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Applications of Space Technology To Mapping of Natural Resources

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1 ABSTRACT

Economic development depends largely on the ability of a nation to fully utilize its natural resources, which depends on detailed knowledge of these resources; what, where, and how much. This information is scarce or lacking in most developing countries, particularly in the Islamic World. Acquiring the needed information by conventional means requires a large investment in time, number of personnel, and therefore, in cost. In the meantime, space-age technology provides the necessary tools to conduct adequate surveys of the natural resources in a timely manner. Such are the means of obtaining the necessary data by digital sensors, stereo cameras, and radar imaging systems. These data can be utilized in mapping structures that may contain oil and gas deposits, high concentrations of economic minerals, areas that are covered by fertile soils, sites that have potential for groundwater exploration, and means to monitor cyclical climatic changes particularly in arid lands. These applications warrant consideration of initiating a project aimed at fully utilizing this new technology for economic development. Thus, it is recommended that the Islamic Academy of Sciences adopt a resolution to initiate and implement "Islamsat", satellite imaging system dedicated to the acquisition of data for mapping the natural resources of the Islamic World.

2 INTRODUCTION

Maps are portrayals of the terrain that are essential to the understanding of the environment and the utilization of the natural land and water resources for the benefit of mankind. That is why map-makers came with civilization.

The earliest known maps are from Mesopotamia and Egypt. The first are clay tablets dating back to 2000 B.C. and containing surveying notes on towns of ancient Babylonia for the purpose of taxation. The second oldest is a map of gold mines in the desert between the Nile River and the Red Sea in Egypt. It is drawn on a papyrus roll in about 1300 B.C. and shows gold mines, roads, the Temple of Ammon and some houses, all in color.

The first "topographic" maps made their debut in China. The oldest known dates back to the second century B.C. It shows much of the topography of the Hunan region of southeast China, where symbols were used for the first time to identify the various mapped features (Wilford, 1982).

From the time of these ancient civilizations through the nineteenth century, mapmakers paced the ground (on foot, with the help of animals, and later automobiles) and sailed the roughtest of seas to measure distances and heights, using increasingly sophispicated tools.

The era of aviation revolutionized the process by allowing the making of maps from aerial photographs. First, a network of "ground control points" were established by ground surveying. The position and elevation of these points were related to a geographic coordinate system adopted for the map. The details between these points were drawn by interpreting aerial photographs.

The pattern of coverage of aerial photographs is critical to the mapping operation. An aircraft flies a series of parallel lines. Along each flight line, pictures are taken at intervals so that each photographs will overlap the preceding one by 60 percent. The spacing of flight lines assures that one strip of photographs has about 20 percent side-lap with the adjacent strip. This pattern assures continuity of coverage and also makes it possible to determine the position of features and their elevations.

In the area covered by two adjacent photographs, every point on the terrain is seen in two different frames. A photogrammetrist examining these photographs uses a stereo-plotting instrument that presents the image from one photograph to the left eye and from the adjacent photograph to the right eye. This creates a three-dimensional view of the terrain. Horizontal distances between the features are measured as well as the heights of hills, the depth of valleys, and the slopes of escarpments.

A most important characteristic of a map is its scale, which is defined as the ratio of a distance on the map to the distance that it represents on the surface of the Earth. Thus, the scale of 1:1,000,000 means a distance of 1mm on the map represents 1km on the Earth's surface. At this scale, it would not be possible to graphically represent the pattern of an urban area where streets might be only about 100 meters apart. Thus, the amount of information that a map can present is directly related to its scale. For most countries in the world, the basic map scale for uniform coverage is 1:50,000, where 1mm on the map represents 50 m on the ground.

To produce photographs for such maps, one must use a precise mapping camera that allows the definition of details. When the camera is mounted in a moving aircraft, it is subject to vibrations from the engine and the atmoshpere. Such vibrations cause tilts in the photographs that introduce distortions that must be removed by photogrammetric procedures.

Just as the introduction of aircraft revolutionized the map-making process, today we witness that space-age technoloogy is about to make another giant leap in cartography by providing mapping-quality photographs from space. The use of spacecraft has the following advantages over aircraft: their orbits around the Earth can be more precisely measured than aircraft flight lines; they fly above the atmosphere and, therefore, avoid its destablizing effects; and, they travel at higher altitudes, which allow the coverage of larger areas in each photographs (El-Baz, 1984a).

During the past two decades, much has been learned about photographing from space. The American Gemini, Apollo, Skylab, Apollo-Soyuz, and Space Shuttle projects obtained various photographs of the Earth utilizing numerous instruments. Similarly, the Soviet Soyuz and Mir missions obtained photographs from Earth orbit. In addition, the American Landsat programme introduced digital imaging from space, where the data is transmitted to ground-receiving stations for later analysis (Figure 1). The French Systime Probatoire d'Observation de la Terre (SPOT) obtains data in the same way. The SPOT system added the feature of stereo (three-dimensional) imaging. The technology of these systems provides an advanced new tool for acquisition of data that are necessary for mapping the Earth and its resources.

3 MAPPING FROM SPACE

From the experience of the last 25 years, it was realized that a single method or platform cannot possibly satisfy all requirements of observing the Earth from space. For example, to acquire repetitive coverage of global weather conditions, a satellite should be as far away as possible from the Earth to obtain images of very large areas. However, to obtain high resolution or detailed photographs for geologic investigations, the satellite should orbit the Earth as low as possible. Thus, unmanned and manned systems were envisioned to fly in high, medium, or low orbits.

The highest orbits were left to the unmanned weather satellites. These are propelled to a height of 36,000 kilometers above the Earth. At this altitude, their motion is equivalent in speed to the rotation of the Earth about its own axis. Such satellites are termed geo-synchronous, and remain above the same point on the Earth to acquire and transmit repetitive images. The intermediate orbits are those from 500 to 2000 kilometers above the Earth, the region where most unmanned imaging satellites are placed. For example, Landsat satellites work at an altitude of 920 kilometers. On the lower end, most manned missions are placed in orbits below 500 to a minimum of 150 kilometers above the Earth. For example, the Space Shuttle

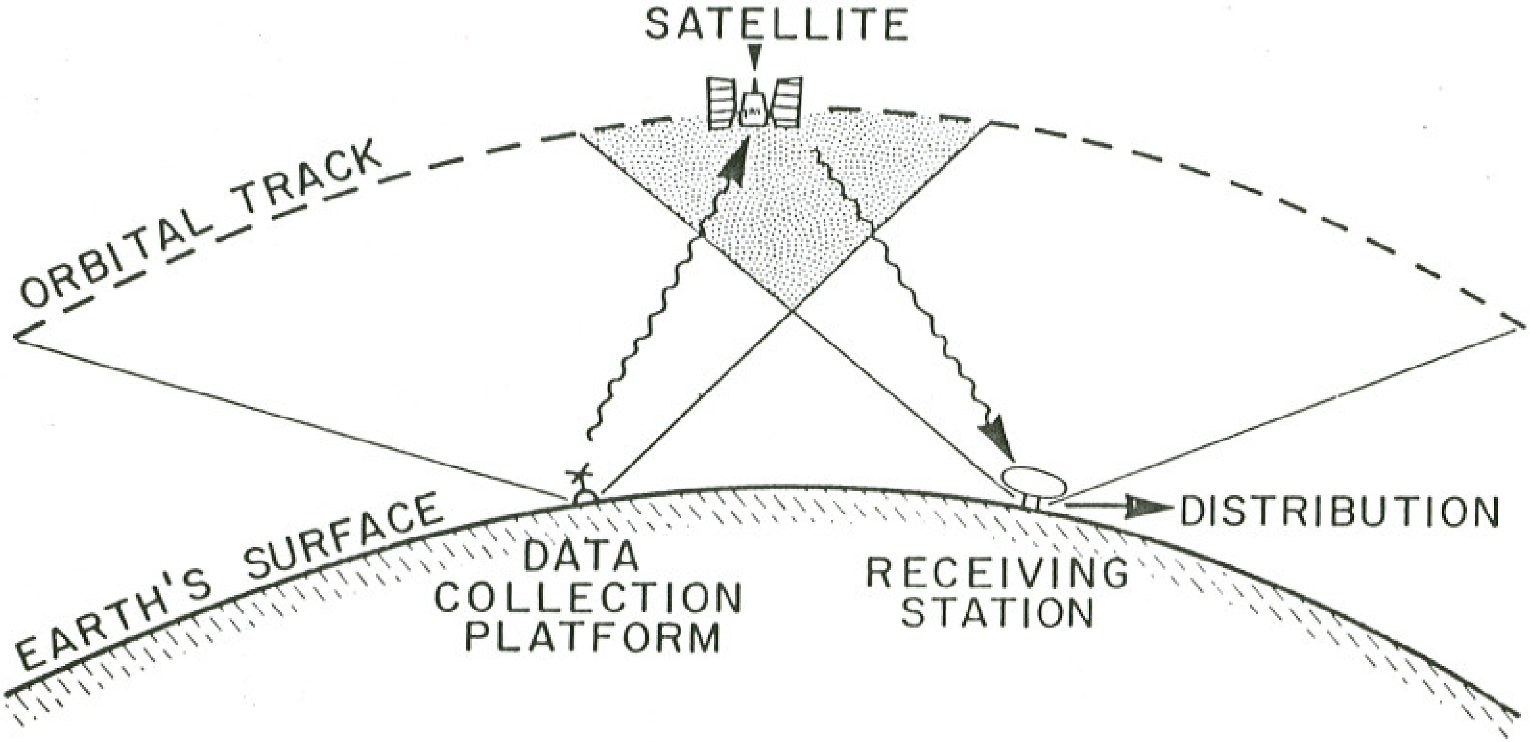


Figure 1. The Operation of Unmanned Imaging Satellites such as Landsat, the Data Collection Platform (DCP), and Ground Receiving Station.

operational altitude is about 300 kilometers.

3.1 Digital Imaging

The first unmanned imaging satellite from the Landsat series was launched on July 23, 1972 (Table 1). Four other satellites from the same series were launched at a few year intervals. After over 200,000 orbits around the globle and millions of images transmitted from space, Landsat has become established as a very useful tool for studying Earth's surface features.

Terrain study, however, was not the driving force in the selection of the particular sensors aboard Landsat. When NASA embarked on the design of the Earth Resources Technology Satellite (ERTS), as Landsat was initially called, there was competition among specialists in mapping, geology, ocean studies, and agriculture. The agricultural specialists required a method to inventory major crops. Their premise was that if space-age technology could provide a quick way to evaluate wheat crops before harvest, the data would have major marketing and political implications. The United States would then be able to better predict worldwide market prices. With this position, the agricultural team won, and the system was designed to acquire data on crop inventories in a timely manner. It included a multi-spectral scanner (MSS), a Return Beam Vidicon (RBV), and later, Thematic Mapper (TM) systems.

3.1.1 The Multi-Spectral Scanner

The Landsat Multi-Spectral Scanners produce images representing four different bands of the electromagnetic spectrum. The four black-and-white bands are designated band 4 for the green spectral region (0.5 to 0.6 microns); band 5 for the red spectral region; band 6 for the near-infrared region (0.7 to 0.8 microns); and band 7 for another near-infrared region (0.8 to 1.1 microns).

Light reflectance data from the four scanner channels are converted first into electrical signals, then into digital form for transmission to receiving stations on Earth (Figure 1). The recorded digital data are reformatted into what we know as computer-compatible tapes and/or converted at special processing laboratories to black-and-white photo images. These images from the four different bands are recorded on four black-and-white films, from which photographic prints are made in the usual manner.

Because each of the four bands records a different range of radiation, the black-and-white images generated for each band provide different sorts of information. For example, the green band (band 4) most clearly shows underwater features and is therefore useful in coastal studies. The two near-infrared bands, which measure the reflectance of the Sun's rays outside the sensitivity of the human eye (visible range) are useful in agricultural studies (El-Baz, 1979).

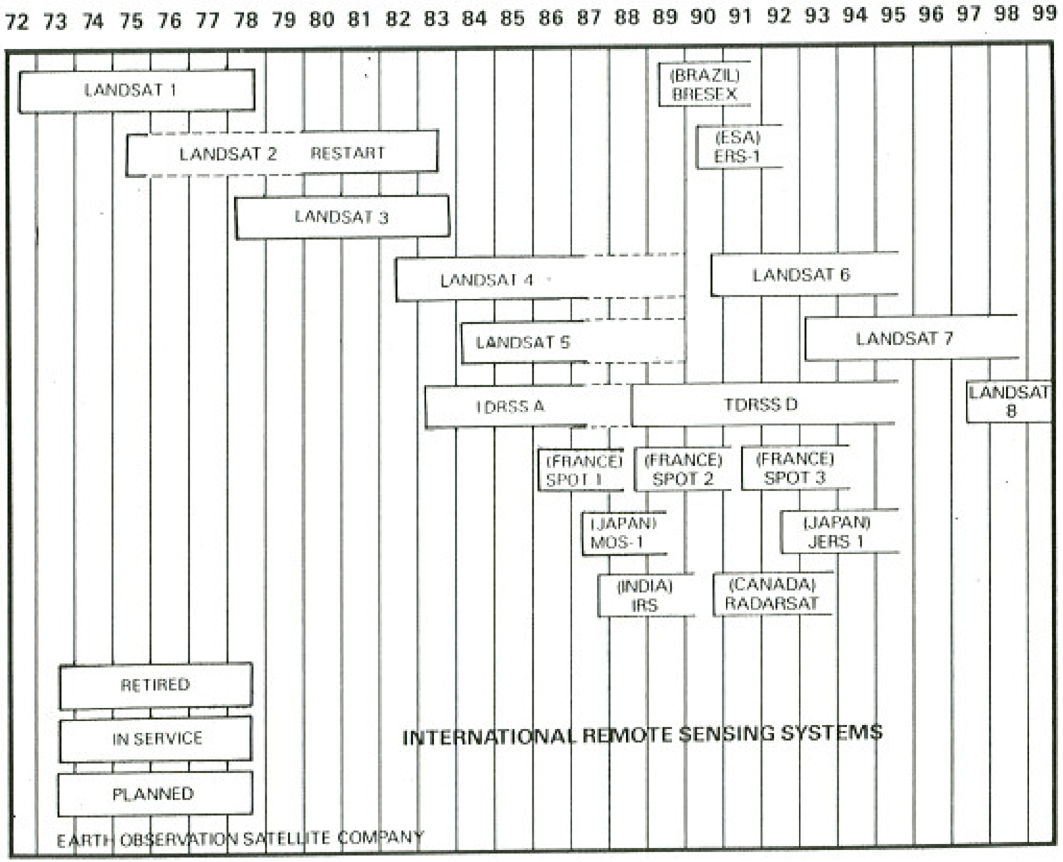
Table 1. Landsat Fact Sheet

The Satellites	Launched	Decommissioned	Sensors
Landsat 1	July 23, 1972	January 6, 1978	MSS (4 Bands), RBV (3 Bands)
Landsat 2	January 22, 1975	February 25,1975	MSS (4 Bands), RBV (3 Bands)
Landsat 3	March 5, 1978	March 31, 1983	MSS (4 Bands), RBV (1 Band-4 Subscenes)
Landsat 4	July 16, 1982	-	MSS (4 Bands), TM (7 Bands)
Landsat 5	March 1, 1984	-	MSS (4 Bands), TM (7 Bands)

Spacecraft	TM Bands	MSS Bands	RBV Cameras
Landsat 1,2	None	4,5,6,7	Bands 1,2,3 (Simultaneous images)
Landsat 3	None	4,5,6,7,8	A,B, and C,D (Side by side images)
Landsat 4,5	1,2,3,4,5,6,7	1,2,3,4	None

MSS BAND NUMBERS		SPECTRAL RESPONSE		TM BAND NUMBERS	RBV SPECTRAL RESPONSE			
Landsat 4,5	Landsat 1,2,3	(Micrometers) MSS	TM	Landsat 4,5	(Micrometers) Landsat 1 and 2			Landsat 3**
			0.45-0.53	1	Band Nos.			Cameras
1	4	0.5-0.6	0.52-0.60	2	1	2	3	AVBCD
2	5	0.6-0.7	0.63-0.69	3	0.48	0.58	0.69	0.51
3	6	0.7-0.8	0.76-0.90	4	to	to	to	to
4	7	0.8-1.1	1.55- 1.75	5	0.58	0.58	0.83	0.75
			2.08- 2.35	7				
	8*	10.41-12.6	10.04-12.5	6	** A and C frames are from the same camera as is B and D.			

* Landsat 3 only



Decommissioned, Active and Planned Digital Remote Sensing Systems Including the American Landsat and TDRSS and those of Other Nations

False-color images are produced when these bands are combined. For example, in the most popular combination of bands 4,5 and 7 the red color is assigned to the near-infrared band number 7. Vegetation appears red; because plant tissue is one of the most reflecting materials; the healthier the vegetation, the redder the image. Also, because water absorbs infrared rays, clear water appears black on band 7, and therefore, this band cannot be used to study features beneath water even in the very shallow coastal zones.

3.1.2 The Return Beam Vidicon

The Return Beam Vidicon (RBV) is a sensing instrument that was originally flown in the interest of the mapping community. It offered better geometric accuracy than was available from the Multi-Spectral Scanner with which the RBV shared space on Landsats 1,2, and 3. Although the RBV is not in operation today (Table 1), images are available through the Eros Data Centre, Sioux Falls, South Dakota and can be utilized in mapping.

The system contains three cameras that operate in different spectrual bands: blue-green, green-yellow, and red-infrared. Each camera contains an optical lens, a shutter, the RBV sensor, a thermoelectric cooler, deflection and focus coils, erase lamps, and the sensor electronics. The cameras are similar except for the spectral filters contained in the lens assemblies to provide separate spectral viewing regions. The sensor electronics contain the logic circuits to programme and coordinate the operation of the three cameras as a complete integrated system and rovide the interface with the other spacecraft subsystems. The three RBV cameras are aligned in the spacecraft to view the same 185-km square ground scene as the MSS of Landsat. The images are stored on the RBV photosensitive surfaces, then scanned to produce the video outputs (Hord, 1986).

3.1.3 The Thematic Mapper

The Thematic Mapper (TM) is a sensor that was carried first on Landsat 4 (Figure 2) with seven spectral bands covering the visible, near-infrared, and thermal infrared regions of the spectrum. It was designed to satisfy more demanding performance parameters from experience gained in the operation of the MSS. The TM picture element (pixel) size is 30 meters square as compared to 80 meters square for the MSS. At this ground resolution, most small agricultural fields may be accurately characterized.

The seven spectral bands were seleted for their passbands and radiometric resolutions. For example, the short wavelength band of the MSS, whose spectral passband is 0.5-0.6 μm, has been able to map underwater features to a far greater extent than was anticipated. Band 1 of the Thematic Mapper coincides with the maximum transmissivity of water and should therefore demonstrate coastal water mapping capabilities superior to those of the MSS. It also has beneficial features for the

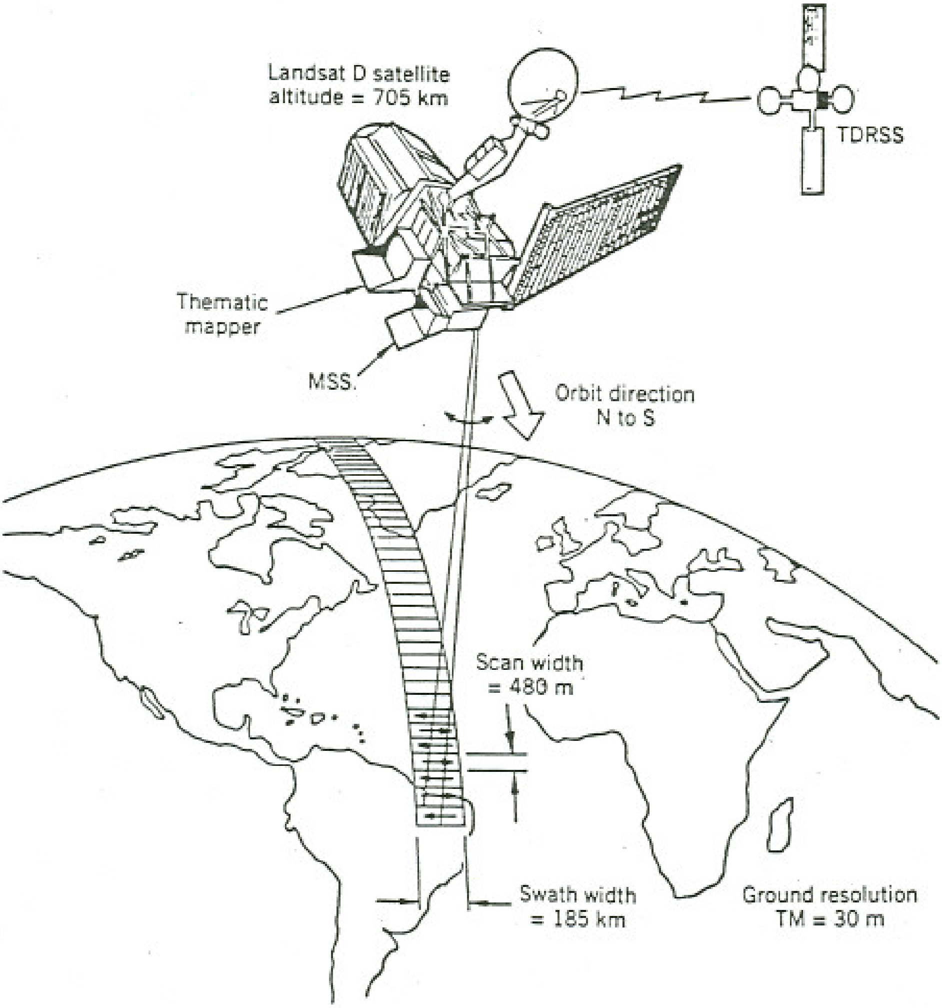


Figure 2. The Thematic Mapper Imaging System which Operated on Landsat 4 (D) and 5 (E); After Hord, 1986, p. 65

differentiation of coniferous and deciduous vegetation. Bands 2-4 cover the spectral region which is most significant for the characterization of vegetation. Vegetation moisture may be estimated from band 5 readings, and plant transpiration rates may be estimated from the thermal mapping in band 6. Band 7 is primarily motivated by geological applications, including the identification of hydrothermally altered rocks. The band profiles which are narrower than those of the MSS are specified with stringent tolerances, including steep slopes in spectral response and minimal out-of-band sensitivity (Hord, 1986).

3.1.4 The SPOT System

The SPOT system was designed by the Centre Nationale d'Etudes Spaciales (CNES) and built by the French industry in association with partners in Belgium and Sweden. Like the American Landsat, it consists of remote sensing satellites and ground receiving stations. The imaging is accomplished by two High Resolution Visible (HRV) instruments that operate in either a panchromatic (black-and-white) mode for observation over a broad spectrum, and a multi-spectral (color) mode for sensing in narrow spectral bands. The ground resolution is 10 and 20 meters respectively.

For viewing directly beneath the spacecraft, the two instruments can be pointed to cover adjacent areas. By pointing of a mirror, it is possible to observe any region within 950km from the nadir, thus allowing the acquisition of stereo photographs for three-dimensional viewing.

3.1.5 Future of Digital Imaging

It is particularly disturbing to note that, as of this writing, NASA is contemplating the termination of the image acquisition capabilities of Landsat 4 and 5, the only two functioning satellites (see Table 1) because of lack of operational funds. This comes after the U.S. Government had turned over the management and sale of the Landsat data to a private organization, the Earth Observation Satellite Company (EOSAT). In the meantime, the U.S. Government has initiated discussion in early 1989 with the French Government regarding the potential of merging the two nation's remote sensing activities. This would entail building two replacement satellites as well as the necessary ground stations to receive the data, leaving to the French company SPOT Image the marketing of the data worldwide.

As to future programmes, the Earth Observing System (EOS) is a planned NASA programme which will support U.S. multidisciplinary Earth science studies employing a variety of remote sensing techniques and scanners with hundreds of narrow spectral bands. It will do so in the 1990s as a prime mission using the space station polar platform. Its primary goal is the generation of longterm Earth science data sets of measurements in the areas of agriculture, forestry, geology, hydrology, oceanography, snow and ice, troposphere and upper atmosphere chemistry, radiation, and dynamics pertaining to global studies of the Earth as a system, emphasizing the interactions of the atmosphere-ocean-land system (Hord, 1986).

3.2 Radar Imaging

Radar imaging has been extensively used to reveal surface features in the rain forest and in polar regions from aircraft altitudes. However, until recently it has not been suitable for use on satellites because:

(a) Power requirements were excessive.
(b) For real-aperture systems, the azimuth resolution at the long slant ranges of spacecraft would be too low for imaging purposes.

The development of new power systems and radar techniques has overcome the first problem and synthetic-aperture radar systems have remedied the second (Sabins, 1978). The first successful experiment was that conducted from lunar orbit on the Apollo 17 mission in December 1972.

In November 1981, the Shuttle Imaging Radar (SIR - A) acquired images of variety of features including faults, folds, outcrops and dunes (Elachi and others, 1982). Among the revealed features are the sand-buried channels of ancient river and stream courses in the Western Desert of Egypt (Figure 3) and in Saudi-Arabia. In the first case, wells were drilled and produced water for an experimental agricultural station. A second flight was also successful and a third is planned on a future Space Shuttle mission.

3.3 Stereo Photography

For mapping the Earth from space, the Space Shuttle orbiters have the following advantages over unmanned satellite platforms:

(a) Multiple launches each year allow coverage of areas during proper seasons with the least cloud cover.
(b) The orbiters are reusable, which means that the cost of orbit insertion is minimized.
(c) The capability of reaching various altitudes, which allows the selection of the required coverage.
(d) The ability to use the orbiter as the photography platform as well as the vehicle to launch a free-flying camera into Earth orbit, if so required, for later retrieval.

The effort to specifically design a camera for mapping the Earth from space was to acquire stereo photographs. This effort began over 20 years ago

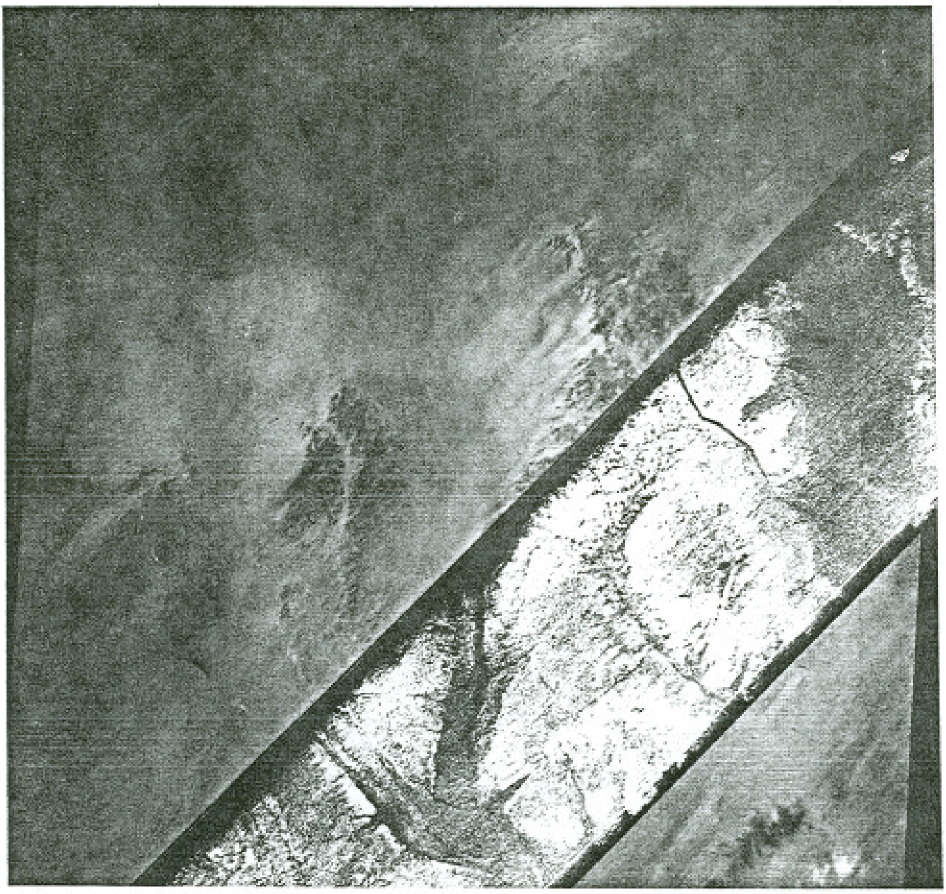


Figure 3. The Track of the Shuttle Imaging Radar (SIR-A) Over a Landsat Image of the Southern Border of the Western Desert of Egypt Showing Ancient River Courses Now Buried Under Sand

and finally paid off in October 1984 when the Space Shuttle Challenger Mission 41-G made the breakthrough. It used an advanced, specifically designed system to obtain mapping-quality photographs from Earth orbit. This system consists of the Large Format Cameral (LFC) and the Attitude Reference System (ARS).

The LFC derives its name from the size of its individual frames, which are 66 centimeters in length and 23 centimeters in width. The 450-kilogram camera has a 305 millimeter f/6 lens with a 40° × 740° field of view. The film, which is 1,200 meters in length, is driven by a forward motion compensation mechanism as it is exposed on a vacuum platen, which keeps it perfectly flat.

About one year earlier, the Metric Camera had flown on the Shuttle in December 1983. However, the German-made Metric Camera was not designed for space operation, could not fly in the Shuttle cargo bay because of the lack of a thermal shroud, did not have an image-motion compensation mechanism, and did not include a stellar altitude reference system (Doyle, 1985).

The spectral range of the LFC is 400 to 900 nanometers, and its system resolution is 100-lines per millimeter at 1,000:1 contrast and 88-lines per millimeter at 2:1 contrast. This adds up to photo-optical ground resolution of 10 to 20 meters from an altitude of 225 kilometers in the 57,000 square kilometer area that is covered by each photograph (which is over twenty times the coverage of a super-wide-angle camera in a high-altitude jet aircraft). The illumination uniformity of within 10% minimizes vigetting. The framing rate of 5 to 45 seconds allows its operation from various spacecraft altitudes.

The film calibration preference is provided by 12-edge fiducials and 45 reseau marks. The radial distortion across each frame is less than ten micrometers. The operating frame rate varies to a maximum overlap of 80% (Figure 4), which provides the required base/height ratio for topographic mapping with 20-meter contours (El-Baz, 1985a).

The ARS is composed of two cameras with normal axes which take 35 millimeter photographs of star fields at the same instant as the LFC takes a photographs of the Earth's surface. The precisely known positions of the stars allow the calculation of the exact orientation of the Shuttle orbiter, and particularly of the LFC in the Shuttle cargo bay. This accurate orientation data, together with the LFC characteristics, allos the location of each frame with an accuracy of less than one kilometer and the making of topographic maps of photographed areas at scales of up to 1:50:000.

On the Challenger's mission, and in addition to nighttime photography, 100 photostrips were taken during 73 daylight orbits. Of the 2,140 frames obtained, only 14% (300 frames) were cloud covered. Of the remaining, 26% (565 frames) are partly cloud covered, and the remainder (1,288 frames) are of excellent quality. Four types of film were used on this initial flight, including the "special order" Kodak black-and-white 3421, natural color 242, and color infrared 131 (El-Baz, 1985a). This flexibility makes the LFC an ideal system for the acquisition of mapping quality, high resolution, stereo photographs for mapping the natural resources of the Earth.

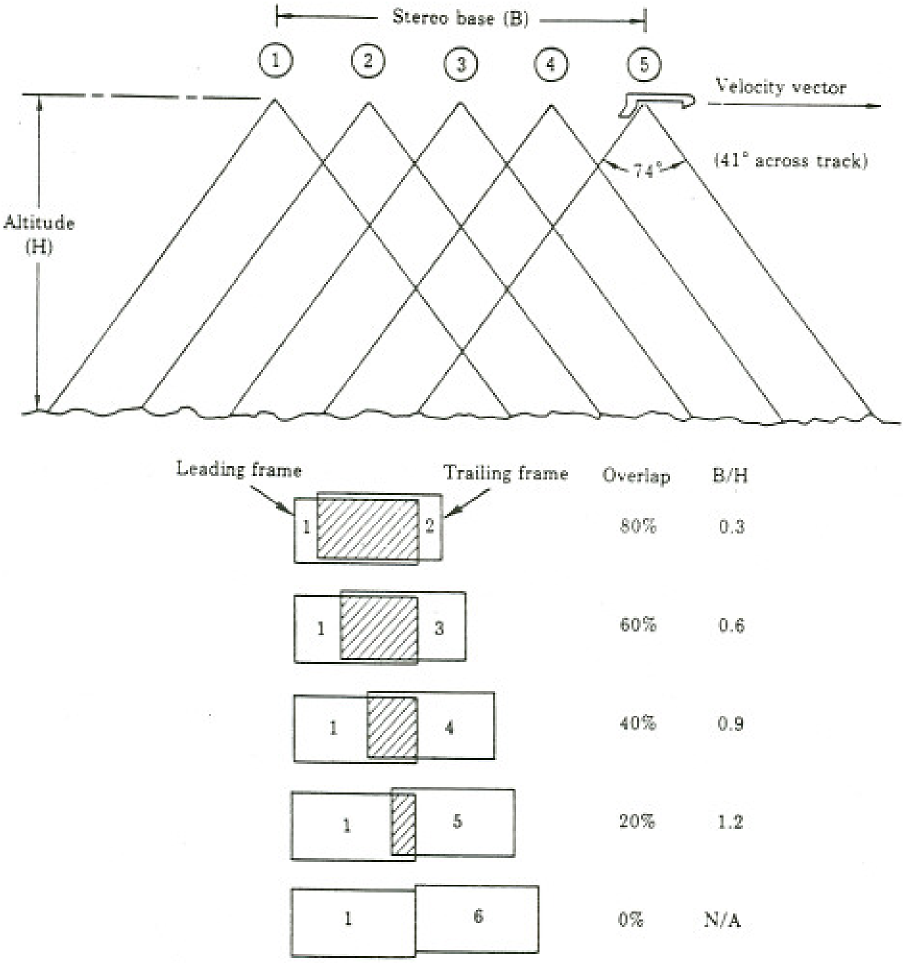


Figure 4. Stereo Photography by the Space Shuttle Large Format Camera (LFC)

4 IMPLICATIONS FOR ECONOMIC DEVELOPMENT

4.1 Oil and Gas Exploration

The oil and gas industry was first to recognize the utility of space images in mapping structures for potential exploration. Oil and gas deposits are commonly found in domal or anticlinal structures. The latter often constitute topographic highs, which are easily mapped based on the drainage pattern in the terrain. The space data are most useful where the terrain is not well-mapped or geologically poorly understood. This is the case of most developing nations including many in the Islamic World.

4.2 Mineral Investigations

Multi-spectral, remotely-sensed data has been applied in mineral exploration to the mapping of fracture systems that control ore deposition and to the detection of surface alteration effects associated with ore deposits (Sabins, 1978). In a few cases concentrations of deposits as copper, iron, uranium, and phosphate have been depicted in such data. Arid lands are the most amenable to spectral remote sensing for such resources owing to the scarcity of vegetation, and consequently, the favorable exposure of surfaces (Kahle, 1984). This has been successfully tested through the use of the Shuttle Multi-Spectral Infrared Radiometer (SMIRR), which was flown in November 1981 (Goetz and others, 1982). The instrument clearly depicted clayey deposits, quartz sands, and limestones and dolomites in the Western Desert of Egypt (El-Baz, 1984b).

Much groundwork has already been done to establish the spectral reflectance properties of minerals in the field and in the laboratory (Rowan and others, 1977). Additional work needs to be conducted particularly in measuring the spectra of minerals, soils, and rocks in the arid and simiarid lands of the Islamic World.

4.3 Desert Reclamation

In arid regions, a space photograph can be considered as a soil map. This is particularly true of color photographs because the color represents the reflectance property of a specific mixture of materials. A case in point is that of an area west of the Nile Delta in the Western Desert of Egypt. The area was the site of a major desert reclamation project that was initiated by the Egyptian Government in the late 1950's called the "Liberation Province".

A photograph of the region taken by the Gemini 5 astronauts in August 1965 showed three zones of color (Figure 5). The segment closest to the Mediterranean Sea appeared mottled. The middle segment appeared bright and the rest of the

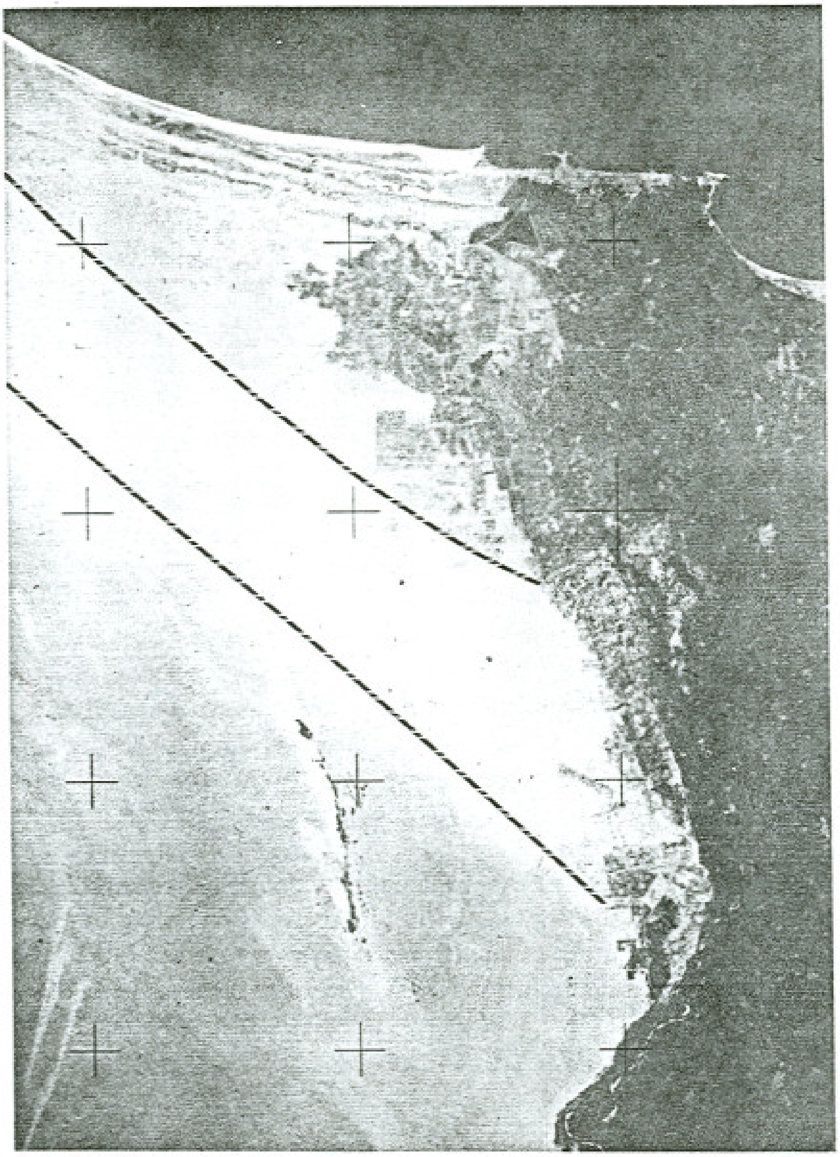


Figure 5. Photograph of the Area west of the Nile Delta Obtained by the Apollo-Sayuz Astronauts in July 1975 and Showing Three Zones in the Desert West of the Nile Delta. It Depicts the Success of Desert Reclamation Only in the Northernmost Zone

desert showed up in a darker color. The same region was photographed 10 years later by the Apollo-Soyuz astronauts on July 1975. The three zones of color remained visible in their photographs.

Field investigations showed that the northernmost segment was made of fertile soil composed of a mixture of clay, carbonate, and quartz particles. The middle segment was occupied by shifting quartz sand, and the southwestern segment was covered by pebbly desert pavement (El-Bas and El-Etr, 1979).

Comparison of the two images (Slezak and El-Baz, 1979) showed that agriculture proceeded at a much faster pace in the northernmost segment (Figure 5). It is unfortunate that most of the early effort of desert reclamation had proceeded in the southernmost and middle zones, which contained the least fertile land. Had the space photographs been available and were correctly interpreted as soil maps, no effort would have been wasted on the infertile land.

4.4 Recognizing Demographic Changes

Demographic variations were always hard to depict from space because of the photo-optical resolution of the imaging systems. This is true not only of the photographs taken by the astronauts with hand-held cameras, but also those obtained by automated systems such as Landsat. However, for the first time from space, the LFC photographs (10m resolution using black-and-white film) reveal details of village dwellings in Ethiopia and Somalia. These photographs, taken from 225km above earth, can even be compared to aerial photographs, taken from an altitude of 6 km (Figure 6).

The LFC photographs clearly show the land use patterns in the two countries where the land plots are typically very small. From these patterns, it is easy to decipher the type of agriculture and probable sources of water. It is also possible to interpret the approximate number of people that live in a given area, if a reasonable estimate of the occupants per doweling is made available. These characteristics allow the use of the LFC photography in demographics studies, particularly in arid and semi-arid terrain.

In the Ethiopia-Somalia example, the LFC photographs allow the recognition of the following:

(a) The agricultural patterns where the land plots are irregular and small.
(b) The migration pattern of people and the location of their camp sites.
(c) The estimation of the number of people in a given area.
(d) The best routes to supply the refugees with life-supporting aid.
(e) The most probable sources of ground water for potential use.

4.5 Monitoring Climate Change

Arid and semi-arid regions of the world are plagued by variations in the amount

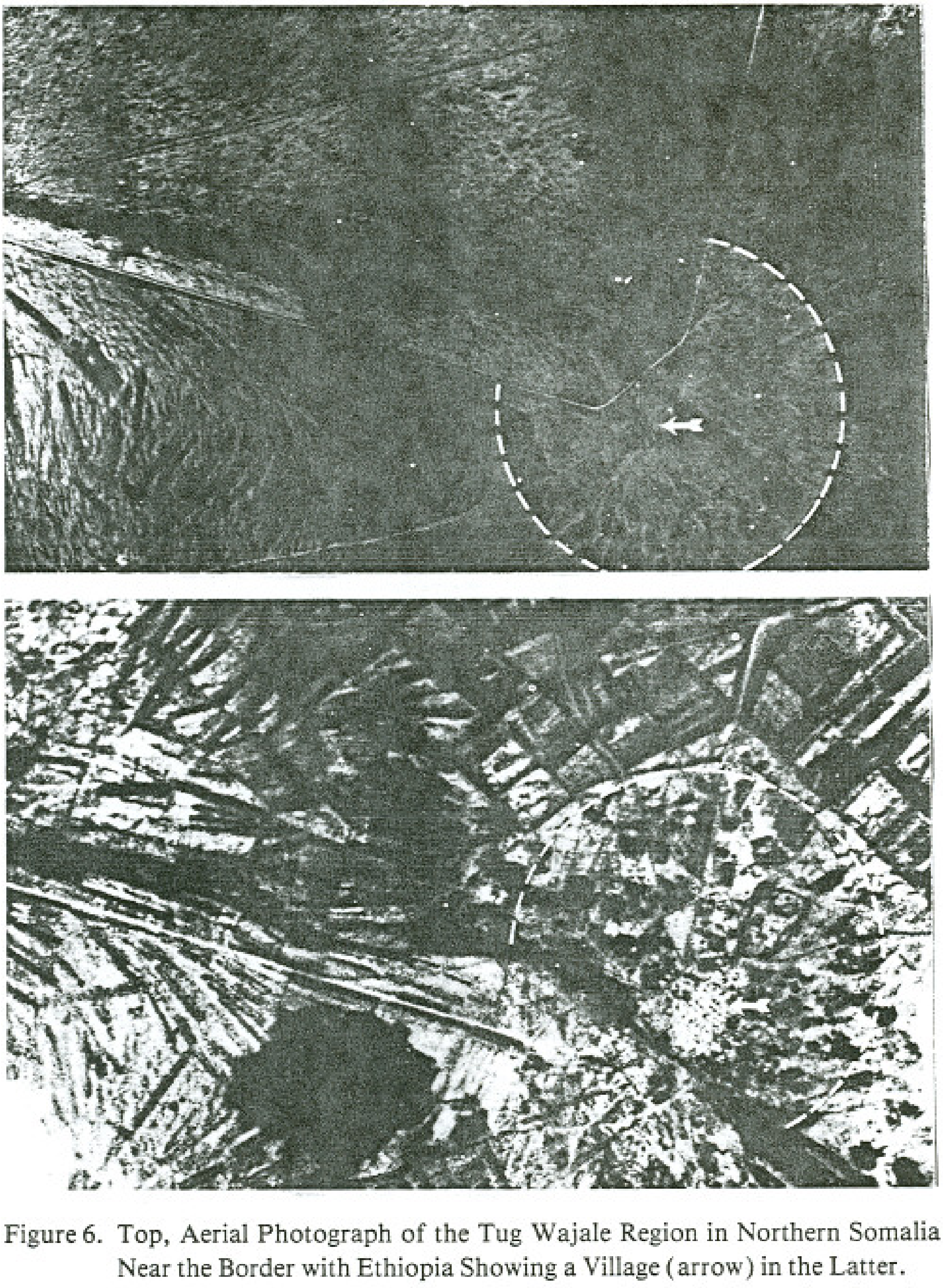


Figure 6. Top, Aerial Photograph of the Tug Wajale Region in Northern Somalia Near the Border with Ethiopia Showing a Village (arrow) in the Latter. Bottom, Photograph by the LFC Taken After the Drought Showing Migration of People to, and Increase of Agriculture in Somalia

of rainfall. These variations are cyclical in nature and appear to follow the eleven-year cycle of sunspots. Prediction of wet and dry episodes requires long-term observations of the climatic regime. This is hampered by the scarcity or lack of meteorological stations in the affected lands.

One way of understanding such climatic changes is to monitor river and wadi outflow as well as water levels in natural and man-made lakes. The lake Nasser behind the High Dam at Aswan, Egypt, presents a case in point. It is a body of water that stretches for 500km south of the dam. At top capacity, the reservoir holds approximately 170 billion cubic meters of water, which is enough to satisfy Egypt's needs for over three years.

Space Shuttle astronauts obtained numerous photographs of the Lake Nasser region on several missions. These photographs were requested by the author during briefing sessions in support of on-going research. They include some that were taken in November 1981, when the Lake was nearing full capacity. At that time, there were fears that the Lake might rise to beyond 183m above sea level and endanger the dam itself (El-Baz, 1985b). For this reason, a 200m-wide canal was dug to serve as a spillway to carry water above the 178m level to Tushka Depression, 22km to the west of the lake. Shortly thereafter, the level of water in Lake Nasser started declining. The reason was the scarcity of rain in the source areas of the Nile, Particularly in Ethiopia. This trend continued for three years (Figure 7)

The Space Shuttle photographs taken by the LFC in October 1984, were compared to those taken earlier. Detailed stereoscopic analysis clearly showed the drop in the lake level, by more than 20 meters in 3.5 years, which is about ten-times the normal seasonal variation between April and November of a given year. Thus, an effort should be launched to make use of these new tools for monitoring longer-term changes. Its objectives would be to follow the changes and to make the results of water quantity forecasts available to policy-makers in Egypt and other nations. Such long-term forecasting of the Nile is essential to the economic stability of countries in East Africa. Monitoring of similar bodies of fresh water in the rest of the Islamic World would be essential to proper planning of the use of this vital resource.

4.6 Groundwater Exploration

Perhaps the most important application of mapping the Earth from space is in the location of new groundwater resources, particularly in arid and semi-arid regions of the world. To this day, most groundwater exploration concentrates on relatively shallow acquifers in porous rocks such as sandstones or limestones. Little if any attention has been given to deep acquifers in fractured basement rocks such as granites. Major fractures in such rocks drain vast regions and have an enormous capacity for storing fresh water, at deep horizons that are far removed from pollution sources. This largely untapped source for groundwater has the potential of transforming the economic base in most countries of the Islamic World.

Figure 7. Space Shuttle Photograph of Part of Lake Nasser Behind the Aswan High Dam Showing Marks Left by the Previously Higher Water Level

5 CONCLUSION

It is clear that space-age technology has provided us with a new tool to map the natural resources of the Earth. Numerous manned and unmanned missions have provided us with data that can be utilized on an experimental basis for the selection of the most suitable types of data for specific mapping needs. This experimentation and research should be encouraged throughout the developing nations.

For operational use, however, the need exists for a system to provide data on a timely manner. It would also be most advantageous if these data are made available to the developing countries first to satisfy the urgent and specific needs of economic development.

Therefore, it is concluded that the Islamic World requires a satellite imaging system to satisfy its requirements. Islamic countries have among them the necessary financial resources and enough of the technical expertise to initiate such a project. The recommended system, Islamsat (this term was coined in El-Baz, 1983, and the system was detailed in El-Baz, 1984c), would include the most suitable instruments from those that are available today for the remote sensing community. Such components would be selected based on a study by the Islamic Academy of Sciences which should adopt this project and spearhead the necessary deliberations that would lead to its implementation. In this way we would assure using the most advanced technology for mapping of the natural resources in the Islamic World in the service of economic development.

REFERENCES

1 . Doyle, F.J. (1985) Interview: Frederick J. Doyle and Gottfried Konecny, Photogrammetric Engineering and Remote Sensing, p. 1160-1169.

2 . Elachi, C. and others (1982). Shuttle Imaging Radar Experiment. Science, Vol. 218, No. 4576, p. 996-1003.

3 . El-Baz, F. (1979) Egypt as Seen by Landsat. Dar El-Maaref Press, Cairo, Egypt, 65 color plates and text.

4 . El-Baz, F. (1983) Islamsat: A Technologically Advanced System for Efficient Charting of Natural Resources. International Conference on Islamic Sciences and Technology. Universiti Teknologi Malaysia, Kaula Lumpur, Malaysia.

5 . El-Baz, F. (1984a) Observing Earth from Space. Aviation Space, Spring 1984, Vol. 2, No. 1, p. 30-34.

6 . El-Baz, F. (1984b) The Desert in the Space Age. In: Deserts and Arid Lands, El-Baz, F., editor, Martinus Nijhoff Publishers, The Hague. The Netherlands, p. 1-29.

7 . El-Baz, F. (1985a) New Mapping-Quality Photographs of the Earth and their applications to Planetary Comparisons. Lunar and Planetary Science XVI. Lunar and Planetary Institute, Houston, Texas. p. 207-208.

8 . El-Baz, F. (1985b) A Dam Against Famine. National Geographic, Vol. 167, p. 595.

9 . El-Baz, F. (1984c) Al-Qamar Al-Sinaie Al-Islami ''Islamsat''. AlFaisal Magazine, Riyadh, Saudi Arabia, Issue 85, p. 91-102.

10. El-Baz, F. and H.A.El-Etr (1979) Color Zoning in the Western Desert of Egypt. In: Apollo-Soyuz Test Project, Summary Science Report, Volume II, NASA SP-412, p. 203-217.

11. Goetz, A.F.H. and others (1982) Mineral Identification from Orbit: Initial Results from the Shuttle Multi-Spectral Infrared Radiometer. Science, Vol. 218, No. 4576, p. 1020-1024.

12. Hord, R.M. (1986) Remote Sensing Methods and Applications. Wiley Series in Remote Sensing. Hohn Wiley & Sons, New York, 362 p.

13. Kahle, A.B. (1984) Measuring Spectra of Arid Lands In: Deserts and Arid Lands, F.El-Baz, editor, Martinus Nijhoff, The Hague, The Netherlands p. 195-217.

14. Rowan, L.C. and others (1977) Discrimination of Hydrothermally Altered and Unaltered Rocks in Visible and Near-infrared Multi-Spectral Images. Geophysics, Vol 42, p. 522-535.

15. Sabins, F. F. Jr. (1978) Remote Sensing Principles and Interpretation W.H. Freeman, San Francisco, 426 p.

16. Slezak, M.H. and F. El-Baz (1979) Temporal Changes and Depicted in Orbital Photography of Arid Regions in North Africa. In: Apollo-Soyuz Test Project, Summary Science Report, Volume II, NASA SP-412, p. 263-272.

17. Wilford, J.N. (1982) The Mapmakers: The Story of the Great Pioneers in Cartography from Antiquity to the Space Age. Vintage Books, New York.