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IMPLICATIONS OF INFORMATION FROM LANDSAT-4 FOR PRIVATE INDUSTRY

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The broader spectral coverage and higher resolution of Landsat-4 Thematic Mapper (TM) data open the door for identification from space of spectral phenomena associated with mineralization and microseepage of hydrocarbon. Digitally enhanced image products generated from TM data allow the mapping of many major and minor structural features that mark or influence emplacement of mineralization and accumulation of hydrocarbons. These improvements in capabilities over multispectral scanner data will accelerate the acceptance and integration of satellite data as a routinely used exploration tool that allows rapid examination of large areas in considerable detail.

There is a fortuitous synchronous development of satellite remote sensing, and the concepts of plate tectonics and vertical migration of hydrocarbons - two paradigms which are reshaping geological exploration thinking. The steadily improving quality of satellite data is providing geologists with a valuable tool with which to test, revise and exploit these new concepts.

TM AND GEOLOGIC EXPLORATION

Since the early 1960's, the science of geology has been undergoing a major revolution. The new paradigm of plate tectonics and seafloor spreading is replacing the older paradigm of a rigid, stable earth. Inherent in the acceptance of plate tectonic theory is a growing appreciation of the role of plate motion in determining the location of mineral deposits and hydrocarbon accumulations. It is fortunate that developments in spaceborne remote sensing have paralleled these developments in geologic thinking. As a consequence, we have remote sensing tools that view the earth with appropriate scale and scope to enable us to appreciate and map the regional structures that reflect the motions of continent-sized segments of the earth's crust. We received our first glimpses of the earth from space with photos from the Apollo and Gemini flights. The first three Landsat satellites gave us near ubiquitous high resolution (80 metre) coverage in four spectral bands. These data

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have had and continue to have enormous impact on all facets of perception and management of renewable and non-renewable natural resources and the environment.

Before speculating on the impact of the new data types from Landsat-4, it is useful to take a look at the role data from the first three Landsat satellites have in geologic exploration and their current level of acceptance. In a general sense, Landsat data has made its major contribution to hydrocarbon exploration in the spatial domain. In mineral exploration, Landsat has revealed some spectral information, but again the major contribution is spatial. The synoptic view of over 34,000 square kilometres of the earth's surface on a single Landsat image permits the detection and mapping of major regional structures associated with the geologic development of entire geologic provinces. It is also possible, through special digital enhancements, to map some of the more subtle surface expressions of fracturing, folding and alteration associated with buried hydrocarbon accumulations and the emplacement of mineral deposits. The data make it possible to interrelate widely separated geologic features and detect subtle changes that occur over tens of miles and, hence, have gone unnoticed on conventional types of data. Perhaps most important of all, the new perspective that the view from space provides stimulates us, or forces us, to think of geology in new ways and perceive new possibilities. Truly it isn't a panacea but it is an extremely powerful tool. It has not by itself "found" an oil field or mine, but it has made significant contributions to the exploration thinking that led to the discovery of millions of barrels of oil and millions of tons of ore.

At this point, it is appropriate to consider how industry regards this new tool. Bob Porter (President, Earth Satellite Corporation) once characterized the oil and gas and mineral exploration industries' acceptance of Landsat data or any technical innovation as progressing through three stages:

1. An initial "Gee Whiz" stage;
2. An "Interesting but not yet commercial" stage; and finally
3. Full acceptance and integration of the innovation as a bona fide exploration tool.

The progression through these stages appears to be a direct function of the geologists' and geophysicists' experience and familiarity with the tool; in this instance, satellite data. Consequently, not all exploration groups progress through each stage in unison.

In the earlier "Gee Whiz" stage, the geologist may be impressed by the presence of a familiar structure or landform that is visible on the imagery, or by a subtle feature visible on an exotic digitally enhanced color image. At this stage, some are tempted to see satellite data as the answer to all exploration woes, and the potential to "oversell" its capabilities is a real danger.

This stage is usually quickly replaced by the "Interesting but not yet commercial" stage where imagery produced from the Landsat data is viewed mainly as a cheap, low resolution, aerial photo substitute. To so view Landsat imagery is to miss both the unique geologic perspective of the imagery and the potential contribution available through computer processing and data base integration of the digital data.

The final stage is characterized by the integration of the geologic information gleaned from the Landsat imagery with a complete oil and gas or minerals exploration model. At this point, the exploration geologist fully appreciates the potentials and limitations provided by the satellite system and routinely applies the satellite data to the design and execution of exploration programs. This whole process takes time. It took the gravity meter and the seismograph about 40 years to make the transit; the digital computer has progressed more rapidly.

At present, I think a healthy percentage of the exploration community is working out of the second stage of acceptance. There is a great promise that the Thematic Mapper data will provide the results necessary to convince the exploration geologist and, more importantly, the exploration financial managers, to move fully into the final stage. However, in order for this to occur, there must exist a continuity of data and, equally important, an availability of data at a reasonable (that is, user justifiable) price.

The two major advantages of the Thematic Mapper data on Landsat-4 over the MSS system are its increased spatial resolution and its greater number of narrow, strategically placed, spectral bands (Table 1). These new data are so spectacular, they will undoubtedly stimulate a new round of the "Gee Whiz" phase. The increased spectral resolution is allowing us to map altered zones associated with mineralization based not only on iron oxide but on the basis of recognizing rocks and soils rich in hydroxyl groups, such as many of the clays formed as a product of hydrothermal alteration. The increased spectral range and resolution promise the ability to detect some types of vegetation changes that are associated with anomalous mineralization. This will be particularly helpful where soil and plants obscure the bedrock. This capability is not definitely proven, but theoretically possible and highly anticipated.

There is a second revolution going on in petroleum exploration geologic thinking in addition to the plate tectonic revolution. The old paradigm calls for tightly sealed hydrocarbon traps retaining for long periods of time (tens or hundreds of millions of years) petroleum that was generated and migrated in the distant past. The newly evolving paradigm envisions a much more dynamic scenario in which most, if not all, traps leak, and the generation and migration of hydrocarbons is a continuing process. This implies that there is very little, if any, really old oil or gas, rather, only new hydrocarbons generated from old rocks or retained in old traps. The hydrocarbon leaked from these imperfect traps moves vertically through the overlying rocks to the surface and, in the course of its movement, produces a host of chemical changes. The near surface environment manifests this leakage in a variety of geochemical, biological, geobotanical, or geomorphological anomalies or the simple presence of hydrocarbon itself.

Mineral exploration is not immune to the consequences of this paradigm. This peripatetic hydrocarbon has caused the emplacement of a vast amount of lead, zinc, uranium, and silver and has potentially played a role in localizing some deposits of gold, copper, and barite. This means that both petroleum and mineral geologists will need to be cognizant of the depositional and thermal histories of areas.

In the remainder of the talk, I would like to give you an appreciation of a few of the ways that the increased spectral and spatial resolution of the Thematic Mapper will affect geologic exploration. First, the increased spatial resolution. It is clear to us that, with careful computer and photographic processing, the quality of the TM digital data enables sharp photographic enlargements to a scale of 1:50,000 and, in some cases, larger. With clearly interpretable imagery at these scales, exploration geologists are able to significantly refine their structural interpretations compared to those made from 80 metre resolution MSS imagery.

- What was detectable only as a lineament on MSS imagery might be able to be confidently mapped as a fault.
- More importantly, some of the smaller features that indicate direction of movement along faults will be identifiable in the TM imagery, where they are lost in the lower resolution MSS imagery.

Southern Ontario (Example)

There are relatively few TM scenes available of areas with strong oil and gas interests, however, the July 25 image of Detroit does include some of the oil and gas fields of southern Ontario, Canada.

Thematic Mapper False Color Composite of Southern Ontario

On the false color image of the Ontario area, we have delineated some of the more prominent linears along with the location of the Malden, Colchester and Leamington oil and gas fields. At the Malden and Colchester fields, the hydrocarbon accumulations are in fractured, dolomitized, Ordovician limestones. The fractures trend WNW. It's a safe bet that the lineament marked on the imagery is the surface expression of a major through-going structure which is controlling the subsurface fracturing.

The Leamington field is a little younger and is located in ancient reef deposits. Reefs are known to prefer the high edge of structural blocks. The intersecting lineaments mapped on the imagery may well define two intersecting normal fault zones responsible for the uplift of a block edge and the localization of the Silurian reef.

Cement, Oklahoma (Example)

The most exciting potential contribution of the TM data is the availability of seven carefully placed spectral bands. For oil and gas exploration, these spectral bands will be extremely useful for the detection of possible surface rock alteration and geobotanical anomalies associated with microseepage of hydrocarbons from buried oil and gas accumulations. As the leaking hydrocarbons find their way to the surface, they alter the chemistry of the rocks through which they pass. At the surface, several things can occur: the altered surface chemistry may change the spectral and erosional characteristics of the surface rocks and soils and/or it may create variations in the density, type or vigor of any vegetation growing in the altered soils.

As a portion of our TM investigations, we are assessing TM's ability to identify and delineate areas of surface alteration due to microseepage of hydrocarbons at the Cement oil and gas field. The Cement field is overlain on the surface by the Rush Springs Sandstone. The Rush Springs Sandstone is a characteristic red color due to an abundance of ferric iron-oxides. The reducing chemical environment associated with the hydrocarbon microseepage appears to have altered the insoluble ferric iron to soluble ferrous iron, allowing it to be leached out of the sandstone. The result is a bleaching of the sandstone overlying the oil and gas field. We have only recently received our TM coverage of the Cement area. Our spectral analyses are therefore in their earliest stages. These next few images are pictures of our interactive image processing system and demonstrate our first cut approach at delineating the bleached area associated with the Cement field.

Cement NCC/HSV

The iron oxide rich areas are delineated on the imagery as areas of orange to red color. The quarter frame image shows the location of the red coloration following closely the outcrop of the Rush Springs Sandstone. However, the area overlying the Cement oil and gas field is one of those areas where the Rush Springs appears to have lost its strong iron oxide signature.

DEATH VALLEY, CALIFORNIA (EXAMPLE)

The first place to assess potential of TM data to map different rock types is in an area of low vegetation density and diverse rock types. Within the present range of the TM system there is clearly no more vegetation free area than Death Valley, California.

(Death Valley NCC/Death Valley FCC) - (Eigen/HSV)

The following imagery are of an approximately 1/3 TM scene area of the Death Valley, California overpass on 17 November, 1982. The scene includes a natural color, false color, eigen and HSV image.

The Hue, Saturation and Value (HSV) image is one of the more exciting images for geologic applications. Through the use of two ratios as hue and saturation, and the first eigenband as the value, the resulting HSV image possesses the spectral information of a ratio image and the spatial integrity of the first eigenband.

The hue of the image is controlled by the ratio of TM5 (1.6 microns) over TM2 (0.56 microns). The color assignments are such that high ratio values are red with decreasing values passing through the spectrum ending with the lowest values in blue. The saturation of the image is controlled by the ratio of TM5 (1.6 microns) over TM7 (2.2 microns).

TM2 was chosen for its sensitivity to ferric iron oxides; TM7 for its sensitivity to hydroxyl bands and TM5 for its high variance and broad information content. The 5/2 ratio will have high value (red hue) over areas of high ferric iron content, vegetation, as well as an assortment of other surface materials. The 5/7 ratio will have particularly high values (high saturation on the output image) over areas which contain hydroxyl bearing minerals or surface materials containing free water (e.g., clays, hydrated salts and vegetation). The first eigenband represents a positively weighted sum of the seven TM bands and thus provides excellent geomorphologic information allowing for precise geographic locations of the image's spectral information.

We suggest comparison of this image with the 1:250,000 scale Death Valley sheet of the Geologic Map series of California. Through comparison with the geologic map, some interesting examples of the unique information content of the HSV image appear along the northeastern flank of the Panamint Mountains, the eastern Funeral Mountains and the northern portions of the Resting Spring Mountains. The lower Paleozoic marine section along the northeastern flank of the Panamints is clearly distinguished from the older (PC?) section to the west. The small outcrops of Tertiary volcanics overlying the Paleozoic section are also clearly distinguishable. Note, however, that the Paleozoic marine section to the north (Tucki Mountain area) is spectrally "confused" with the Tertiary volcanics. The Tucki section is distinctly different from the Paleozoic sediments to the south of Black Water Wash, however, it is not immediately clear why its 5/2 ratio should be so spectrally similar to that of the Tertiary volcanics. Along the eastern portions of the Funeral Mountains and the Resting Spring Range, there are several examples of stratigraphic horizons which are clearly mappable on the HSV imagery and have been grouped into the Cambrian marine unit on the 1:250,000 scale geologic map. Although such groupings are obviously necessary during geologic mapping, the ability to map the individual lithologic beds on the HSV imagery significantly augments the information available on the geologic maps.

SUMMARY

We in the exploration industry find ourselves in a very challenging situation. World consumption of energy and mineral commodities is ever increasing, while at the same time, we are at a point where most of the large easy-to-discover, cheap-to-produce petroleum accumulations and mineral deposits have been located and many of these already exploited and depleted.

However, on the bright side, our technology is continuing to develop new tools with which geologic explorationists can evolve and test new geologic concepts. These new concepts allow the geologist to view exploration challenges with a new set of glasses, leading to such discoveries as finding oil in fractured volcanic rocks in the Great Basin of Nevada and to the thought of drilling through igneous and metamorphic rocks to find underlying oil in the Appalachian Mountains.

The improvements of Thematic Mapper data over multispectral scanner data brings us to the point that we are able to exploit satellite imagery at about the same scale that we have used aircraft data in the past. Certainly, improved spatial and spectral resolution and wider spectral coverage would be welcomed and stereoscopic imagery will be a great boon. However, it appears to us that the present TM system offers a near optimum balance between resolution requirements and data handling capabilities.

In summary, we feel confident that specially enhanced Thematic Mapper imagery will make a very significant contribution to the oil and gas and mineral exploration communities. The TM's increased spatial resolution will enable the production of larger scale imagery, which will greatly increase the amount of geomorphic and structural information interpretable. TM's greater spectral resolution, combined with the smaller, more homogeneous pixels, should enable a far greater confidence in mapping lithologies and detecting geobotanical anomalies from space. The results from its applications to hydrocarbon and mineral exploration promise to bring the majority of the geologic exploration community into that final stage of acceptance and routine application of the satellite data.

Table 1
COMPARISON OF LANDSAT -1, -2, -3 and -4 MULTISPECTRAL
SCANNER CHARACTERISTICS WITH THOSE OF LANDSAT-4 THEMATIC MAPPER

	MSS	TM
Resolution:	∿80m	∿30m
Wavelength bands:		
	4 = 500 - 600nm	1 = 450 - 520nm
	5 = 600 - 700nm	2 = 520 - 600nm
	6 = 700 - 800nm	3 = 630 - 690nm
	7 = 800 -1100nm	4 = 760 - 900 nm
		5 = 1550 - 1750 nm
		6 = 10,400 - 12,500nm
		7 = 2080 - 2350nm