buried nuclear explosions in granite rock in Algeria and in basalt below a coral reef in the Pacific ocean.

C. China. China's early nuclear tests were atmospheric, but information on any underground testing is not readily available.

VI. NTS VISUAL INSPECTION EXERCISE

In order to evaluate the visual inspection methods that we have outlined in this report, we designed an exercise at the Nevada Test Site. Several historic underground nuclear test locations were visited to conduct the reconnaissance with an initial visual survey, using preliminary photo documentation. The objectives were to (1) use aerial photos and topographic maps to find the likely area where testing occurred; (2) document surface features (cultural, operational artifacts, geologic disturbances, etc.); and (3) analyze the visual data to assess whether enough clues remained to suggest that underground nuclear testing had been conducted and if so, where SGZ was located. We note that this exercise does not include situations where there has been the attempt at concealment by overburial, low yield, decoupling, and/or surface restoration after the test. By establishing a reference basis for obvious surface effects of underground nuclear tests, we will have a foundation upon which to build future methods to address concealed tests. However, for this report, we note that most of the test areas inspected are sufficiently old that natural revegetation and surface modifications have obscured evidence of testing activities to the point where they are not easily distinguished with aerial photos. Eleven candidate underground tests were selected by a third party to represent sites where surface visual features are evident. We chose five sites (Table 5) for the inspection exercise. Only approximate locations were given and our task was first to identify these approximate locations on topographic maps and aerial photos and then plan methods of access by roads or trails. Once in the general area where we suspected the test, we surveyed the area for visual clues of past activities. These clues included ground and vegetation disturbances, operational artifacts, and geologic disturbances.

The following summaries briefly highlight our findings and interpretations, from which we conclude that careful visual inspection can reveal a number of evidence types that indicate the nature of past underground testing activities.

Table 5. Candidate Sites for Visual Inspection Exercise

Hole Name	Event Name	Date of Test	DOB (m)	Announced Yield (kt)	Geologic Setting
U-19az	Houston	11/90	594	20 - 150	Tested in hard rock with little soil cover near mesa edge
U-19ab	Towanda	5/85	661	20 - 150	Tested in welded tuff below a narrow valley
U-3lt	Minero	12/84	244	<20	Center of cluster of tests below sandy alluvium
U-3me	Kinibito	12/85	579	20 - 150	Near major fault
U-2dg	Carpetbag	12/70	662	220	Along major fault in alluvium-filled valley underlain by tuff

1. Houston (U-19az)

The location of this test area was complicated by the fact that it was in an area of previous cultural activity over 1 to 2 km^2, consisting of prepared surfaces and roadways. Inspection of the area quickly showed that a group of security perimeter fences still circled areas of past activities. From aerial photograph inspection, it was determined that Houston was the southernmost fenced area of the group, but accessibility by auto had to be assessed to find a safe means of approach over soft ground. The perimeter fence was still standing and an obvious "strongback" (a steel structure anchored in concrete for supporting heavy downhole weights) indicated the suspension of a large mass. Although no subsidence crater was evident, ground cracking was clearly apparent on the smooth prepared surfaces, which conspicuously lacked the normal vegetation for this area. The cracks were revealed by vegetation (Figure 8), such that linear traces of grass about 15 cm wide formed a crisscross pattern on the surface. This pattern defined traces extending radially away from the perimeter fence as well as concentric about the fence. Upon further inspection, the grass traces formed in linear depressions only a few centimeters wide that had collected enough rainfall to support new vegetation. This crack pattern extended over a roughly circular area more than 200 m wide centered about the strongback. Cracks were also present in the welded tuff bedrock surrounding the prepared surfaces, and these showed evidence of having been formed recently since they were not filled with detritus as one would expect on geologically formed surfaces. Also, some of these cracks in the bedrock showed offset downward towards the strongback

(Figure 9). The surface within the perimeter fence was strewn with dozens of coaxial cables (Figure 10) that extended from the strongback out to the perimeter fence, and a mound of pea gravel typical of stemming material was observed within the fenced area.

The combination of extensively prepared ground, stemming material, surface cracks suggestive of underground subsidence, coaxial cables used for sophisticated monitoring devices, and a strongback typically used to suspend a heavy object are strong indications of an underground explosion. There is no evidence of economic mining in the area, nor did geologic exposures present evidence of minerals. It remains unclear as to whether or not the explosion was nuclear, but it is hard to justify the existence of the numerous cables for anything but a sophisticated test. Follow-up work could use mapped surface features to delineate areas for radionuclide and aftershock monitoring.

Figure 8. U-19az (Houston). View of graded surface showing revegetated surface cracks defining concentric and radial patterns that indicate a central point likely to be SGZ.

Figure 9. Crack in bedrock showing offset downward toward the area of prepared ground and presumably SGZ. Note the 10-cm ruler for scale.

Figure 10. U-19az (Houston). Coaxial cables used for test diagnostics are usual features of nuclear testing.

2. Towanda (U-19ab)

Careful use of topographic maps and aerial photos guided our search up a small valley that showed no signs of any operations other than a poorly defined track. On approach to the test area, our first clue was a graded area in the valley along one side of the track that was unvegetated. Aerial photos showed this area to be of a size necessary for a staging platform. Within several hundred meters of this area, amidst bushes over a meter high, we found a perimeter fence extending across the valley over an area about 200 m wide, and a steel well casing protruding from the ground. Further inspection revealed numerous coaxial cables strewn across the ground and generally leading to a central location within the fenced area. The fenced area was bounded on one side of the valley by low cliffs of bedrock that showed numerous blocks spalled from their face, the blocks showing light-colored unweathered faces in stark contrast to the desert varnish on most bedrock surfaces (Figure 11). Closer inspection of the low cliffs showed open cracks in the bedrock extending radially away from the center of the fenced area (Figure 12). The cracks ranged in width from 4 to 15 cm with exposed lengths of over 10 m. Although much of the bedrock was covered by soil ~0.5 m thick, the cracks were unfilled, empty to a depth approaching 2 m.

The existence of a graded area, a perimeter fence, coaxial cables, and protruding well casing suggests underground operations. But the conspicuous block spall and large rock cracks strongly indicate that large-scale rock movement occurred in this area, rock movement that could only be explained by a recent earthquake or detonation of a very large underground explosion. Because of the proximity to an area showing cultural artifacts not typical of a mining operation, the surface cracking and block spall suggest underground testing of a nuclear device.

Figure 11. Block spall along low cliff near perimeter fence of Towanda. Note the light-colored fracture surfaces (fresh) in contrast to the darker (old) surfaces.

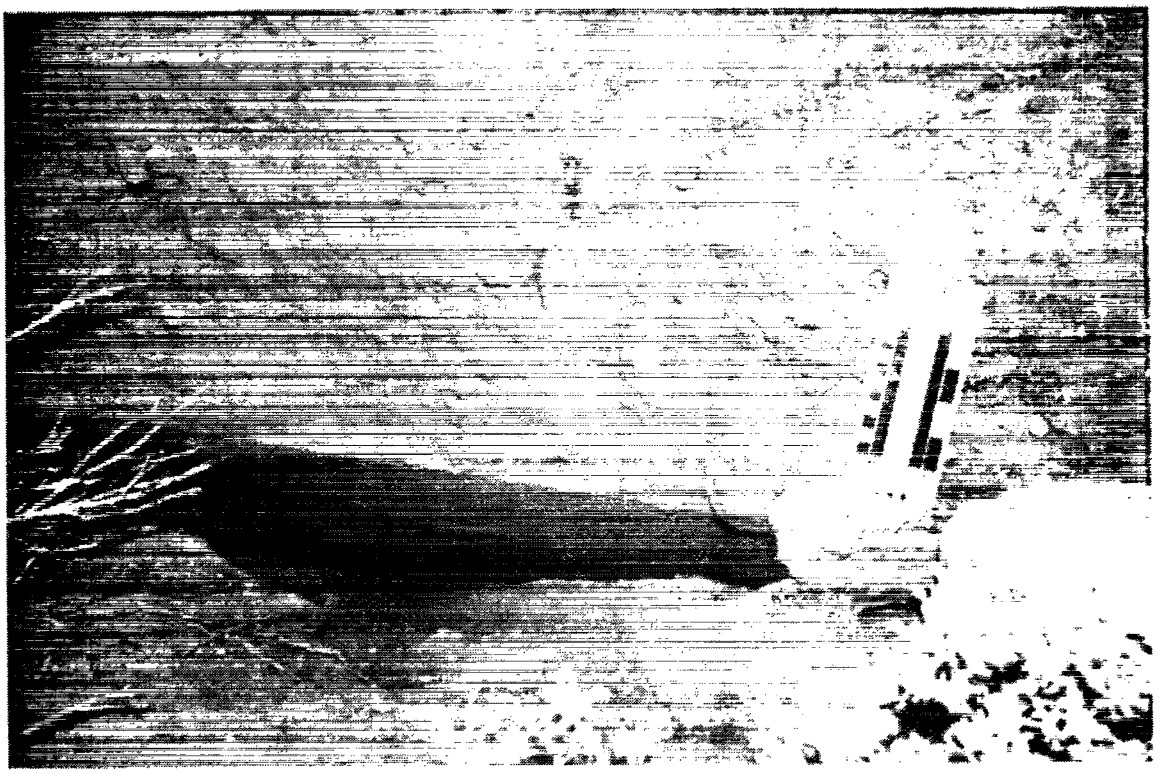

Figure 12. U-19ab (Towanda). Newly opened crack in bedrock covered by a veneer of soil. Such cracks may follow preexisting joint patterns in the bedrock, but to show this much fresh opening, require recent ground motion of large amplitude.

3. Minero (U-3lt)

Located in a wide desert valley, this site was among several possible test locations easily distinguishable on aerial photos. Topographic maps showed numerous access roads crossing the area. The site was marked by a conspicuous subsidence crater ~100 m wide and ~10 m deep (Figure 13). The crater was bounded by a perimeter fence, and numerous cables lay strewn across the area. Many of the cables were of the fiber-optic type (Figure 14). Primarily radial surface cracks were delineated by vegetation along which compass bearings were measured and plotted to pinpoint SGZ.

The large subsidence crater, fiber-optic cables, radial cracking, and stemming material are all typical sorts of geological and cultural effects of nuclear underground testing. For this geologic situation in a desert alluvium-filled valley, where mining activities, maar volcanism, or other crater-forming processes are absent, such a large crater and related cultural features are strongly indicative of nuclear testing.

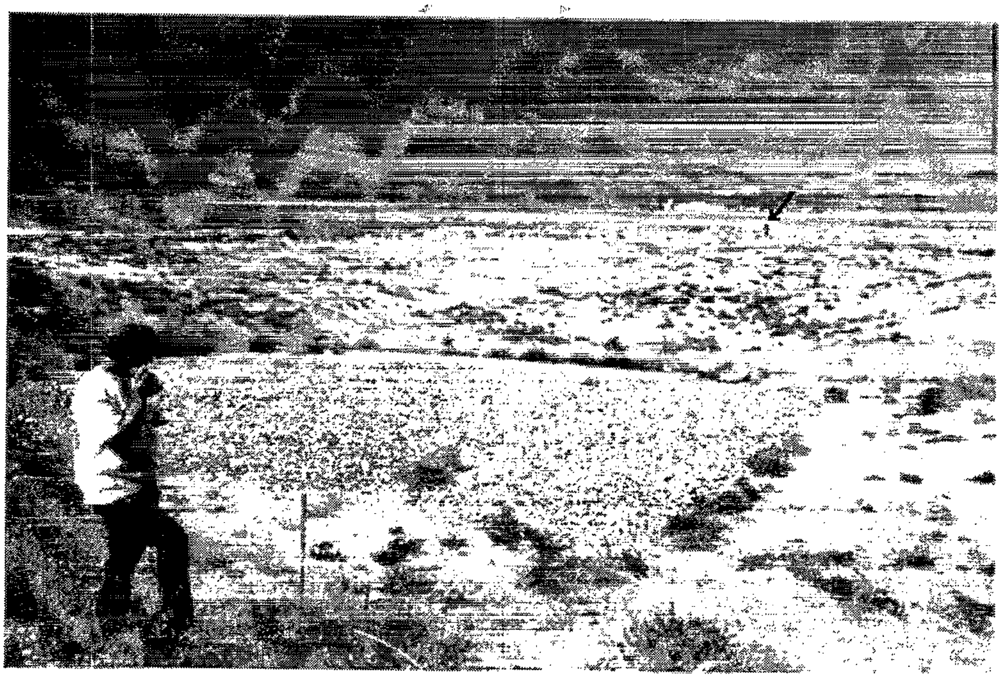

Figure 13. Minero collapse sink showing stemming material and perimeter fence post in foreground. Geologist is using a radio to communicate with teammate at the other side of the sink (arrow).

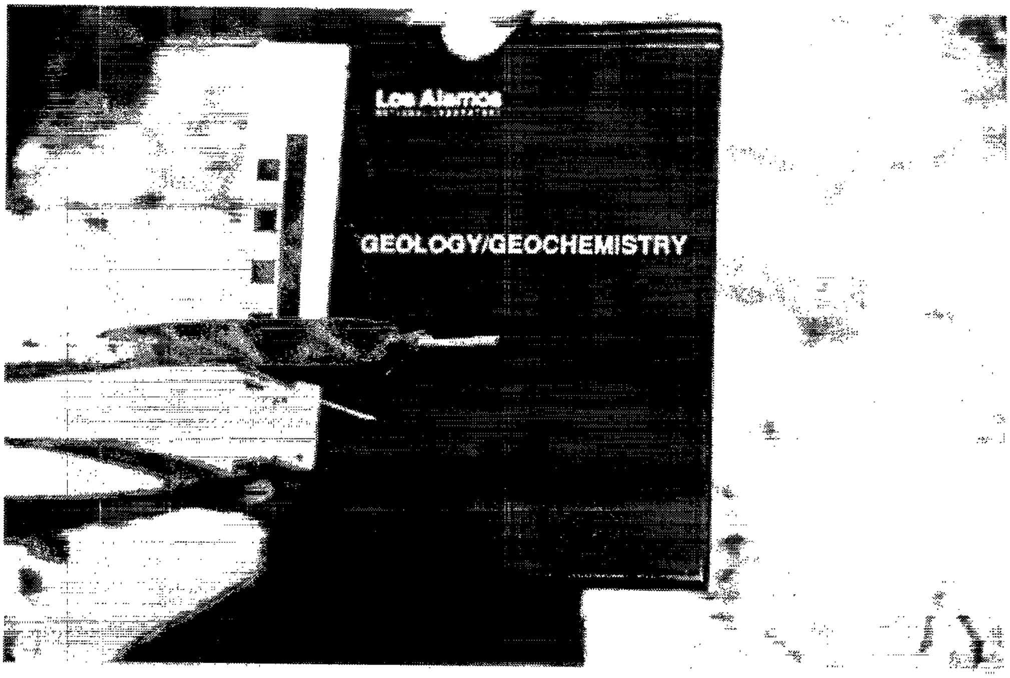

Figure 14. Photograph of expensive fiber optic-cable found at Minero. Such cable is used only for high-quality data transmission suggesting a sophisticated application.

4. Kinibito (U-3me)

This test area is located along a desert basin fault, and the area was well marked by an extensive area of prepared ground stretching nearly 0.5 km from a fenced area of prepared ground. Tangential to the fenced area on the flat valley floor was a recent fault scarp that showed up to 0.5 m of vertical offset where it was within ~1 km of the fenced area (Figure 15). The scarp cut a desert pavement and produced disturbed ground (fluff). During our investigations, use of a portable computer saved time in compiling observations and measurements, while allowing rapid access to reference materials (Figure 16).

If underground testing has occurred in a geologic environment characterized by through-going tectonic faults, detonation of nuclear devices will likely produce new movement on those faults, which can be readily observed (Dickey, 1968; Hawkins, 1983). This observation is particularly important for interpretation of teleseismic and aftershock signals because they will be influenced by both the explosive source and renewed fault activity.

Figure 15. Reactivation of movement along an existing fault near the test area (Kinibito), showing offset of desert pavement (just to the top left of the field notebook shown for scale). Along this fault, which was only prominent near the test area, the soil was disturbed, being inflated or "fluffed" as a result of rapid vertical acceleration and slap-down not characteristic of natural tectonic movement.

Figure 16. Photograph of geologists recording field notes and map information on a portable computer during field operations at an inspection site.

5. Carpetbag Area (U-2dg)

The Carpetbag fault was unknown prior to the event of the same name. We offer this example to show how dramatic reactivation of a major fault can be when triggered by a large underground nuclear test. Figure 17 shows the main scarp of the Carpetbag fault.

Figure 17. Carpetbag fault scarp showing ~3 m of vertical offset. The lower 2 m of vertical scarp defines offset produced by the Carpetbag event while the upper 1 m is sloped as a results of erosion on an earlier natural fault movement. The area to the right of this fault is a graben structure ~0.5 km wide and ~2 m deep that was formed during the nuclear test. Such large-scale fault reactivation is unknown by any other human activity other than nuclear testing.

VII. CONCLUSIONS

In this report we have summarized our investigation of visual inspection as an integral component of on-site inspection for CTBT verification. Our approach included literature reviews, an informal workshop and interviews with personnel experienced with post-shot effects, features, and operations of underground nuclear testing, and field exercises to evaluate the effectiveness of visual inspection techniques. In giving a brief overview of underground nuclear test phenomena and their effects on cultural, geological, and floral/faunal features, we have illustrated the basic components of visual inspection. Important considerations include knowledge of the geological setting and test emplacement configuration. Although horizontal and vertical emplacement techniques will produce similar cultural and geological effects, there may be significant differences in inspection techniques required for each. In this report, we have only outlined general procedures, logistics, equipment, and personnel expertise required for visual inspection. Although case histories have been mentioned briefly in this report, we strongly feel that they should be expanded to fully cover available literature with special attention to include foreign test sites. The visual inspection exercise described in this report serves to illustrate the type of work that needs to be done at other test sites in order to more fully develop the procedures. Field studies at foreign sites might afford valuable experience for inspection in territories where less is known about nuclear testing features. In conclusion, with this discussion of visual features and documentation techniques and the brief illustrations of our field exercises, we have shown how visual inspection is accomplished and why it is an essential component of an on-site inspection.

REFERENCES

Ad Hoc Committee on a Nuclear Test Ban, 1996, Draft comprehensive test ban treaty: Conference on Disarmament CD/NT/WP.330/Rev.1, Geneva.

Adushkin, V. V., and Spivak, A. A., 1994, Geologic characterization and mechanics of underground nuclear explosions: Defense Nuclear Agency Tech. Rep. (Contract No. DNA 001-93-C-0026), Alexandria, VA.

Allen, B. M., Drellack, S. L., and Townsend, M. J., 1997, Surface effects of underground nuclear tests: Geology/Hydrology Group report, Bechtel Nevada.

Allred, D. M., Beck, D. E., and Jorgensen, C. D., 1965, A summary of the ecological effects of nuclear testing on native animals at the Nevada Test Site, *in* Proceedings of the Utah Academy of Sciences, Arts, and Letters, vol. 42, Part 2, pp. 252-260.

App, F. N., 1985, Permanent displacement of the ground surface resulting from underground-nuclear-test-induced ground shock, *in* Olsen, C. W., and Donohue, M. L., eds., Proceedings of the Third Symposium on Containment of Underground Nuclear Explosions: Lawrence Livermore National Laboratory Proceedings, CONF-850953, v. 2, pp. 409-424.

Baldwin, M. J., and Townsend, D. R., 1995, Geotechnical source book for DNA underground weapons effects tests: Raytheon Services Nevada Report TSP:DGP:071:95.

Barosh, P. J., 1968, Relationship of explosion-produced fracture patterns to geologic structure in Yucca Flat, Nevada Test Site, *in* Eckel, E. B., ed., Nevada Test Site: Geological Society of America Memoir 110, pp. 199-217.

Boardman, C. R., 1970, Engineering effects of underground nuclear explosions, *in* Proceedings - Symposium on Engineering with Nuclear Explosives: American Nuclear Society and U.S. Atomic Energy Commission Report CONF-700101, vol. 1, pp. 43-67.

Bolt, B. A., 1976, Nuclear explosions and earthquakes, the parted veil, W. H. Freeman and Company, San Francisco, 309 pp.

Carothers, J. E., et al., 1995, Caging the dragon—The containment of underground nuclear explosions: U.S. Department of Energy Report DOE/NV-388, Defense Nuclear Agency Report DNA-TR-95-74, 726 pp.

Carr, W. J., 1965, Preliminary results of subsurface investigation of fractures in Yucca Flat, Nevada Test Site: U.S. Geological Survey Technical Letter Yucca-57, 15 pp.

Dickey, D. D., 1968, Fault displacement as a result of underground nuclear explosions, *in* Eckel, E. B., ed., Nevada Test Site: Geological Society of America Memoir 110, pp. 219-232.

Drellack, S. L., 1988, Crack mapping procedures: Informal Memo Geo-0451, Fenix & Scisson, Inc., 6 pp.

Drellack, S. L., Jr., 1989, Fenix & Scisson post-shot surface effects mapping procedures: Fenix & Scisson training procedure GP-001, 8 pp.

Garcia, M. N., 1987, Photogrammetric method for determining sink volumes at the Nevada Test Site, *in* Olsen, C. W., Donohue, M. L., and Wander, S., eds., Proceedings of the Fourth Symposium on

Containment of Underground Nuclear Explosions: Lawrence Livermore National Laboratory Proceedings, CONF-870961, v. 2, pp. 446-455.

Garcia, M. N., 1989, Photogrammetric methods applied to surface mapping and volumetric studies at the Nevada Test Site, Nevada: Photogrammetric Engineering and Remote Sensing, v. 55, no. 8, pp. 1197-1201.

Garcia, M. N., Drellack, S. L., Jr., and McKinnis, W. B., 1989, Field and photogrammetric procedures for mapping surface effects produced by subsurface nuclear testing at the Nevada Test Site, Nye County, Nevada: U.S. Geological Survey unpublished Open-File Report (draft).

Glasstone, S., and Dolan, P. J., 1977, The Effects of Nuclear Weapons (third edition): U.S. Department of Defense and the Energy Research and Development Administration, U.S. Government Printing Office, Washington, D.C., 653 pp.

Hawkins, W., 1983, Review of surface effects from underground nuclear explosions near the Yucca Fault, Nevada Test Site, *in* Olsen, C. W., compiler, Proceedings of the Second Symposium on the Containment of Underground Nuclear Explosions: Lawrence Livermore National Laboratory Proceedings, CONF-830882, v. 3, pp. 115-137.

Houser, F. N., 1969, Subsidence related to underground nuclear explosions, Nevada Test Site: Seismological Society of America Bulletin, vol. 59, no. 6, pp. 2231-2251.

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, 129 pp.

Howard, N. W., 1983, LLNL site characterization for containment of nuclear tests: Lawrence Livermore National Laboratory Report UCRL-53446, 33 pp.

Kunkle, T. D., 1994, An Introduction to Underground Nuclear Phenomenology or What Happens When the Bomb Goes Off: Los Alamos National Laboratory Personal Communication - Informal Document.

Maldonado, F., 1977, Composite postshot fracture map of Pahute Mesa, Nevada Test Site, June 1973 through March 1976: U.S. Geological Survey report USGS-474-243, 8 pp.

McKeown, F. A., Young, R. A., Williams, W. P., and Brethauser, G. E., 1967, Geologic effects of the LONG SHOT explosion, Amchitka Island, Alaska: U.S. Geological Survey Technical Letter: Long Shot-3, 73 pp.

Nordyke, M. D., 1964, Cratering experience with chemical and nuclear explosives, *in* Proceedings of the Third Plowshare Symposium—Engineering with Nuclear Explosives: U.S. Atomic Energy Commission Report TID-7695, pp. 51-73.

Snyder, R. P., 1971, Composite postshot fracture map of Pahute Mesa, Nevada Test Site: U.S. Geological Survey report USGS-474-100, 13 pp.

Snyder, R. P., 1972, Surface effects of the DIAMOND SCULLS (U12t.02) event: U.S. Geological Survey report Rainier Mesa-16, 10 pp.

USACDA and USOSIA, 1990, Text of Treaties and Protocols, Treaty Between the United States of America and the Union of Soviet Socialist Republics on the Limitation of Underground Nuclear Weapon Tests, U.S. Arms Control and Disarmament Agency and the U.S. On-Site Inspection Agency.

U.S. Congress, Office of Technology Assessment, 1989, The Containment of Underground Nuclear Explosions, OTA-ISC-414, Washington, D.C., U.S. Government Printing Office.

U.S. Department of Energy, 1994a, Comprehensive Test Ban Treaty Research and Development FY95-96 Program Plan: The U.S. Department of Energy Office of Nonproliferation and National Security Office of Research and Development (NN-20), DOE/NN-0003.

U.S. Department of Energy, 1994b, United States Nuclear Tests, July 1945 through September 1992, DOE/NV-209 (Rev. 14) (Available from U.S. Department of Commerce, National Technical Information Service, Springfield, Virginia, 22161).

U.S. Geological Survey, 1970, Geologic and hydrologic effects of the MILROW event, Amchitka Island, Aleutian Islands, Alaska: U.S. Geological Survey Report USGS-474-71, 75 pp.

U.S. Geological Survey, 1972, Geologic and hydrologic effects of the CANNIKIN underground nuclear explosion, Amchitka Island, Aleutian Islands, Alaska: U.S. Geological Survey Report USGS-474-148, 87 pp.

U.S. Geological Survey, 1974, Bathymetry of Cannikin Lake, Amchitka Island, Aleutian Islands, Alaska: U.S. Geological Survey Report USGS-474-203, 24 pp.

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* Olsen, C. W., compiler, Proceedings of the Second Symposium on Containment of Underground Nuclear Explosions: Lawrence Livermore National Laboratory Proceedings, CONF-830882, v. 1, pp. 393-410.

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