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A Radar Investigation of North Louisiana Salt Domes

Understanding energy-target interaction and target and terrain characteristics is critical in the mission planning phase of a remote sensing investigation.

Abstract: *An imaging radar mission over the North Louisiana Salt Dome area was designed to explore the possibility of providing terrain data concerning faulting associated with solution collapse and/or upward movement of the salt as well as doming over the salt mass itself. To maximize the possibility of data acquisition, the mission was flown to provide orthogonal looks at minimum depression angles in order to accentuate the minimal terrain relief in this area. However, terrain slopes (generally less than depression angle), vegetative cover, and lack of expression of structure provided a surface environment from which structural data could not be extracted in spite of the high quality of the imagery.*

Introduction

An article in the *Peruvian Times* of October 27, 1972, informed the reader that "SLAR looks through the trees, strips off the vegetation and shows the ground underneath. . . Finally, claim its users, the map is a true one, with none of the distortion inherent in an aerial photograph." On May 7, 1976, the *Kansas City Star* carried an article in which it was stated that "Six images from ERTS-1 last year showed that the Sinai Peninsula has huge water, oil and mineral resources." Documenting a capability of the ERTS-1 imaging system not previously recognized, it further stated, ". . . The second is the Mediterranean off-shore area in northern Sinai which has not been explored . . . Uranium was also detected in northwestern and southern Sinai."

Since the beginning of the utilization of remote sensing techniques in geologic exploration, such oversell, intentional or otherwise, has resulted in the development of skepticism concerning the value of remote sensing devices, particularly to the user who has experienced failure when success has been promised. Numerous papers have pointed to successful utilization of remote sensing devices, but rarely have investigators probed deeply enough to determine why hoped-for data had not been revealed in less successful ventures.

The Mission

The North Louisiana Salt Dome area (Figure 1), an area for which available geologic data are not as voluminous as for some of the other sites previously considered, is currently being investigated as a region suitable for radio-active waste disposal. Of prime concern is information

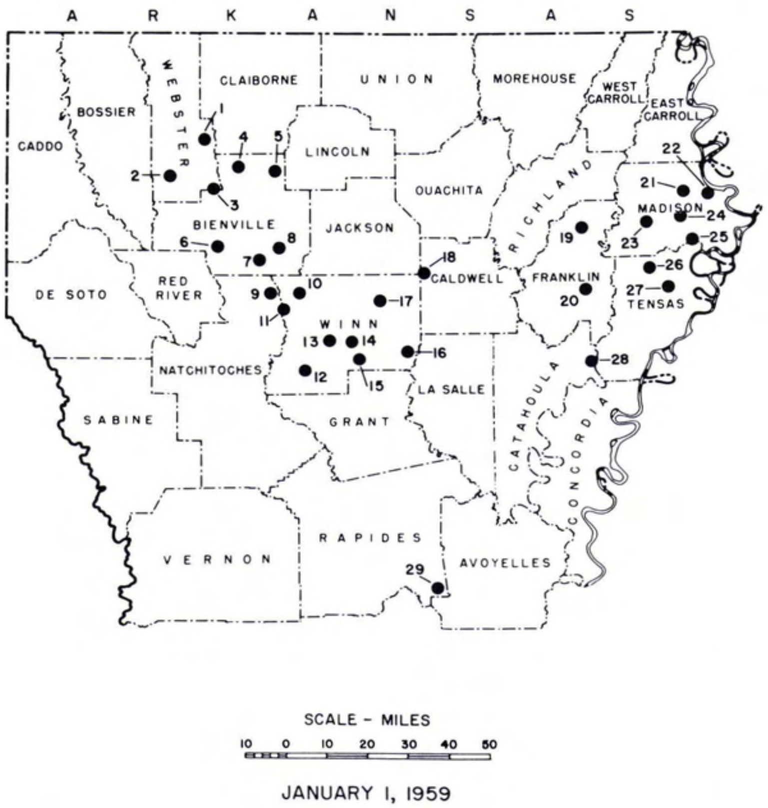

FIG. 1. Location of known salt domes in the North Louisiana Salt Dome area (modified from a map by the Louisiana Geological Survey):

1. Minden	7. Prothro	13. Winnfield
2. Bistineau	8. Rayburn's	14. Cedar Creek
3. Vacherie	9. Chestnut	15. Packton
4. Gibsland	10. Price's	16. Castor Creek
5. Arcadia	11. Drake's	17. Sikes'
6. Kings	12. Coochie Brake	18. Chester

concerning surface faulting or other movement which might indicate solution collapse and/or that upward flowage of the salt is taking place today or has taken place in the recent past. In order to obtain such information, all existing geophysical data are being evaluated; ground investigation has been initiated and devices for monitoring movement are being installed. Investigative techniques which offer even a slight possibility of providing the needed information are being evaluated and will be utilized when deemed at all feasible for the revelation of the desired data. Thus, with the hope of revealing surficially expressed fracture trends which might indicate the nature and degree of movement in the dome, a side-looking airborne radar (SLAR) survey was conducted. Although the aim of the mission was realized only to a limited degree, the utilization of SLAR imagery for vegetation discrimination was further documented and the revelation of circular vegetation anomalies not previously identified suggests a potential existence of domes heretofore unknown.

FLIGHT SYSTEM PARAMETERS

The radar used for this mission was an X-band (3 cm) synthetic aperture system. Depression angles between 5° in the far range and 15° in the near range were selected to provide maximum shadowing in this area of relatively uniform terrain and low relief. Recognizing that the revelation of desired structural or even topographic data might be look-direction dependent, orthogonal looks were provided with sufficient overlap of adjacent flight lines to place each terrain feature in a near and far range position. With each topographically expressed structural feature imaged from more than one direction and at different depression angles, it was essentially assured that in one image it would be in optimum position for shadowing, that is, with the range direction parallel to the direction of maximum slope of a dome or normal to a linear trend.

Resolution was not a particularly significant factor in this mission. The nominal resolution of 12 metres both in range and azimuth direction was more than adequate to effect the expression of the features being investigated.

Terrain Configuration and Vegetation

The North Louisiana Salt Dome area is a region of uniformly gently rolling topography and modest relief. River or stream valleys are often bordered by broad marshy areas. Maximum relief in the area is 400 feet. However, in the detection of linear or circular features associated with salt domes, other factors are more important; e.g., local relief between structurally defined valleys and adjacent topographic highs, between domal uplifts and adjacent depressions, and between solution-developed topographic depressions over domes and adjacent terrain not modified by salt movement. The revelation of such features through shadowing on radar imagery, in the case of a heavily vegetated area such as this, requires the conformation of the vegetation canopy to the underlying terrain.

Domes in the target area share few common characteristics in topographic expression. Local relief across the domes, with one exception (200 feet), does not exceed 150 feet. With the exceptions of Vacherie (1 by 3 miles) and Cedar Creek (0.8 by 0.5 miles), estimated dome diameters range from 1.0 to 1.5 miles (Table 1).

Ten of the 19 domes in this area have been mapped on the basis of topography, surface geology, and gravity data, and four of the remaining nine have been mapped by two of the three methods (Martinez *et al.*, 1976). In some instances gravity data do not agree closely with surface mapping of topographic expression as to the location of the salt domes. Furthermore, locations of known domes as defined on the radar imagery in some instances also differ slightly from positions as previously mapped.

Although large areas have been cleared for grazing or as a result of logging, the vegetation in this area continues to be dominated by pines on the interfluves and by broadleaf deciduous forest in the valleys and adjacent swamps. Because the pine areas are continuously being logged and planted, tree height is not uniform, being dependent upon the growth period since planting.

Due to the extensive activity of man in this area, generalizations are difficult, but vegetation in the valleys appears somewhat taller than the vegetation on the better drained interfluves. Tree heights of up to 90 feet were measured in the field in what appeared to be virgin or revegetated mature timber stands, and heights in excess of 100 feet were measured on the imagery.

Target Detection in SLAR Imagery

SLAR imagery revealed differences in vegetative cover which in general correlated with topography, but seldom were domal uplifts prominent enough to cause radar shadowing, even at these low depression angles. The contrast between broadleaf deciduous valley forest and pine interfluve forest is indicated by tonal contrast in the radar imagery, the broadleaf vegetation returning a stronger signal than the pines (Figure 2). Tonal and textural contrasts in X-band radar (wavelength = 3 cm) are due primarily to the configuration and microrelief of the vegetation canopy and the dielectric properties of that material (Reeves, 1975). In the mission area no penetration to the ground through the forest canopy would be realized at such low depression angles (Figure 3). Only in areas of pasture or other low vegetation might soil dielectric properties influence radar return.

Strong contrast in vegetation height between the far range side of a timbered area and adjacent pasture land in combination with the low depression angle is responsible for extensive shadowing throughout most of the imagery (Figure 4). Not unexpectedly, there is also variation in tree height within timbered areas. This is indicated by the shadowing behind individual trees or groups of trees which stand higher than those adjacent. As is indicated (Table 2), any group of trees which stands only 10 feet above adjacent trees in the far range will cast a shadow approximately 115 feet across the adjacent canopy.

TABLE 1. CHARACTERISTICS OF NORTH LOUISIANA SALT DOMES (MARTINEZ *et al.*, 1975)

		Cap Rock			Salt Stock					Topography				Geology	
Name of Dome	(1973) Rank Anderson et al	Found	No. of Wells	At Depth (feet)	Found	No. of Wells	At Depth (feet)	Probable Shape	Diameter (miles)	High Ground Over Dome	Central Depression	Lowest Elevation (feet)	Relief (feet)	Normal Surface Formation from ORNL sub 4112-10, Fig. III-A-5	Oldest Surface Formation
Arcadia		Yes	5	1282	Yes	4	1400	Circular	1.5	Yes	Yes	280	60	Cook Mt.	Cook Mt.
Bistineau		Yes	1	1375	Yes	1	2305 (Flank)	Circular	1	No	Yes	140	40	Pleistocene	Cretaceous
Castor Creek	7	No	0		No	0				No	No	67	35	Pleistocene Cockfield	Pleistocene
Cedar Creek	6	Yes	3	569	No	0		Ellipse	.8×.5	Yes	Yes	75	65	Pleistocene	Cook Mt.
Chester		Yes	1	4350	Yes	1	4840					130	90	Cockfield	Cockfield
Chestnut		Yes	2	1757	Yes	2	2450 2437			Yes		150	110	Recent Alluvium Cockfield	Carrizo
Coochie Brake		No	0		Yes	1	(Flank)	Circular	1.5	No	Yes	160	100	Pleistocene	Cockfield
Drake's		Yes	4	200	Yes	2	850	Circular	1	Yes	Yes	120	120	Pleistocene	Wilcox
Gibsland		Yes	7	612	Yes	5	885			Yes	Yes	190	30	Sparta	Sparta
King's	5	Yes	3	161	Yes	3	192			No	Yes	165	40	Cane River Cockfield	Cretaceous
Milams		Yes	1	4147	Yes	1	4430			Yes		150	90	Cook Mt., Pleist.	Cook Mt.
Minden		Yes	25+	1190	Yes	8+	1912	Circular	1	Yes	No	260	100	Cook Mt.	Cook Mt.
Packton		Yes	1	6266	Yes	1	6425			Yes	No	180	45	Cockfield Sparta	Cockfield
Price's	4	No	0		No	0	1058			Yes	Yes	120	80	Pleistocene	Wilcox
Prothro	2				Yes	1	(Flank)			Yes	Yes	180	150	Sparta	Cretaceous
Rayburn's	3	Yes	2	80	Yes	2	130			Yes	Yes	190	90	Sparta	Cretaceous
Sikes		Yes	1	4435	Yes	1	4931			Yes	No	165	85	Cockfield Sparta	Sparta
Vacherie	1	Yes	8	658	Yes	4	777	Ellipse	1×3	Yes	Yes	180	200	Pleistocene	Wilcox
Winnfield	8	Yes	29		Yes	26	200	Circular	1	Yes	Yes	140	120	Cockfield	Wilcox

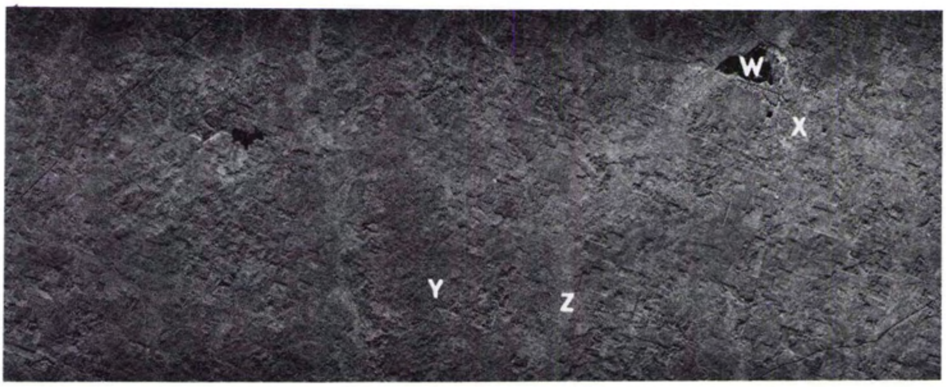

FIG. 2. Acquisition scale (1:400,000) print imaged at depression angles between 5° and 10°. Characteristic contrast of return from upland pine (Y) and valley deciduous (Z) vegetation aids in mapping stream valleys and identifying topographically expressed linears. W = Black Pond; X = Jonesboro, Louisiana.

As stated previously, because of, at best, low relief between domes and adjacent terrain, shadowing of domes seldom occurred. Taking into consideration the dimensions of recognized domes in this area, and assuming a uniform slope from crest to adjacent trough (maximum distance 0.5 miles), we note that in order for a dome to produce a radar shadow the minimum relief at 5° depression angle must be 230 feet, or at a 15° depression angle, 707 feet. This requires slopes of 9 feet per hundred (462 feet per mile) and 27 feet per hundred (1415 feet per mile) at 5° and 15°, respectively. This suggests that definition of a dome on a radar image solely on the basis of topographic expression would probably not be realized unless the high point of the dome is located, not in the center, but near the margin of the dome and thus provide for the development of a sufficiently steep slope locally between dome and adjacent terrain to effect shadowing. As indicated by the sparsity of shadowed areas other than those resulting from timber stands on the near side of clear areas, such local relief is rarely achieved.

Enhancement of linear features also requires the development of slopes which exceed those in this area. Although an actual terrain rarely conforms to geometric patterns or develops a relief characterized by uniform slopes, examination of a hypothetical cross section of low relief terrain (Figure 5) suggests that an optimum depression angle for revelation through shadowing of contrast between a near range slope dipping away from the flight line and a far range slope dipping toward the flight line in this environment is not achievable. Assuming slopes of 5° (defined by a local terrain relief of approximately 9 feet per hundred feet), imaging of such slopes at a depression angle of 10° should result in a maximum (but only nominally so) amount of energy scattered from surfaces dipping both toward and away from the images being directed away from the antenna and approximately the same amount of energy from both slopes being reradiated toward the antenna. Furthermore, on the very rough surfaces (a condition existing because of dense vegetative cover) backscatter is relatively independent of incidence angle.

At acquisition scale (1:400,000) a dome of 1 mile in diameter would appear as 0.16 inches on the image and at the enlarged scale of 1:50,000 a dome of 1 mile in diameter would be displayed at approximately 1.3 inches in diameter. The probability of identification of faults associated with movement of the dome is questionable inasmuch as one would not expect the faults to extend more than approximately 1

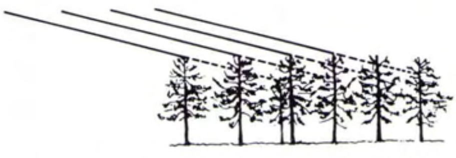

FIG. 3. Imaging at low depression angles in forested area does not permit penetration of vegetation because of the distance the signal must pass through the cover during which time it is continuously attenuated and scattered.

FIG. 4. Enlargement (6× acquisition scale) to a scale of 1:67,000 of a portion of a SLAR image. Depression angle is approximately 9°. Note shadows east by forest across adjacent pasture land.

mile from the dome, a distance which is not sufficient on acquisition scale imagery (0.16 in) to define a linear trend.

The fact that SLAR imagery does not effectively shadow salt domes of the North Louisiana Salt Dome Basin or identify potential fractures associated with domal uplifts should not be interpreted as a criticism of the capability of SLAR, for there appears to be no indication of surface structures associated with domal uplift in currently available published data. It appears reasonable to conclude that the lack of detection of surface faulting on imagery is due to the nonexistence of surface faults rather than to a deficiency in the imagery. Although SLAR imagery has often revealed linear trends not otherwise detected, such is not the case in this mission.

TABLE 2. SHADOW LENGTHS (IN FEET) OF OBJECTS AT NEAR, MID-RANGE, AND FAR RANGE.

Height of Object (feet)	Far Range (5°)	Mid-Range (10°)	Near Range (15°)
2	22.86	11.34	7.47
4	45.72	4.18	14.93
6	68.58	34.03	22.40
8	91.44	45.38	29.86
10	114.30	56.72	37.33
20	228.60	113.44	74.65
30	342.90	170.16	111.98
50	571.49	283.61	186.64
70	800.00	397.05	261.29

Examination of the imagery of known salt domes at 1:50,000 did reveal concentric patterns of tonal or textural contrast and sometimes circular drainage patterns and/or curves in highways or roads. Using such patterns, together with circular topographic anomalies, the imagery was carefully examined for potential revelation of additional domes which had not previously been mapped by other methods. Concentric vegetational patterns proved to be the most helpful and 11 additional sites of potential domes were identified (Figures 6, 7, and 8).

CONSIDERATION OF OTHER METHODS AND SYSTEMS

In surveys conducted in terrain such as this, the area might have best been imaged at several depression angles in order to determine an optimum.* Although use of depression angles between 5° and 15° could be defended on the basis of maximum shadowing (a condition not realized), there is justification for suggesting a steeper depression angle in order to better accentuate the contrast between the return from slopes dipping away from nadir into topographic depressions and slopes dipping toward nadir into the depressions. It has been observed in calibrated radar scatterometer studies conducted on field crops (not forest vegetation)

* This option was not available at the time of imaging with the system utilized.

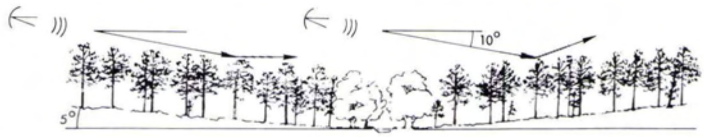

FIG. 5. Schematic presentation showing imaging at mid-range depression angle across a typical valley in the North Louisiana Salt Dome area.

at the University of Kansas that at higher depression angles a 20° contrast in incidence angle might result in an identifiable contrast. Whether or not such would apply to forest vegetation has not yet been ascertained from actual field tests.

In the Northern Louisiana Salt Dome Basin, the association with the domes of salt springs from which water issues at temperatures somewhat elevated above that in adjacent terrain suggests the possibility that thermal infrared imagery might have provided better information concerning the location of fractures along which seeps occur. Thermal infrared scanners can detect temperature differences in the order of 1°C and if such contrast exists between the warm soil and water at the springs and adjacent terrain it should be detected.

If salt water effluence occurs along faults or fractures associated with doming, it is reasonable to expect stress of vegetation or differences in species composition of the vegetation. The detection of stressed vegetation is best accomplished using a near infrared photographic film-filter combination. This is also effective for discerning differences in make-up of the plant community. Maximum stress should be detected during the summer when water supply is sparse. If temperature differences are sufficient in the ground water system between salt springs and adjacent terrain and salt concentrations are relatively low, the areas of increased temperature might experience earlier foliation and later defoliation of the vegetation, the optimum time of photographing being either in early spring or late fall.

A better understanding of movement, both in time and place, would be realized if a controlling regional pattern of fractures or folds could be identified. Structures in Lower

FIG. 6. Comparison of surface expression of known domes and topographic and/or vegetative anomalies suggestive of domal uplift. Left, Price's Dome. Right, anomaly suggestive of domal uplift. Scale = 1:89,000.

FIG. 7. Comparison of surface expression of known domes and topographic and/or vegetative anomalies suggestive of domal uplift. Top center, King's Dome. Lower left, anomaly suggestive of domal uplift. Scale = 1:100,000.

Cretaceous rocks have been well defined and there exists an apparent unexplained relationship between the axial regions of synclines and salt domes, especially in Webster, Beinville, and northwestern Winn parishes where the synclinal axes have a northeast-southwest orientation. In an effort to identify a regional pattern previously undetected, mosaics were prepared from near and far range channel records for both directions of flights. All four mosaics show a similar northeast linear trend, but no control of dome location or orientation other than along synclinal axes is suggested. This trend is not to be unexpected as it has been mapped as one of two trends identified throughout the Mississippi embayment.

SUMMARY

Radar is basically a reconnaissance tool. In the past it has proved to be most effective in the identification of regional structures, trends, or fracture patterns. Roughness of soil, rock, or vegetation; dielectric properties (chemical composition, moisture content) of surficial materials; or topographic expression of rock units may singly or together generate a return signal from the target which contrasts with that from adjacent terrain. Topographic expression of salt domes in this area is only poorly to moderately identifiable in radar imagery or by traditional techniques. Significant associated fractures, if present, cannot be detected. Vegetative anomalies are associated with many known domes and are suggestive of the existence of numerous others. The validity of such anomalies as indicators of domes has yet to be determined by field investigations. In the light of the poor to near lack of topographic expression of the domes or associated faults, identification of recent movement is not to be expected. Such specific conclusions apply only to this environment and do not in any way suggest that radar has not been and cannot continue to be effective in other applications. They do, however, point out the importance of understanding energy-target interaction and target and terrain characteristics in the mission planning phase of any remote sensing investigation.

FIG. 8. Comparison of surface expression of known domes and topograpic and/or vegetative anomalies suggestive of domal uplift. Left, Gibsland Dome. Right, anomalies (2) suggestive of domal uplift. Scale = 1:100,000.

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