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CR-158055

United States Department of the Interior
Geological Survey

Late Diagenetic Indicators of Buried Oil and Gas: II, Direct Detection Experiment at Cement and Garza Oil Fields, Oklahoma and Texas, using enhanced LANDSAT I and II Images

(E79-10099) LATE DIAGENETIC INDICATORS OF BURIED OIL AND GAS. 2: DIRECT DETECTION EXPERIMENT AT CEMENT AND GARZA FIELDS, OKLAHOMA AND TEXAS, USING ENHANCED LANDSAT 1 AND 2 IMAGES (Geological Survey) 49 p

N79-18373

Unclas

G3/43 00099

by

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Open-File Report 79-243
1979

23680

This report is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards.

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ILLUSTRATIONS

Late Diagenetic Indicators of Buried Oil and Gas: II, Direct Detection Experiment at Cement and Garza Oil Fields, Oklahoma and Texas, using enhanced LANDSAT I and II Images

ABSTRACT

The Cement oil field, Oklahoma, was a test site for an experiment designed to evaluate LANDSAT's capability to detect an alteration zone in surface rocks caused by hydrocarbon microseepage. Loss of iron and impregnation of sandstone by carbonate cements and replacement of gypsum by calcite are the major alteration phenomena at Cement. The bedrock alterations are partially masked by unaltered overlying beds, thick soils, and dense natural and cultivated vegetation. Interpreters biased by detailed ground truth were able to map the alteration zone subjectively using a magnified, filtered, and sinusoidally stretched LANDSAT composite image; other interpreters, unbiased by ground truth data, could not duplicate that interpretation.

Similar techniques were applied at a secondary test site (Garza oil field, Texas), where similar alterations in surface rocks occur. Enhanced LANDSAT images resolved the alteration zone to a biased interpreter and some individual altered outcrops could be mapped using higher resolution SKYLAB color and conventional black and white aerial photographs suggesting repeat experiments with LANDSAT C and D.

INTRODUCTION

An investigation was undertaken to determine if enhanced LANDSAT images could discriminate the surface alteration zones in bedrock at the Cement oil field, Oklahoma, in order to evaluate LANDSAT's usefulness as a direct detector of oil and gas deposits. Donovan (1974) described the nature of the alterations at Cement and outlined possible mechanisms whereby they may have originated. Part one of this two part report (Donovan and Dalziel, 1977) attempted to formulate a general model for hydrocarbon microseepage and suggested several geophysical and remote detection applications which might serve to isolate alteration zones. This part of the report summarizes a LANDSAT experiment designed expressly to delineate the alteration aureole at Cement (and a secondary test site at the Garza oil field, Texas) with computer-enhanced images. The work was supported, in part, under NASA Contract S-54039A.

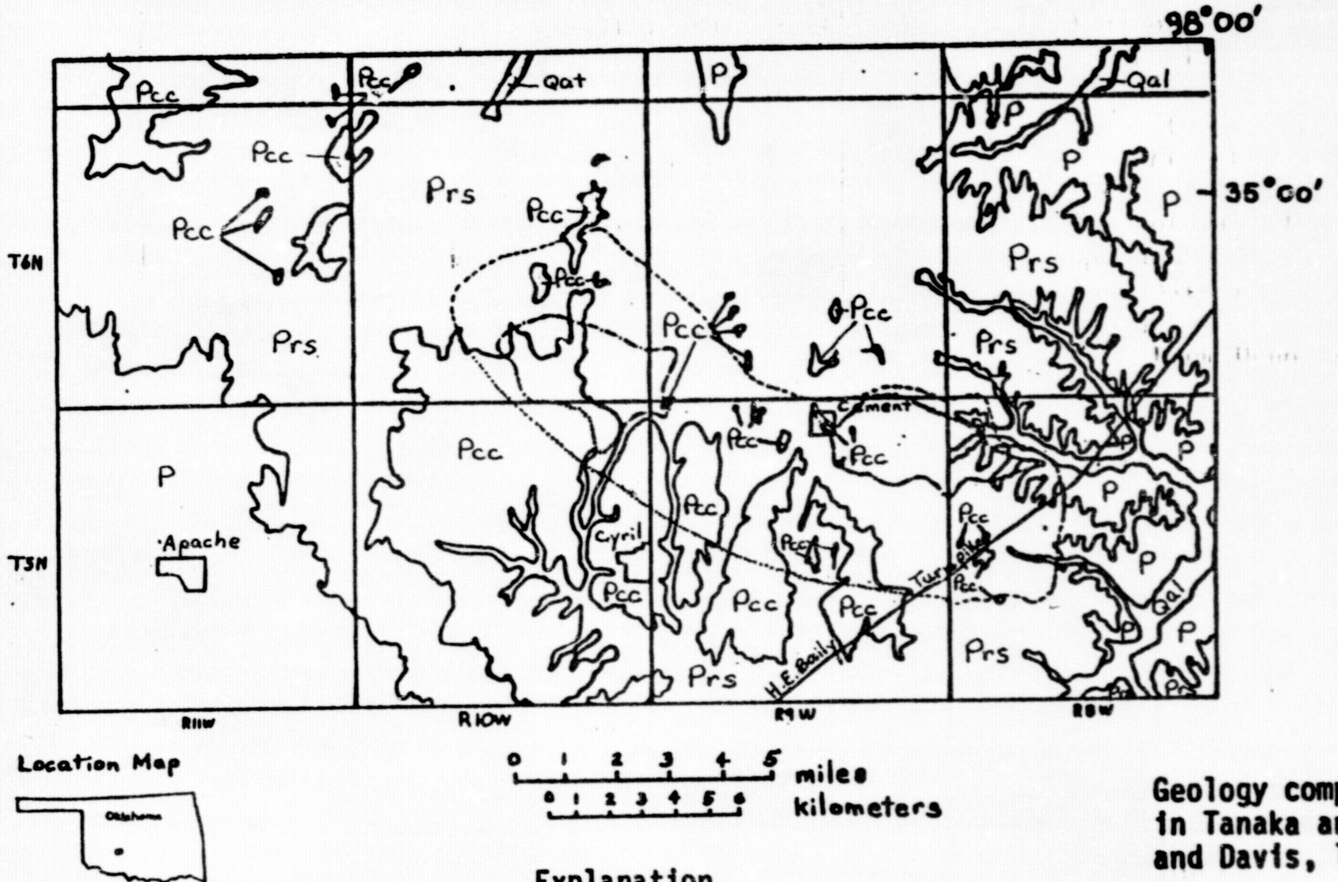
THE PROBLEM

Surface mapping and geological, geochemical, and isotopic analyses have clearly demonstrated that the Cement oil field has undergone a long history of oil and gas microseepage (Donovan, 1974). The evidence for this seepage manifests itself at the surface in a restricted zone along the crest of the Cement anticline as isotopically unique carbonate cementation in sandstone and replacement of gypsum and a broader area of discoloration (due to iron loss) in normally red-brown sandstone that closely coincides with the vertical projection of the oil and gas producing zones. Because the Cement field presents a striking model for petroleum microseepage studies and because the effects of this seepage are so boldly evident in the rocks there, it was selected as a key study area to evaluate the suitability of using computer-enhanced LANDSAT multispectral images to detect alteration aureoles over oil deposits and thus serve as a direct detection tool. This was believed to be especially appropriate because the spectral reflectivity of rocks is particularly sensitive to variations in the amount of oxidation state of the transition elements, especially iron (Hunt and Salisbury, 1970; Hunt and others, 1971; Rowan and others, 1974; Goetz, 1975). However, the vividness of the diagenetic alterations mapped at Cement is more than offset by masking by unaltered beds, thick monochromatic soil cover, dense vegetation, and the cultural and agricultural overprint. For these reasons, the Cement field provides an extremely difficult yet realistic test site for an objective evaluation of LANDSAT's alteration-zone detection capabilities.

METHOD

A wide range of computerized enhancements was generated in the attempt to discriminate altered from unaltered rocks. The image processing techniques used both individual and combinations of LANDSAT bands and combined some of the following processing techniques: contrast stretches, "sine" stretches, simulated true color, false color, boxcar filters, ratios, classification/separation methods, ratio and hybrid color composites, and digital enlargements of the data. Some enhancement processing methods were employed based on previous experience involving classification/separation techniques and others were suggested after study of reflectance spectra of altered and unaltered rocks measured in the laboratory or field. Initially, summer, fall, and winter scenes were used without noticeable variations; subsequent enhancements and those described here were done on an October, 1973, scene, chosen because it was exceptionally free of noise and clouds. We originally thought that the seasonal changes would have a measurable impact on the vigor of vegetation, the area of soil/rock obscured by vegetation, and the spectral response of vegetation types, but the time frame had no real impact on the scene or final processed results. The enhancements listed above were done at the U.S. Geological Survey, Image Processing Facility, Flagstaff, Arizona. Detailed descriptions of the procedures can be found in Eliason and others (1974), Chavez (1975), Chavez and others (1977), Condit and Chavez (in press) and Taranik (1978).

High altitude color, and conventional black and white and color



Geology compiled from Davis in Tanaka and Davis, 1963 and Davis, 1955

Explanation

Stratigraphy

System	Series	Group		Formation
Quaternary	undifferentiated		Qal	Flood plain alluvian
			Qat	Alluvium and terrace deposits
Permian	Guadalupian		Pcc	Cloud Chief
		White Horse	Prs	Rush Springs
		El Reno	P	Rocks older than Rush Springs

Symbols

Geologic contact

Area of carbonate cementation and replacement in Cloud Chief Formation and Rush Springs Sandstone (dotted where not exposed)
From Donovan, 1974

Area of discoloration of Rush Springs Sandstone (dotted where concealed by Cloud Chief Formation)
From Donovan, 1974

Figure 1. Geologic and location map, Cement area, Oklahoma

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infrared vertical aerial photographs were studied to provide additional detail and a series of visual observations and hand-held photography experiments were conducted from light aircraft. Soil, geochemical, isotopic, and geologic maps were compiled or constructed to quantify the observable surface alterations and these maps provided the basic set of reference materials for comparison with the enhanced images. Similar techniques were used at a secondary test site (Garza oil field, Texas). An attempt to map alteration phenomena in the Powder River basin, Wyoming, was aborted because the Tertiary coal-bearing sequences outcropping throughout much of the basin and underlying rocks, where exposed, are commonly masked by a secondary gypsum coating; presumably it is precipitated as an end-product of the oxidation of sulfur components in the coal and coaly shales. This problem needs to be investigated with care and is beyond the scope of the problem at hand.

THE TEST SITES

The Cement Oil Field

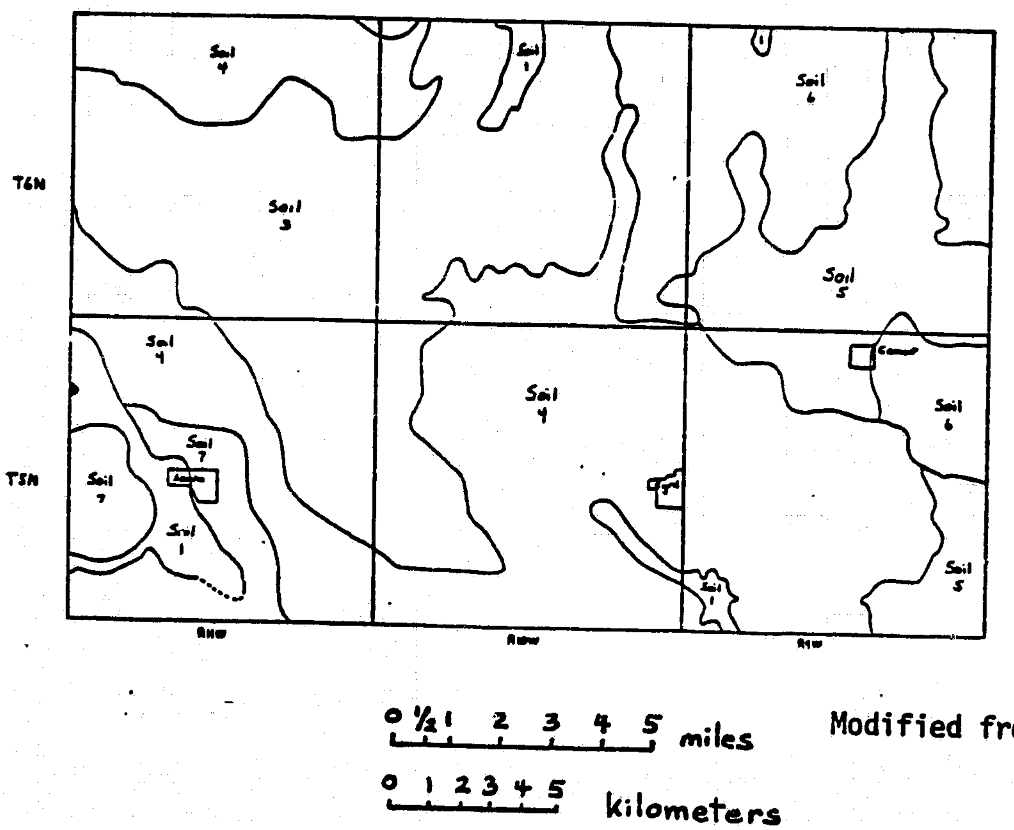
The Cement oil field is located in the southeastern Anadarko basin in Caddo and Grady Counties, Oklahoma. The field is a multizone anticlinal oil and gas accumulation in a sequence of clastic, evaporite, and carbonate rocks of Early Pennsylvanian to Early Permian age. The structure is a northwest-southeast trending elongate asymmetric doubly plunging anticline. Details of the geology can be found in Reeves (1922), Harlton (1960), and Herrmann (1961). The general geology of the region is shown on fig. 1. By 1968, the Cement field had produced more than 120 million barrels of oil; the remaining reserves are estimated to be 14.5 million bbl placing it in the Giant class (Halbouty, 1968).

An area of about 75 km^2 is productive. Approximately half of the oil and gas production is from Permian sandstone reservoirs, the rest is from Pennsylvanian clastic and carbonate rocks. The following quote (Donovan, 1974, p. 429) summarizes the nature of the surface alterations at Cement and how they may have developed:

"Striking mineralogic and chemical changes occur in outcrops of a Permian redbed sequence overlying oil-productive parts of the prolific multireservoir oil accumulation at the Cement anticline... Gypsum beds along the flanks are altered abruptly to erosion-resistant carbonate rocks at the crest of the fold in the Keechi Hills. Associated sandstones, typically red and friable in the surrounding region, are altered to pink, yellow, and white on the flanks of the Anticline and to hard carbonate-cemented gray sandstone at the crest. The zone of cementation, confined to sandstone intervals, extends to a depth of at least 2500 ft.

"Calcitized gypsum exceptionally deficient in C^{13} and light-carbon/heavy-oxygen cements directly overlie petroleum-productive zones near regions where fluids have superior vertical avenues of communication (faults and an unconformity at shallow depths and of limited extent along the crest). Away from these avenues of leakage, the influence of hydrocarbons on the isotopic composition of the carbonate cements decreases systematically. Color changes in the sandstones are related to reduction and dissolution of iron in the presence of hydrocarbons.

"Much of the hydrocarbons leaked from Missourian reservoirs beneath the crustal unconformity. Dense crude oil from stratigraphically discontinuous reservoirs along the basinward flank of the structure are associated with low-salinity pore water. Paraffinicity and salinity of waters



Modified from Moffatt, 1973

Explanation

Soil 1. Deep, loamy and sandy, nearly level soils on flood plains

Soil 3. Deep and moderately deep, loamy, nearly level to sloping soils on uplands

Soil 4. Deep and shallow, loamy, nearly level to steep soils on uplands

Soil 5. Deep, sandy, very gently sloping to hilly soils on uplands

Soil 6. Deep and shallow, loamy, very gently sloping to hills on uplands

Soil 7. Deep, loamy, nearly level to gently sloping soils underlain by loamy or clayey material; on uplands

Figure 2. Soil map, Cement area, Oklahoma

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decrease systematically with increasing depth of burial; these salinity variations, initially effected by ingress of water squeezed from expandable clays in the bordering basin, may have played a role in the selective solution of low-molecular-weight fractions. Water, vertically expelled along the crest, was desalted in passing from sandstone to shales. Large volumes of sandstone thereby were cemented off in shallow Permian rocks in places over the crest; the uncemented sandstones are petroleum-productive down the flanks."

The surface alterations described above were documented by careful field mapping. Although Rush Springs Sandstone outcrops displaying the discolorations and mineralization are abundant, they are commonly small and overlain by unaltered beds of the Cloud Chief Formation and (or) thick soil cover and dense vegetation.

The topographic surface in the Cement area is generally rolling and cut by deep drainage channels. The Cement anticline is topographically expressed and the crestal reaches of the structure are accentuated by the erosion-resistant Keechi Hills (Reeves, 1922). Streams in the region are bordered by cottonwood, oak, sycamore, and willow trees and dense underbrush. Valley slopes and uplands are well drained and the uplands are covered by scrub oak and grasses where they are not under cultivation. Peanuts, grain sorghum, cotton, alfalfa, wheat, and melons are cultivated in the immediate or surrounding area. The average annual precipitation in the region is about 70 cm and there are approximately 220 days between the first and last killing frosts of fall and spring.

Soils of the region typically are well-developed zonal Red and Yellow Podzolic soils (U.S. Soil Conservation Service in Millar, and others

Figure 3. Color change in Rush Springs Sandstone in east-west section line road. View is to the west, diagonally up the eastern plunge of the Cement anticline.

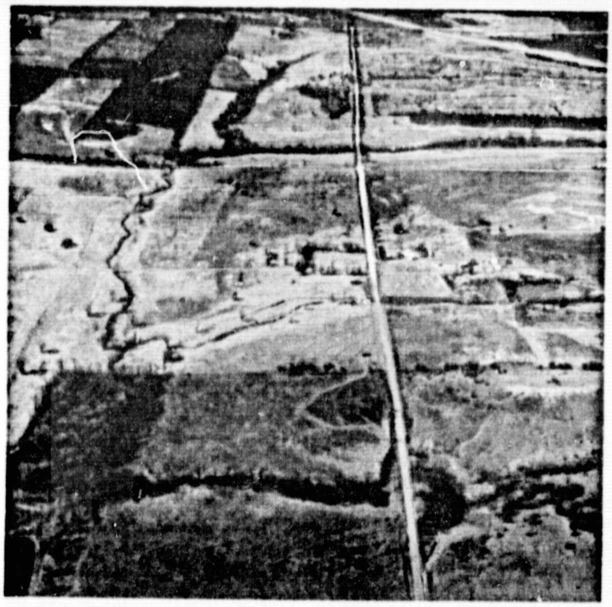

Figure 4. Low oblique aerial photograph of color change in Rush Springs Sandstone along southern flank of Cement anticline in east-west section line road. The Cement structure strikes diagonally across the photograph from lower left to upper right. View is to the east.

Figure 5. Contact between unaltered and altered (bleached) Rush Springs Sandstone in drainage channel along south flank of the Cement anticline. View is to the west.

Figure 6. Low oblique aerial photograph of the contact between unaltered and altered Rush Springs Sandstone shown in figure 5. View is to the east and the color contact can be seen along the south channel wall in the far to middle distance where it disappears beneath cultivated soil-cover.

Figure 7. Low oblique aerial photograph of the color contact in Rush Springs Sandstone in road cut along north-south section line road. View is to the northeast and the crest to the Cement structure is to the right.

Figure 8. Bleached Rush Springs Sandstone abruptly grading upward to limonitic-stained sandstone in road cut near the crest of the Cement anticline.

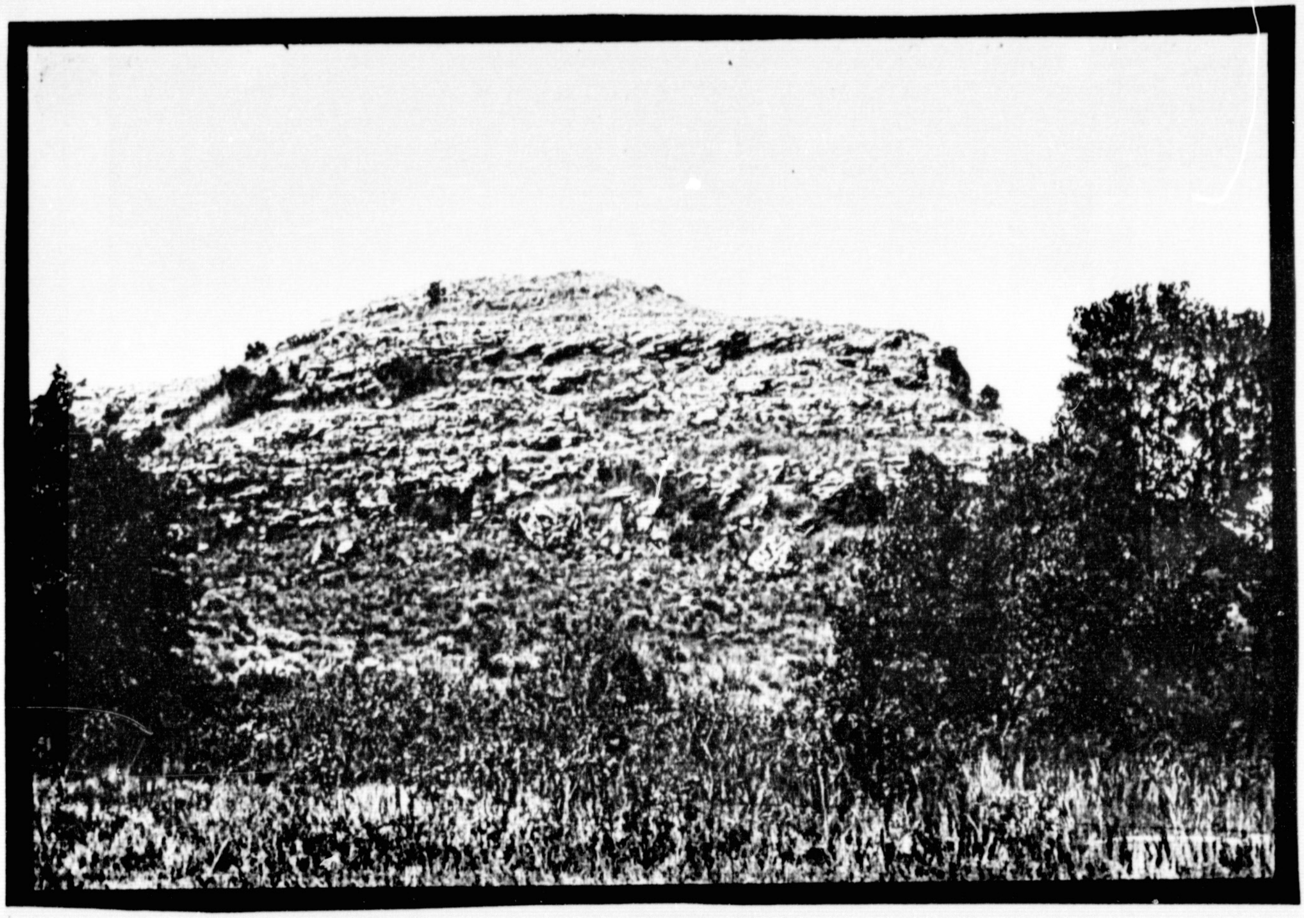

Figure 9. Carbonate impregnated, erosion resistant Rush Springs Sandstone butte of the Keechi Hills, East Cement.

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Figure 10. High oblique aerial photograph of part of Keechi Hills, East Cement. View is to the northeast.

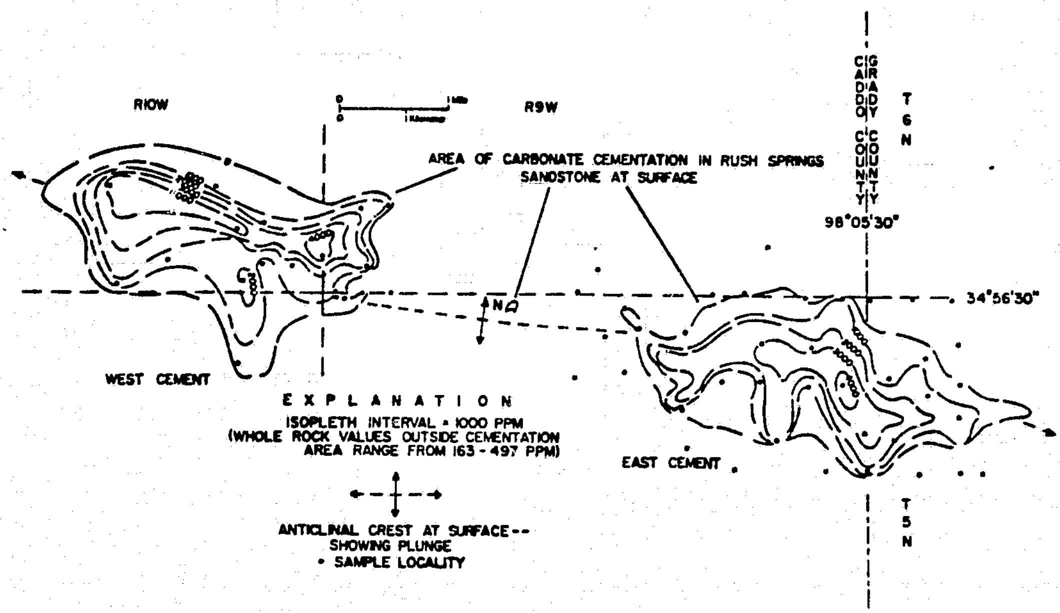


Figure 11. Variation of manganese held in carbonate cement of outcropping Rush Springs Sandstone, Cement oil field, Oklahoma. Isopleth interval: 1,000 ppm. From Donovan and Dalziel, 1977.

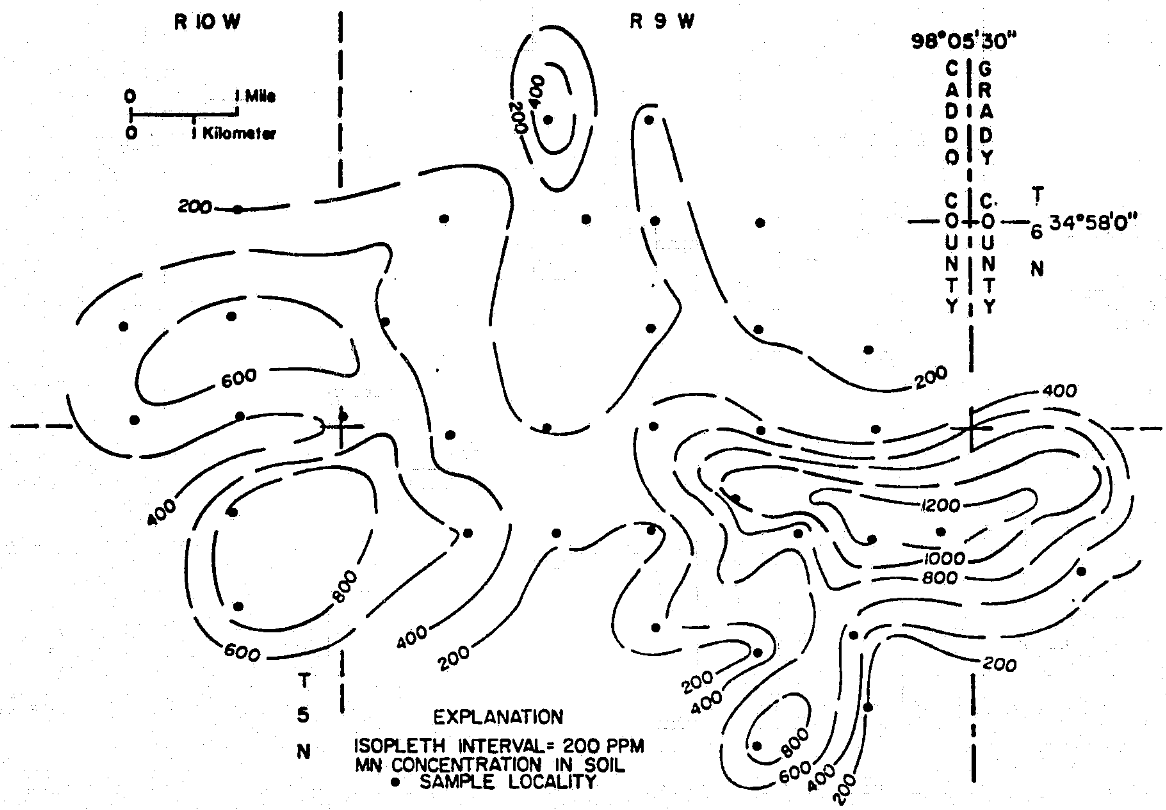


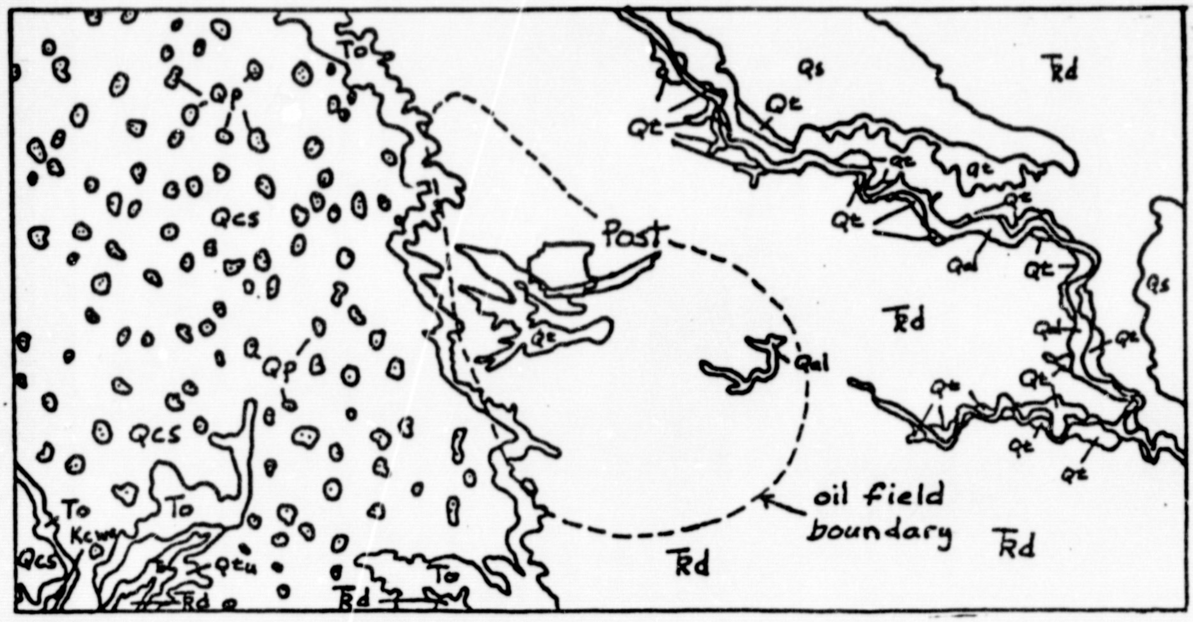
Figure 12. Variation of manganese concentration in soils, Cement oil field, Oklahoma. Isopleth interval: 200 ppm. From Donovan and Dalziel, 1977.

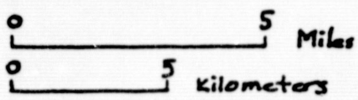
1965, fig. 11-3). At least four major associations (subdivisions) have been mapped in the Cement region (fig. 2). A comparison of figures 1 and 2 demonstrates the close (genetic) relationship between bedrock lithology and overlying soils.

Figure 3 is an example of the remarkable color change evident in a section line road crossing the eastern plunge of the Cement anticline. Figure 4 is an aerial view of the color contact in a road on the southeastern flank of the structure. The color contact along the southern flank of the field is shown in figure 5 and figure 6 is an aerial view of the same contact viewed from the opposite direction. Figure 7 shows the contact in a road cut on the north flank of the structure. These photographs clearly demonstrate the limited areal extent of the exposures at Cement. In figure 8 bleached sandstone grades upward into limonitic stained sandstone which in turn is overlain by vegetated but poorly developed red-brown soil. This sequence is not common at Cement. Presumably, the limonitic stain develops as a result of the upward (capillary?) movement and subsequent precipitation of iron oxides in an oxidizing environment. The soil cover and limonite stain restrict detection of the bleached rock from vertical look-angles; the limonite stained zones themselves are areally too limited for LANDSAT's resolution although under more ideal conditions they can be separated from other materials (Rowan and others). Ground and aerial photographs of carbonate-cemented sandstone buttes of the Keechi Hills are shown in figures 9 and 10. Several kinds of geochemical anomalies occur at Cement; examples of trace metal (Mn) variations in the carbonate cement and the overlying soil are shown in figures 11 and 12.

The Garza Oil Field

The Garza oil field is located in southwest-central Garza County, Texas, along the northeast edge of the Permian basin. The discovery well there was drilled on a localized topographic high in 1935.





Modified from Bureau of Economic Geology, University of Texas, April, 1967

Explanation

System	Series	Group	Formation	
Quaternary	Holocene		Qal	Alluvium
			Qs	Windblown sand
	Pleistocene		Qt	Fluviatile terrace deposits
			Qp	Playa deposits
			Qcs	Windblown cover sand
			Qtu	Tule Formation
Tertiary	Miocene		To	Ogallala Formation
Cretaceous	Lower		Kcwa	Comanche Peak Ls, Walnut Clay, undiv. Antlers sand,* undivided
Triassic		Dockum Group, undiv.	Rd	

***Trinity Sand of U.S.G.S. usage.**

Figure 13. Geologic and location map, Garza area, Texas.

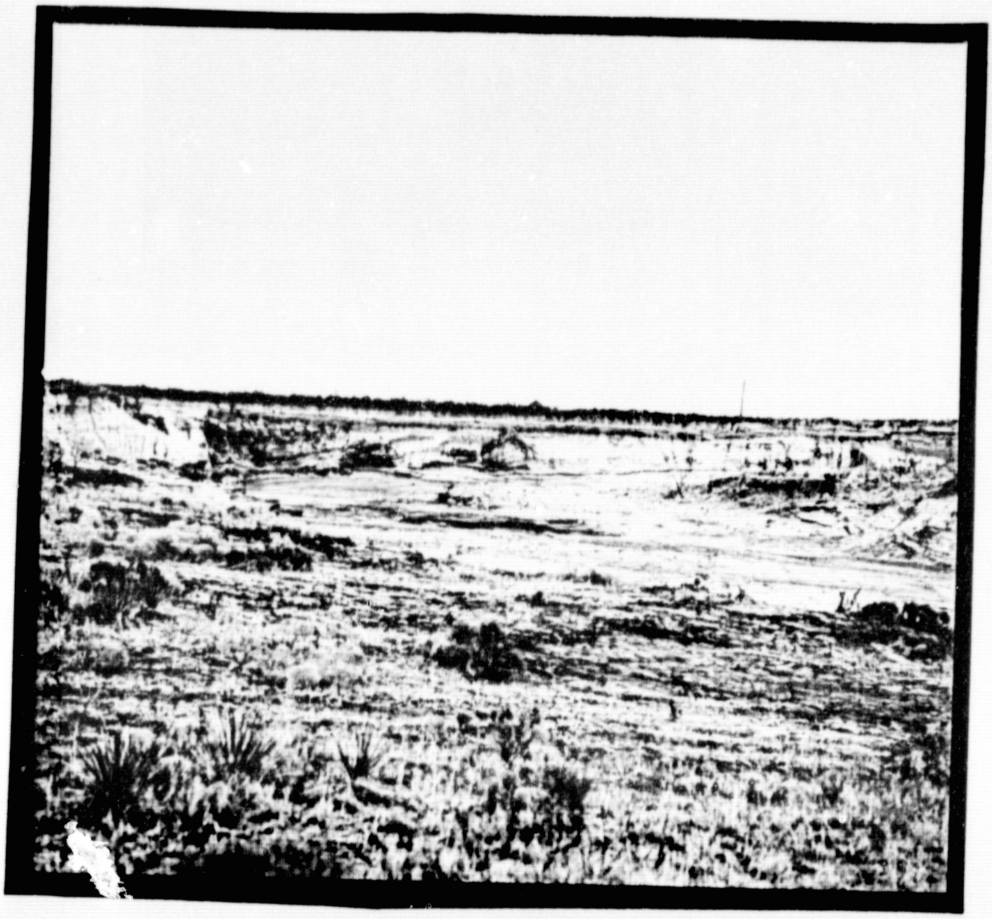


Figure 14. Bleached Triassic Sandstone in drainage channel, Garza oil field, Texas.

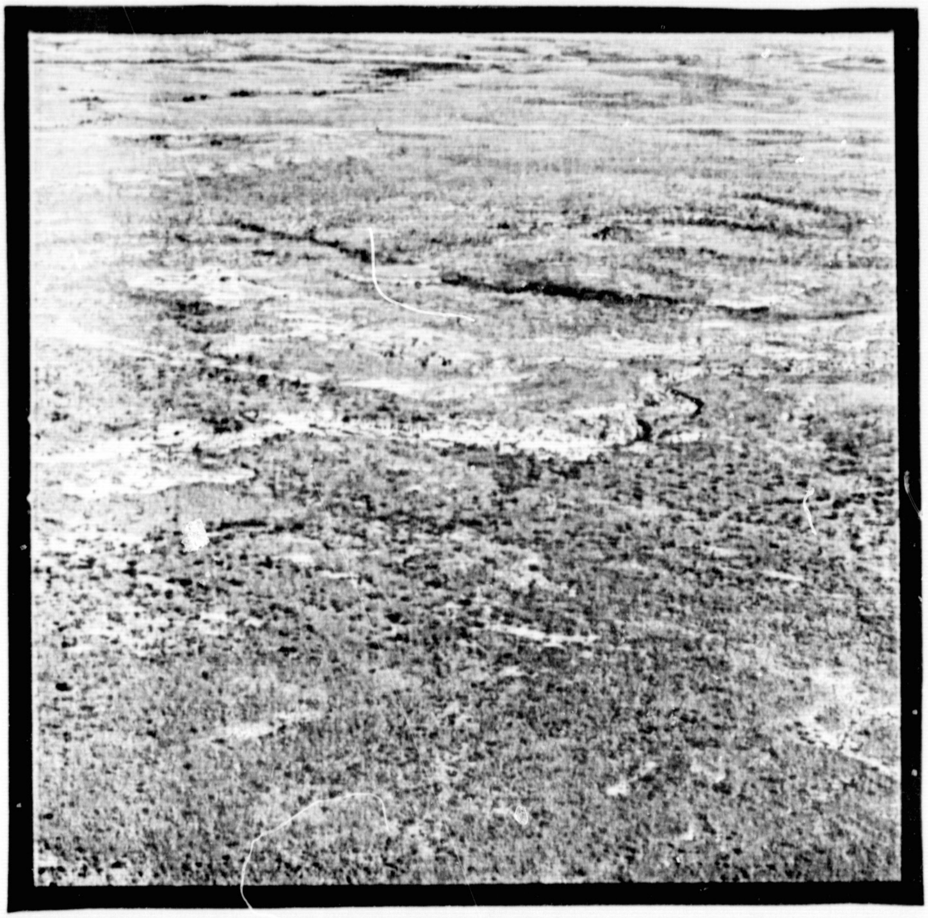


Figure 15. Oblique aerial photograph of bleached Triassic sandstone, in drainage channel, Garza oil field, Texas.

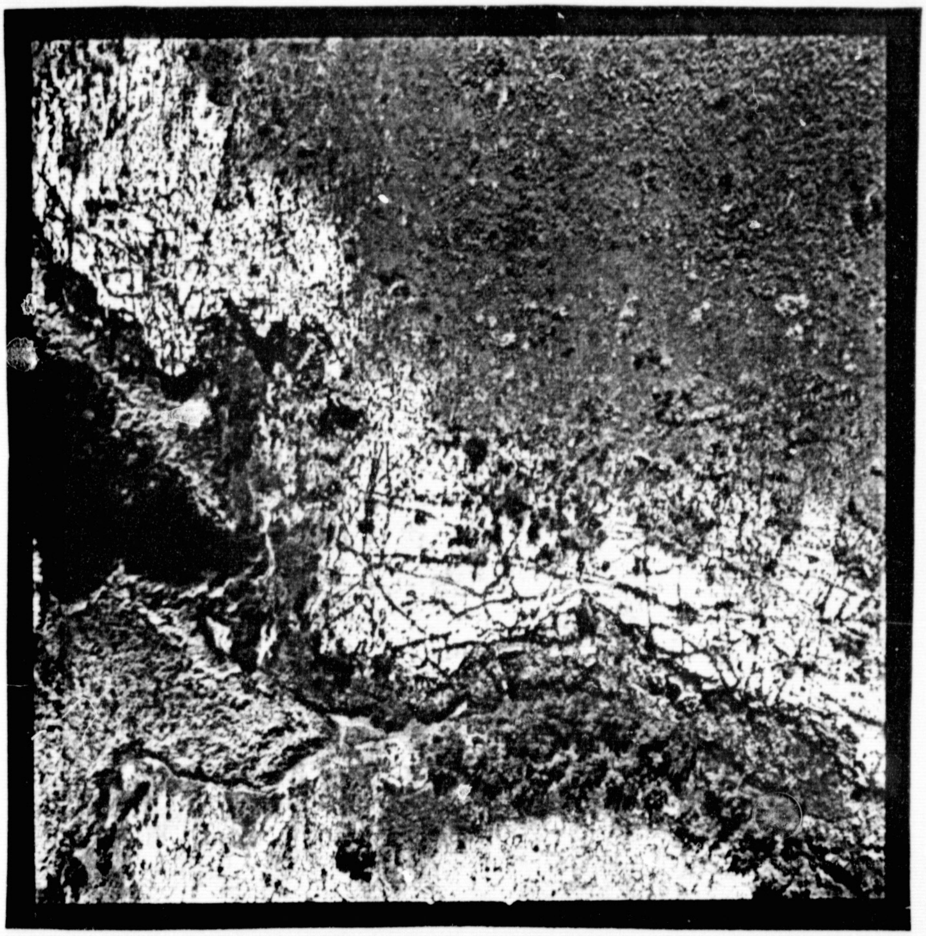


Figure 16. Low oblique photograph of bleached Triassic sandstone, and joint-controlled vegetation pattern, Garza oil field, Texas.

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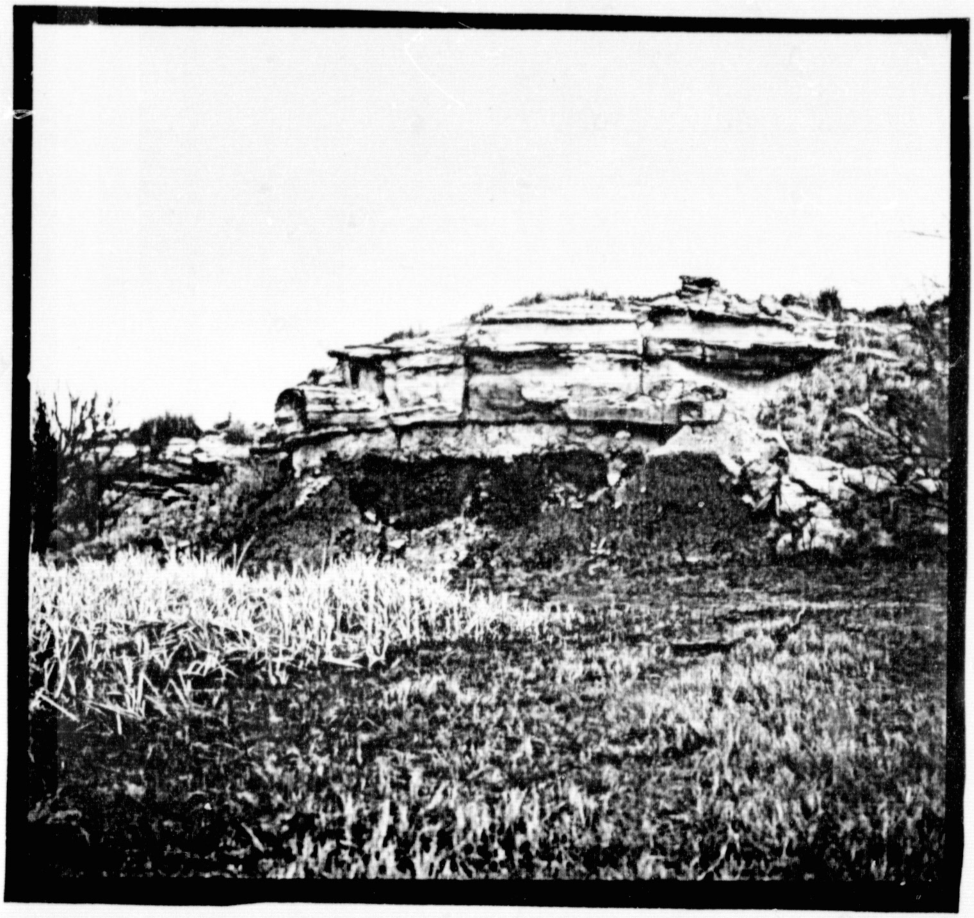
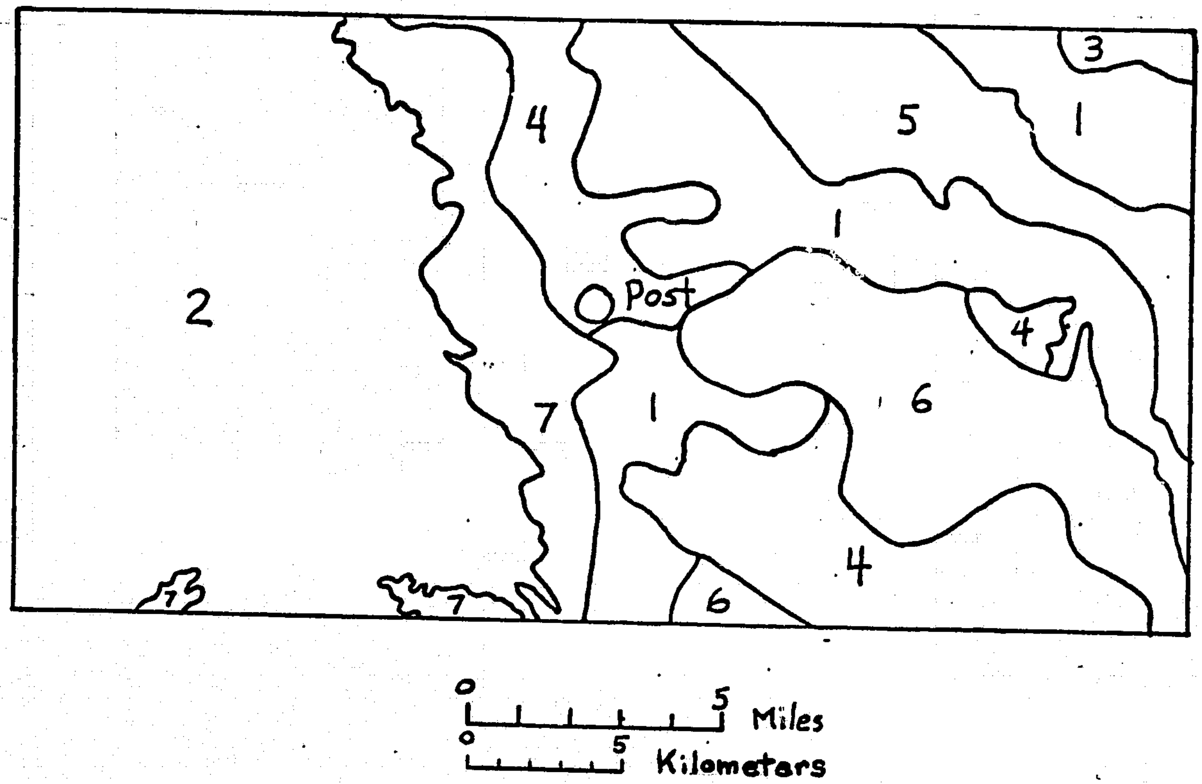


Figure 17. Bleached Triassic fine-grained sandstone caprock and bleaching in proximal 0.3 m of underlying shale, Garza oil field, Texas.

The Garza structure is an anticline with several minor domes and saddles; it has a maximum relief of 40 m. Most oil is produced from irregular porous lenses in an anhydrite-bearing dolomite of Permian (Leonardian) age at an average depth of about 810 m. Some deeper production was developed in the period 1955-1966. An area of about 46 km^2 is productive. The producing zone is overlain by red sandstone, shale, and interbedded anhydrite and salt which in turn are overlain by outcropping Triassic "red beds" that are partially overlain by buff colored Tertiary non-marine deposits of the High Plains escarpment (fig. 13). About 66,000,000 bbl of oil have been produced as of January 1978.

Although the oil field and surface anomaly are considerably smaller and less significant than Cement, the cultural overprint is less dense and the soil, alluvium, and vegetation cover are comparatively thin. The discolored areas (in Triassic red beds) are less-well distributed areally and they are narrowly stratibound in thin sandstone units (figs. 14 and 15). Although we have no detailed documentation, we suggest (Donovan and Dalziel, 1977) that seeping fluids may have effused vertically along joints and fractures (fig. 16) and then spread laterally along permeable sandstones. A thin zone of red shale immediately underlying the bleached sandstones is also bleached presumably owing to proximity to reducing agents carried in the overlying permeability channels (fig. 17).

The topographic surface in the Garza area is generally flat to rolling. Erosion resistant buttes are sporadically distributed throughout the Central Rolling Plains and the western part of the area is dominated by the High Plains escarpment. Drainage channels eminate from the escarpment and transect the Rolling Plains to the east. The High Plains are thoroughly



Modified from Richardson, Grice and Putnam, 1975

Explanation

Soil 1. Gently sloping to steep, moderately deep clay loams, and rough broken land

Soil 2. Nearly level to gently sloping, deep loams

Soil 3. Nearly level to gently sloping, deep fine sandy loams

Soil 4. Nearly level to gently sloping, moderately deep and deep clay loams

Soil 5. Nearly level to gently sloping and undulating, deep fine sands and loamy fine sands

Soil 6. Nearly level to gently sloping, deep clays

Soil 7. Gently sloping to steep, deep fine sandy loams and loams, and rough broken land

Figure 18. Soil map, Garza area, Texas.

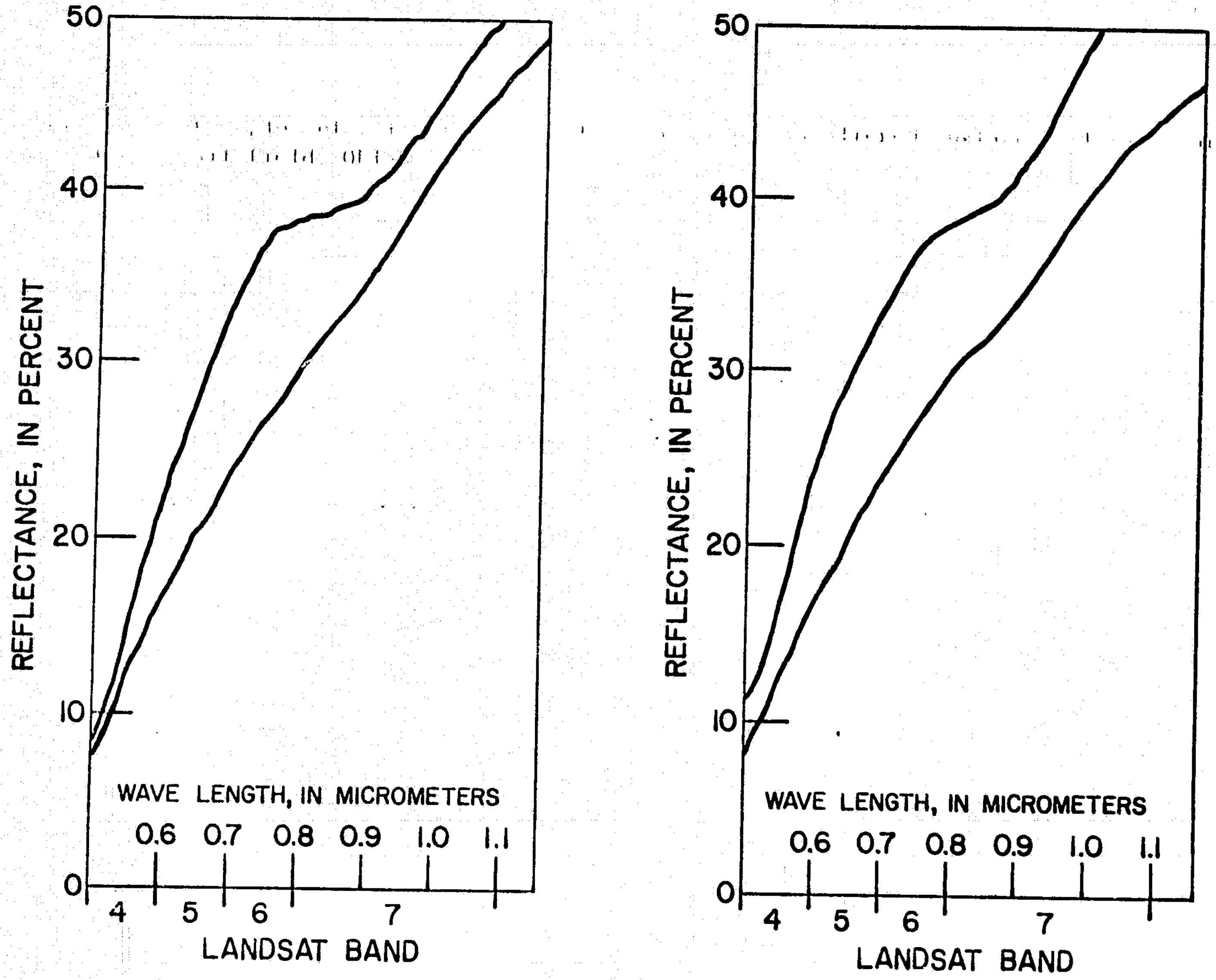


Figure 19. Examples of reflectance spectra for variously altered surface rocks (varying iron content), Cement oil field, Oklahoma.

cultivated in the immediate area (mainly cotton and grain sorghum) and the Rolling Plains vegetation is predominately a mesquite-buffalo grass association. Average annual precipitation is about 48 cm and there are an average of 216 freeze free days per year.

Seven major soil associations have been mapped in the Garza region (fig. 18).

RESULTS

Cement Oil Field

Visible and near-infrared reflectance spectra for altered and unaltered rocks have generally different profiles and there are marked differences in the shapes of the spectral curves for differently altered rocks (Figure 19). However, neither the high spatial detail of the alteration nor the overall pattern of alteration is effectively resolved in LANDSAT images; the blanketing effects of the generally thick soils and dense vegetation (plus cultural overprint) mask the bedrock alterations in a way similar to that described by others (Huntington and Green, 1978; Rowan and others, 1974, p. 29). This is perhaps because the spectral shape differences for altered rocks may be destroyed during the formation of the overlying soils.

Computer enhanced images were studied by three "unbiased" interpreters (unfamiliar with the surface geology and alterations at the test sites) intermittently over a period of about three years. Two "biased" interpreters (completely familiar with the surface geology and working with all the detailed ground truth reference data and maps) also worked with the images. Comparisons of the results of both groups of interpreters were made periodically as new data products became available for interpretation.

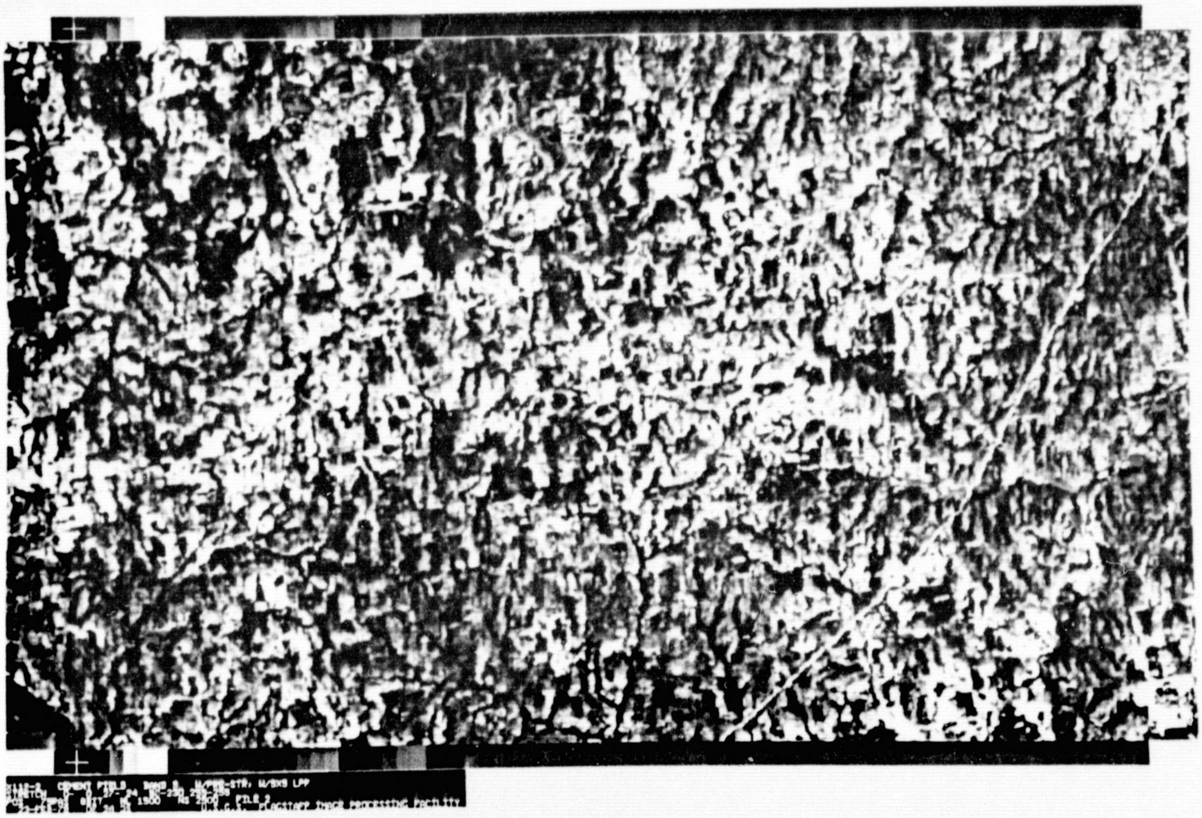


Figure 20. Sine stretched, magnified and filtered color composite image of LANDSAT bands 4, 5, and 7, Cement area, Oklahoma.

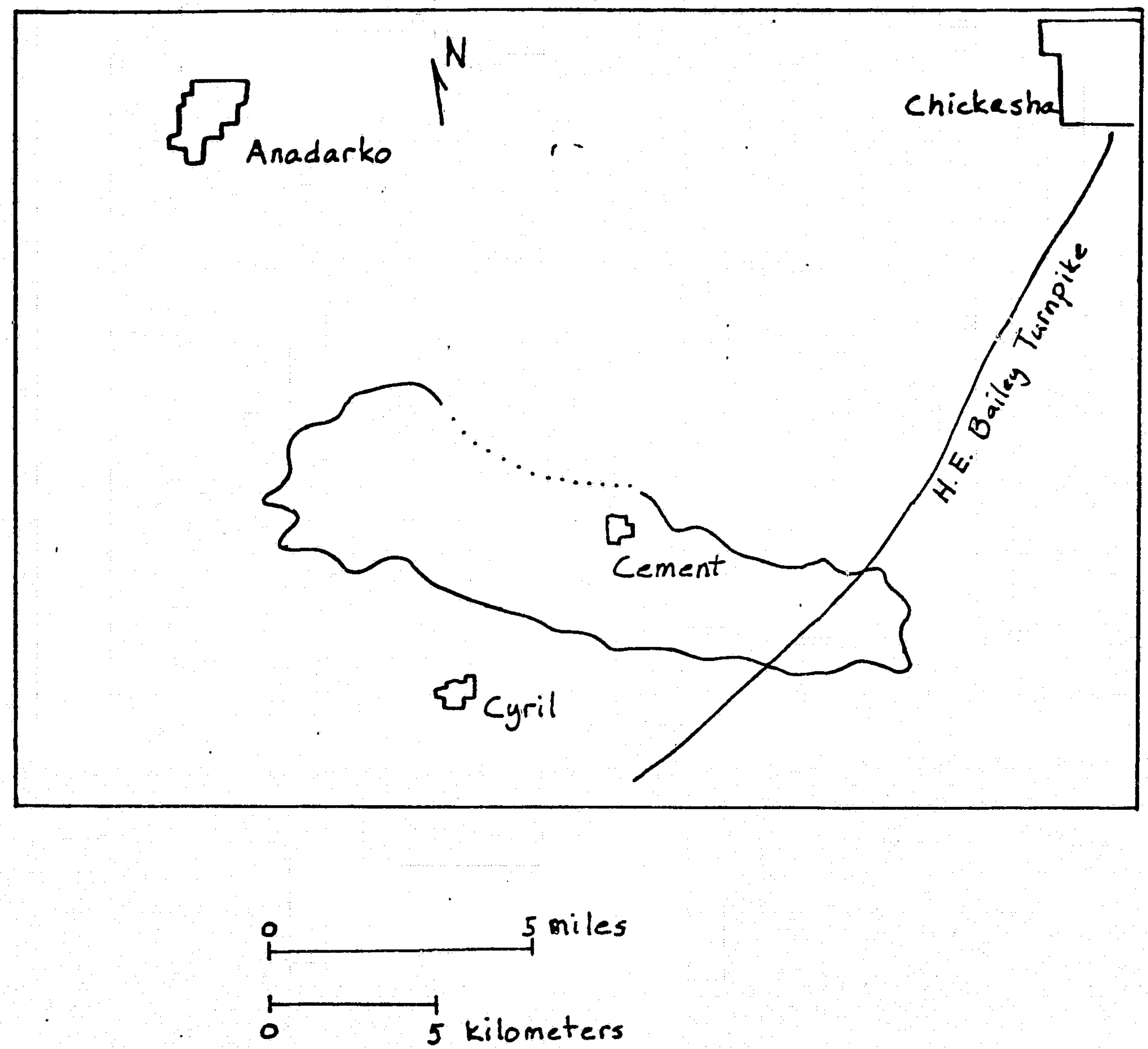


Figure 21. "Biased" interpretation of the alteration zone at Cement mapped from Figure 20.

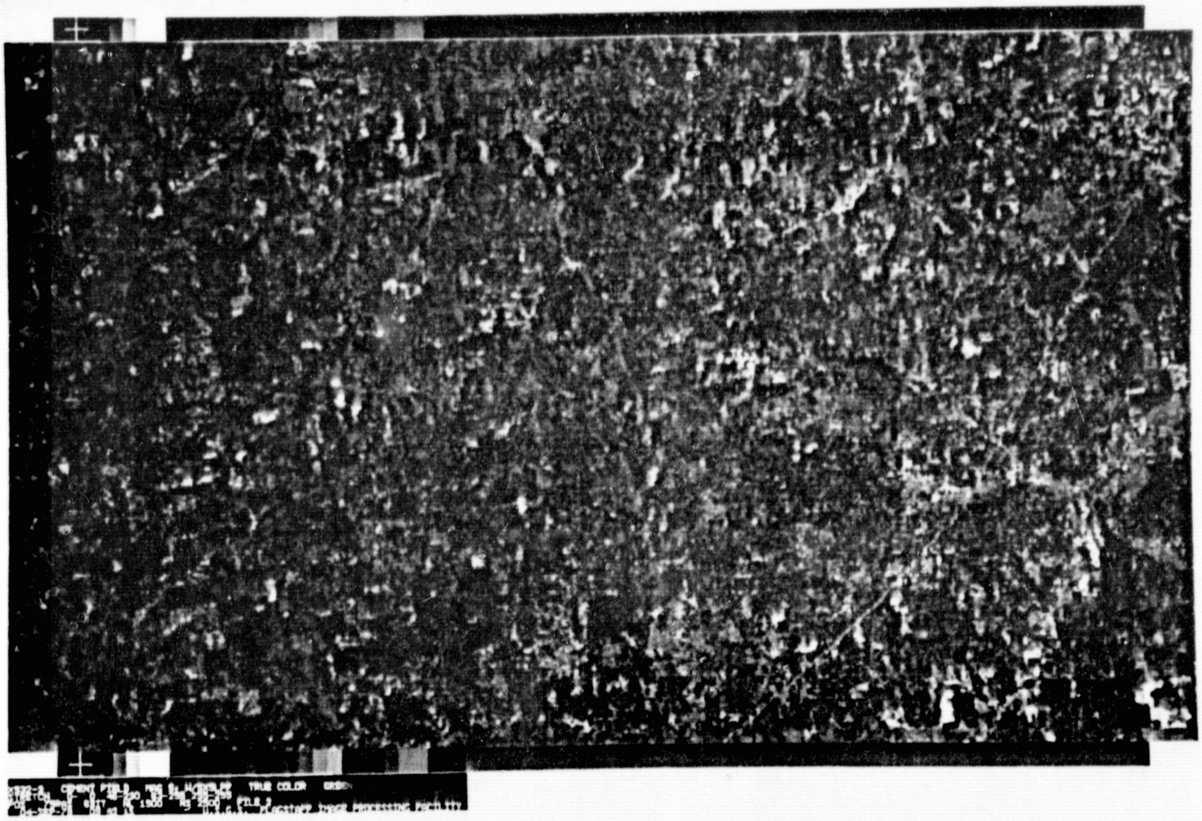


Figure 22. Simulated true color LANDSAT image, Cement area, Oklahoma.

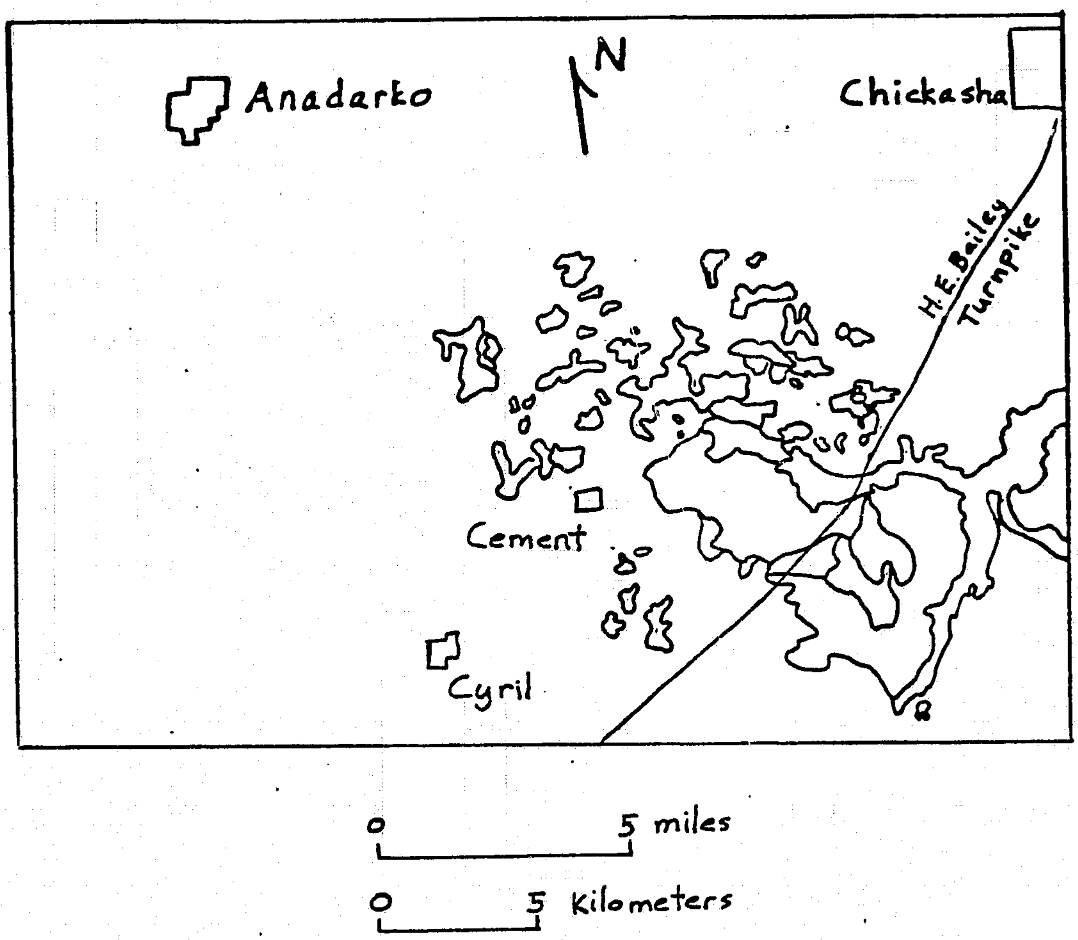


Figure 23. Example of "unbiased" visual classification pattern mapped from a simulated true color LANDSAT image similar to Figure 22. The areas segregated were classified by color and appear to represent combinations of bedrock, soil, and vegetation patterns.

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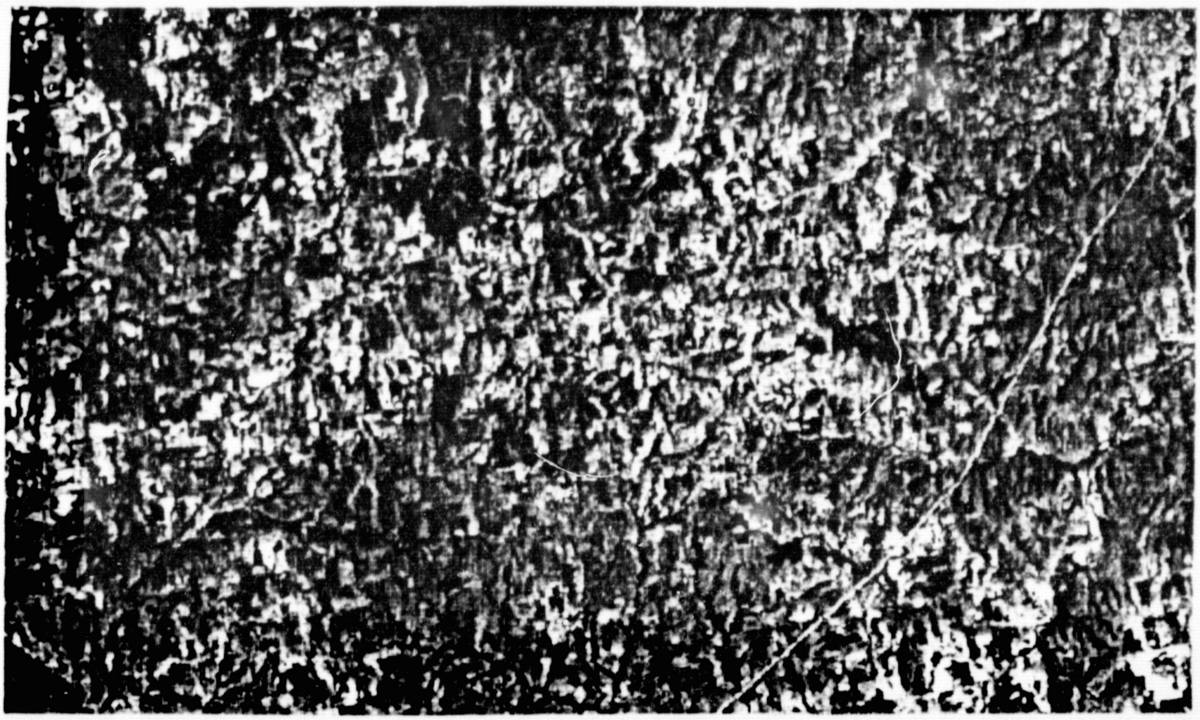

Figure 24. False color LANDSAT composite image, Cement area, Oklahoma.

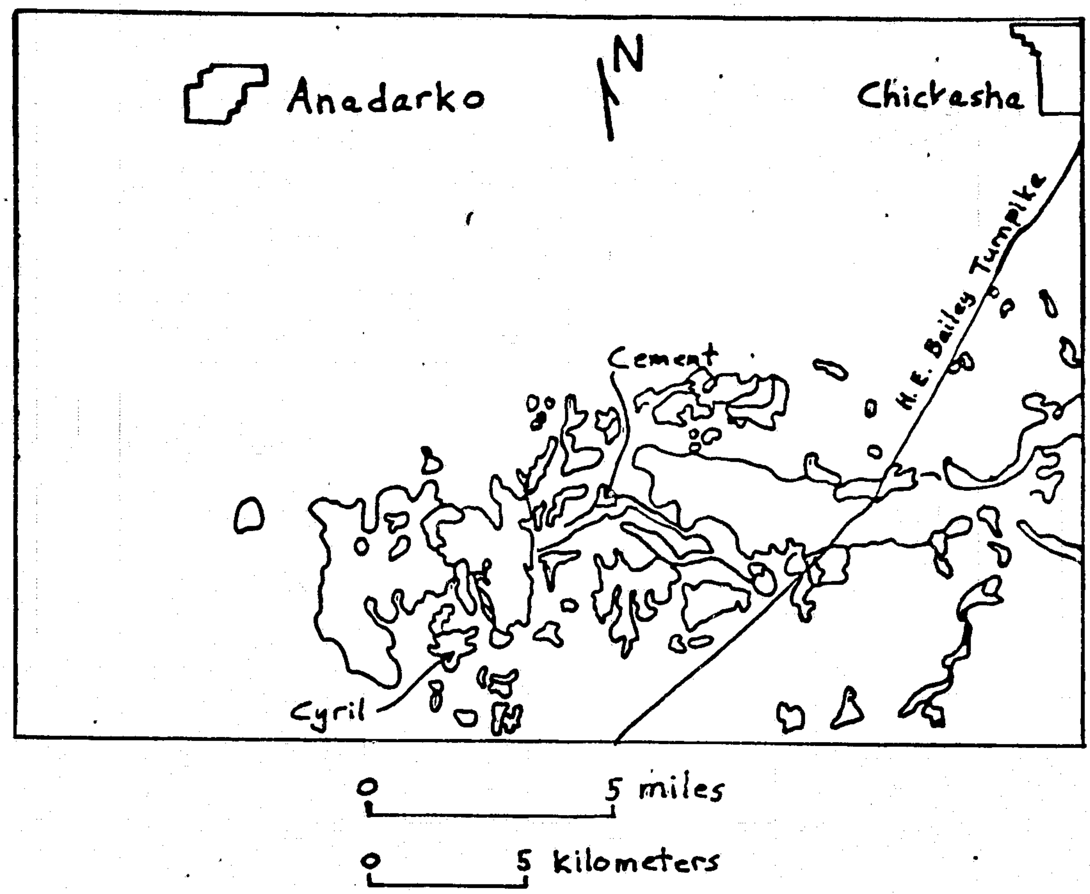

Figure 25. Example of "unbiased" visual classification patterns mapped from a false color LANDSAT image similar to Figure 24. The areas segregated were classified by color and appear to represent combinations of bedrock, soil, and vegetation patterns.

Neither group of interpreters was able to isolate the alteration pattern at Cement with two exceptions: a "biased" interpreter mapped suggestions of the alteration zone at Cement on a sinusoidally stretched image (Donovan, 1975) but "unbiased" interpreters were unable to duplicate that interpretation. Similar results, described here, were obtained on a digitally magnified-scale, sinusoidally stretched and filtered, color composite image (figs. 20 and 21). Study of the data bases showed suggestions of the anomaly only in a band 5 scene whose dynamic range had been enhanced by a three-cycle sine-stretch. A 5 x 5 magnification (done by expanding each pixel into a 5 x 5 grid) was performed on the stretched band 5 data-base (plus bands 4 and 7) followed by a low pass 5 x 5 boxcar filter (for smoothing). These three data-bases were then composited into a color image. The discrepancies between "biased" and "unbiased" interpretations may arise because "unbiased" interpreters tended to use a visual classification scheme based on like colors, shades, and tones: the resulting patchwork classifications are unrelated to the anomaly of interest (figs. 22, 23, 24, and 25). "Biased" interpreters tended to integrate variations owing to subtle spectral differences within the known anomaly into a tonal and color pattern that resembles the model provided by other, independent, data.

If an effective haze-removal has been accomplished (Chavez, 1975), band ratios will suppress at least first order topographic features enabling a better display of albedos which might reflect variations in color or surficial materials. The ratio of band 6 to 5 best separates major material types such as water, soil and rock, and vegetation. The band ratio 5 to 4 is best suited for discrimination among and within soil and rock types and the band ratio 6 to 7 best discriminates among vegetation types.

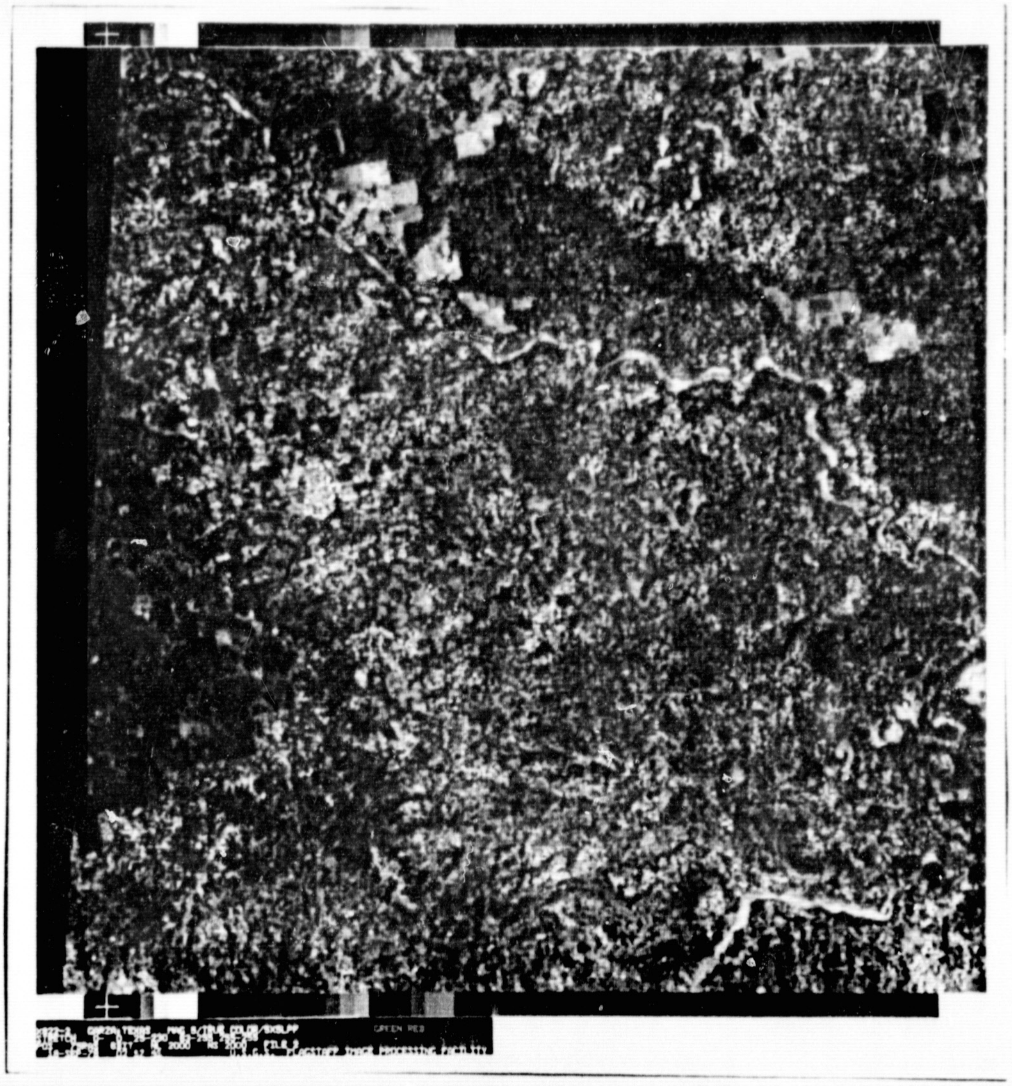

Figure 26. Simulated true color LANDSAT image, Garza area, Texas.

Figure 27. Linearly stretched and magnified false color composite image of LANDSAT bands 4, 5, and 7, Garza Oil field, Texas.

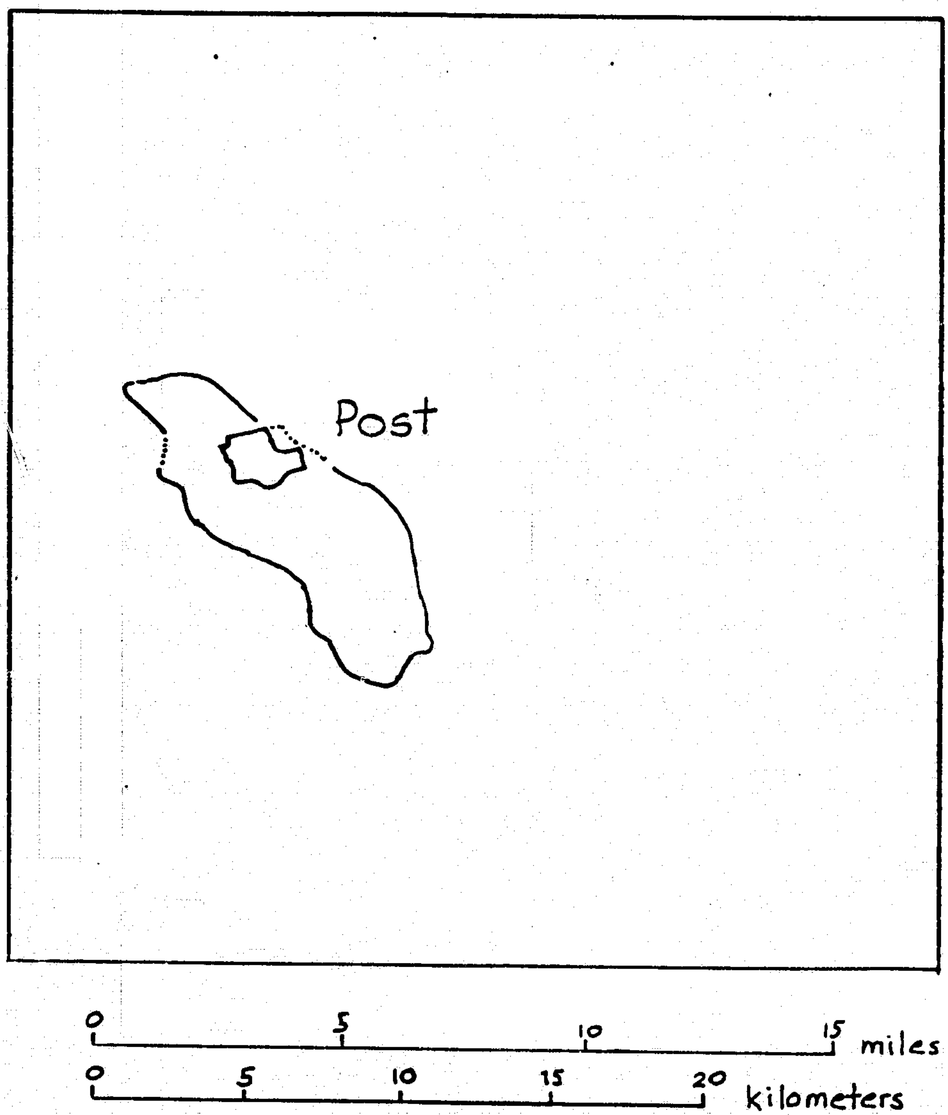

Figure 28. "Biased" interpretation of the alteration zone at Garza, mapped from Figure 27.

Based on the work of Rowan and others (1974; and oral commun.) we anticipated that a 5 to 4 ratio would discriminate discolored (iron depleted) from normally colored rock; however, these images did not reveal any hint of the anomaly at Cement.

Additional experiments, including airborne geochemical sampling, gamma ray and aeromagnetic surveys, have been or will be reported elsewhere (Donovan and others, 1975; Donovan and others, 1979; Donovan and others, unpub. data).

Garza Oil Field

Outcrops of altered beds or their averaged spectral effects are too small or subtle to be resolved in a simulated true color LANDSAT image (fig. 26). However, a biased interpreter was able to map a light area on a linearly stretched 5 x 5 magnified false color image which approximates the known oil field boundary (figs. 27 and 28), and it is possible to map some individual outcrops (altered?) on enlarged SKYLAB color photographs (resolution ∿30 m; fig. 29). Similarly, these areas can also be mapped on conventional black and white aerial photographs primarily by using tonal differences to distinguish probably altered bedrock from other kinds of surficial materials. Comparisons of maps derived from SKYLAB and aerial photographs (not shown) indicated about a 50% correspondence of areas interpreted to be altered. These results suggest repeat experiments with the improved resolution (∿30 m) of LANDSAT C and D.

SUMMARY

LANDSAT's capacity to detect the alteration zone at the Cement test site is limited, primarily, but not solely, because of a lack of spatial

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Figure 29. Portion of SKYLAB S190B photograph of the Garza area, centered on the town of Post. Scale: approximately 1:250,000. When enlarged to a scale of approximately 1:62,500 individual outcrops can be mapped.

resolution in the imaging system. Ground truth studies documented that the alterations are generally not uniform over the entire producing area of an oil field; commonly they are stratibound and occur in sporadic and irregular patches (with exposed areas commonly less than 50 m^2) probably controlled by lateral and vertical permeability variations in host rocks. This observation, coupled with the fact that the bedrock alterations at the test sites are largely covered by unaltered beds, varying amounts of generally monochromatic soil, windblown sand, and vigorous vegetation, precludes effective, unique, or unbiased discrimination of the alterations using LANDSAT images. However, an interpreter, biased by detailed ground truth maps and completely familiar with the area, can isolate a suggestion of the general area of alteration at Cement. Repeat trials with unbiased interpreters failed to duplicate mapping of the alteration pattern.

At Garza, areas of alteration could easily be detected in an enhanced false color LANDSAT image by a biased interpreter and could also be mapped with a modest degree of reliability using SKYLAB and aerial photographs.

Although the Cement and Garza oil fields are geologically well suited for a LANDSAT direct detection experiment, their climatological and geographic setting combine against marked success because of the spatial and spectral resolution limitations of the imaging system. An investigation of LANDSAT's capabilities at a test site located in a more arid region with less well developed soils and less vigorous vegetation could prove fruitful.

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