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THE ENVIRONMENT OF SOUTH-CENTRAL TUNISIA AS OBSERVED ON LANDSAT SCENE 206/036

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AS OBSERVED ON LANDSAT SCENE 206/036

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ABSTRACT

One Landsat image in south-central Tunisia was analyzed to demonstrate the application of remote-sensing technology to regional development. A preliminary analysis included 1) major landscape features; 2) gypsum-encrusted soils; and 3) phosphate-bearing beds exposed in the Gafsa mining district.

The products specifically used for this report include: 1) A false-color composite (FCC), which had been linearly stretched to enhance contrast, and to which a modulation transfer function correction (a high-pass filter 3 pixels by 3 pixels wide) had been applied to enhance fine topographic relief. 2) A sinusoidally stretched false-color composite, on which mappable gypsum-encrusted soils and saline soils are detectable in greater detail than on the existing soil map of Tunisia at 1:500,000 scale. 3) A sinusoidally stretched band-ratio false-color composite, from which a thematic map of most phosphate-bearing beds in the Gafsa mining district was prepared.

Recommendations for future Landsat image interpretation in Tunisia are offered.

INTRODUCTION

A Landsat image covering south-central Tunisia was selected for digital processing and analysis in July 1977. Digital processing was done at the U.S. Geological Survey computer facility at Flagstaff, Arizona, in September 1977, and a preliminary analysis of various Landsat data products was performed late in October 1977.

Purpose and scope

The object of this work was to utilize both digitally processed Landsat products and the information obtained from them in a demonstration of remote-sensing technology to be given in Tunisia in November 1977 by specialists of the U.S. Geological Survey. The project was sponsored by the Office of Science and Technology (TA/OST) of the Agency for International Development (AID), U.S. Department of State, under PASA Agreement IC/TAB-000-577, but little work was done until the summer of 1978, when it was possible to check and slightly extend the scope of the original analysis. Results are summarized in this report.

Scene and image selections were constrained by at least two unrelated factors: 1) A Tunisian/AID desire to maximize the application of Landsat data to regional development: South-central Tunisia, which is transitional between the semiarid and arid desert environments, offers a variety of managerial challenges to foresters in the northwestern part, to agriculturalists in the coastal plain and oases where soil erosion and desertification are major concerns, and to the economic geologist interested in major phosphate and lead-zinc deposits; and 2) short turn-around time to purchase computer-compatible tapes (CCTs) from the Survey's EROS Data Center, Sioux Falls, South Dakota, so that the image could be processed, duplicated, and analyzed in time for a mid-November 1977 presentation in Tunis. Landsat scene 206/036, image 1199-09311, acquired on February 7, 1973, met both requirements and was selected for digital processing and analysis (fig. 1).

The scope of the analysis, likewise, was limited by time and availability of funds. Only spatial analysis was attempted, using a single Landsat image, even though seasonal and even yearly analysis of several images might reveal changes in vegetation, and changes due to natural flooding of flood plains and sebkhas (sebkrets) (flat, commonly saline depression floors). The various products obtained from the computer were enlarged photographically at the semi-reconnaissance scale of 1:500,000. At that scale 1 mm on the photographic product represents is 500 meters on the ground; this is to say that the scope of the analysis is bound by scale rather than by the nominal resolution of the original Landsat image, which is approximately 100 meters.

Within the self-imposed limitations of this analysis, the project has three main objectives: 1) To establish correlations between the information contained in a variety of Landsat data products on one hand, and the body of existing knowledge about south-central Tunisia on the other; 2) to select and recommend those data products most appropriate for the analysis of specific features such as water bodies, soils, rock types, and delineation of problem areas affected by soil erosion and desertification; and 3) to show how Landsat data products can be used to supplement information already available on many types of maps, even in a region as intensely studied as south-central Tunisia.

Personnel

The project chief was Joseph O. Morgan, remote sensing specialist, U.S. Geological Survey, Reston, Virginia. Image processing was supervised by Pat S. Chavez, Jr., Flagstaff, Arizona, and image selection and analysis of data products were done by Maurice J. Grolier and Patricia A. Schultejann, Flagstaff, Arizona.

The planned visit to Tunisia took place November 17-20, 1977, when Grolier paid a short visit to Dennis Morrissey, USAID Program Economics Officer, Tunis, and to Ahmed Souissi, Direction of Soils and Surveys Mapping, and Chief, Remote Sensing Laboratory, Ministry of Agriculture. On Saturday morning, November 19, 1977, a variety of digitally enhanced

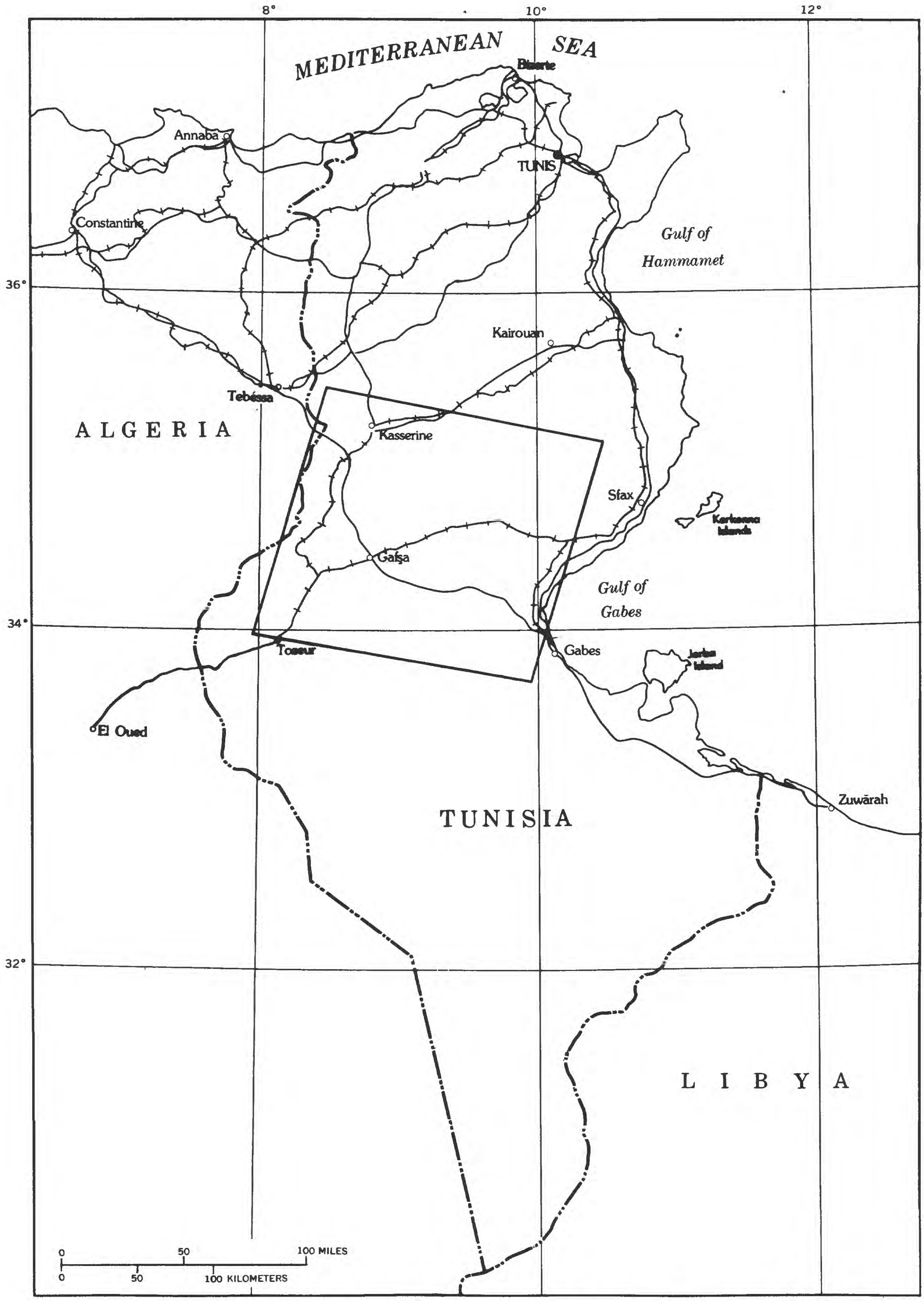

Figure 1. Index map showing outline of Landsat scene 206/036, southern Tunisia.

data products derived from Landsat image 1199-09311, which had been photographically enlarged at the scales of 1:500,000 and 1:250,000 were described at a meeting which convened at the Soils Division in Tunis. After the meeting, most of the data products were left with Mr. Ahmed Souissi for analysis by the staff of the Soils Division. Attendees at the meeting were:

Mr. Mohsen Hamza, Soils Division

Mr. Ahmed Souissi, Director of Soils and Survey Mapping, and Chief, Remote Sensing Laboratory

Mr. Touhami Chattaoui, Agronomist, Soils Division

Mr. S. Khalfallah, Pedologist, Soils Division

Mr. A. Hentati, Geomorphologist, Soils Division

Mr. Ali Hamza, Geomorphologist, Soils Division

Mdm. S. Selmi, Geomorphologist, Soils Division

Mr. M. Zaier, Soils Division

Dr. Delhumeau, Pedologist, Soils Division

Mr. Lehotsky, Geologist, Tunisian Geological Survey

Mr. Zebid H., Hydrologist, Water Resources Division

Mr. Kallal R., Hydrologist, Water Resources Division

Mr. J. P. Delhoume, Pedologist, ORSTOM*

Mr. J. Bonvallot, Geomorphologist, ORSTOM

Subsequently, two of the participants at this meeting, Messrs. Touhami Chattaoui and Ali Hamza, accompanied by Mr. Azouz Ganouchi, hydrologist, Tunisia Water Resources Division, visited Chavez and Grolier in Flagstaff, Arizona, on November 7-8, 1978, while on leave from a 2-week course in remote sensing offered at the Office of Arid Land Studies, University of Arizona, Tucson, Arizona.

GEOGRAPHY

Physiography

Landsat scene 206/036 covers a nominal area (185 km x 185 km) in south-central Tunisia, which includes parts of several physiographic

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*ORSTOM: France, Office de la Recherche Scientifique et Technique d'Outre-Mer.

provinces (fig. 1). The largest and most outstanding of these is the southwestern part of the Tunisian Dorsale in the northwestern quarter of the scene. The Tunisian Dorsale is the northeastern extension of the Saharan Atlas mountain range of Algeria, and the High Atlas mountain range in Morocco. It consists of a series of northeast-trending limestone mountain ranges, which culminate at Kaf ash-Sha'nabi (Mt. Chambi; altitude, 1,295 meters) near the Algerian border. The Dorsale is bordered by high and low steppes (grassland and shrub plains), which decrease in altitude eastward toward the coastal plain along the Mediterranean coast. The low steppes extend inland and northwest of the Gulf of Gabes from Sfax toward Kairouan over a dry alluvial plain, which is of significant agricultural importance in the As Sahil (Sahel) close to the littoral. Grassland also extends southward toward the chotts, or depressions of inland drainage. The extreme southern part of Landsat scene 206/036 covers a small part of the Gulf of Gabes, Chott el Fedjadj, the northern part of Chott el Djerid, and the easternmost part of Chott el Rharsa. The physiographic units of southern Tunisia were defined and mapped by Le Houerou (1959).

Most of the area covered by Landsat scene 206/036 lies between 34° and 35° N. latitude. The environment of south-central Tunisia changes from a semiarid to arid hot-temperate or hot environment with decreasing latitude and altitude (fig. 2). The highlands in the Dorsale are subject to freezing weather in winter, but the Dorsale acts as a physical and climatic barrier, which separates it from the steppes and the inland depressions farther south. The southern region experiences great ranges in daily and annual temperatures, and precipitation there is highly irregular from year to year, as is common in semiarid and arid regions. North of the chotts, the average annual rainfall ranges from 100 to 250 mm, and in the extreme northwestern part of the scene, from 250 to 400 mm. Occasionally, polar air masses reaching the Gulf of Gabes collide with dry Saharan air, engender large convection cells and cloud masses over the Tunisian mainland, and cause catastrophic cloudbursts and floods such as those of September-October 1969 (Pias, 1970; Poncet, 1970; Stuckmann, 1970; Clarke, 1973).

Vegetation

The two major vegetation formations of Tunisia are Mediterranean woodland and steppe grassland. Aleppo pine predominates in the mountain ranges of the Dorsale region, and steppe grasses such as esparto grass, grow where rainfall is less than 400 mm per year. Relative air humidity is high along the coast, where olives are grown without irrigation. One of the two main olive-growing areas in Tunisia is located in the low steppe west of Sfax (Safaqis); it is imaged in the northwestern corner of Landsat scene 206/036. Farther south, most cultivation, including truck gardening, date palms, and fruit trees depends on irrigation from wells and springs. Barley, however, is cultivated in wetty bottoms without irrigation. Farming and gardening are common agricultural practices in the low steppes, and droving of livestock, sheep, and goats from the lowland toward the highlands (transhumance) is required there because of summer drought (fig. 3).

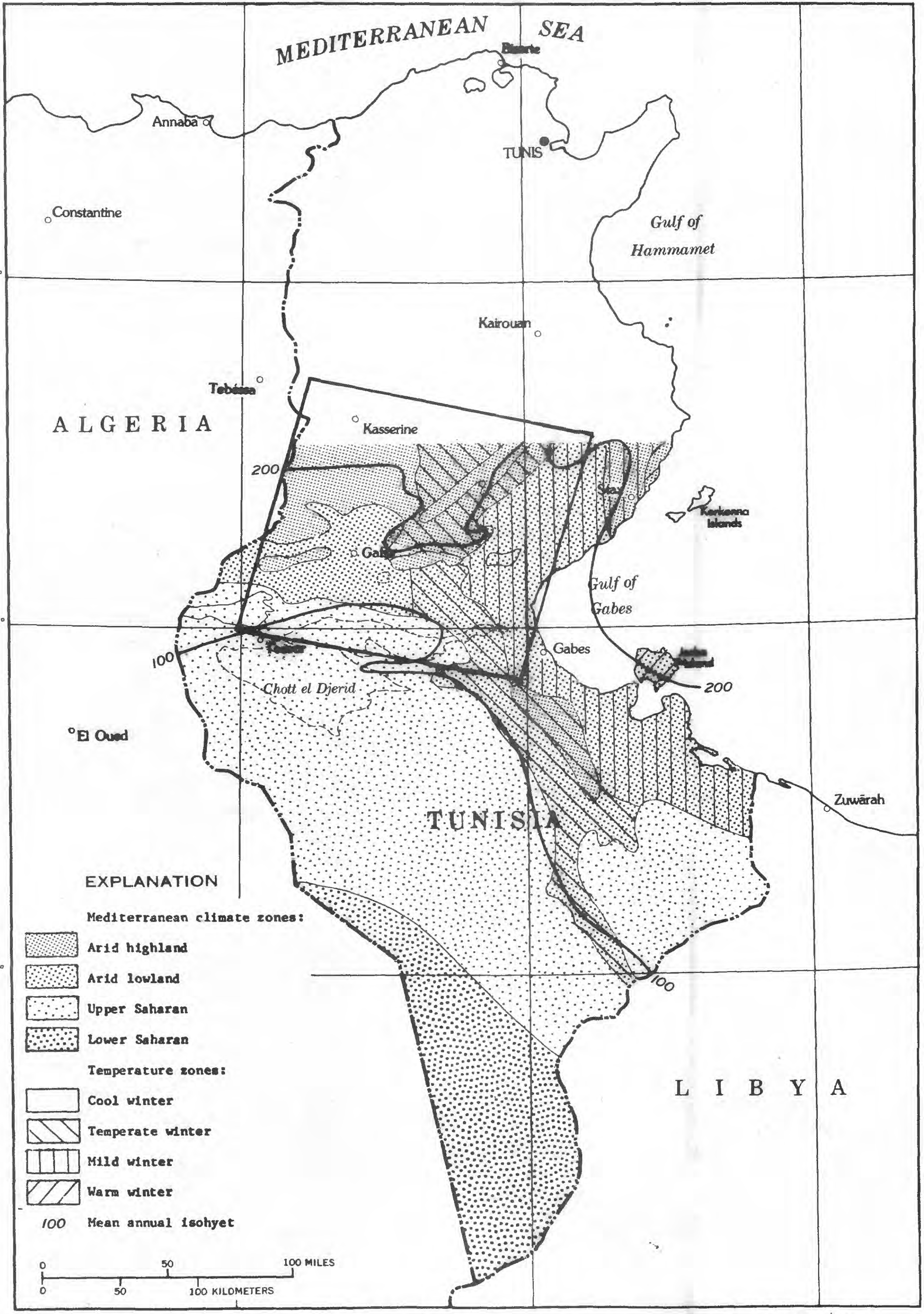

Figure 2. Index map showing major climatic zones, southern Tunisia. (from Floret and others, 1976).

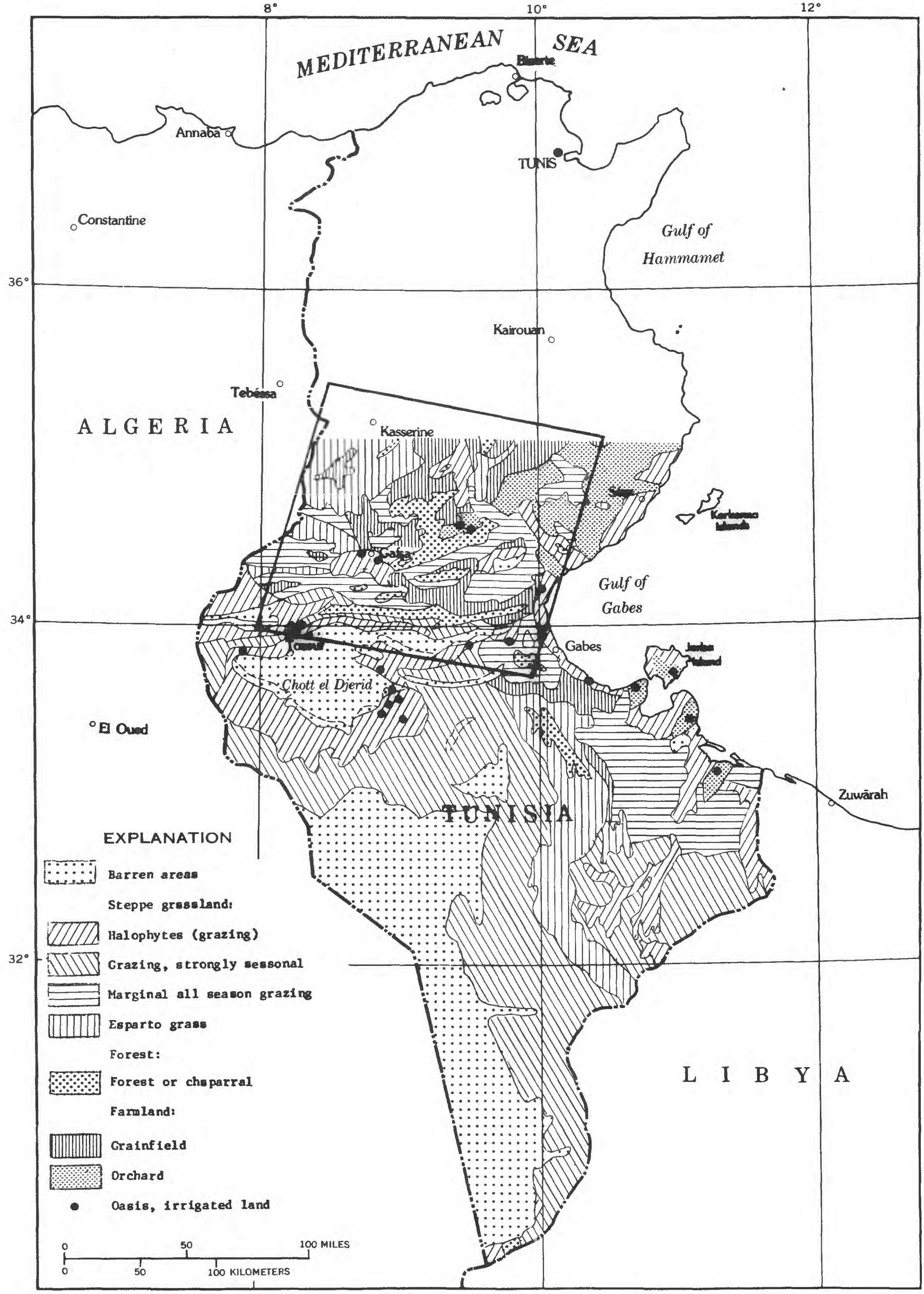

Figure 3. Index map showing major types of land use, southern Tunisia. (from Floret and others, 1976).

Drainage network

The drainage network consists of intermittent streams which drain toward the coastal plain or closed depressions, which are variously termed sebkha, sebkret, sebkra, sebkhat, garaet, and chott (shott) and are dried beds of shallow saline lakes commonly occupying a closed structural depression. A major east-trending divide across the Tunisian Dorsale, south of Kasserine separates northeast-draining streams from south-draining streams flowing toward Gafsa. The major northeast-draining stream is Wadi el Hadjal, which receives discharge from many northwest-bank tributaries, and from Wadis el Fekkah and el Hatab, up-stream from the region of Gammouda. The south-draining streams include Wadi Si Aich and its tributaries Wadi al Hogueff and Wadi Errocof, and Wadi el Kebir, which joins Wadi Si Aich at Gafsa, to form Wadi Bayech. Wadi Bayech normally is a tributary of Wadi el Melah, but at exceptional flood time it flows toward Chott el Guettar. Southwest of Gafsa, drainage is toward Chott el Rharsa. Wadi el Leben is the main east-flowing stream across the alluvial lowland toward the Gulf of Gabes.

From north to south, the main closed depressions are: Sebkret Mecheguige, Chott en Noual, in the low-steppe region: Garaet Duara and Chott el Guettar near Gafsa, and Chotts el Fedjadj, el Djerid, and el Rharsa. Lac des Affial (Elephant Lake), 20 km southeast of Kasserine is an ephemeral fresh-water lake (possibly a garaet).

Natural resources

The esparto grass of the steppes is used for manufacture of cellulose and quality paper at mills in Kasserine. The principal mineral resource is phosphate, which is being mined west and south of Gafsa. South of Gafsa, an iron deposit is being developed at Jabal al Onk. There also are minor deposits of lead and zinc in the Dorsale mountain ranges near Kasserine.

Population and political subdivision

Most of the area shown on Landsat scene 206/036 is sparsely populated, less than 25 persons per square kilometer, except along the coast of the Gulf of Gabes (fig. 4). Political subdivisions include parts of five wilayats (governorates), which are named after their capital cities. From north to south, they are (fig. 1): Kasserine, el Kairouan, Sfax (the latter two outside the scene), Gafsa, and Gabes (just outside the scene). The 1970 population estimate for Kasserine was 229,000 inhabitants, and 365,000 for Gafsa.

Transportation and communications network

The major cities of Kasserine and Gafsa are linked to the coastal plain and the ports of Susah, Sfax, and Gabes (outside Landsat scene 206/036) by road and railroad. A major highway links Gabes to Gafsa, and another one to Sfax. New port facilities on the Gulf of Gabes

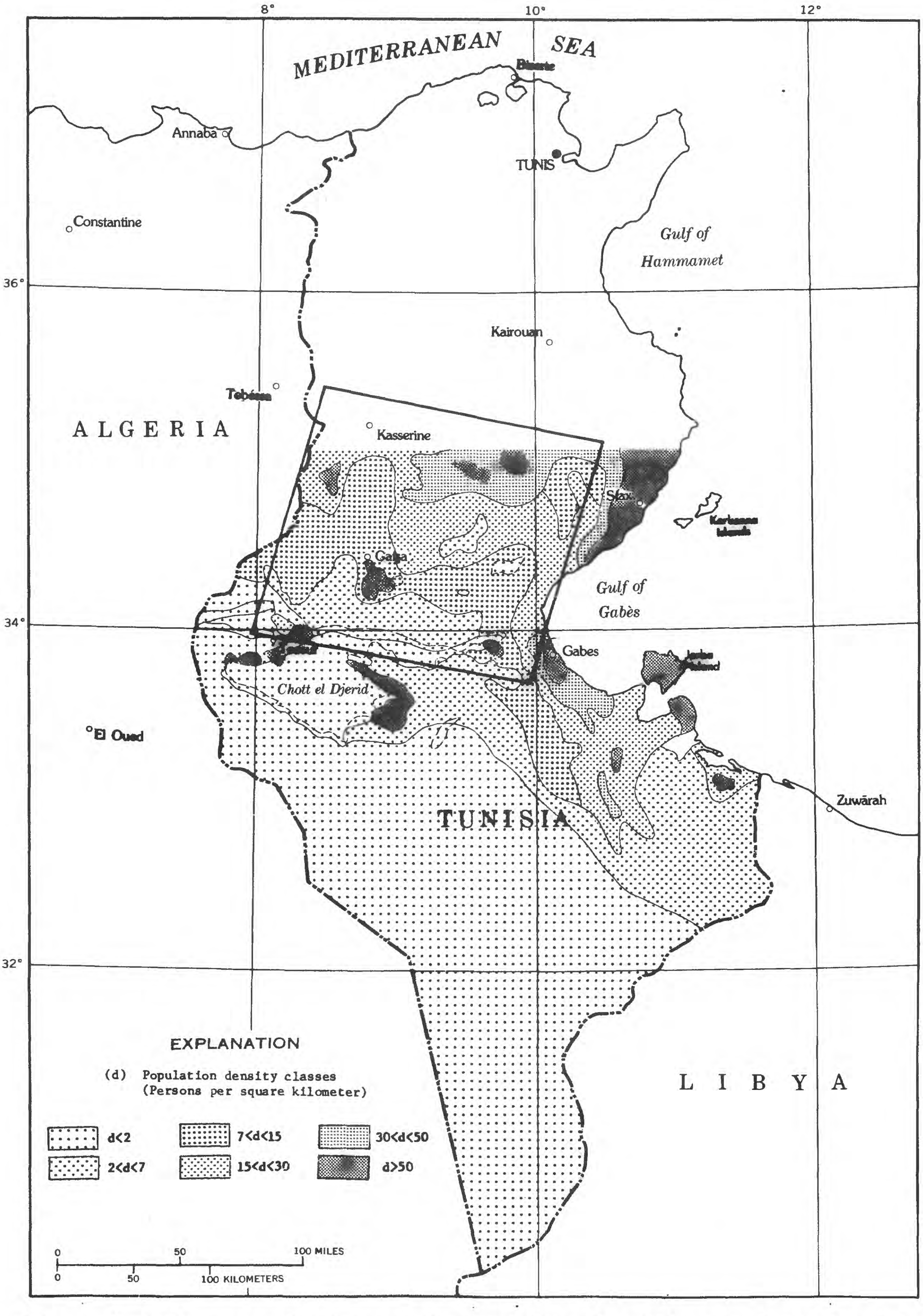

Figure 4. Index map showing rural population densities, southern Tunisia. (from Floret and others, 1976).

have recently been built at Ghanush, where fertilizers are manufactured, and also north of La Skhirra. Oil brought by pipeline from Djebel Douleb, 25 km north of Kasserine, and from the Edjeleh oil field in the Algerian Sahara is exported through the port at La Skhirra.

SOILS OF LANDSAT SCENE 206/036

The soils of Landsat scene 206/036 are shown on the soil map of Tunisia at the scale of 1:500,000 (Division des Sols, 1973); they are described in detail in a report by Belkhodja and others (1973). Their regional distribution in relation to physiographic and geomorphic units in Tunisia is described in a report by Belaid and Belkhoja (1970).

The soils of Landsat scene 206/036 consist of sols bruns developed over calcareous crusts in the forested ranges of the Dorsale (Tunisian Atlas) in the northwestern part of the scene. Lithosols, rendzinas, or calcrete (locally known as Torba beds), are exposed on many of the deforested ranges, and also on bajadas and piedmont slopes north of Gafsa. Farther east, sierozems occur in some of the high steppes, and on the coastal plain. South of Gafsa, in the grassland region, and on the piedmont slopes which surround the closed depressions formed by chotts, gypsiferous soils or soils developed over a gypsum crust are dominant. Saline soils form within and around the chotts, and also in patches along a narrow belt along the coast of the Gulf of Gabes (fig. 5); their regional distribution is shown on a map prepared by Belkhodja (1969). The saline soils of Tunisia described by Belkhodja (1969, p. 47) fit only a few of the soil categories outlined in the U.S. Department of Agriculture Soil Taxonomy (1975) or the French Soil Classification (Aubert, 1965). Likewise, duricrusts formed of calcrete and gypcrete (Goudie, 1973), which are so widespread in south-central Tunisia, may require the introduction of new soil classes into the Unified Soil Classification System (de O. S. Horta, 1980). To a geologist interested in climatic changes throughout the Quaternary Period, and in artifact evidence of the former presence of modern man and his precursors in the region, the most serious drawback of conventional soil maps at the intermediate scale (i.e., 1:500,000 scale) is that soil units, irrespective of age, are lumped together and mapped as a single homogeneous unit, where they are derived from parent materials of similar lithologic composition.

The complexity of soil formation in Tunisia was pointed out by Belaid and Belkhodja (1970, p. 24). For the geologist, the problem of soil map interpretation is particularly acute in south-central Tunisia, where development of calcareous and gypsiferous soils took place repeatedly on piedmont slopes at some time of the Quaternary, to be followed by gullying, slope erosion, and soil degradation when climate change set in, a scenario of landscape evolution described long ago by Coque (1962).

Soil erosion

Soil erosion in Tunisia, where agricultural land is being developed to grow food for an expanding population, poses severe management problems. Soil erosion is intensified in some areas, where existing soils and parent materials are inherited from older times in the Quaternary Period when

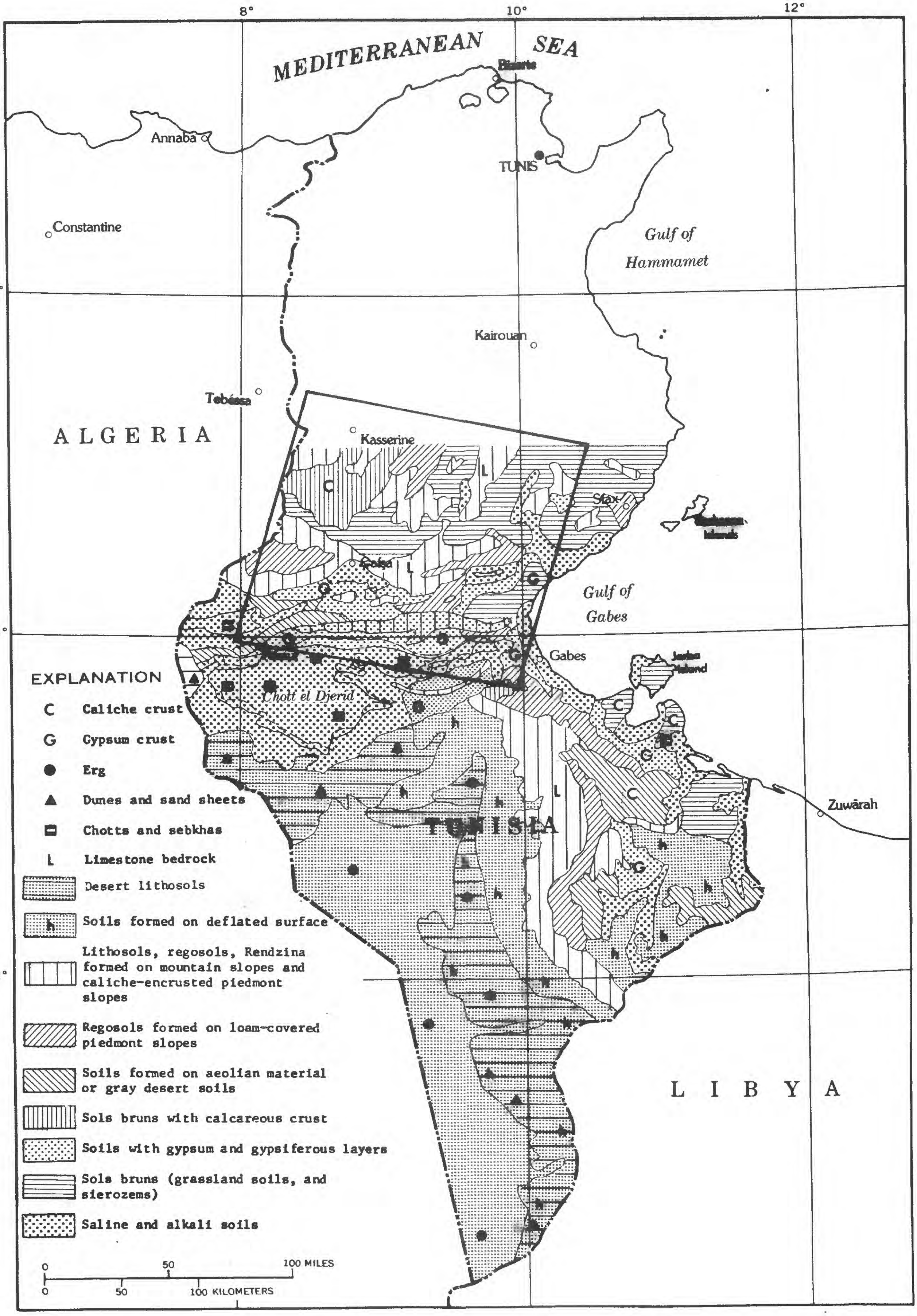

Figure 5. Soils map, southern Tunisia. (from Floret and others,1976).

they formed under wetter climatic conditions. Some of the older soils no longer develop under the more arid conditions now prevailing, and soil degradation sets in. Elsewhere, accelerated erosion, that is erosion accelerated by man through deforestation, overgrazing, soil malpractices, and cultivation of marginal agricultural land in response to economic and political pressures, has been dominant (Belaid, 1970).

It is small wonder, therefore, that an erosion map of Tunisia was prepared and published in 1967 at the scale of 1:500,000; it also was later published at the 1:1,000,000 scale (Belaid, 1970). The map shows the regional distribution of three main types of soil erosion: water, wind, and mass wasting, as well as their intensities in relation to parent materials, topographic relief, and geographic location. In the area of Landsat scene 206/036, water erosion is dominant as far south as Gafsa, either through sheet wash or gullying. Badland topography and barren gypsum crusts are common. South of Gafsa, in the region of closed depressions and along dry stream channels, deflation takes over as a major erosive agent (Belaid, 1970).

Desertification

True desert zones, that is zones where a vegetative cover is totally lacking most of the time, occur only in the southernmost part of Tunisia. In the area of Landsat scene 206/036, only sebkha floors--or rather the salt pans where salts are excessive for phanerogams (flowering plants)--are truly desertic (Floret and others, 1976). However, desertification, or the processes which result in a degradation, reduction, or total disappearance of vegetation, is widespread throughout south-central Tunisia. The susceptibility to erosion of some soils which developed under more humid climatic conditions in late Pleistocene or early Holocene and are no longer in equilibrium with the present bio-climatic environment has been pointed out above. Likewise, some plant associations are but relics of a more humid past, and cannot regenerate naturally where disturbed by man. Nevertheless, natural causes are not held responsible for desertification in Tunisia (Floret and others, 1976, p. 4). Most investigators of the past climatic conditions in Africa north and south of the Sahara Desert are unable to identify long-range climatic trends toward either increased aridity or increased humidity during the last few thousand years, in spite of short recurring cycles of dry and wet years.

In that sense, south-central Tunisia greatly differs from Libya and Egypt. The Libyan Desert and the Western Desert, west of the Nile River, are deserts that have had a total lack of rainfall for at least the last six thousand years. In south-central Tunisia, however, overgrazing, the opening of new land in the steppes to agriculture because of an ever-expanding population, and deforestation are the man-made causes of desertification (Floret and others, 1976).

The desertification problem in south-central Tunisia has been sufficiently acute to warrant compiling one of the first desertification maps ever published, scale 1:3,000,000 (fig. 6), and a desertification susceptibility map at 1:1,000,000 scale (Floret and others, 1976). The latter map shows the relationship between degree of desertification and

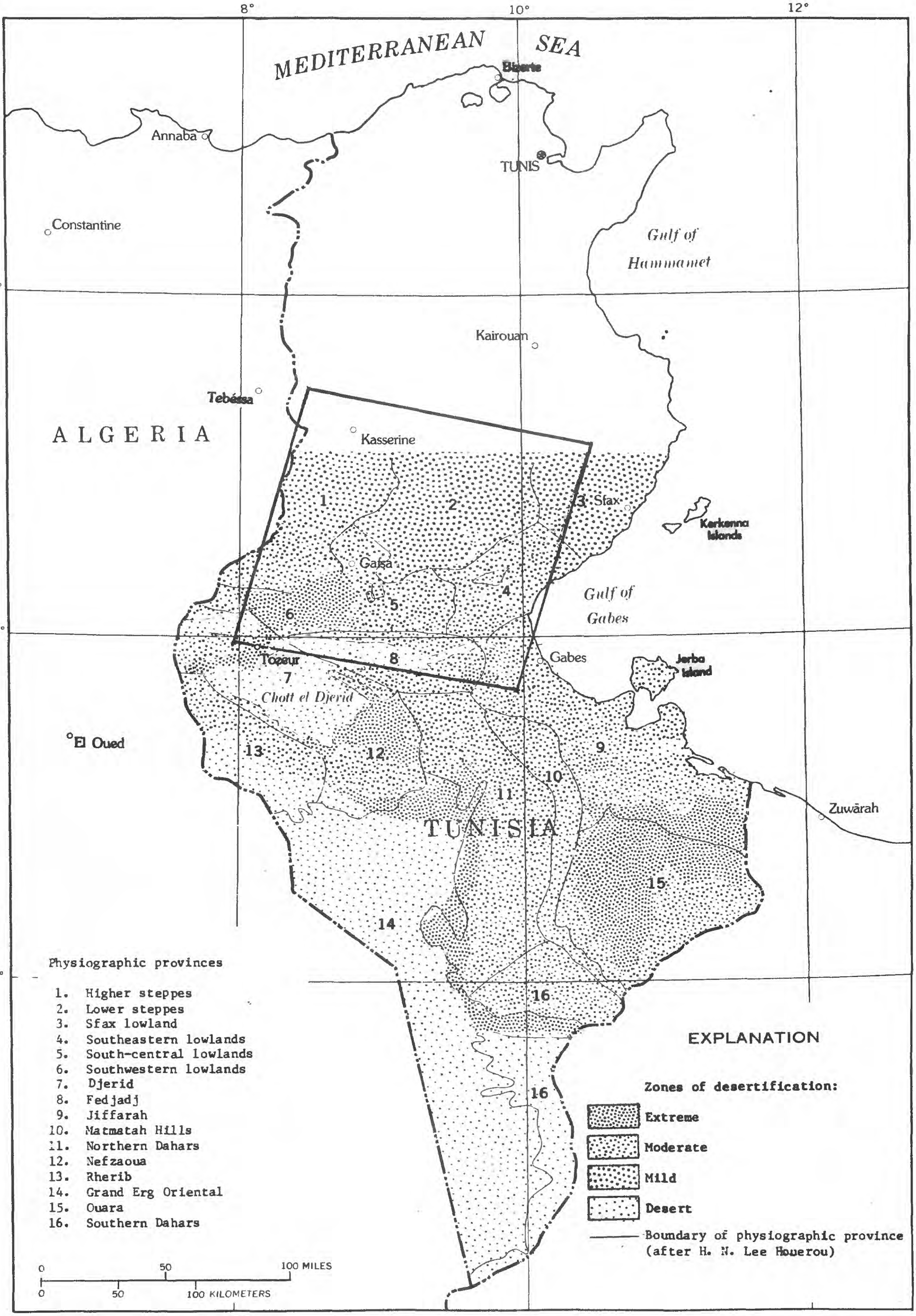

Figure 6. Desertification map, southern Tunisia.

(from Floret and others,1976).

climate, soil types, agricultural land use, and population pressures. According to it, the area in Landsat scene 206/036 where desertification is most acute includes the piedmont slopes southwest of Gafsa, and the plains between Chotts el Djerid and el Rharsa. In this area, there appears to be a strong correlation between a desertification on one hand, and overpopulation and overgrazing on the other.

PREVIOUS LANDSAT IMAGE ANALYSIS OF SCENE 206/036

Landsat image 1199-09311, February 7, 1973, or parts thereof, has already been analyzed on an experimental basis by previous workers. In 1977, Mohammed El Ammami and Ali Hamza, Soils Division, Tunisia Ministry of Agriculture, prepared a soil map and a soil erosion map at the scale of 1:200,000, which correspond to the areas of the Sbeitla quadrangle, in central Tunisia (northwestern part of the scene). They used a photographic enlargement of band 5, and visually delineated areas of homogeneous gray tones, checking these isotonal units against field data, and the accuracy of their own image interpretation against existing soil maps of the Sbeitla quadrangle at 1:100,000 and 1:500,000 scales. The results of their study were presented by Tarhar Aloui, Chief Engineer, Soils Division, at a symposium entitled "Soil Mapping and Remote Sensing" which was held at the Food and Agricultural Organization (FAO) headquarters, in Rome, Italy, from August 29 to September 9, 1977 (Aloui, 1977, pt. 1, p. 9-12).

Lithosols, rendzinas, and sols bruns appear white or light gray on positive prints of band 5, hydromorphic soils are dark gray, and saline soils or brackish muds still darker. Major landforms, such as mountain ranges, pediments, and bajadas, and the older erosional processes responsible for their formation are easily identified or inferred on band 5. Calcareous layers in the mountain ranges, where solution features are common, appear light gray; dissected surfaces are easily differentiated from areas where solution features are dominant through their high drainage density. Solution features or piedmont slopes appear dark gray, whereas stream channels, alluvial cones, inland deltas, and badlands appear in white tones. As limited as visual analysis of a single band, band 5, may be, the general conclusion of the study is that band 5 may be useful in refining the areal accuracy of some soil units, which are already mapped by conventional means.

Landsat scene 206/036 has been studied in much greater detail within the framework of Project ARZOTU, which deals with the study of the "Arid Zones of Tunisia" by remote sensing (Sta-M'Rad and Long, 1975). Project ARZOTU is a Tunisian-French experimental project, jointly undertaken by the Tunisian National Agronomic Institute (INRAT) and by the Gabes Office of France Center of Phytosociological and Ecological Studies (CEPE), a section of the French National Science Research Center (CNRS). Also associated to this project are specialists from the Gabes Office of the French Office of Overseas Science Research (ORSTOM). The program in part is funded by the French National Space Agency (CNES). Black and white transparencies and computer-compatible magnetic tapes of two landsat images covering Landsat scene 206/036 were purchased by project ARZOTU from the EROS Data Center, Sioux Falls, South Dakota.

During the 1975 phase of the program, visual analysis, including time-sequence analysis, was carried out on photographic enlargements at the scale of 1:200,000 of Landsat images 1109-09311, November 9, 1972, and 1199-09311, February 7, 1973. Black and white positive and negative prints of the four bands, as well as false-color composites (FCCs) were used in the analysis. Ground truth against which image interpretation was checked either had already been collected under project "Parcours du Sud", or was gathered in the test zone of Zugrata concurrently with image analysis (fig. 7). Project "Parcours du Sud" had been a joint research venture, involving many Tunisian and French agencies under the sponsorship of United Nations organizations, mainly FAO and U.N. Educational, Scientific, and Cultural Organization (UNESCO) (Sta-M'Rad and Long, 1975, p. 4). The test zone of Zugrata covers an area of 200,000 hectares, which extends west of Gabes, between Sebkret en Noual in the north and Chott el Fedjadj in the south (Debussche, 1975, p. 6, fig. 1; fig. 7 of this report).

The 1975 phase of the program is described in a report by Debussche (1975). The main conclusions of the report, which are based mostly on visual analysis of bands 5 and 7 and false-color composites thereof, using green filters for band 5 and red filters for band 7 (Debussche, 1975, p. 21-32) are summarized below:

1) Landsat image 1199-09311, February 7, 1973, is unusually dark in all bands in its northerwestern part. This regional increase in dark-gray tones northwestward (Debussche, 1975, p. 22) probably is due to a high soil moisture content following rainfall in regions of higher altitude--steppes and mountains--shortly before image acquisition, or is due to denser vegetation at higher altitudes.

2) Features with low reflectance, such as water, moist or saline soils, areas of dense vegetation, and the shadowed slopes of mountain ranges are best analyzed on negative prints.

3) Water and moist soils are best contrasted against dry land and bedrock in bands 6 and 7, but because of greater sunlight penetration of water, and therefore greater reflectance in band 4, areas of shallow water along the coast, in lagoons, swamps, and ponds are best interpreted in band 4. Deep water such as sea water appears black on bands 5 and 7, and FCCs, whereas shallow-water and moist soils, which generally are lighter gray on bands 5 and 7, appear in various shades of green on FCCs.

4) Vegetated areas such as forests, oases, and irrigated fields are easily detected on band 5, but are not easily identified and differentiated on positive prints of band 5. Difficulties encountered in image interpretation are illustrated by examples selected in the test zone of Zugrata.

Forested mountain slopes appear black on band 5 and very dark red on false-color composites. Field data indicate that the forests consist of Aleppo pine and junipers. Some oases, which appear black on band 5 and dark gray on band 7 appear black on FCCs. Other oases, which are dark-gray on band 5, appear dark red on FCCs.

Irrigated areas, which appear black on positive prints of band 5, and light gray on band 7, appear red on FCCs, and are differentiated from non-irrigated farmland by their geometry. Farmland where vegetation is vigorously growing appears darker gray on band 5 than on band 7. The green filter applied to band 5 in a 4_B, 5_G, 7_R FCC is opaque to farmland, but the red-filtered band 7 is translucent to it. Therefore, farmland appears red on a 4_B, 5_G, 7_R FCC, and is easily identified on it. From an agronomist or soil scientist standpoint, one of the main advantages of using an FCC in land-use analysis derives from the easy identification of agricultural land. On the other hand, halophytes, which were actively growing in early February 1973 (Zugrata test zone) are not immediately differentiated by gray tones on band 5 or red color alone on FCCs, but need to be identified through their location close to a sebkha.

METHODS OF STUDY AND IMAGE INTERPRETATION

The Landsat data products utilized in this analysis of the environment of south-central Tunisia are either black and white or multi-spectral false-color renditions of image 1199-09311, February 7, 1973. They were prepared from a computer-compatible magnetic tape (CCT) by computerized digital image processing. The digital image was then manipulated by computer to take advantage of its full dynamic range, which is much greater than either its photographic equivalent or the optical sensitivity of the human eye. In this type of processing, image content and quality are maximized by the computer, and automated interpretation is minimized . This approach is particularly adapted to geologic analysis of an image of the terrestrial surface, where "random, coherent and natural noise (vegetation and cultural effects) are easily misinterpreted by automated interpretive techniques" (Condit and Chavez, 1979). The technique of maximizing image content and quality is that used by the U.S. Geological Survey in Flagstaff, Arizona (Condit and Chavez, 1979), and is similar to that used by the Image Processing Laboratory (IPL) of the Jet Propulsion Laboratory (JPL) in Pasadena, California (Goetz and others, 1975). The series of steps necessary to obtain various Landsat products is shown diagrammatically in figure 8.

A glossary of terms as they apply to digital image processing, summarized from Condit and Chavez (1979) is included in Appendix 1. Only the Landsat digital image is being described for this report. A digital image is a two-dimensional array of picture elements or pixels The reflectance brightness of each pixel is expressed numerically by integer values, and each integer value, termed a digital number (DN), corresponds to a shade of gray on a black and white image. The CCTs received from the EROS Data Center, Sioux Falls, South Dakota, contain dynamic range of 0-63 digital numbers (DN) for band 7, and 0-127 DN for bands 4, 5, and 6. The data are processed at the USGS Computer Facility

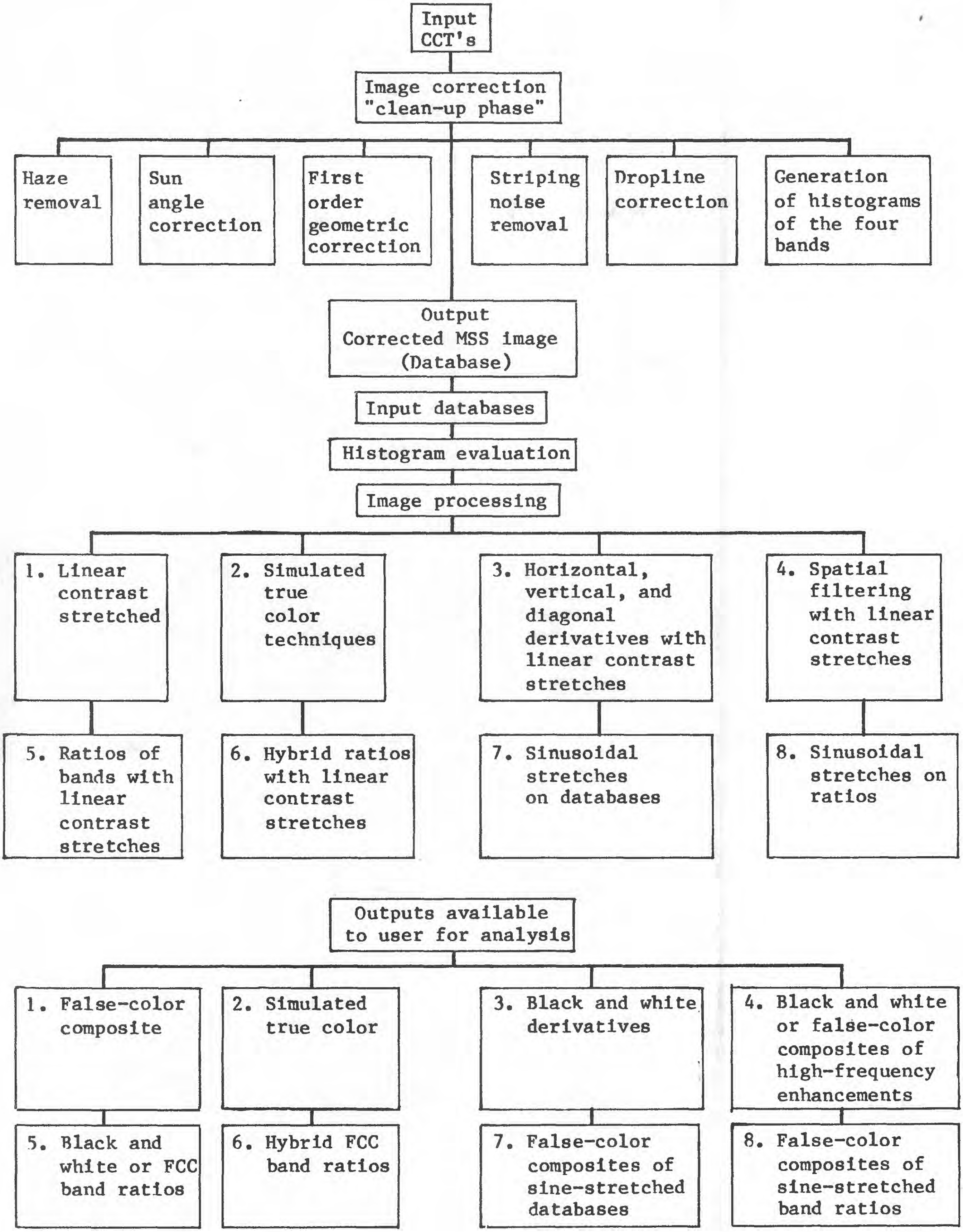

Figure 8. Flow chart showing the various steps followed in the image correction and the image processing phases of digital image enhancement.

in Flagstaff, Arizona, retaining the dynamic range through all processing steps, but most hard-copy reproducing systems, including the USGS one in Flagstaff, output hard-copy products with a digital number range of range of 0-255 DN. On black and white images, 0 denotes black on the image and absence of radiation on the ground, and 255 denotes white or saturation of the image and maximum radiation from the ground. The horizontal rows of pixels are referred to as lines, and the vertical columns as samples. Each pixel represents an area of the Earth's surface 57 x 79 meters (m). The total image is composed of about 2,340 lines, and 3,240 samples, or 7.5 x 10^6 pixels, and represents an area approximately 185 km on a side.

Each of the Landsat data products obtained after image correction and enhancement (fig. 8 and table 1) was analyzed by studying available maps and comparing them to it. Comparison was achieved, whenever feasible, by superposing a map over a Landsat image at the same scale. No exhaustive nor completely up-to-date bibliographic search could be undertaken within the short time available for this project, but some of the more pertinent geologic maps available from the U.S. Geological Survey Library prior to our November 1977 visit to Tunisia were used in the analysis. A number of soil reports and the soil map of Tunisia at 1:500,000 scale were made available to us by Messrs. M. Hamza and A. Souissi, Tunisia, Soils Division, at the time of the November 1977 visit. They also were used in the analysis. The maps, reports, and also regional geologic studies conducted previously by other workers in the area of Landsat scene 206/036, that were used in this report are referred to in the various chapters and in the references cited on the end of the report.

Table 1. Landsat data products derived from Landsat image 1199-09311, February 7, 1973, and used in this report.

Databases (Positive prints, black and white)	Scale	Interpretation
Band 4 - w/o Modulation Transfer Function (MTF)	1:500,000	General
Band 5 - w/o MTF	1:500,000	General
Band 6 - w/o MTF	1:500,000	General
Band 7 - w/o MTF	1:500,000	General
Band 7 - w/o MTF (Negative, black and white)	1:500,000	General saline soils
Band 5 - w/MTF	1:250,000	General saline soils

Table 1. continued

False-Color Composites (FCC)	Scale	Interpretation
Band 4B*, 5G*, 7R* - w/o MTF	1:500,000	General
Band 4B, 5G, 7R - w/MTF	1:250,000	Sebkhas saline soils
Simulated True Color Composites (STC)		
Band 3B, 4G, 5R	1:500,000	General
Sine-Stretched False-color Composites (FCC_s)*		
Band $4_sB^\dagger$, 5_sG, 6_sR	1:500,000	Land use
Band 4_sB, 5_sG, 7_sR	1:500,000	Natural vegetation
Band 4_sR, 5_sG, 6_sB	1:500,000	Natural vegetation
Band-Ratio False-color Composites (RCC) - Linear Stretch		
Ratio 5/4B, 6/4G, 7/4R	1:500,000	Quaternary deposits Seeps, springs & streams Vegetation
Ratio 5/4B, 7/4R, 7/5G	1:500,000	Holocene alluvium Agriculture land use Natural vegetation
Ratio 5/4R, 6/4G, 6/7B	1:500,000	Natural vegetation
Band-Ratio False-color Composites (RCC_s) - Sine Stretch		
Ratio $6/4_sB$, $7/4_sR$, $5/6_sG$	1:500,000	Bedrock geology, especially phosphate deposits
Ratio $5/4_sB$, $7/4_sR$, $6/7_sG$	1:500,000	Bedrock geology

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* B, Blue; G, Green; R, Red: Each color refers to the color of the filter applied to the black and white positive film transparency of a particular band or band-ratio utilized in preparing a false-color composite.

† 4_sB means band 4 data base, sinusoidally stretched to enhance minute tonal contrast, and filtered blue to form an FCC with 2 other sine-stretched bands.

Table 1. continued

Derivatives (Black and white)	Scale	Interpretation
Horizontal Derivative - Band 6	1:500,000	Structural and economic geology
High-Pass Filter (HPF) - Black and White and False-Color Composites FCC		
101 x 101 HPF - Bands 4B, 5G, 7R	1:500,000	Structural geology (regional linear trends). Structural geology (local linear trends)
35 x 35 HPF - Band 4G, 5B, 7R	1:500,000	

Image interpretation

All Landsat data products of Landsat image 1199-09311, which were generated by computer and enlarged to the scale of 1:500,000, were analysed. Their relative usefulness in detecting and identifying specific geographic features is shown in figure 9. A preliminary interpretation of soils and geology has also been made on sine-stretched FCC$_s$ and on linearly stretched band-ratio false-color composites (RCCs). Only an interpretation of gypsiferous soils and phosphate-bearing beds can be included in this report, because of time limitations.

Geographic features that were detected or identified on the stretched FCC are coded on figure 9 as follows:

Physiographic features: 1

- Ranges: 1-a
- Steppes: 1-b
- Piedmont slopes, pediments, bajadas: 1-c
- Closed depressions (sebkhas): 1-d
- Coastline: 1-e
- Stream channels: 1-f

Drainage network: 2

Vegetation: 3

- Forest: 3a
- Grassland: 3b
- Halophyte: 3c
- Cultivated fields: 3d
- Fallow or abandoned fields: 3e
- Olive groves: 3f
- Palm trees in oases: 3g
- Large irrigated farms: 3h

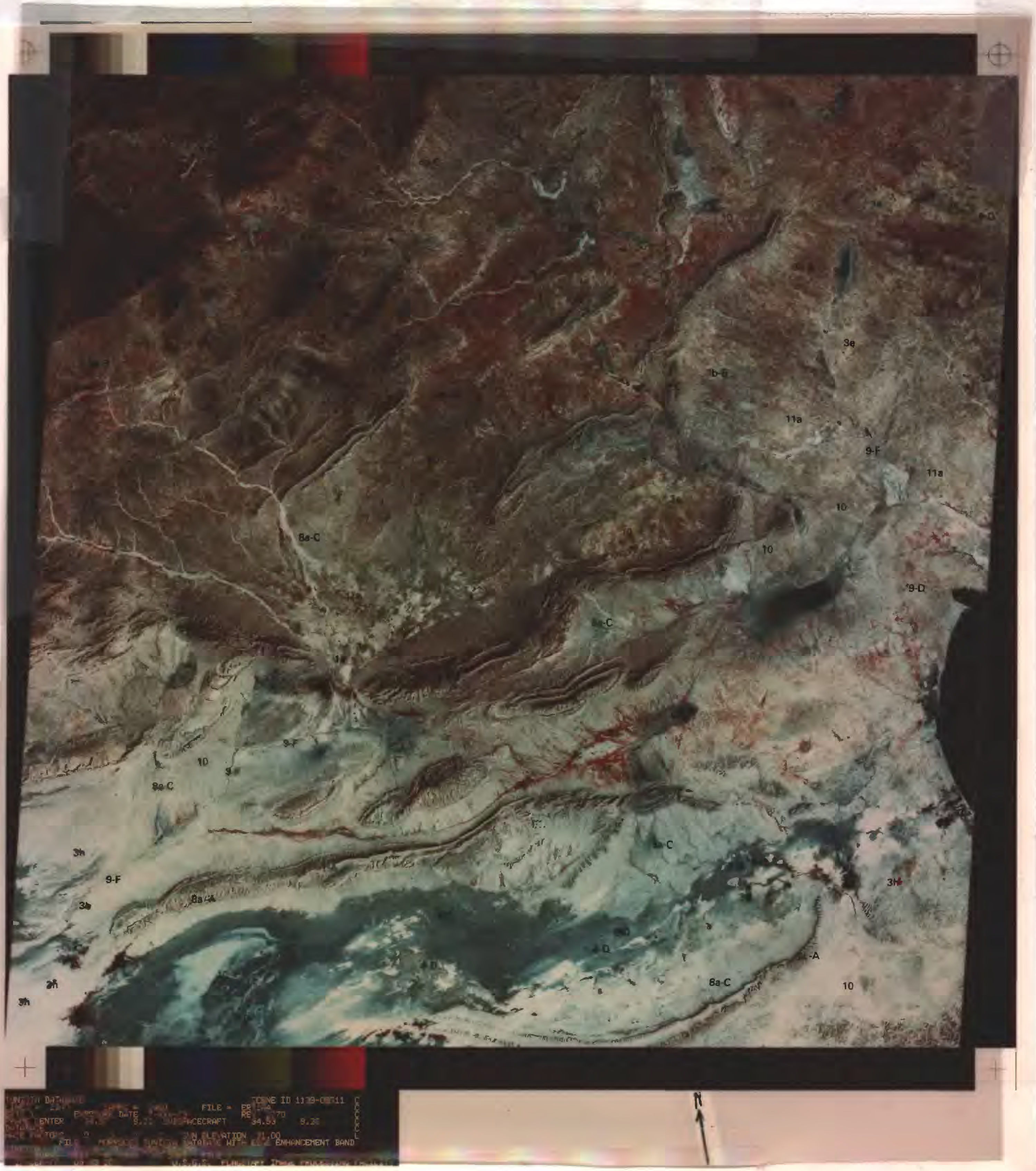

Figure 9. Geographic features detected or identified on stretched false color composite (4-blue, 5-green, 7-red) with modulation transfer function of Landsat image 1199-09311, Feb. 7, 1973. Symbols refer to coded units given in text. Scale 1:1,000,000.

Population: 4

Communications: 5

Soils: 6

Geology: 7

Erosion: 8

Water erosion: 8a
Wind erosion: 8b

Water: 9

Roads, railroads, and pipelines: 10

Desertification: 11

Mottled vegetation due to overgrazing: 11a
Undrained, abandoned fields: 11b

Folded ranges of the Tunisian Atlas are enhanced by shadows falling on northwest-facing slopes. Sun elevation above the horizon is high--31°--, and mountain ranges with high relief above valleys and steppes are partly shadowed, but topographic obstacles of low relief are not detectable. The drainage network stands out in several ways: Dry alluvial channels appear white on the FCC, because of color addition in all three bands (4-blue, 5-green, and 7-red). Dry alluvium has a high reflectance in all three bands, but moist alluvium and moist soils appear in bands 4 and 7 in various shades of gray according to moisture content, and in various shades of light blue-green on the FCC, because of absorption of some red and blue light in bands 4 and 7. Standing water in sebkhas and the Mediterranean Sea ranges from black to light blue, depending on depth and turbidity of water. The boundary between land and water is very sharp because of the virtually complete absorption of solar radiation by water in the near-infrared region (band 7). Aureoles of dark to light greenish-blue hues denoting soils of decreasing moisture content and salinity surround the water bodies in the sebkhas. The obvious increase in light hues across the FCC from northwest to southeast is related to a decrease in vegetation density from the high, densely forested mountain ranges in the Tunisian Atlas, toward grassland in the steppe regions (probably dormant at time of acquisition). This regional increase in albedo is related to decrease in vegetative cover, which in turn reflects the increasing aridity southward (fig. 2).

Forests of Aleppo pine grow on northwest-facing slopes of the mountain ranges in the Tunisian Atlas. They are identified as dark-red patches; the darker the red color, the denser the forest. Grassland and shrubs produce a mottled red pattern in the steppes. Halophytes, which are growing on the valley floors along stream channels and around some sebkhas, are identified by a bright red color, which follows the dendritic pattern of alluvial stream channels, and also by their location close to sebkhas.

Some olive groves are purplish red, and can be further identified by their geometric (rectangular) outlines, and locations in the lower steppes. Other groves are also identified near the city of Kasserine. The signature of palm trees, an evergreen like the Aleppo pine, is very dark red, or black where very dense; it allows one to detect, but not to identify, groves of palm trees in oases.

Cultivated fields are easily identified; they occur in multiple shades of red, and if large enough, are identified by their geometric pattern. The largest and most prosperous farming areas are in the Sahel, and also in the intermontane valleys and grassland regions of the Tunisian Atlas. The most intensely cultivated land is located on northwest-facing valley slopes, where it takes advantage of orographic precipitation. The more arid southeast-facing slopes are in the rain shadow of most mountain ranges.

Irrigated farms, particularly in the southern part of the image, appear black or bright-red, and can be identified by means of their rectangular outlines.

Incipient desertification, possibly due to overgrazing and insufficient drainage, is suggested by the red mottled appearance of the plains inland from the Sahel, and also by the high albedo (white color) of formerly cultivated land north of Gafsa, as well as the soils on piedmont slopes between Chott el Djerid and Chott el Rharsa.

A city as large as Gafsa (422,225 inhabitants in 1975) can be identified through the dark blue green hues typical of most big cities imaged on Landsat FCC, but Kasserine cannot. The identification of the city of Gafsa is further aided by a star-shaped outline, which may coincide with the fortified ramparts of the medieval city wall. Other cities are detected only through large dark-red to black patches of urban and suburban vegetation (palm-tree groves and truck gardens) associated with them. Both Gafsa and Kasserine are located in or near watergaps, a familiar urban emplacement throughout the world. This location is more easily perceived on a Landsat FCC than on conventional topographic maps. Smaller settlements, darker red to black on the FCC, can be identified as small oases or villages because of their alignment and possible concentration along roads or highways (south shore of Chott el Fedjadj). The small bay north of the city of La Skhirra does not appear on any available topographic maps. It appears to be a shallow-water harbor, which was recently built to accommodate oil tankers, which are loading crude oil at the pipeline terminal located on the southern tip of the bay. All these observations can be correlated with information displayed on existing topographic and road maps (fig. 7).

Sections of roads and railroads are easily detected by their white or dark-gray tones and their linear trends on the FCC, but cannot be distinguished from each other. The apparent change in albedo along different reaches of the same road may be artificial, and due to the changing tonal contrast of the roadway against the landscape background, rather than to a change in the composition of road mettle. Some highway sections, particularly north and northeast of Qafsah, can be identified by a dark-red linear signature, which represents vegetation bordering the road: possibly Eucalyptus trees planted to shade the highway or a nearby irrigation ditch running parallel to the road.

The fine-detailed texture of a Landsat scene near the resolution limit of the imaging system is supressed because of the constraints of digital sampling theory. Usually, this situation means that topographic features such as sharp ridges and erosional landfoms take on an artificial "rounded" appearance on the image. In terms of the frequency domain, this effect, known as the Modulation Transfer Function (MTF), is due to the inability of the imaging system to accurately sample the high-frequency content of the scene. The Modulation Transfer Function can be corrected by enhancing those high frequencies which have been suppressed, and leaving the lower frequencies which have been correctly sampled, unchanged. The MTF correction is obtained by moving a high-pass filter across the image, extracting only the high-frequency information. By adding it back to the original digital image, very fine detail in the spatial domain is brought back to the correct balance. A formal mathematical treatment of the treatment has been given by Chavez (1975). On an FCC with MTF correction, gullying by water erosion is made obvious as the dominant erosional process on most of the folded ranges of the Tunisian Atlas. The channel density on dissected mountain slopes increases southward across the image; this increase is directly related to a decrease in plant cover, and increasing aridity southward. This interpretation of the drainage network is greatly facilitated by the Landsat product. Even a Landsat image unenhanced by the MTF correction is preferable for analysis to a topographic map at the same scale, because the countless gullies observed on the image cannot be portrayed on the map at such high density.

Wind erosion and sand transport are most evident through the high albedo (white color) of drifting sand and the tapering plumes associated with it. Sheets of drifting sand taper west-southwestward across the floor and the southern border of Chott el Djerid, suggesting that the dominant direction wind is east-northeasterly. More vaguely defined sand plumes also occur west of Tozeur. The vegetation mounds of nebkhas known to occur around the borders of Chotts el Fedjadj and el Djerid (Coque, 1962; Belaid, 1970) contribute to the high albedo of the land surface around the sebkha floors, but cannot be detected because of their small dimensions.

The intensity of solar radiation being reflected from the terrestrial surface varies with angle of incident sunlight, wavelength, albedos of individual soil or rock types, texture (grain size), moisture content, vegetation, etc., and angle of slope of the reflecting surface. The spectral signatures of different soil and rock types on Landsat data products are easier to recognize and to interpret when the influence of topography (the one constant included in each of the four spectral bands 4, 5, 6, and 7) on the reflectance is eliminated. This is digitally achieved by ratioing, pixel by pixel, one band by another (Rowan and others, 1976). On theoretical grounds at least, a linearly or sinusoidally stretched band-ratio false-color composite becomes an excellent tool to identify and map soil and rock units of varying lithologic composition.

Systematically comparing the soil and geologic content of each of the Landsat data products prepared for this project (including stretched band-ratio false-color composites) to existing soil maps (Division des Sols, 1973) and geologic maps (Castany, 1951) of Tunisia is an enormous task. It is clearly beyond the scope of this report. On an experimental basis, however, it was decided to find out if gypsum-encrusted soils and saline soils on one hand, and phosphate- and iron-bearing beds of economic importance to Tunisia on the other, could be identified on some of the computerized data products available, and how the mappable detail on the image compared with that of existing maps at the scale of 1:500,000.

For gypsum-encrusted soils and saline soils, a false-color composite of image 1199-09311 (4-blue, 5-green, 7-red), previously stretched sinusoidally, produces a wealth of readable soil data, which are not mapped on the existing soil map of Tunisia (Division des Sols, 1973) at the scale of 1:500,000. In the southeastern part of scene 206/036, for instance, gypsum-encrusted soils develop at various altitudes on piedmont slopes which flank the eastern tip of Djebel Aziza. These gypsiferous soils are lumped together into one single unit on the soil map (Division des Sols, 1973), irrespective of the altitude of the piedmont slope on which they occur, and irrespective of age; however, green-black and bluish patches corresponding to the same gypsiferous soils are clearly differentiated on the sine-stretched FCC. The areal distribution of these colored patches seems to carry pedologic significance, as it closely coincides with the extent of gypsum-encrusted piedmont slopes of different ages, as mapped by Coque (1962) at the scale of 1:100,000 (fig. 10). A geologic (that is, an age-wise) interpretation of these gypsum-encrusted soils, showing how they fit in the late Quaternary prehistoric sequence, Acheulean, Mousterian, and Neolithic, is given in figure 11. Two longitudinal profiles, diagrammatically showing piedmont slopes ascribed to three different cycles of erosion from the crest of Djebel Aziza to Rebat ben Khalouf, and also in the northwest slope of Djebel Drhoumess, 25 km northwest of Tozeur, were recently published by Coque (1977, p. 203, fig. 28). Subtle differences in reflectance, which are due to topographic relief and normally would be eliminated on ratioed data products, are enhanced along with other detail on the sine-stretched FCC being analyzed.

Many more saline soil units on the floors of Chott el Fedjadj and Chott el Djerid can be distinguished on the sine-stretched FCC than on the soil map (Division des Sols, 1973). In addition, rectilinear markings of unknown origin appear in the sebkha floor at the western end of Chott el Fedjadj. The lateral and vertical zonations of saline soils located around closed depressions is well known, as is the zonation of halophytes associated with them, in relative order of tolerance to the salinity of the ground water (Hunt, 1966). Perhaps the colored units appearing on the linearly stretched and sine-stretched FCCs in the areas of Chotts el Fadjadj and el Djerid can be traced to such zonations.

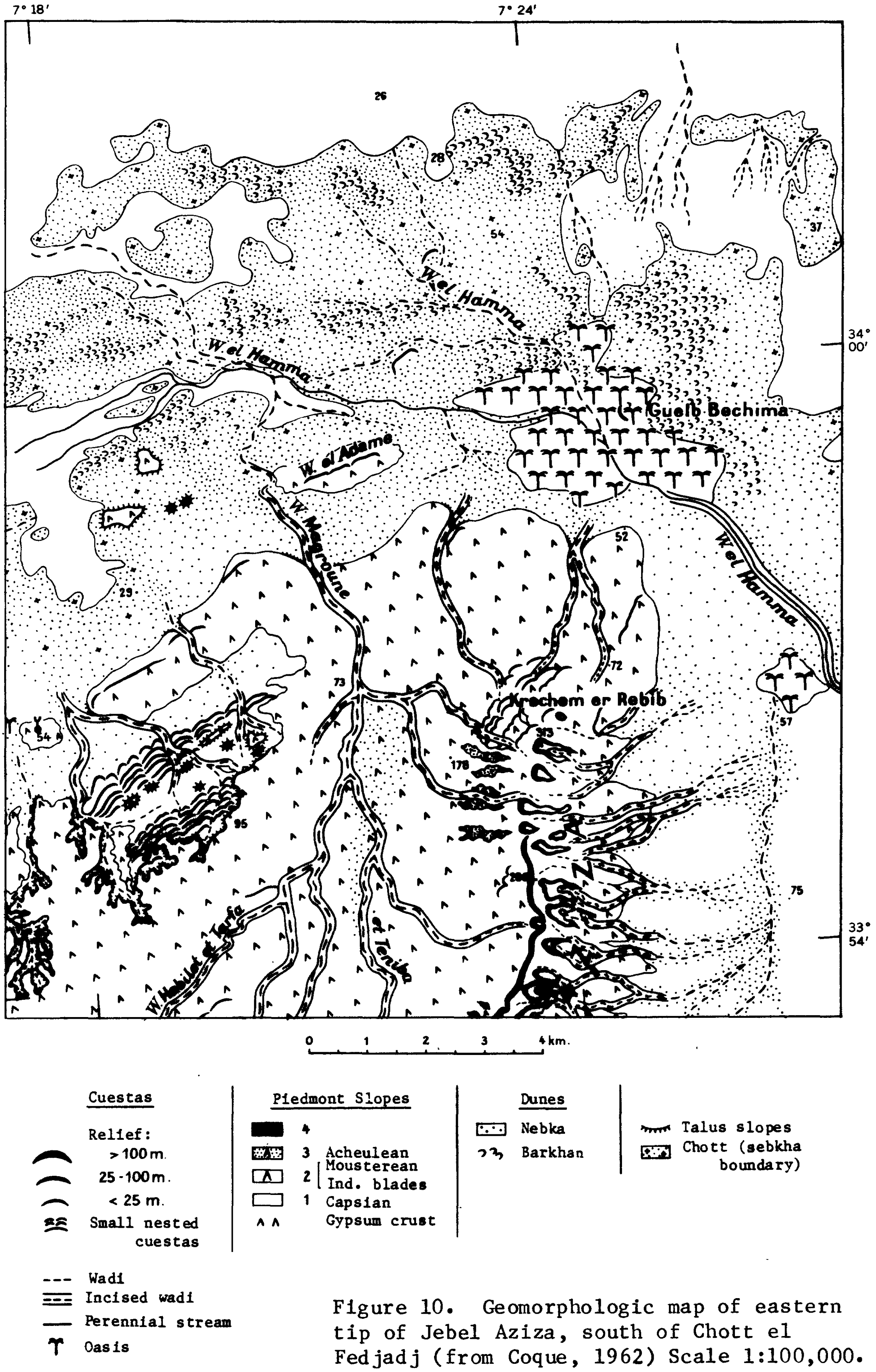

Figure 10. Geomorphologic map of eastern tip of Jebel Aziza, south of Chott el Fedjadj (from Coque, 1962) Scale 1:100,000.

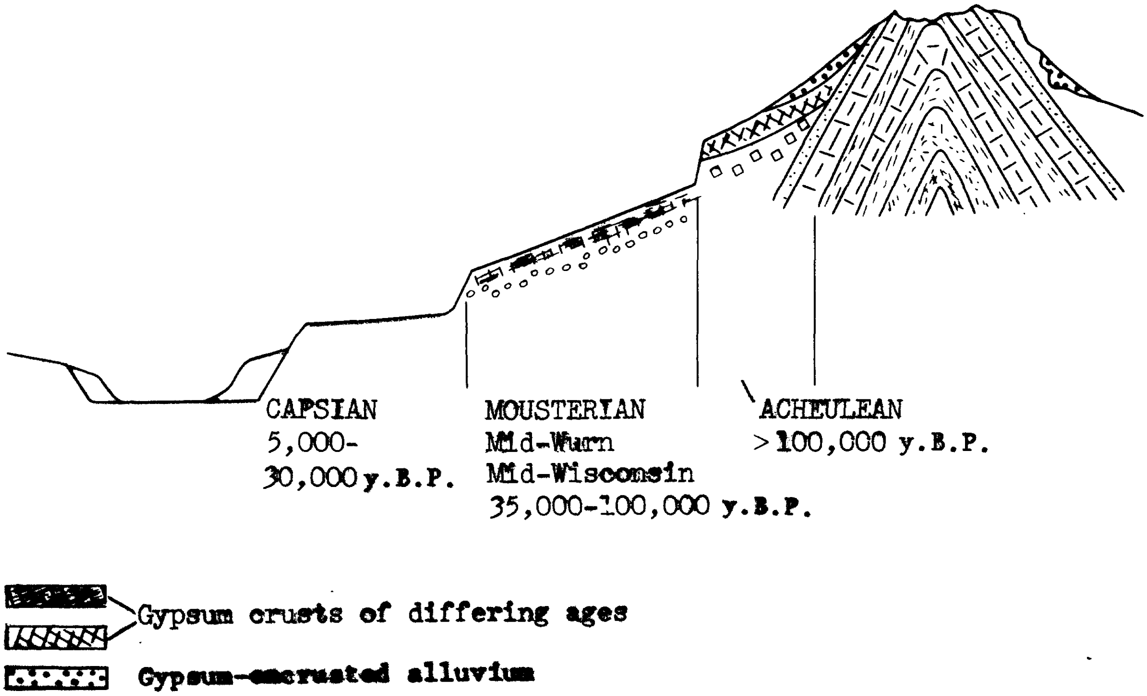

Figure 11. Cross-profile of gypsum-encrusted piedmont slopes in the Gafsa region, diagramatically showing at least two ages of gypsum crusts and underlying colluvium on which Neolithic artifacts are found. Only the lower terrace lacks a gypsum crust or powder (after Coque, 1962).

Of even greater importance to the interpretation of the regional distribution of saline soils on Landsat products is the two-fold classification of saline soils based on albedo: salant blanc (white saline soil), and salant noir (black saline soil), according to French terminology (Gaucher and Burdin, 1974, p. 11, 29). Salant blanc consists of efflorescences made up of white compounds: sodium, magnesium, and calcium chlorides, and sulfates; salant noir is made up of sodium carbonate and bicarbonate in which clay and organic matters are dispersed. The colored units and the markings displayed on the sine-stretched FCC are possibly due to differences in moisture, salt and gypsum content, or to the presence of drifting sand and burying mud. Their nature can be determined only by comparison of the image with large-scale soil maps, or by field sampling. It is hoped that the accuracy of our image interpretation can be tested in the field with the assistance of soil scientists familiar with Tunisia.

Like soil units, rock units of similar lithology can be identified and mapped, using band-ratio false-color composites (RCCs) (Rowan and others, 1976). Precise identification requires a knowledge of the reflectance spectra of the rock types, primary minerals, or alteration minerals under investigation. The reflectance spectra of phosphate minerals were not known to the writers when this report was being prepared, and therefore no logical reason for the identification of phosphate-bearing beds on the sine-stretched band-ratio false-color composite (RCC_s: $6/4_s$-blue, $7/4_s$-red, and $5/6_s$-green) of Landsat image 1199-09311, is being offered. On this particular band-ratio false-color composite (RCC_s), a mottled pattern of black and green to blue-green dots most closely coincides with phosphate-bearing beds of middle Eocene age, which are delineated on the geologic map of Tunisia at the 1:500,000 scale (Castany, 1951). The areal extent of these phosphate-bearing beds, mostly west and south of Qafsah, is outlined on figure 12. A similar but narrower and lighter pattern of black and green dots occurs on the cuestas north and south of Chotts el Fedjadj and el Djerid. This latter pattern does not coincide, however, with phosphate-bearing beds outlined on the geologic map of Tunisia (Castany, 1951) or the mineral deposits map of Tunisia (Niccolini and others, 1966), and is not shown on figure 12.

The detection and identification of phosphate rock through the unique spectral signatures of phosphate mineral constituents in bands 4, 5, 6, and 7 of Landsat image 1199-09311, February 7, 1973 is not described here (Grolier, Davis, and Schultejann, unpub. data).

A diffuse aureole appears as a dark to light-green subcircular patch on the FCC and a dark green to black, densely dotted patch on the RCC_s near Djebel el Mdilla, about 19 km south-southwest of Qafsah. This aureole, which resembles aureoles of ferric oxides described as alteration products in a mineralized district of Nevada (Rowan and others, 1976), is interpreted as consisting of phosphate-bearing beds because it coincides with exposures of Eocene rocks shown on the geologic map of Tunisia (Castany, 1951).

Structural trends may be more easily identified on Landsat images than on existing geologic maps. Noteworthy in Landsat image 1199-09311 is a belt

Figure 12. Landsat image showing phosphate-bearing beds (middle Eocene) and iron ore localities in the Gafsa region, south-central Tunisia. Image interpretation done on sine-stretched band ratio false color composite ($6/4_s$ blue, $7/4_s$ red, $5/6_s$ green) Landsat image 1199-09311, Feb. 7, 1973. Scale 1:500,000.

of layered rocks of Early Cretaceous age (Castany, 1951), which strikes east-northeastward across a thin veneer of Quaternary colluvium north of Chott el Fedjadj. Crosscutting relationships observed on linearly stretched and sinusoidally stretched FCCs are such that these Cretaceous rocks appear to be unconformable under the Tertiary rocks exposed in the folded mountain ranges farther north.

CONCLUSIONS AND RECOMMENDATIONS

1. The set of Landsat data products described in this report was prepared in October 1977 at the USGS Computer Facility in Flagstaff, Arizona, using a computer-compatible tape of image 1199-09311, acquired on February 7, 1973. The original purpose was to utilize the products in a demonstration of the computerized-image-processing technique, in preference to automated image classification schemes by other image-processing laboratories.

2. The main advantages of these products are: 1) the burden of analysis is on the analyst, not the computer; 2) the products derived from this technique are approximately 40 times cheaper than similar products generated by automated classification schemes.

3. The set of Landsat data products used in this analysis represents a practical financial compromise between products of basic research and mass production. Image interpretation in this project depends upon intensity of contrast stretching, selection of band ratios, and photographic reproduction and enlargement over which the analyst has no control.

4. Landsat image 1199-09311 used in this project was selected for spatial analysis of Landsat scene 206/036, because of immediate availability of a computer-compatible tape from the EROS Center during the summer of 1977. This tape was available then only because it had been requested and purchased a few years earlier by the ARZOTU Project, UNESCO. The resulting redundancy of effort in image analysis could not be anticipated at the start of this project.

5. The scope of the ARZOTU project was broad enough to warrant an effort involving many Tunisian and French agencies, a large staff of specialists, time-sequential analysis of the scene, and collection of basic ground-truth data in the Zugrata test zone (fig. 7). Sequential as well as spatial analysis of Landsat scene 206/036, and collection of ground-truth data in the Zugrata test zone were performed previously by investigators of Project ARZOTU. The current USAID/USGS remote sensing program in Tunisia may benefit from consultations with specialists familiar with south-central Tunisia. The latter might help determine the kinds of ground truth required, and give access to ground truth previously collected.

6. The physical and human environments of Tunisia, unlike those of many other developing countries, are well known. Specifically, large-scale soil and geologic maps, which were not available for the preparation of this report, cover most of the scene under investigation. Scale of the Landsat data products prepared by the U.S. Geological Survey and made available to the Soils Division, Tunisian Republic Ministry of Agriculture in November

1977 and 1978, is, however, too small for systematic and detailed regional analysis. Some of the problems in soil and geologic analysis discussed in this report are better solved at larger mapping scales.

7. Objectives of the USAID/USGS remote sensing project in Tunisia are to provide instrumentation for photographic reproduction and visual interpretation of remote sensing imagery and to provide multidisciplinary training in the art and science of image interpretation, field verification of results, and presentation of findings. Computer-processed Landsat data products such as those described in this report constitute the primary input to the Tunisian photographic reproduction and interpretation laboratories.

8. In order that this spatial analysis of image 1199-09311 does not remain an academic exercise, it is recommended that the major findings contained in this report be discussed with Tunisian specialists, and checked against large-scale maps and in the field. Some of these findings are:

a) Some mappable soil units, particularly gypsiferous and saline soils, are differentiated in great detail on sine-stretched FCCs. These units correlate well with broader soil units shown on the existing soil maps of Tunisia at the 1:500,000 scale (Division des Sols, 1973). They correspond to some gypsum units that formed on piedmont slopes at different times in the late Quaternary period (Coque, 1962), and to zoned saline soils around sebkhas. The same comments probably extend to the caliche-encrusted soils, which occur from the latitude of Gafsa to the northern border of the scene.

b) Objectives for future work might include the preparation, possibly with the aid of automated classification schemes, of large-scale thematic maps of gypcrete-calcrete soils. On these maps, soil units could be differentiated not only on the basis of parent material and degree of slope, but also on the basis of friability, thickness of encrusting material, and geomorphologic position (piedmont slopes of different ages) rather than topographic location. The practical applications of such a program would be to establish relationships between soil age and friability on one hand, and susceptibility to erosion and suitability for agricultural land use on the other. The scientific payoff would derive from a refinement of Quaternary rock stratigraphic units in Tunisia, and bracketing them within the time-stratigraphic scale. As previously shown by Coque (1962), many of the rock units capped by gypsum soils accumulated under climatic conditions alternating from moist to dry. The different sets of human artifacts occurring as fossils in these rock units (Coque, 1962; Ferring, 1976) suggest that critical steps in human evolution are associated with major climatic changes.

c) Phosphate-bearing beds in the Gafsa region are easily and immediately delineated on a sine-stretched band-ratio false-color composite (RCC_s) ($6/4_s$-blue, $7/4_s$-red and $5/6_s$-green) of Landsat image 1199-09311. An aureole of alteration minerals (possibly including ferric-oxide minerals) was observed near Djebel el Mdilla, 19 km south of Qafsah, on both FCC and RCC_s of the same image.

A thematic map of most phosphate-bearing beds in the Qafsah region (fig. 12) shows that sine-stretched band-ratio false-color composite (RCC_s) of a Landsat image can be a powerful tool in mineral exploration of potential phosphate ore deposits. Tunisia is a major phosphate producer and exporter in the Mediterranean world. Therefore, because this use of the sine-stretched RCC_s has successfully been used to detect and identify known phosphate-bearing beds, it could be extended on an experimental basis to other phosphate-producing countries in the semi-arid environment, such as Morocco and Jordan, and then applied to countries having suspected phosphate-producing potential, such as Oman.

d) Monitoring areas susceptible to erosion and desertification in Tunisia with the aid of Landsat images is feasible. The preliminary spatial analysis of image 1199-09311 shows, however, that vegetation classification in Tunisia, as in other parts of the world, might be more effectively accomplished through one of the existing automated schemes, and that sequential analysis is also required.

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APPENDIX I

Glossary

(After Condit and Chavez, Jr., 1979)

albedo (Janza, 1975): The ratio of total radiant energy returned by a body to the total solar radiant energy incident on a body.

aspect ratio distortion: A difference in spatial scale that exists within an image (geometric distortion) such that within an uncorrected Landsat 1 image, features are longer (because they are imaged at a higher resolution) in the horizontal direction that they are in the vertical direction.

atmospheric scattering (Lapedes, 1974): A change in the direction of propagation, frequency, or polarization of electromagnetic radiation caused by interaction with atoms of the atmosphere.

color composite: Technique in which two or more black and white images, with reflectance values expressed in gray tones, are each assigned a color (blue, green, or red), and combined or composited into a single polychrome image.

colorimetric variations: Changes in both the intensity and wavelength of light.

computerized automated interpretation: Various methods used by a computer to recognize a specific spectral signature of a pixel and to place it into one of several selected classes.

digital image: A two-dimensional array of positive integers that correspond to discrete spectral reflectivity values arranged in a checkerboard pattern over a target area.

digital imaging system: A combination of instruments that measure radiation reflected from a target and translate its intensity into an electronic signal which is recorded as a digital value on a preselected scale.

digital number: An integer value related to the brightness (or intensity of radiation) for an area within an image. The value falls within a preselected range; for example, Landsat data are manipulated in eight-bit format, with values from 0 to 255 possible. Shortened to DN.

dropped lines: A line or horizontal row of picture elements that is missing from an image.

filtering: A technique that allows the user to enhance either large patterns (low-pass filtering) or detail (high-pass filtering) within an image. A low-pass filter is the neighborhood average (defined by user as n x m pixels) of DN values around a particular pixel; a high-pass filter is the original DN value of the pixel minus the low-pass filter or neighborhood average DN value around the pixel.

noise: Patterns that are not received from the target but rather introduced by the camera, digital recording, data transmission, and reception and data reduction. Can be divided into two types: coherent noise, which has a systematic pattern, and random noise, which has no pattern.

pixel: Contraction of "picture element." A digital image is divided into a checkerboard pattern of gray shaded squares, each referred to as a pixel.

ratioing: The process of dividing each picture element digital number in one image (or band) by the corresponding picture element digital number of another band.

saturation: The condition in which a further increase in radiation produces no further increase in recorded radiation.

solar illumination angle: The altitude of the sun, measured in degrees of angular distance from the horizon as seen from the target (0° = horizon, 90° = solar zenith). Also referred to as sun elevation, sun angle, illumination angle.

spectral bands: Preselected parts of the electromagnetic spectrum. Usually selected by eliminating all other parts of the spectrum by filtering or allowing only a given frequency or range of wavelengths to reach a scanner or detector element.

spectral reflectance: (Janza, 1975): Ratio of reflected power to the total power incident or incoming to the surface at a specific wavelength.

stretch: A technique which allows the user to change the contrast by either increasing or decreasing range of an image. Also referred to as contrast stretching.