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United States Department of Agriculture
Soil Conservation Service **Chester, PA 19013**

Subject: Ground-Penetrating Radar (GPR) buried ordnance detection on Kahoolawe, Hawaii, 26-28 January 1993 **Date:** 18 February 1993

To: Nate Conner
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Purpose:
To investigate the potential of using GPR techniques to detect buried and potentially dangerous buried ordnance on Kahoolawe

Participants:
Jim Doolittle, Soil Specialist, SCS, Chester, PA
Saku Nakamura, Assistant State Soil Scientist, SCS, Honolulu, HI
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Activities:
During the morning 26 January, participants were ferried to Kahoolawe on USMC Sea Knight helicopter. The equipment was unpacked and taken to a calibration site. At the calibration site, dummy ordnance were buried at depths of 7 and 12 inches. The radar detected the buried projectiles at both depths. On 26, 27, and 28 January, multiple transects were conducted with GPR in several areas of the Island. Anomalies were located, excavated, and identified along transects. Severe winds delayed our departure one day. On 29 January, SCS participants were ferried back to Pearl Harbor on an Army Chinook helicopter.

Equipment:
The radar units used in this study was the Subsurface Interface Radar (SIR) System-3 manufactured by Geophysical Survey Systems, Inc. The SIR System-3 consists of the Model PR-8300 profiling recorder. The system was powered by a 12-volt vehicular battery.
The Model 3110 (120 mHz) with a Model 705DA transceiver was used in this field studies. The low frequency 120 mHz antenna was considered the most suitable antenna for penetrating the relatively fine and moderately-fine textured soils of Kahoolawe. Compared with higher frequency antennas, the 120 mHz antenna has greater powers of radiation, longer pulse widths, and emits signals that are less rapidly attenuated by earthen materials.

Results:
Study Area One - 28 January 1993
This study area was located on photo USN 12 KTF 486-65 in an area immediately south and across the road from an observation tower. An impact zone was included in a portion of this study area. A long,

meandering traverse with the GPR was divided into five, one thousand-foot transects. Table 1 summarizes the number of anomalies detected along each transect. Transect one and two were nearest to the impact zone. Each sequential transect was farther removed from the impact zone.

TABLE 1

Anomalies Detected with GPR along 1000 Foot Transects

Transect Number	Anomalies Detected	Within 7"
1	5	2
2	6	3
3	2	1
4	1	1
5	3	1

Five of the seventeen anomalies were ground-truth in observation pits. Two of the anomalies were verified to be projectiles. Two anomalies were confirmed to represent pinnacles of saprolite. One anomaly was not verified and was assumed to have been missed by the observation pit. Each projectile was about 4 inches in diameter and about 7 inches long. One was buried at 7 inches, the other at 17 inches. The orientation of both projectile tips was upwards.

Study Area Two - 28 January 1993

This study area was located in an impact zone on photo USN 12 KTF 486-55. The study area was located north of the observation tower. An impact zone was included in a portion of this study area. Three short transect lines were conducted in this study area. The lengths of these lines varied from 9 to 100 meters. Generally, transect were orientated to cross small hummocks and depressions. It was believed that these features may have been caused by the impact or explosion of projectiles.

Transect line 1 was about 30 meters long. Seven anomalies were detected along this line. The identity of two of the detected anomalies were verified in observation pits. One anomaly was located on the side of a hummock, the other in a depression. The anomalies were identified as exploded shells with fragments buried at depths greater than 2 to 6 inches.

Transect line 2 was about 9 meters long. One anomaly was detected along this line. The anomaly occurred in a depression. While digging a tennis ball sized anti-personnel bomb rolled into the observation pit. The bomb had been lodge in the loose side wall at a depth of about 5 inches. Excavation was immediately halted at this point.

Transect line 3 was about 28 meters long. Four anomalies were detected along this line. One anomaly, located in a depression, was excavated. Again, while digging, a tennis ball sized anti-personnel bomb rolled into the observation pit. The bomb had been lodge in the loose side wall at a depth of about 6 inches. Excavation was immediately halted at this point. No further excavations were attempted during this study.

The two anti-personnel bombs were not the anomalies discerned on the radar profiles. The anomalies detected were larger and occurred at deeper depths. It was presumed that the detected anomalies were buried projectiles. These projectiles would have formed depressions filled with loose soil materials. It was suggested that the anti-personnel bombs had rolled into these depressions and were subsequently buried by eolian/alluvial deposits.

Study Area Three - 28 January 1993

This study area was located in a proposed site for the planting of native cotton and abutilon raised from SCS seed stock. The study area was located on photo USN 12 KTF 486-29. The soils at this site belong to the fine, oxidic, isothermic Typic Eutrustox family. Within the study area, soils had been severely eroded.

Transects were 400 feet long and orientated in a general north-south direction between shelter belts of tamarisk trees. Transect were laid out and surveyed from east to west across the site (line 1 was the eastern-most; line 6 was the western-most). Observation marks were inserted on the radar profiles at 30.5 meter intervals. Table 2 summarizes the results from this survey.

TABLE 2
Anomalies Detected within Site 3

TRANSECT	ANOMALIES DETECTED
1	5
2	5
3	4
4	4
5	9
6	8

The number of anomalies detected at this site was considered high. However, not all of the anomalies detected at this site were believed to represent projectiles. As rocks were on the surface, some of the anomalies detected were presumably rocks.

Study Area Four - 28 January 1993

A 2.9 mile traverse was conducted in a downslope direction on photo USN 12 KTF 486-27 and 43. Soils along this traverse principally belong to the fine, oxidic, isothermic Typic Eutrustox family. Compared with the soils from Study Area Four, soils along the traverse line have a yellow subsoil. Soils had been severely eroded.

Observation marks were inserted on the radar profiles at 0.1 mile interval to provide reference and to segment the traverse. Table 3 summarizes the number of anomalies detected within sequential 0.1 mile intervals of the traverse. The traverse was conducted in a downslope direction.

TABLE 3
Anomalies Detected within Site 4

INTERVAL (MILE)	ANOMALIES
0.0 - 0.1	0
0.1 - 0.2	0
0.2 - 0.3	4
0.3 - 0.4	6
0.4 - 0.5	1
0.5 - 0.6	1
0.6 - 0.7	0
0.7 - 0.8	0
0.8 - 0.9	1
0.9 - 1.0	1
1.0 - 1.1	0
1.1 - 1.2	0
1.2 - 1.3	1
1.3 - 1.4	2
1.4 - 1.5	1
1.5 - 1.6	1
1.6 - 1.7	2
1.7 - 1.8	0
1.8 - 1.9	0
1.9 - 2.0	0
2.0 - 2.1	0
2.1 - 2.2	0
2.2 - 2.3	0
2.3 - 2.4	2
2.4 - 2.5	3
2.5 - 2.6	4
2.6 - 2.7	3
2.7 - 2.8	3
2.8 - 2.9	5

The traverse can be divided in segments having high and low concentrations of anomalies. The average number of anomalies detected per tenth of a mile was 1.4 with a range of 0 to 6. If the detected anomalies represent buried ordnance, portions of the traverse should be approached with caution.

During the course of this survey, it was observed that soils immediately adjoining some sides of large craters often contained a large number of small point reflectors. These reflectors were presumed to represent shrapnel from exploded ordnance.

Discussion:
The size, orientation, and depth to a projectile affects detection. Large objects reflect more energy and are easier to detect than small objects. Small ordnance, unless directly beneath the path of the radar antenna may be missed. Small, deeply buried ordnance are difficult to discern on radar profiles.

The disruption of soil horizons makes some ordnance detectable. On radar profiles, reflections from a projectile may occur at the base of an inverted "V," which marks the point of entry and soil disturbance. Near large craters, numerous point reflectors were often noticed. These reflectors are believed represents shrapnel from exploded ordnance.

The identification of a subsurface reflector is based on knowledge, experience, and inferences. Identification depends on local soil conditions, depth, and geometry of the buried projectile.

In highly attenuating soils, profiling depths are restricted and the identity of subsurface features is often inferred from disrupted or disturbed soils horizons. At many sites, the most distinctive feature may be the disturbed soil materials which fill and cover the projectile. However, caution must be exercised as a number of artificial and natural processes can produce disturbed soil conditions.

Ordnance can be difficult to distinguish in soils containing stratified or segmented layers, numerous rock fragments, tree roots, animal burrows, modern ordnance or disturbed soil conditions. These scattering bodies produce undesired subsurface reflections which complicate the radar imagery and can mask the presence of buried ordnance. Under such conditions, the buried ordnance can be indistinguishable from the background clutter unless signal reverberation exists.

In the search for buried ordnance using GPR techniques, success is never guaranteed. Even under ideal site and soil conditions buried ordnance have been missed with GPR. The usefulness of GPR data depends on the amount of uncertainty or omission that is acceptable.

Conclusions:
1. Ground-penetrating radar can detect buried ordnance on Kahoolawe.

Observation pits confirmed the capability of GPR to detect buried anomalies at within depths of 50 cm in areas of fine textured soils on Kahoolawe. Anomalies were observed in 8 of the 9 observation pits at inferred locations and approximated depths. One anomaly was missed in sampling and was unconfirmed. Six of the eight observed anomalies were unexploded or large fragments from exploded ordnance. Two of the eight observed anomalies were rock fragments. Small object (such as cluster bombs), not directly beneath the radar, may be overlooked.

2. Most depressions and hummocks should be considered as potentially hazardous sites.

On the basis of the study conducted at Study Area Two, it appears that many depression and hummock are the products of the impact or explosion of bombs. Many of these features contain projectiles or their remnants. These areas should be avoided during excavations or excavated with extreme caution.

3. No site should be considered free or buried ordnance.

Study Area Three, the proposed site for the planting of native cotton and abutilon raised from SCS seed stock, was considered a relatively "clean" area, which was generally removed from the bombing areas and relatively free of buried ordnance. Thirty-five anomalies were detected along six traverses. These traverses had a combined length of about 218 m. The number of anomalies detected at this site was considered high. Though many of the anomalies were believed to represent rock fragments, unconfirmed inferences from GPR surveys suggest that this is a potentially hazardous site.

4. A GPR survey of Kahoolawe Island for the detection of buried ordnance is considered impractical and prohibitive.

GPR techniques can detect ordnance buried at shallow depths on Kahoolawe. However, with GPR surveys covering extensive areas, the detection of individual, buried projectiles is often coincidental. Intensive GPR surveys of small areas are more practical. However, even with the most intensive radar survey, "errors of omission" should be anticipated. It is unlikely that "all" ordnance will be detected with GPR.

This was a most unforgettable experience for me. With kind regards.

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