REMOTE SENSING ANALYSIS OF THE SIERRA BLANCA (FASKIN RANCH) LOW-LEVEL RADIOACTIVE WASTE DISPOSAL SITE, HUDSPETH COUNTY, TEXAS

David V. LeMone*, Rebecca Dodge**, Hongjie Xie*,
R. P. Langford* and G. R. Keller*

*Geological Sciences and PACES, University of Texas at El Paso, El Paso, TX 79968
**Geology Department, State University of West Georgia,
Callaway Bldg., Carrollton, GA 30118

ABSTRACT

Remote sensing images provide useful physical information, revealing such features as geological structure, vegetation, drainage patterns, and variations in consolidated and unconsolidated lithologies. That technology has been applied to the failed Sierra Blanca (Faskin Ranch) shallow burial low-level radioactive waste disposal site selected by the Texas Low-Level Radioactive Waste Disposal Authority. It has been re-examined using data from LANDSAT satellite series. The comparison of the earlier LANDSAT V (5/20/86) (30-m resolution) with the later new, higher resolution ETM imagery (10/23/99) LANDSAT VII data (15-m resolution) clearly shows the superiority of the LANDSAT VII data.

The search for surficial indications of evidence of fatal flaws at the Sierra Blanca site utilizing was not successful, as it had been in the case of the earlier remote sensing analysis of the failed Fort Hancock site utilizing LANDSAT V data. The authors conclude that the tectonic activity at the Sierra Blanca site is much less recent and active than in the previously studied Fort Hancock site. The Sierra Blanca site failed primarily on the further needed documentation concerning a subsurface fault underneath the site and environmental justice issues. The presence of this fault was not revealed using the newer LANDSAT VII data. Despite this fact, it must be remembered that remote sensing provides baseline documentation for determining future physical and financial remediation responsibilities. On the basis of the two sites examined by LANDSAT remote sensing imaging, it is concluded that it is an essential, cost-effective tool that should be utilized not only in site examination but also in all nuclear-related facilities.

The separate, but related, problem of establishing any site for a near-surface low-level repository for the Texas Compact or any other national state or compact entity is unacceptable both politically and legally. It would seem that the only viable solution for this continuing impasse between the environmentalists, regulators, stakeholders, and nuclear-related civilian organizations (power plants, medical, industrial, and research) is the adoption of an engineered, monitored, above-grade assured isolation facility. Such a facility would allow continuous monitoring for the length of time necessary for the radioactive waste to decay to a safe level, allow on-demand inspection of the facility, and result in a recoverable, utilizable surface structure.

INTRODUCTION

The proposed Texas Sierra Blanca (Faskin Ranch) low-level radioactive waste disposal site follows the Fort Hancock site as another failed artifact of the national program for the disposal of commercial low-level radioactive wastes in designated state or compact repositories. This national low-level radioactive waste program is in serious disarray, if not moribund. The process of how we arrived at this point is a long and complex story involving political and legal maneuvering over the technical assessment of those state and compact sites selected. The program began with the passage of the Low-Level Radioactive Waste Policy Act of 1980 (this law was later amended in 1985 and is referred to as the Low-Level Radioactive Waste Policy Amendments Act). It is important to remember that this legislation was passed at a time when less sophisticated methods of siting, disposal, engineering, and management were the standard practices.

Prior to this legislation, low-level radioactive waste disposal facilities, such as those at Sheffield, Illinois; West Valley, New York; and Maxey Flats, Kentucky, were closed due to a variety of environmental problems. At the initiation of their operation, they followed the then current, perfectly acceptable, siting and disposal practices for "permanent" disposal. These practices were later determined by the regulatory agencies to present an unacceptable risk to the public. Responsible agencies have had to conduct extensive ongoing remediation efforts in order to stabilize these sites for the protection of public health and safety. Institutional control and active remediation and monitoring will be necessary for the foreseeable future at these sites [1].

The last several years have witnessed the virtual derailment of the long-term prospects for new and existing low-level radioactive waste disposal facilities. Texas, California, Nebraska, New Jersey, North Carolina, and Pennsylvania have now joined Illinois, Michigan, Ohio, and others on the list of casualties. Jim Hodges, the current governor of the state of South Carolina, campaigned and won election on the issue of closing the Barnwell low-level radioactive waste disposal facility to the rest of the nation. In the immediate future, the Barnwell facility will accept annually decreasing amounts of waste until the year 2008. In the intervening period and beyond 2008, the Barnwell facility will service only the eight states of the Southeastern Compact. When South Carolina shuts down Barnwell to the remainder of the nation, there will be no other alternatives for the safe, long-term management of low-level radioactive waste for 31 states, the District of Columbia, and overseas U.S. possessions.

The second operating disposal site is at Richland, Washington. This facility is legally restricted to taking low-level radioactive waste generated from the 11 states of the Northwest and Rocky Mountain compacts [1]. A third possibility for potentially accepting selected low-level type A radioactive waste may be the Envirocare facility at Clive, Utah, 75 miles west of Salt Lake City [1].

Three recent examples of the failure of siting efforts for low-level radioactive waste disposal facilities serve to illuminate the paralysis of the system. The first is the land transfer debacle with the Federal government at Ward Valley, California. The Ward Valley facility was to have served the low-level radioactive waste disposal needs of the Southwestern Compact (California, Arizona, North Dakota, and South Dakota). The second example is the failure of the proposed Boyd County disposal facility in Nebraska. The Boyd County facility was meant to take waste from the Central Compact (Nebraska, Kansas, Louisiana, Arkansas, and Oklahoma). The third example is the denial of the license application for the proposed Texas Compact Sierra Blanca disposal facility in West Texas. The Sierra Blanca facility was to have served the low-level radioactive waste disposal needs of the Texas Compact (Texas, Maine, and Vermont). Sierra Blanca, Boyd County, and Ward Valley have joined the long list of low-level radioactive waste disposal facility siting failures. As with all low-level radioactive waste disposal facility siting processes, Sierra Blanca, Boyd County, and Ward Valley have conducted very expensive processes of site characterization and evaluation [1].

The site being sought in every case is required to be a technically acceptable engineered facility where low-level and intermediate level radioactive wastes may decay to acceptably safe levels within 350 years or less time. This requires detailed knowledge of the local and regional surface and subsurface geology and the physical characteristics of the site and its surrounding area. The accumulation of these base data and the subsequent evaluation of them represent an expensive and time-consuming process. The process can be greatly ameliorated by the utilization of remote sensing. Remote sensing greatly accelerates the process of evaluation, reveals potential fatal flaws, and establishes the pre-facility ground conditions for future remediation discussions. It would have been particularly useful in relation to the failed Fort Hancock site, which like the Sierra Blanca site, is in Hudspeth County [2]. This study evaluates the usefulness of this system at the Sierra Blanca site.

SIERRA BLANCA (FASKIN RANCH) SITE

The Sierra Blanca (Faskin Ranch) low-level radioactive waste disposal site was the third location proposed by the Texas Low-Level Radioactive Waste Disposal Authority (Authority). It was proceeded by an initial South Texas (McMullen County site) and an earlier Fort Hancock sites [2]. The South Texas facility was selected from a final list of some 15 counties and selected on the basis its simple geology and central location. The legislature, however, removed it from consideration in response to the area NIMBY syndrome [2]. The selection area was moved out to the Texas University Lands that are predominantly located in West Texas. The resulting second location at Fort Hancock in Hudspeth County was defeated in a court suit brought by El Paso County. In the 1991 legislative session, a 400 mi^2 (1,035 km^2) geographic box was drawn in Hudspeth County in which the site had to be located. That action resulted in the selection of the Sierra Blanca site. The Texas Natural Resources Conservation Commission (TNRCC) [3] subsequently rejected that site. Each of these proposed repositories failed judicial and legislative tests on the basis of perceived political (e.g., proximity to Mexico) and natural system grounds (e.g., hydrological and geological hazards such as seismic activity, contamination of surface and subsurface waters, surface fissuring, faulting, etc.) [2].

An abbreviated sequence of events leading to the site rejection are as follows. The Authority, after a site evaluation, repository engineering planning, and the development of base line data, filed with the state an application to construct, operate, and close a commercial low-level waste disposal facility and an ancillary application for a water quality permit at the Sierra Blanca site (Radioactive Materials Licence No. RW 3100 and Permit No. 03899) [TNRCC Docket No. 96-1206-RAW] [3]. The Texas Natural Resources Conservation Commission (Commission) between August and October 1996 held public preliminary hearings in Sierra Blanca, El Paso, and Alpine and a final, evidentiary meeting in Austin. The Commission from January 21 to March 5, 1998, held further evidentiary meetings in Sierra Blanca, El Paso, Marfa, and Austin. The application was ultimately denied July 7, 1998, by Administrative Law Judges with the State Office of Administrative Hearings [SOAH Docket No. 582-96-1042] [4].

The primary basis for the denial focused on the failure of the Authority to address two major deficiencies. The first was an inadequate assessment of the faulting adjacent to and beneath the site (site suitability and geological considerations). Secondly, the potential socioeconomic effects on surrounding communities (Environmental Justice) were perceived as being superficial and inadequately assessed and weighed. The Administrative Law Judges considered the first deficiency, by itself, adequate to render the application deficient. A repository site must meet the performance objectives for site stability. Therefore, the site was deemed inadequate on the basis of not making a reasonable assurance of shielding the public from exposure to radiation. Arguments for engineering the site to withstand major quakes were not accepted [3].

The Authority was further charged with examining a series of alternatives: 1) alternative disposal technologies, 2) out-of-state facilities (not Barnwell), and 3) alternative siting locations. The authority recognized 10 separate repository types. The Authority originally adopted a below-grade, near-surface modular concrete canister model [5]. The later alternative choice was an above-grade vault or an assured isolation facility. Normal waste preparation and minimization techniques (e.g., supercompaction, incineration, etc.) were found to be preferable to the more costly alternative disposal types (e.g., vitrification).

The purpose for pursuing the out-of-state search for a repository was in response to the escalating extremely high cost of disposal and accompanying state surcharges at Barnwell (e.g., the South Carolina added state tax of $255/cubic foot). The added potential, now documented, for closure of the site in 2008 to Texas low-level waste makes the examination of this alternative essential. Envirocare, at Clive, Utah, 75 miles west of Salt Lake City, has a potential for selected type A waste as defined as well as NORM wastes and other remedial wastes. The amount of waste that could be sent was considered to be relatively small. Alternative burial repository sites are not possible for the Texas Compact outside the designated 400 square mile area in Hudspeth County. An above-grade Assured Isolation Facility is apparently not affected by this latter restriction [6].

TEXAS COMPACT AND ASSURED ISOLATION

After the rejection of the Sierra Blanca disposal site, the Authority actively examined and researched the Assured Isolation Facility (AIF) proposal [1,6,7]. A low-level radioactive waste assured isolation facility is very likely much more acceptable to the general public than a below-grade, near-surface disposal facility. The public sees a visible surface structure being controlled, maintained, and monitored, not a hidden menace lurking below ground waiting to contaminate the hydrosphere and biosphere. The geographic solution to the problem of placement would seem to be in locating the facility in the less densely populated regions of either northern or western Texas. An assured isolation facility site could be built virtually anywhere in these areas. Establishing such a facility addresses the need for immediate centralization of waste from around Texas into a single locale as well as waste now temporarily stored in Maine and Vermont.

In the 1999 legislative session, the AIF concept was brought up in the appropriate House and Senate committees. The AIF concept was widely discussed in the legislature and in hearings and enjoyed overwhelming support over the disposal option. There were some questions as to whether an AIF would comply with the state's current Compact obligations. The question was submitted to the Attorney General's office. The Attorney General's opinion, issued May 18, 1999 [8], states that the development of an AIF facility complies with the state's current Compact obligations. However, the question of whether it meets permanent isolation or disposal is moot. Whether it will ultimately be an option for "permanent" disposal and thereby satisfy the Compact is not predictable. It should be noted that an AIF could, at a future date, transfer selected or all waste modules to a disposal site or it could be closed in situ. However, if the option of disposal or AIF in situ backfill were chosen, it would preclude inspection and active maintenance [1,7].

Despite broad support for the AIF related bill, it died because a joint House-Senate bill could not be agreed upon prior to the close of the 1999 legislative session. However, in a late legislative action, the Authority and its responsibilities, funding, and personnel were merged with the Texas Natural Resource Conservation Commission effective as of September 1, 1999. The Commission then assumed the state's obligations to the Compact and has continued work on the AIF concept and potential siting candidates to date. It should be noted that, in the unlikely event that the Commission decides to pursue the near surface disposal option in the future, they will be restricted to the same block as that formed by the 1991 legislature (Eagle Flat Study Area, 400 mi^2 or 1,035 km^2), as that law was not changed.

In order to evaluate the Sierra Blanca site, it is necessary to examine the tools being used (remote sensing), examine the geological setting, evaluate the remote sensing contribution to this site, and then compare this site with the prior evaluated Fort Hancock site [2]

REMOTE SENSING

Remote sensing is not a new tool for the radioactive-related industries. It has been utilized in the search for uranium ore bodies since the late seventies [9]. Remote sensing analysis involves methods of measuring portions of the electromagnetic spectrum, such as ultraviolet, visible, infrared, and microwave radiation emitted and reflected from the earth and its ionosphere. Primarily fixed-wing aircraft, orbiting spacecraft, and satellites record the data. Remote sensing as defined does not include the traditional geophysical methods such as gamma ray spectroscopy and magnetic surveys [9].

Remote sensing, with the exception of low frequency microwaves, has limited capability for direct measurement of the subsurface. Subsurface conditions, however, are often revealed in surficial features that are enhanced by utilizing remote sensing methods. Remote sensing yields essential geological information based upon the recordable multifaceted properties of the earth's surface. Structural activity, for example, is reflected in faults and fracture systems. These may be recognizable as linear patterns, topographic expressions, distribution and density of vegetation, zones of moisture concentration, lithologic distribution, etc.

Physical properties typically include spectral reflectance and emittance and back scattering measured by synthetic aperature radar systems (SAR). The system used in this study is the LANDSAT series. The initial satellite in that series became operational July 23, 1972. LANDSAT - I was also known as the Earth Resources Technology Satellite (ERTS). This satellite had a multi-spectral system that captured data for a digital image system for computer - compatible tapes. Area size coverage was 185 km x 185 km. Spatial resolution was on the order of 80 m. The four bands recorded included: green (0.5 - 0.6 /micrometers [μm], red (0.6 - 0.7 μm), near infrared (0.7 - 0.8 μm), and near infrared 2 (0.8 - 1.1 μm). The 103-minute period of the satellite enabled LANDSAT - I to cover the globe in 18 days. Images, of course, were variable in response to seasons, time of day, and cloud cover [9,10].

The next major utilizable instruments in the series were LANDSAT IV and V. LANDSAT IV was launched in 1982. These satellites utilize Thematic Mapper (TM) imagery. This imagery involves seven spectral bands; they are: 1, blue (30-m resolution); 2, green (30-m resolution); 3, red (30-m resolution); 4, near infrared (30-m resolution); 5, near infrared (30-m resolution); 6, thermal infrared (120-m resolution); and 7 far infrared (30-m resolution). This system (TM) allows construction of image data maps with scales of 1:50,000.

In 1999, LANDSAT VII began accumulating images utilizing an Enhanced Thematic Mapper (ETM +) imaging system. This system utilize the same bands as LANDSAT V with the addition of panchromatic band 8, which covers the wavelengths of bands 2, 3, and 4. This system (ETM +) enables the development of images at a vastly improved 1-24,000 scale.

In addition to the development of 1:24,000 and 1:50,000 maps, it is possible to enhance the image by addition of topographic and other maps (e.g., geology, soils, etc.). The result is the construction of a three dimensional (3-D) map. This is accomplished by draping a digital elevation model (developed by the U.S.G.S.) over the image. Once this has been accomplished, the 3-D map is made, at which point geologic and other data can be added to the model.

It is possible at that time to manipulate the system to tilt the map in any direction, rotate the map through the entire360^0, and zoom in or zoom out on the image. Additionally, the image may be sliced vertically. An excellent example by Arizona State's Professor Steve Reynolds of the utilization of this 3-D slicing system in structural geology is available on the Internet.

The LANDSAT series is not the cutting edge of remote sensing technology. Foreign and domestic military systems in the past, as in the present, are far advanced over commercial systems. The current Afghanistan military action is an example of this. Unmanned aerial vehicles (UAVs or drones) are coming to be a more common feature of this military action [11]. The first generation UAV, called the Predator, utilizes radar, infrared sensors, and video cameras. The second generation UAV, the Global Hawk, formerly scheduled to enter active service next year, has reportedly been in action on 2001. It is reported to be capable of flying at 65,000 ft (19,817 m) as opposed to the 15,000 ft (4573 m) ceiling of the Predator. It is capable of taking off, landing, and is operated from a computer. The Global Hawk has infrared and radar sensors with a surveillance range of 100 mi (161 km). The Global Hawk has flown from California to Australia and landed without human intervention [11].

Commercial satellite imaging has become of age in large part due to the release of the Global Positioning system (GPS) developed and released by the military. Space Imaging of Thorton, Colorado, has developed the highest resolution (0.82 m), commercial imaging system by utilizing the Ikonos satellite. Ikonos passes over the same spot every 3 days. American military satellites reportedly have had image systems smaller than this for some time [12]. DigitalGlobe, another commercial organization, is scheduled next year to be operational with a 0.5-m resolution [12]. This study, however, is confined to utilizing the LANDSAT V and VII images, which are readily available and relatively inexpensive.

GEOLOGICAL SETTING

Location

The Sierra Blanca site lies in the Northwest Eagle Flat Basin. It is approximately 160-km southeast of El Paso, Texas, in the Trans-Pecos region. The basin lies in the Bolson subsection of the Mexican Highlands section of the Basin and Range physiographic province [13,14,15] (Figure 1). The Bolson subsection is typically characterized by broad, internally drained basins, which are flanked by rugged, discontinuous fault-block mountains. Three features dominate this part of the Trans-Pecos region of Texas: (1) the extensive Hueco Bolson; (2) the Salt Basin-Lobo Valley basin complex, and between these features a highland area. The highland area is composed of mountains separated by three smaller basins: Northwest Eagle Flat, Southeast Eagle Flat, and Red Light Draw (Figure 1). The Northwest and Southeast Eagle Flat basins form two topographic sub-basins within the Eagle Flat structural basin. Total relief in the area is approximately 1,285 m, with elevations ranging from 2,261 m in the Eagle Mountains to 975 m on the Rio Grande in Red Light Draw.

Northwest Eagle Flat Basin is a closed topographic depression (518 km^2) that drains into Grayton Lake playa near its southeastern end. Southeast Eagle Flat Basin is drained by the ephemeral Eagle Flat Draw. Coalescent alluvial fans create a low drainage divide between the two basins, 7.2-km east and 27 m above the floor of Grayton Lake. The repository site was in the south-central part of the Northwest Eagle Flat basin. Gravity and seismic surveys indicate that the thickest basin fill lies beneath Interstate Highway 10 [16]. Core studies support the inference that this area is the structural low and depocenter for the basin [16].

Geologic History

The Eagle Flat area experienced a long history of tectonic deformation that produced a mosaic of rock types in the upland areas. The oldest outcrops are Precambrian metavolcanics of the Carrizo Mountain Group [17]. These rocks were thrust onto younger Precambrian talc schists, marbles, conglomerates, and shales [18,19]. Marine sediments that dramatically thicken southward from the edge of the Diablo Plateau were deposited during most of the Paleozoic and Mesozoic [20,21]. Complex thrust faults formed during the Late Cretaceous - Early Tertiary Laramide orogeny. Extrusive and intrusive magmatism in the Eagle and northern Quitman mountains ranging in age from 38 to 17 Ma (million years) created thick volcanic suites and plutons [20,21,22]. The volcanic terrains remain as topographic highs, with elevations above 2,130 m in the Eagle Mountains.

Regional crustal extension began in the late Oligocene or early Miocene. Fault-block subsidence overlapped temporally with volcanism, and some intrusions occur along faults [22]. Significant fault-block deformation continued into the Pliocene, post-dating the last volcanic rocks. The Hueco and Salt basins had the greatest subsidence and contain the thickest basin-fill deposits. These basins continued to subside in the Holocene and have Quaternary fault scarps [23]. Fault scarps offset the surfaces of Southeast Eagle Flat and Red Light Draw basins in only two places [23] (Figure 1). Elsewhere, including all of Northwest Eagle Flat Basin, Tertiary and Quaternary faults do not offset the exposed surfaces, of mid-Pleistocene through Holocene age.

Basin Morphology

The morphology of Northwest Eagle Flat Basin is typical of the closed, undissected basins in this region [24]. Hills and mountains form the uplands. These areas are being eroded and expose Cretaceous bedrock or have bedrock covered by a thin soil. Below the uplands is a highly varied piedmont. Well-defined, extensive piedmont alluvial fans and bajadas are found only adjacent to the Eagle Mountains and Streeruwitz Hills in the eastern part of the basin. To the southwest, there is a more poorly defined piedmont, consisting of a broad, low relief pediment and alluvial fan that merges imperceptibly with the alluvial flat. South of Blanca Draw is a low range of hills of soil-covered Cretaceous limestones and sandstone bedrock. These hills extend down to the floor of Blanca Draw with no intervening piedmont. Local gravels fill small drainages in the hills, but these do not form alluvial fans or a piedmont distinct from the Cretaceous upland.

Gravels and coarse sands are only encountered beneath the floors of axial streams. The rest of the floor consists of a soil developed in silty and sandy muds. Discontinuous Holocene aeolian sand sheets, less than 1 m thick, have partially buried the silty sediment and the soil.

Basin-Fill Sediments

Lithification of the sediments in Northwest Eagle Flat Basin varies with depth of burial [16]. Conglomerates, sandstones, and mudstones are found deeper in the cores, whereas friable gravels, sands, and muds are found in shallower intervals. Over 100 cores drilled in the Northwest Eagle Flat Basin reveal four textural classes: gravels; sands; sandy muds, muddy sands, and muds; and axial channel sands which form 5- to 10 m-thick packages of well-sorted, clean sands that exhibit trough cross-bedding, ripples, and other current-formed structures.

A typical core contains an upper section, 10s to 100s of meters thick, of alternating centimeter- to meter-thick beds of sandy mud with isolated axial channel sands. Deeper in the core, near the top of bedrock, muddy sands and sands from a few centimeters to 0.5 m in thickness are more common. At the base of the basin-fill deposits, silty gravel and gravel units become abundant. Gravels are thickest along the margins of the deepest basin fill, attaining 61 m near the center of the basin. The sandy muds that make up the bulk of the section are macroscopically remarkably structureless. Evidence of soil-forming processes is much more common. Thin rhizocretions and root molds are present in many horizons. Well-developed paleosol horizons are common only in the upper 50 m of basin fill.

Basin-floor aggradation probably ended about 100,000 - 350,000 years ago, when the landscape stabilized and a calcic soil formed across most of Northwest Eagle Flat Basin [25]. This exposed surface of erosion and nondeposition, termed the Arispe surface [25], has been dated as early-Late Pleistocene or a little older. In the latest Pleistocene, the Arispe surface was incised 4.6 to 7.6 m to form an axial drainage system, Blanca Draw. After incision, the washes were refilled by a combination of slopewash down the draw flanks and axial braided streams flowing down Blanca Draw. Blanca Draw contains an upward fining succession of deposits, the uppermost 1 m containing fine-grained, silt-rich, sand-poor sediment [25]. Radiocarbon dates of 16,500 to 2,350 BP (Before Present) from snails and humates suggest that the refilling of the axial network probably began earlier than 16,000 years ago and was largely completed by 2,350 years ago. Currently the wash floors lie 2.3 to 3 m below the Arispe surface. Some tributaries of Blanca Draw have been filled by aeolian sediment and no longer form continuous drainages.

Depth to Bedrock

Borings are the main source of information for the deeper Tertiary and Quaternary fill of Northwest Eagle Flat Basin [16]. Where the slope is well constrained, the subsurface bedrock contact slopes at 2% to 5%. This angle is similar to the average slope of the exposed bedrock uplands and much steeper than the 0.43% slope of the present alluvial flat. The outstanding feature of the bedrock surface is a buried escarpment, whose slope exceeds 15%, that underlies part of the proposed repository site. The escarpment may form part of the southern margin of the graben that created Northwest Eagle Flat Basin [16]. Normal faults offset Cretaceous strata north of Sierra Blanca, near the projected trend of the buried escarpment.

SIERRA BLANCA SITE REMOTE SENSING ANALYSIS

LANDSAT Thematic Mapper (TM) imagery has been used since 1982 to map exposed geologic structures in bedrock. It has proven useful for mapping exposed surface offset in unconsolidated Pleistocene and Holocene sediment [2,26]. TM imagery has also been used successfully to map bedrock structures buried beneath unconsolidated sedimentary cover; especially where such buried structures control surface and near-surface geologic and hydrogeologic processes in unconsolidated cover. Such geologic processes often include controls on groundwater flow. These mapping capabilities have been key in conducting a preliminary structural interpretation of the Sierra Blanca (Faskin Ranch) Low-level Radioactive Waste Disposal Site in Hudspeth County, West Texas. Earlier work [2] on the failed Fort Hancock site validated the utilization of remote sensing as a major cost-effective tool in the site selection process.

At the Fort Hancock site, these authors found violations in exclusion criteria 3, 7, and 8 and inclusion criterion 20 (Table I) based on interpretation of LANDSAT TM imagery with 30-m resolution, mapping at a scale of approximately 1:50,000. Exclusion 7 is concerned about tectonic processes, such as faulting, folding, seismic activity, or volcanism. Image interpretation showed the presence of a young fault scarp with evidence of repeated movements (the Campo Grande Fault) in unconsolidated sediment adjacent to the site. This indicated an unacceptably high level of risk of repeat faulting, and also made the possibility of modeling the site difficult (exclusion 20). The interpretation also revealed structurally controlled drainages in unconsolidated, unfaulted layers overlying faulted and fractured bedrock. These alignments are formed through the reactivation of geologic structures by periodic, low-magnitude movements that maintain fracture zones within unconsolidated sediments that overlie faulted bedrock.

Exclusion 8 deals with areas that should be avoided because such surface geological processes as mass wasting, erosion, slumping, landsliding, and weathering occur with such frequency and severity as to adversely affect site performance. The LANDSAT imagery interpretation showed evidence of rapidly eroding (exclusion 8), structurally controlled drainages that upon field investigation were found to be associated with mass wasting and slumping. Mass wasting appeared to be associated with ground water intrusion (exclusion 3) into the near surface within the site. These three exclusions at the least require ground truth examination to determine whether or not they present fatal flaws for the site. Printed images can be used for fieldwork in the efforts to obtain the necessary surface documentation on these exclusions.

LeMone and others [2] concluded that "in retrospect, had the LANDSAT material been available and the expertise developed enough at the time of decision on the Fort Hancock site, the site would have been most likely rejected by them.” The recognition by the Authority of these problems would have saved them a great deal of time, money, and labor. Remote sensing using LANDSAT images is an effective early analytical tool to determine the presence of potential fatal flaws. Additionally it provides a base line document for determining physical and financial remediation responsibility.

Following the successful application of LANDSAT image interpretation to the Fort Hancock site, the authors began to investigate the mapping capabilities of Enhanced Thematic Mapper (ETM) imagery for similar applications, in this case, over the Sierra Blanca (Faskin

Ranch) site (images 1,2,3,4). The ETM+ imagery has higher spatial resolution (15 m) than the older TM imagery (30 m). This allows mapping at larger scales, with more detail. Interpretation was accomplished at a scale of approximately 1:25,000 using the higher resolution imagery. The goals for this interpretation were to look for the kinds of exclusion/inclusion evidence that were successfully interpreted during the previous study.

Specifically, the imagery has been used to address four elements that might have led to an early exclusion of the proposed site. These include:

- The necessity to avoid tectonic processes such as frequent faulting that might significantly affect site performance (exclusion number 7)
- The necessity to preclude ground water intrusion into the waste (exclusion number 3)
- The necessity to avoid areas where surface geologic processes might affect site performance (exclusion number 8)
- The necessity to be able to characterize, model, analyze, and monitor the site (inclusion number 20)

Evidence for recent or recurring fault activity was sought in both the bedrock outcrop areas and the areas covered by unconsolidated sediments. Within bedrock outcrop areas in small scattered mountain ranges throughout the study area, both faults and fractures are easily mapped with the high-resolution imagery. These faults and fractures show up primarily as structurally controlled drainages, and in some cases, actual offset of outcrop patterns. The key element to suggest recent or recurrent fault activity would be the extension of the structurally controlled drainages into the areas of unconsolidated sediment cover. There is very little indication of this, except closely adjacent to the range fronts where the sediment cover is very thin.

The basinal areas do not show evidence of structurally controlled drainages, which are known to form in several ways, including those through the reactivation of geologic structures by "continued stresses." These types of drainages are generated by a stress field "with similar orientation to that which generated the buried structure, but of a reduced magnitude such that the overlying cover is not significantly deformed" [26, p. 86]. This type of periodic, low-magnitude fault reactivation can maintain fracture zones within unconsolidated sediments that overlie faulted bedrock, resulting in the development of structurally controlled drainages in unconsolidated sediments. It does not appear to be active in the Sierra Blanca area. There is also no evidence of actual fault offset in unconsolidated sediments in the Sierra Blanca study area.

In the previously studied Fort Hancock study area, there was evidence for rapid development of drainages in unconsolidated sediments associated with the type of low-magnitude fault reactivation described above. These drainages were characterized by deep, linear gullies that were in alignment with bedrock fault and fracture zones. Inspection in the field revealed active slumping and mass wasting activity associated with these drainages.

In the Hueco Basin, deep, linear gullies are associated with the presence of near-surface/surface-active fissures within the unconsolidated sediments. Piping and sapping processes operating within fracture zones in the unconsolidated sediments overlying faulted bedrock create these features. This indicated that groundwater intrusion was probably creating a situation where surface geologic processes (collapse features, piping, and sapping) might affect site performance (exclusion number 8). In addition, the piping and sapping phenomena represents groundwater intrusion into near-surface sediments, activating concerns that exclusion number 3 is in play.

The absence of evidence that low-magnitude fault reactivation is maintaining fracture zones within unconsolidated sediments in the Faskin Ranch area indicates that excluded surface geologic processes and groundwater intrusion that would be expected are not indicated as problems in this area. In the Fort Hancock area, several lines of evidence suggest exclusionary problems, such as active faulting, surface geologic processes, and groundwater intrusion. This resulted in the conclusion of LeMone and others [2] that the Fort Hancock site could not be effectively modeled (inclusion number 20). In particular, the strong evidence of reactivated faults and fracture zones precluded modeling. There is no evidence interpreted from the imagery in this study to suggest that structural reactivation is a problem that would hinder geologic modeling in the Sierra Blanca site.

CONCLUSIONS

Using the newer, higher resolution ETM imagery to search for evidence of excluded and included indications in the Sierra Blanca (Faskin Ranch) site should have shown indications of fatal flaws in more detail, if they are present. However, the enhanced images do not reveal such fatal flaws. The authors conclude that the tectonic activity in the Sierra Blanca site is much less recent and active than in the previously studied site. Therefore, the interpretation of the ETM would not have prompted an early abandonment of the site, as would have been the case in the earlier study at Fort Hancock [2]. Most critically, it must be remembered that it provides baseline documentation for determining physical and financial remediation responsibility. On the basis of these two sites examined by LANDSAT remote sensing, it is concluded that it is an essential, cost-effective tool that should be utilized in all nuclear-related facilities.

Realistically the problem of establishing any site for a new, near-surface low-level repository for the Texas Compact or any other national state or compact entity is politically and legally unacceptable. It would seem that the only viable solution for this continuing impasse between the environmentalists, regulators, stakeholders, and nuclear-related civilian organizations (power plants, medical, industrial, and research) is the adoption of an engineered, monitored, above-grade assured isolation facility [1,6]. Such a facility allows for continuous monitoring for the length of time necessary for the radioactive waste to decay to a safe level, allows on-demand inspection of the facility and its waste, and results in a recoverable, utilizable surface structure.

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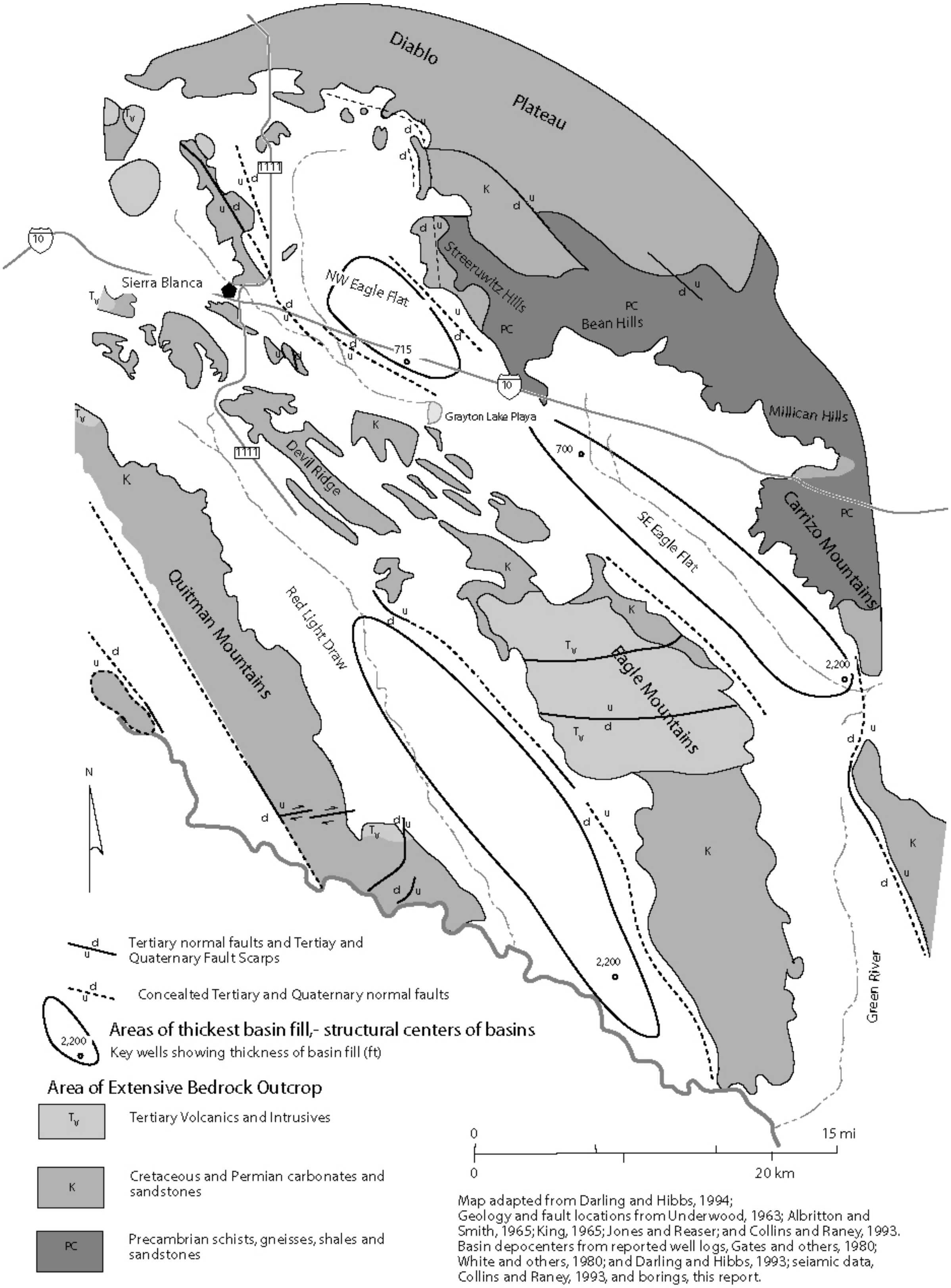
TABLE I. Modified from March 1985 CRITERIA FOR SITE SELECTION
(Based on 10 CFR 61, NUREG 0902, TDH Draft Reg. Guide 6.1 and TRCR guidelines)

EXCLUSIONS

1. Disposal sites shall not be located in the 100-year floodplain, coastal high-hazard zone, or wetlands.
2. The site should be located so that drainage is minimal and easily manageable. This generally indicates an area with an existing grade of 5 percent or less.
3. The site should be located so that there is sufficient depth to the water table to preclude groundwater intrusion, perennial or otherwise, into the waste.
4. Any groundwater discharge to the surface within the disposal site shall not originate within the hydrogeologic unit used for disposal.
5. The site shall not be located on the recharge zone of the major or minor aquifers of Texas.
6. The disposal site shall not be located in an area where future population growth or developments are likely to affect the ability of the site to meet its performance objectives.
7. Areas must be avoided where tectonic processes, such as faulting, folding, seismic activity, or volcanism occur with such frequency and extent to significantly affect site performance.
8. Areas should be avoided where surface geological processes such as mass wasting, erosion, slumping, landsliding, and weathering occur with such frequency and severity as to adversely affect site performance.
9. The site shall not be located in an area where severe meteorological conditions such as tornadoes, excessive winds, or thunderstorms occur with sufficient frequency as to adversely affect site performance.
10. The disposal site shall not be located where nearby facilities or activities could adversely impact the site's ability to meet performance objectives.
11. The site should not be located within or adjacent to national or state parks, monuments, or wildlife management areas.
12. The site should be located in an area of minimal archaeological significance but should not be located adjacent to a historic site designated by the State Historical Commission.
13. The site should not be located in an area where disposal operations could adversely affect the habitat of endangered or protected species.
14. Areas should be avoided which have economically significant, recoverable natural resources which, if exploited, would result in the failure of the site to meet performance objectives.
15. The area to be used for actual disposal operations should have no recorded easements on it.
16. The site will not be within 20 miles upstream or up drainage from the maximum elevation of the surface of any reservoir that has been constructed or is under construction by the United States Bureau of Reclamation or the United States Corp of Engineers or has been approved for construction by the Texas Water Development Board as part of the state water plan under Subchapter C, Chapter 16, Water Code. (H. B. 449)

INCLUSIONS

17. The proposed site should be accessible. Rail or barge transportation is desirable.
18. The site should preferably be located on existing state-owned land to minimize site acquisition problems and cost.
19. The site should be located such that transportation problems are minimized.
20. The site should be capable of being characterized, modeled, analyzed, and monitored.



Map adapted from Darling and Hibbs, 1994;
Geology and fault locations from Underwood, 1963; Albritton and Smith, 1965; King, 1965; Jones and Reaser; and Collins and Raney, 1993.
Basin depocenters from reported well logs, Gates and others, 1980; White and others, 1980; and Darling and Hibbs, 1993; seiamic data, Collins and Raney, 1993, and borings, this report.

Fig. 1. Map of the area surrounding Faskin Ranch.

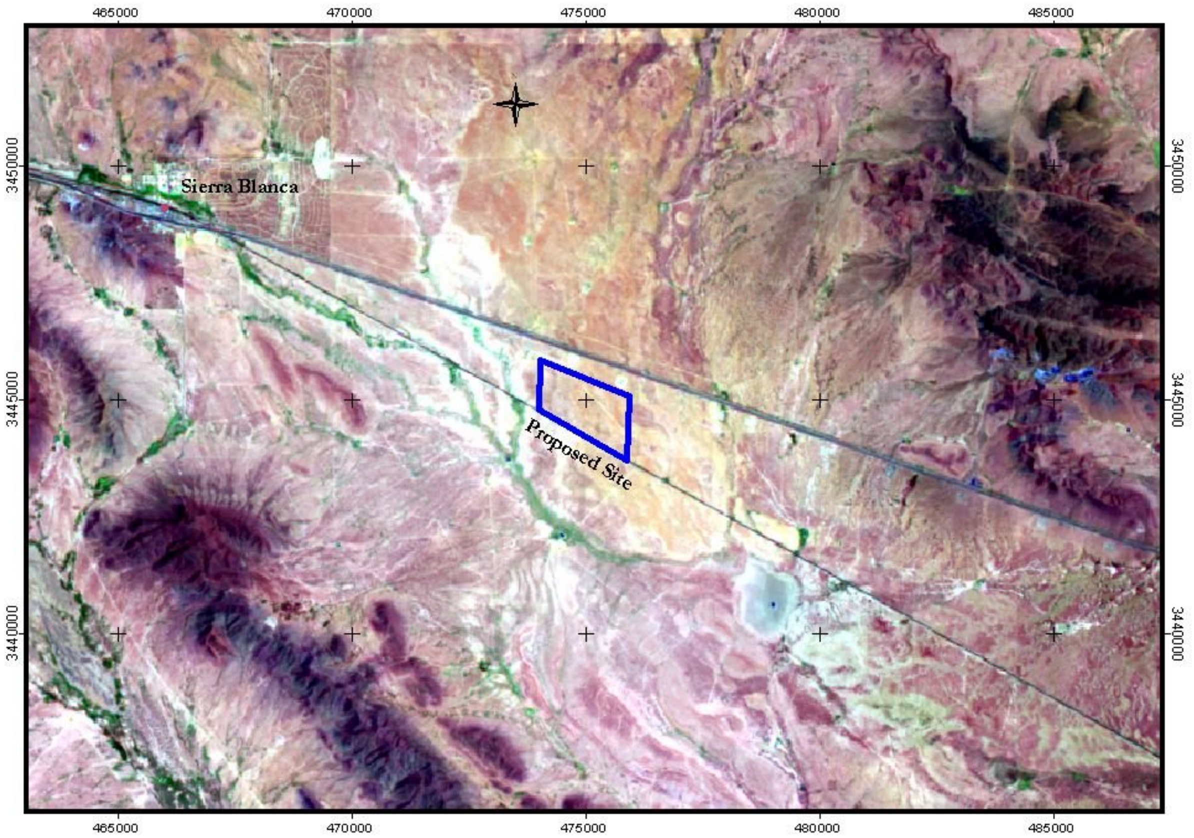


Fig. 2. TM 32/38 (5/20/1986), False Color(bands 742), Coordinate System: WGS 1984, UTM Zone 13N(Image 1)

Scale = 1:100,000

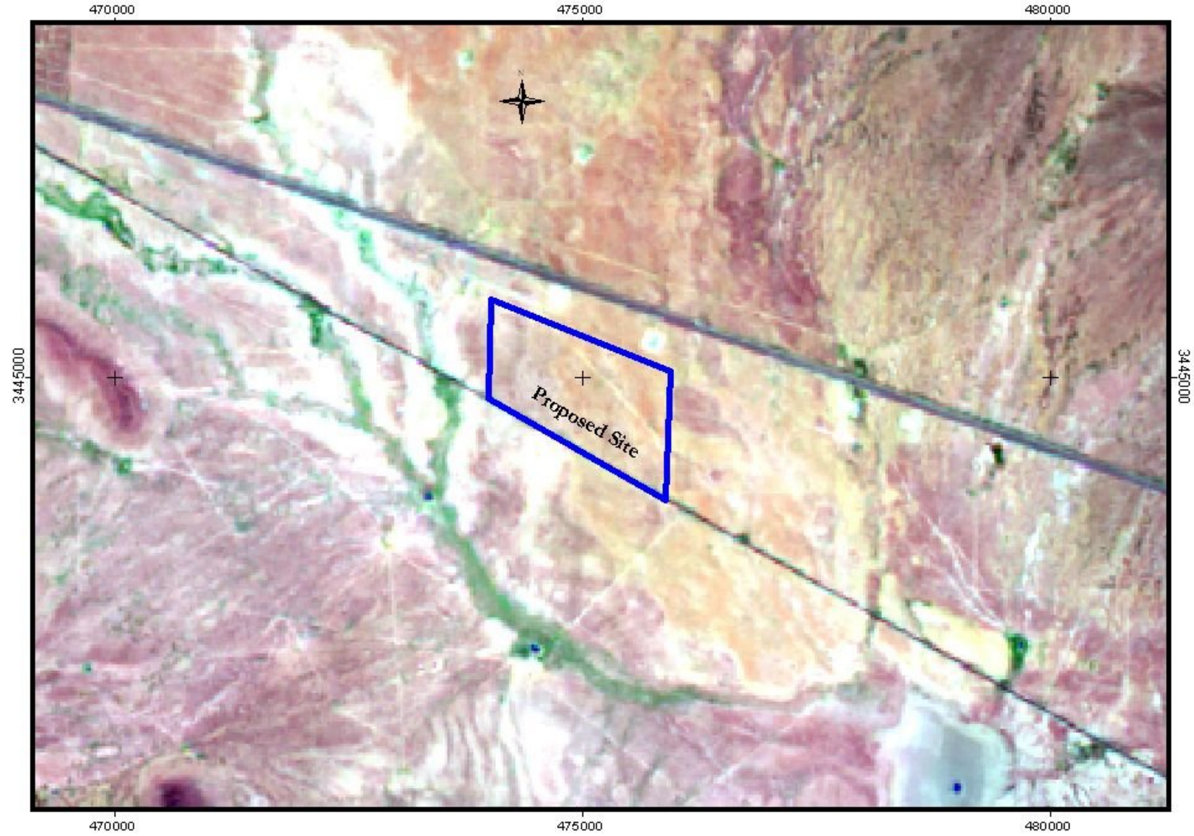


Fig. 3. TM 32/38 (5/20/1986), False Color (bands 742), Coordinate System: WGS 1984, UTM Zone 13N(Image 2).

Scale = 1:50,000

0.5 0 0.5 Kilometers

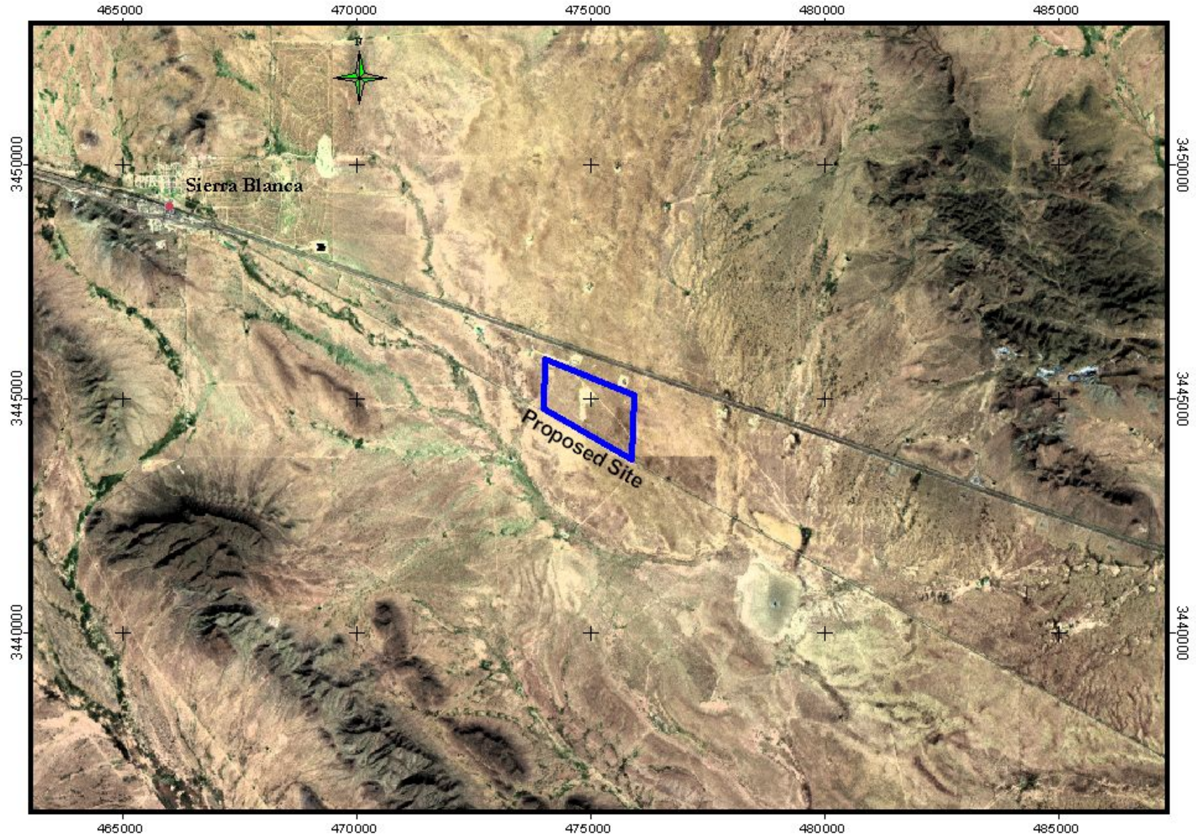


Fig. 4. ETM+ 32/38 (10/23/1999), False Color (Bands 742 fused with pan) Coordinate System: WGS 1984, UTM Zone 13N(Image 3).

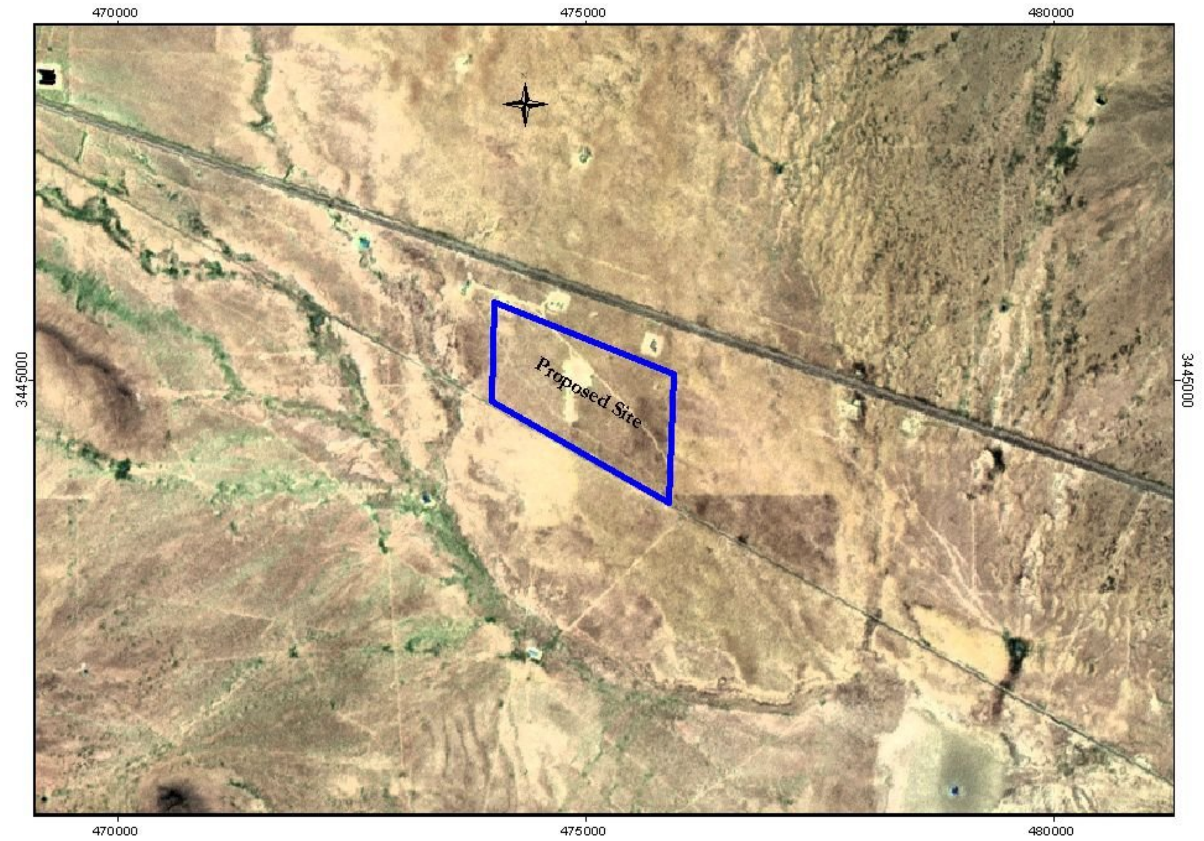


Fig. 5. ETM+ 32/38 (10/23/1999), False Color (Bands 742 fused with pan) Coordinate System: WGS 1984, UTM Zone 13N (Image 4).

Scale = 1:50,000

0.5 0 0.5 Kilometers