UCRL-CR-114729
P.O. #B208872

Study of the Nevada Test Site Using Landsat Satellite Imagery

Peter D. Zimmerman

July 1993

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED *gys*

DISCLAIMER

Work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract number W-7405-ENG-48.

This document was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor the University of California nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial products, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or the University of California, and shall not be used for advertising or product endorsement purposes.

Final Report on Purchase Order B208872

"Study of the Nevada Test Site Using Landsat Satellite Imagery"

**Center for Strategic and International Studies
1800 K Street, NW, Suite 400
Washington, DC 20006**

Peter D. Zimmerman, Principal Investigator

In the period covered by the purchase order CSIS has obtained one Landsat image and determined that two images previously supplied to the principal investigator under a subcontract with George Washington University were inherently defective. We have negotiated with EOSAT^a over the reprocessing of those scenes and anticipate final delivery within the next few weeks.

A critical early purchase during the subcontract period was of an EXABYTE tape drive, Adaptec SCSI interface, and the appropriate software with which to read Landsat images at CSIS. This gives us the capability of reading and manipulating imagery "in house" without reliance on outside services which have not proven satisfactory.

In addition to obtaining imagery for the study, we have also performed considerable analytic work on the newly and previously purchased images. A technique developed under an earlier subcontract for identifying underground nuclear tests at Pahute Mesa has been significantly refined, and similar techniques were applied to the summit of Rainier Mesa and to the Yucca Flats area. An entirely new technique for enhancing the spectral signatures of different regions of NTS was recently developed, and appears to have great promise of success.

Finally, in collaboration with Nancy Del Grande of LLNL, we have come to understand the mechanism by which the observed thermal signatures of underground detonations are probably produced.

^a Earth Observation Satellite Company, operators of the Landsat system.

1. Purchase of imagery

Landsat 5 acquired an image of the Nevada Test Site on 4 December 1991 (911204). This image was acquired less than 8 full days after the 26 November 1991 BRISTOL event. The BRISTOL test was one which Ms. Del Grande and the CSIS group had instrumented with thermistors in order to measure the thermal diffusivity of the ground within and outside of the spall zone before and after the event. Although the order was placed early in the period of the subcontract, the data tape was not created until 2 January 1993 and delivered to CSIS a few days later.

Subimages from the 911204 scene covering the Yucca Valley have been extracted, and the BRISTOL site positively identified.

Under a previous subcontract the P.I. ordered imagery of NTS acquired by Landsats 4 and 5 on 22 August 1991 (910822), a daytime scene, and 30 August 1991 (910830). Despite the fact that the scenes were ordered for delivery on 8mm EXABYTE tapes, EOSAT made them on 9-track media, not readable by CSIS. Autometric, Inc. in Alexandria, VA was able to transcribe the 9-track tape to an EXABYTE cartridge which was then read at CSIS. The scenes were found to suffer from several major defects:

The band six (10.5-12.5 μ thermal infrared) data from both scenes had been incorrectly processed by EOSAT and were totally useless. Because this study seeks to identify underground explosions by changes in the thermal properties of the surface (among other tools), without band six data the images were of no value.

The 910822 image, specified as a 100 km square subscene, was mislocated within the entire scene ordered. The location error was so great that at least one area of interest, Pahute Mesa, was not within the scene at all.

The 910830 scene was inverted with south "up". Hence, the specified coordinates for the upper left hand corner of the scene forced the image to be shifted so that none of the area of interest was within the data set delivered.

As of this writing we have reached agreement that EOSAT will reprocess both scenes to include the maximum possible overlap; both scenes will be correctly located. In addition, EOSAT has agreed to orient the two scenes true north and south ("map oriented") and to register them to the UTM section appropriate to NTS. Unfortunately, EOSAT claims to be unable to rotate the night image (910830) to place north "up". Transposing a 4480 x 4480 matrix is beyond the capability of the computers used at CSIS, but we believe that we can transpose a 512 x 512 matrix. Thus, it will be necessary to extract a subscene from the 910830 data, rotate it, and then match that scene as closely as possible with a similar subscene from the 910822 image. While tedious, this process certainly appears feasible. We await the delivery of the data.

2. Pahute Mesa

2.1 Characteristics of the area

Pahute Mesa was originally selected for study because it included several relatively "famous" events (e.g. GOLDSTONE) and because the high mesa had significantly more ground cover than Yucca Valley. It was believed that an underground explosion might cause changes in the surface which would affect the health of the vegetation on the surface. These might include damage to delicate root structures (reducing the vigor of the ground cover), cracking of the surface to permit better local collection of scarce rainwater (perhaps producing increased vigor which decreased with distance from ground zero), and covering of the vegetation with dust, thus reducing the characteristic reflection of healthy green plants by physical -- rather than biological -- means. The dust signature would not, of course, be terribly persistent.

However, it has been reported that in the years before the signing of the Threshold Test Ban Treaty (1976) which limited tests to 150 kiloton yield, Pahute Mesa was the site of several very high yield explosions, and that in more recent years tests of relatively high yield have been carried out in Area 20. Since the diameter of the spallation zone is roughly the same as the depth of burial, it would not be unreasonable to expect that the spall zones from "ancient" and modern tests overlap. In turn, this could cause confusion in determining both thermal properties and vegetation stress. This would be particularly the case if severe ground cracking produced persistent water traps.

In August of 1990 and 1991 the principal investigator visited NTS to obtain ground truth. While examining the area projected to be in the spall zone of the HOYA event (planned for study in the next phase of this project), it became clear that the entire mesa was truly disturbed by its history as a test site, and that its detailed study may pose more difficulties than anticipated.^b

2.2 Multispectral studies

Four Landsat "floppy disk datasets" of Pahute Mesa have been acquired. These are dated 13 August 1985 (850813), 16 October 1985 (851016), 12 May 1986 (860512), and 28 March 1987 (870328). In addition, Pahute Mesa appears on the 911204 quarter scene which was recently delivered, but no attempt to study the newest data has yet been made.

The May, 1986 and March, 1987 scenes have been studied in the most exhaustive detail. Using ground truth obtained in August, 1990 a set of "classification data" was established for the area near the SALUT (15 June 1985, DOB 608m) and GOLDSTONE (28 December 1985, 549m DOB) test sites. After making the on-site inspection it was possible to determine which end of

^b I nearly broke my right leg when it went into a heavily overgrown and concealed crack. This was a vivid illustration of the size of the cracks (as deep as my knee) and the dense vegetation growing along them.

the GOLDSTONE bulldozed area had housed the instrumentation trailers and which was the GZ. Training areas for the classification program were identified as being within the bulldozed area over the ground zero; within the bulldozed area, but at the end where the trailers were parked; in the grassland around the GZ (the "inner collar"); an area of grassland surrounding the inner collar (the "outer collar"), and a region of grassland distant from any GZ and expected to be outside the spall zones of any of the tests conducted recently in the area.^c In addition, one area surrounding the GZ of the DARWIN event (25 June 1986, DOB 549m) was also identified.

Seven-band spectra were computed for each of these areas using the March dataset and plotted. The plots were displayed as:

$$(\text{DataNumber}_{\text{band,site}} - \text{Average DataNumber}_{\text{band}}) / (\text{standard deviation}_{\text{band,site}})$$

This plot is shown as Figure 1.

Subtracting the average brightness for all areas separates the spectra into two clusters: graded ("bladed") areas and grassland. Except for the area occupied by the trailers, which probably includes some effects from the adjacent grass land due to the low resolution of the thermal IR sensor, all of the grassy areas are warmer than the bladed areas. The bladed area of DARWIN appears very much like that of GOLDSTONE, except that it is significantly cooler, potentially explained by the fact that the DARWIN event was more recent than the GOLDSTONE one. We observe that the area labelled "grass" and representing apparently undisturbed grassland several hundred meters from any known GZ, is significantly different in absolute reflectance and curve shape as compared to the grassland adjacent to the GOLDSTONE GZ. This provides confidence that it is genuinely possible to discern physical changes on the mesa resulting from underground testing. Until the December, 1991 image is analyzed, this is the most recent image available covering the Pahute Mesa area.

In fact, supervised classification using the data of the 860512 scene -- the results of which were provided to LLNL during an earlier subcontract with George Washington University -- based on ground truth data, demonstrated clearly that, with only one false alarm, it was possible to distinguish between areas surrounding tests and areas which had only been bladed, but where no test had yet occurred. The anomaly is DARWIN which had not been conducted as of the date of the image, but which appeared very similar to GOLDSTONE and could be misclassified unless very narrow tolerances for the classification were adopted.

Supervised classification of the March, 1987 data correctly identifies DARWIN as an area in which a nuclear test has been conducted.

^c A certain amount of geophysical confusion was probably produced in this study by the BENHAM test of 19 December 1968 at a depth of 1400 meters. In contrast, GOLDSTONE was conducted at a depth of about 550 meters.

3.0 Rainier Mesa

As color imagery already provided to LLNL demonstrated, using *unsupervised* classification and automated cluster determination we have been able to locate spectrally distinct regions on the summit of Rainier Mesa which correlate approximately with the location of tunnels in the mesa and which terminate at points on the scarp which line up well with the tunnel adits which are clearly visible in the 30 meter IFOV data. These spectrally distinct regions were particularly apparent in the January, 1986 data. The physical mechanisms which resulted in the apparent localization of the tunnels are not yet understood.

In order to gain a better understanding of the processes which may be signalling the presence of fairly deep (approximately 400 meters beneath the surface) tunnels, very much more effort would be required. This would certainly involve a revisit to the surface taking care to examine the regions which stood out in the classified images, the careful analysis of all Landsat images already purchased in which Rainier Mesa appears, very careful registration of the satellite imagery with the tunnel maps, and probably an aerial overflight with short-, medium-, and long-wavelength IR sensors in order to provide significantly higher ground resolution.

4.0 Yucca Flats

4.1 General observations

Yucca Flats has been the subject of much of the effort of this project since its origin even before Livermore provided funding. Along the way we have detected and studied several circular features which surround the Gzs of atmospheric tests conducted during or before 1958. These scars resulted from the ignition of the desert grasses, and the subsequent denuding of the areas. More than 30 years after the last atmospheric tests in Nevada, the scars have not healed, illustrating both the power of the (relatively low yield, < 50 kt) nuclear devices and the fragility of the desert ecosystems.

Many of the images which have been studied show the evidence of the Yucca Valley fault system. The IR reflectance of the desert floor clearly changes sharply along the line indicated on the USGS geological 1:24000 quadrangle of the area, even though the map indicates the same alluvium surface to either side of the fault. This is seen in Figure 2, which also illustrates the extreme spectral similarity of the material at the base of the SEDAN crater and on the flanks of that crater.

4.2 New spectral techniques

During the examination of the infrared spectra to the east and west of the Yucca Valley fault, it became clear that a technique which removed shadow and texture effects from the spectra would be useful. Indeed, what appeared most necessary was a way to remove the *correlations* between the spectral bands. That is, an area which appeared bright in the visible blue was apt

to appear bright in the visible green and red, and possibly in other bands as well. When the intensities of each pixel in each Landsat sensor band are plotted on appropriate scatter graphs it is clear that brightnesses are, indeed, correlated. The principal components are the eigen vectors of the distribution, and the first principal component contains the greatest range of brightness variation^d. For any given pixel, one may approximate the first principal component by averaging the data numbers from each of the seven bands, although the image processing software used for this project calculates the principal components exactly.

The contribution of the overall average brightness can be removed, then, by dividing through, pixel by pixel, by the value of the first principal component evaluated for that row and column in the image. This division must be done in floating point arithmetic, and the result then scaled as an integer between 0 and 255. A pixel with a value exactly equal to that of the first principal component would be assigned a data number of 127 in this scheme.

Figure 3 illustrates the power of this technique to display both similarities and differences between spectra. While the four spectra displayed in Figure 2 are superficially similar, when they are divided by the first principal component, and the brightness correlation removed, it becomes apparent that the flank and interior of SEDAN are virtually identical from 0.5μ to 10.5μ , while the samples east and west of the fault are strikingly different from one another in the mid- and long-wavelength regions, and differ from the SEDAN samples in all spectral regions. The identity of the interior and exterior of the SEDAN crater is simply explained by noting that the last rock excavated from the crater is probably identical to the first left behind, and that both regions are distinct from the undisturbed surface.

Work is already in progress to create new datasets from the existing data of Yucca Flats and Pahute Mesa in order to explore the utility of the pseudochannels defined by dividing the original data by the first principal component. A second illustration of the power of this method to differentiate between spectra is shown in Figures 4 and 5 which show spectra from the burned circle surrounding the GZ of the SHASTA atmospheric test.

The classes labelled one through four move radially outward from the ground zero, with the inner boundary of class 1 placed just outside the visible circular feature at the center of the burned area. This small circle is at the ground zero and is largely paved over; the tower which held the device was located there. Classes one and two are wholly within the burned area, three is a transition, and four is outside of the affected area. The pseudospectra are strikingly different, particularly in the visible region.

Class 5 is the actual ground zero point; "class 12" is a base camp nearby, and includes both concrete and a significant number of metal buildings. The low emissivity of the metal roofs probably accounts for the difference recorded in the thermal IR band.

^d See any book on digital image processing for details; one useful source is A.K. Jain, *Fundamentals of Digital Image Processing*, Prentice Hall (Englewood Cliffs, NJ: 1989).

Color photographs 1 through 4 show Yucca Flats in May of 1986. Photos 1 and 2 show bands 7, 4, and 2 (as red, green blue). The first picture of this pair is a normally-processed, stretched and approximately color-balanced image using as its inputs the original data numbers; the second picture shows the effect of dividing by the first principal component and then scaling each of the three bands. Photos 3 and 4 show the scene in bands 6, 5, and 4 (also as red, green, and blue). Once again, the first picture shows a normally processed scene while the second shows the result of dividing the original data by the first principal component and then scaling the quotients.

4.3 BRISTOL

The bladed area at the BRISTOL ground zero has been positively identified in the 911204 image, and preliminary spectra have been extracted for several regions running from the bladed area north and east into normal desert. These are shown in Figure 6, except that the data from band 6 (thermal IR) have been stretched so that the originally-measured span of data numbers (92-120) now falls between 1 and 250. Figure 7 shows the original data numbers (including those from band 6) divided by the first principal component.

Class 1 as identified on the spectra lies within 200 meters of the GZ of the event, with its center about 100 meters from ground zero. Class 2 is adjacent to class 1 and extends another 150-180 meters from the GZ (i.e. from about 200 m to about 400m with its center at about 300 m). Classes 3 and 4 lie progressively farther away, each by an increment of 180 meters (6 pixels). While classes 1 and 2 ought definitely to be within the spall zone, class 4 should lie either outside the zone or at its edge. The DN from band 6 is virtually identical for classes 1 and 2 but rises slowly as one moves farther out to classes 3 and 4, indicating a slow increase in temperature.

This is fully in accordance with the thermal diffusivity measurements of Nancy Del Grande, which show that the after-event diffusivity is *higher* than the before-event value. That would tend to make the spall zone *cooler* in the winter morning than its surroundings since the increased thermal diffusivity will conduct solar heat away from the surface more rapidly. Thus, one expects the DN from band 6 to be smaller near the ground zero, within the spall zone, than at distances beyond the most strongly shocked region.

The next step in the analysis will be to create image-to-image and image-to-map transforms for the January, 1986, May, 1986 and December, 1991 images of Yucca Flats so that, in the area of BRISTOL, all three images can be overlaid one upon the other. Following that, the pixels corresponding to the instrument fields where thermistors were deployed in August, 1991 will be determined and the corresponding band 6 data numbers compared. The radiances measured at-satellite will then be converted as nearly as possible into temperatures. Undoubtedly some scaling will have to be performed in order to compensate for the different ambient temperatures. In no way can the May and January ground temperatures at NTS be expected to be otherwise comparable.

Finally, we hope that EOSAT will be able to deliver correct data from the August, 1991 acquisitions so that the intended comparisons can be made. When these data are finally made available, they will be registered to the other data sets so that proper comparisons can be made.

5. Work necessary to conclude this project

Two critical images have not been delivered to the principal investigator, despite his best efforts and those of LLNL to obtain them on a reasonable schedule. Once those images are in hand they will be matched to the existing imagery of Yucca Flats and Pahute Mesa (and Rainier Mesa if LLNL desires). The spectra, images, and thermistor data will be compared in order to determine if observable signatures were produced by the events since March, 1987 in both areas of study.

One additional Landsat scene ought to be purchased for this project: an image acquired near the end of August, 1992 which will permit study of the site under weather conditions similar to those which prevailed when our instruments were running. Furthermore, this image would be from a time about 8 months after BRISTOL, and would give some opportunity for determining the evolution of any signatures produced by the event.

When all of the data have been delivered and inspected, we will begin the task of applying the classification techniques which proved so useful on Pahute Mesa in 1986 and 1987 imagery to more recent pictures. In particular, we must find a suite of techniques which (a) maximize the discrimination provided by the available data, (b) find events clearly and with few false alarms or noise, (c) work in both summer and winter -- or identify discriminant functions which are seasonally specific, and (d) which work in each of the different geologies for which we have data.

This work will require approximately three man-months of the time of the principal investigator, probably spread out over six months, and six man-months of work by an intern or research assistant. In order to maximize the effectiveness of the intern, he or she should be provided with a computer capable of running the RSVGA image processing system manufactured by Eidetic Digital Imaging. While the second machine need not be the equivalent of the machine used by the PI and provided by LLNL under an earlier contract with additional peripherals acquired under this subcontract, it should probably be a 25 Mhz or faster 386SX machine with a floating point coprocessor, 170 Mb hard drive, and 24 bit color graphics card (e.g. the ATI Industries XL24 which retails for about \$150). Both computers should be fitted with the newest versions of the RSVGA image processing software; the PI's machine should receive the newest versions of the TerraMar software. If parts remain available from ZEOS, maker of the "upgradeable" 33 Mhz 386 computer used by the PI, that machine should be upgraded to a 486 processor in order to speed computation.

6. Acknowledgements

The Principal Investigator thanks CSIS intern Paul Kengor for his contributions to the project. He also thanks Ms. S.R. Zimmerman for her assistance in preparing the spectra for figures 2, 3, 4, and 5.

Pahute Mesa, March, 1987 Enhanced Spectral Distribution

Figure 1

Sedan Crater and Fault Regions Plot of raw data numbers

Figure 2

Sedan Crater and Fault Regions Data divided by first principal comp.

Figure 3

Burned Circle Spectra of Selected Regions

Figure 4

Burned Circle Spectra of selected areas/(First PC)

Figure 5

BRISTOL

Spectra of Selected Regions

—*— class 1 —+— class 2 —*— class 3 —□— class 4

Figure 6

BRISTOL

Spectra of Selected Regions/First PC

—x— class 1 + class 2 * class 3 -□- class 4

Figure 7

Color Photo 1: Bands 7, 4, and 2 displayed as red, green, and blue. Contrast-enhanced data.

Color Photo 2: Bands 7, 4, and 2 displayed as red, green, and blue. Unstretched data divided by the first principal component.

Color Photo 3: Bands 6 (thermal IR), 5, and 4 displayed as red, green, and blue. Contrast-enhanced data.

Color Photo 4: Bands 6, 5, and 4 displayed as red, green, and blue. Unstretched data divided by the first principal component.

DATE

FILMED

1 / 26 / 94

END