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Rupert Haydn, Helmut Bonarius, Manfred Schramm

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As Henry Morton Stanley 100 years ago crossed the black continent, he was only able to map and explore a narrow strip of the unknown continent. Today the remote reconnaissance satellites give continuous images of all areas of the Earth. However, data from space can only be used after intensive processing. Many processing steps are required in order to create this infrared false color image from a Landsat satellite photograph. It shows the southwestern region of the Tagant region in the center of Mauretania. The image brilliance as well as the wealth of detailed information can be attributed to the use of a special computer program. This precision processing is especially valuable for a universal interpretation basis. In addition, the satellite image was more useful for orientation in the terrain than the map material available, which was usually out of date. The greenbelts are represented here in a yellowish color, and enter the image from the northwest. The steep fissure between the highly differentiated Tagant plateau in the east and the older rock formations below them can be seen from the upper center of the image to the lower right image edge. These are the so-called Mauretanides. /151*

Only 9% of the land surface of our planet has been exploited for agriculture. Just like in the energy area, sufficient data must be available about the topography, geology, vegetation characteristics of the ground in the individual regions must be known in order to provide food. There are wide gaps in this area.

In order to close these gaps, several institutions, including the Federal Ministry for Research and Technology, the German Research Association DFG, the European Space Agency ESA and the European Community EG are making a considerable

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*Numbers in the margin indicate pagination of original foreign text.

effort to advance the science of remote reconnaissance. This is done to gain knowledge and monitor natural resources and our surroundings, and to watch their continuous changes.

Remote reconnaissance from space is playing an ever-increasing role in development aid projects.

Satellites are revolving around the Earth and they are scanning various color ranges. In this way, a multispectral photograph is created. The conversion from a satellite image to the thematic map has been the topic of intensive basic research, which was already carried out all over the world in 1972. At that time, the first Earth observation satellite Landsat of the American Space Agency NASA was launched.

The resolution on the ground is about 80 m. Considering the resolution capacity of presently available remote reconnaissance platforms, thematic maps can only be produced on a scale of 1:200,000. This disadvantage is caused less by the reconnaissance process but more by the present state of photography technology. For later detailed studies, it can be ignored for wide area and rapid reconnaissance of basic information.

The image data shown gives the reflection conditions on the Earth's surface in four spectral ranges:

Channel 4: 0.5 to 0.6 μm (yellow-green)
Channel 5: 0.6 to 0.7 μm (red)
Channel 6: 0.7 to 0.8 μm (infrared)
Channel 7: 0.8 to 1.1 μm (infrared)

The first two channels are in the range of visible light.

In addition to spectral photography, in order to interpret the images it is necessary to represent large regions with the same illumination conditions from space; this is a consequence of the solar-synchronous trajectory. On the

Landsat spectral photographs, it is always 10:00 o'clock in the morning. Comparison of photographs taken over the year gives additional information about the changes in terrestrial phenomena.

One of the important preconditions for exploiting multispectral data from satellites is image evaluation supported by computers. Over the last few years, several systems of digital image processing have been developed (see Bild Wissenschaft Journal No. 10/1978).

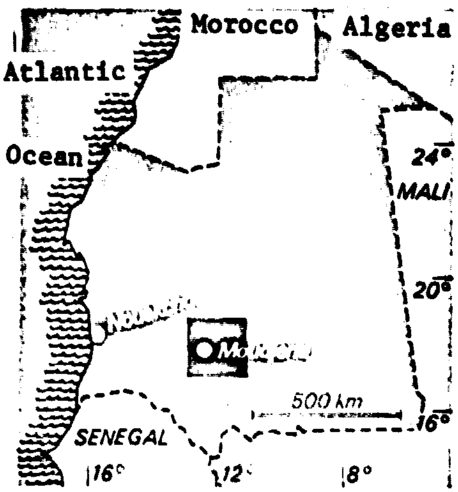
In the meantime, it has become recognized that in spite of the many possibilities of using digital processing methods, which are certainly important, there is an additional important factor for the success of satellite image evaluation: this is the experience of an Earth scientist experienced in image interpretation. The computer evaluation and the interpretation by experienced specialists must complement one another as much as possible. The use of satellite remote reconnaissance in practice is not at all to be taken for granted today.

In order to test the possibilities of remote reconnaissance by satellites even in development aid projects, the German Association for Technical Collaboration (GTZ) in Eshborn/Taunus requested that the Central Office for Geophotogrammetry and Remote Reconnaissance in Munich and the Institute for Planning Data in Frankfurt carry out an evaluation of satellite images of the Tagant region /152
in Mauretania. This contract can be considered as an initial pilot project within the framework of the national development aid.

Mauretania is a country in the Sara-Sahel zone in West Africa which extends over almost 12° in latitude. It extends in the north from Morocco and Algiers to the southeast and east to Mali and in the south to Senegal. In the west, the Atlantic Ocean represents the only natural boundary, and the south the valley of Senegal. The country has a length of 700 km and access is difficult from the Atlantic coast because there are no natural harbors. Two-thirds of Mauretania are desert and only the part south of 17 latitude circle belong to the Sahel zone, which has a different climate from the other parts of the country.

Geologically, Mauretania belongs to the Precambrian crystal table of the West African plate. This is an old, folded and worn-down socket, which in the West is made up of gravel, crystalline schists and quartzites.

Establishment of the capital Nouakchott, the establishment of new population centers in the mining area and its subsequent development, and also the continuing drought since 1968 have led to redistributions of the population in various regions. Therefore, Nouakchott already has 135,000 population in 1977, and it was founded in 1957.



The Tagant region (black) lies inside the Islamic Republic of Mauretania (dark on the map) within the Sahel zone of West Africa. This is the region of investigation of the satellite image evaluation.

The climate of Mauretania is primarily tropical in nature. In the summer, we have rains and precipitation of 300 mm and more in the southern parts of the country. In the winter, the northeastern Passat wind prevails as an extremely dry wind. The precipitation decreases rapidly towards the north, sometimes below 100 mm in the subtropical part of the country.

For the summer temperatures of up to 50° in the desert area, the daily variations amount to up to 35°. According to the climate conditions, the south of the country belongs to the transition zone from the Sudanese Savanna to the desert. The Savanna has a relatively sparse vegetation. To the north of the arid Savanna, the plant growth becomes sparser and is restricted finally to only drybeds in the Wadis and the individual oases with groundwater supply.

We selected the Tagant region as the investigation region. It has an area of about 42,000 km^2, somewhat smaller than the German state of Lower Saxony. The Tagant region can be divided into two zones: There is a highly structured and folded western part and an eastern table-like part. The highly structured western part is drained by the double network of the Qued el Abiod River and the Tamourt en Naaj River, which both end in the Depression of Gabou.

Semi-nomadic tribes inhabit the region. Their livelihood is based on camel herds, goatherds and sheep herds. In addition, they grow grain along the Wadis and in the region of the smaller dams after the rain.

The completion of the National Road 1 from Aleg to Kiffa was especially important for the development aid and the desired improvement of the agricultural base. This occurred in 1976. A number of new population centers and farming areas developed along this road, and the road also functions as a natural dam.

It is also planned to make more intensive agricultural use of certain suitable regions or to renew dams which had been built during earlier development projects. Also, new dams will be built at suitable locations. All of these measures will serve to improve the living conditions for the inhabitants and to stop the continuing migration away from the area.

During the satellite evaluation, an area of 34,000 km^2 was processed with /153
the purpose of obtaining a geological, pedological (ground science) and vegetation inventory, at a scale of 1:200,000. The purpose of the evaluation was to obtain a so-called land potential map, primarily oriented for advancing the state of agriculture.

In this project, we were not able to fall back on established procedures. First of all, it was necessary to carry out careful planning.

As a realistic concept, we developed the following project plan:

1. Intensive information processing, i.e., examination of all available literature and computer processing of satellite images.

2. Visits to the region, which will only require minimum time because of preliminary information preparation.

3. Cartographic processing of results.

The information processing occurs in several phases. From the literature, we selected the most important data -- for example, a collection of the previously existing thematic maps: we cataloged all of the water locations shown on topographic maps or the infrastructure, i.e., the roads and villages. Satellite images were processed digitally, the distortion is removed and they are corrected, and finally enlarged to a scale of 1:200,000. This was the working scale /157 for the entire project. The result of this processing phase is digitally improved and specially processed satellite images. They are then interpreted. In an infrared false color image, for example, red always means vegetation, and there are individual gradations: light red means loose vegetation, full red means dense vegetation. This correspondence is based on experience obtained from previous photo interpretation of other regions.

Geological conditions are more difficult. Based on unified gray scales /158 and color scales, one can recognize continuous geological structures -- for example, cliff plateaus. Whether one is dealing with a certain geological feature -- for example, granite or sandstone -- must be clarified by a comparison with the available literature, the description of the landscape of this region.

These steps had been previously carried out on the "green table" (not in the field). Therefore, one can distinguish spectral phenomena. For example, light red sand fields always appear as pure yellow in satellite images. In addition, the surface structure of dune fields is always typical.

Checks are then made in the terrain once this information has been collected. One can only establish whether the interpretation was correct by making an on-site inspection. In addition, one can clarify remaining questions. The hand-drawn maps are compared with reality in order to improve them, and to complete them where necessary. Then the results are collected.

Two weeks were sufficient to clarify everything which had remained in question during the preliminary work. For example, the areas which had the appearance of turtles in the satellite images were a puzzle. These are dark-green rock formations which are separate from one another. In reality, these were found to be completely flat areas which are covered with "desert paint."

The desert paint is a typical weathering phenomena in arid regions. This /159 is a thin, usually brown-black cover on rock formations and other stone surfaces, which covers the surface just like a dull varnish. From the interpretation of the satellite image, we first assumed that this was a table-like high plateau.

We were also able to give a more detailed interpretation of the vegetation distribution. For example, the very dense vegetation can be found in the region of small dams,where, as a rule, millet is planted. This could not be recognized /160 from only the spectral properties of a satellite image.

The journey to the Tagant region resulted overall in a very good correspondence between the preliminary evaluation of the satellite images and the natural features of the area. The satellite images were very useful as orientation aids. The maps were deficient at some points and sometimes contained errors.

After studies at the location were carried out, the participating scientists were consulted: ground scientists, geologists, hydrologists. The working results are discussed and incorporated into the new and improved thematic maps. Three maps are the most important results: a geological map, a ground map and a vegetation map.

The geological map contains 14 units characterized by different colors, corresponding to the different formations. The map shows the course of several line-like structures which had not been known previously, and in some cases there were many fracture structures.

The ground map contains eight differentiation units. In classical air interpretation as well as in satellite evaluation, surfaces which have a homogeneous appearance can be differentiated from one another. However, it is not possible to describe the ground types using these ground characteristic values. In our project, we attempted to describe the process of soil creation.

The vegetation map contains a total of five density stages, starting with the vegetationless regions (density step 0) up to intensively used vegetation surfaces (density step 5).

The representation of all of this data in the form of thematic maps is a substantial result of the overall project: this forms the foundation for additional planning activity in the Tagant region. It was also possible to establish an evaluation method for exploitation in the future and to show this clearly on a map.

The individual steps, for example, extend from roaming grazing areas, where it seems impossible to exploit the region agriculturally, up to regions with very many possible land uses.

This collection of maps contains much information on how to give Mauretania development aid with certain goals. Based on this data, one can decide which type of aid will be appropriate in which regions.

This example of satellite image mapping demonstrates how much an application-oriented remote reconnaissance of an area can contribute. Of course, remote reconnaissance alone is not capable of replacing terrain studies, but it can give a synoptic overview of certain ground science topics. In other words, large areas are covered simultaneously on the same image under the same illumination conditions.

This means that one can extrapolate from a small region to a large region. If this were only done on the basis of spectral intensities, as shown in a satellite image, one would fail. This cannot be done with only a single image.

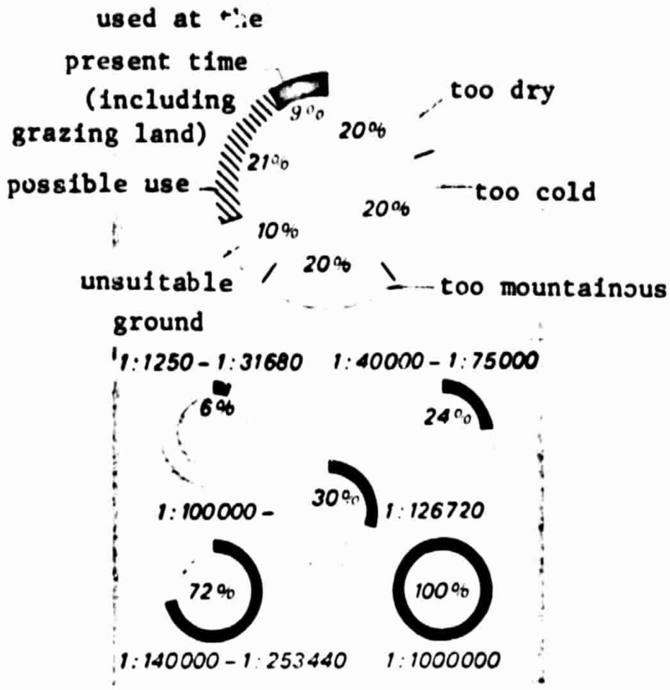
It becomes even more difficult if one uses several images at various times. Therefore, it is absolutely necessary to have additional information in order to carry out the interpretation. This was actually done in processing Step 1. /161

The next step is a feasibility study, a study within which exploratory drilling is carried out in order to investigate water conditions, measure water capacity, and carry out similar measurements. One can then decide where one should build fountains.

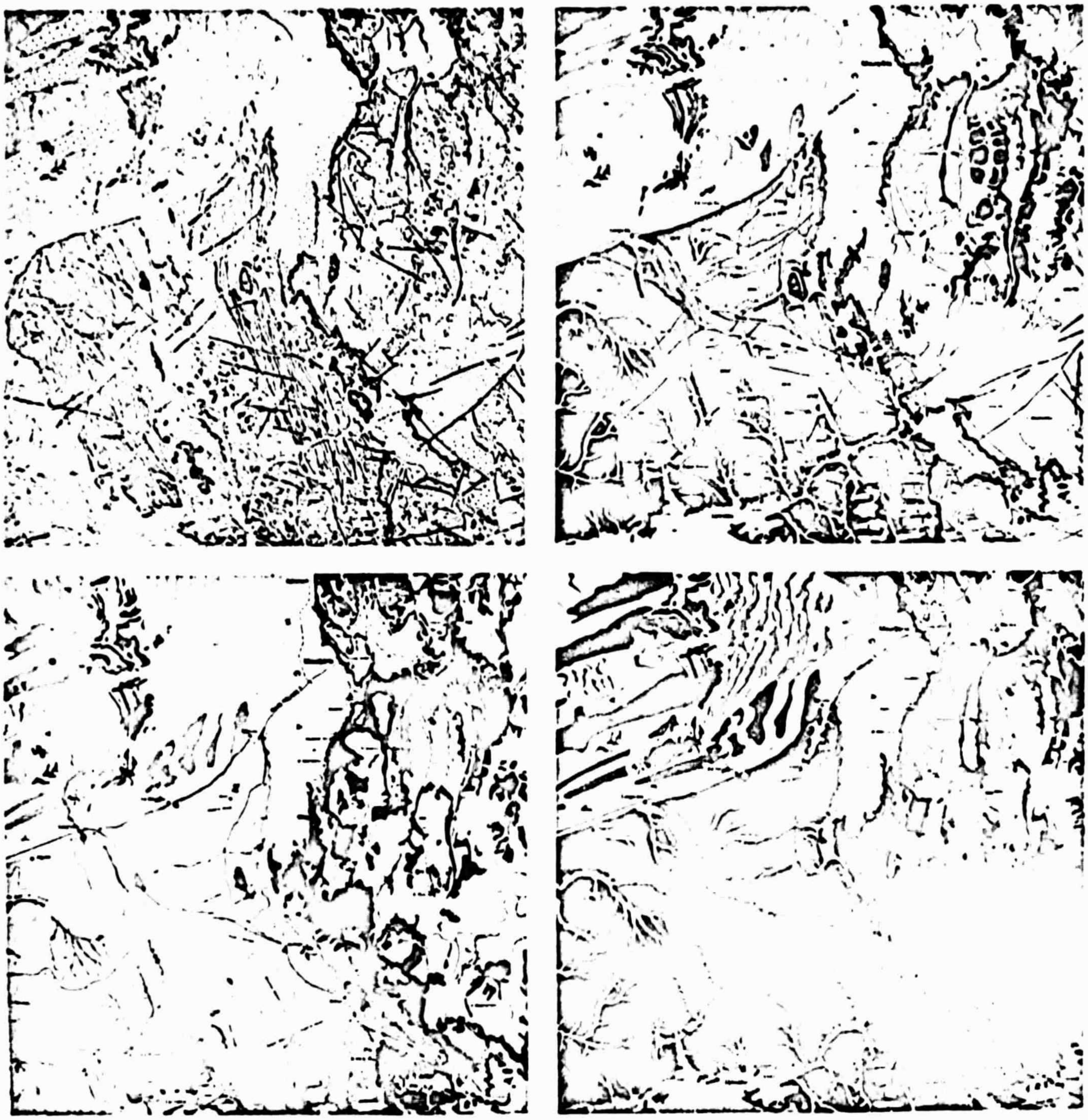
The deciding agencies can make their decisions using our investigation results and to plan the next step.

The interpretation places high requirements for digital image processing, and is oriented according to the desires of the individual disciplines. We are not only talking about image enhancement, but also the most accurate possible representation of scientific detailed phenomena. There can be no universally useable image presentation. The processing in the upper left has the purpose of presenting vegetation details. The regions which appear in red in the original false color image contain fresh and very dense vegetation. They are presented here as clearly defined and therefore easily cataloged and limited black areas. These are planting regions in the areas around dams, wet grasslands, palm forests and acacia forests. The less dense bush and tree vegetation cannot usually be seen on IR false color images and is usually represented in lighter gray tones and shows the finely structured net of the dry rivers and the rapid drop of the Tagant

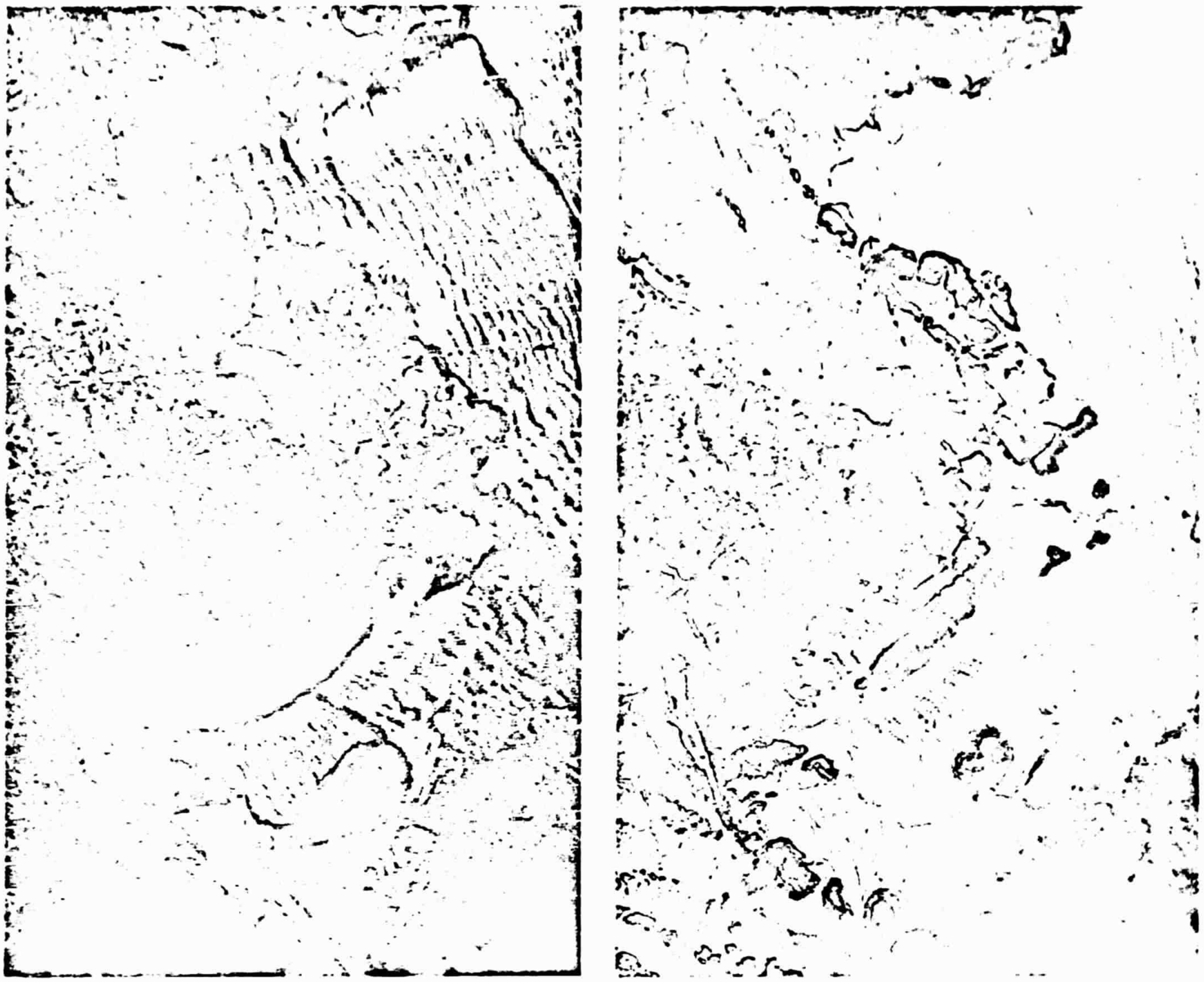
More than two-thirds of the land surface of our planet cannot be used for agriculture. The graph shows the percentage distribution of the land regions. One could use twice as much land for agriculture as is already in use. The figure below shows the percentage of the Earth surface which has been mapped and at what scale. There are 1:1,000,000 maps for all regions. "Measurement table sheets" (about 1:1,250) are only available for about 6% of the Earth surface. Because of Landsat 1, 2 and 3, complete maps at a scale of 1:200,000 will become possible. The successor Landsat D and other planned satellite missions will increase the accuracy of the Earth maps to 1:50,000.



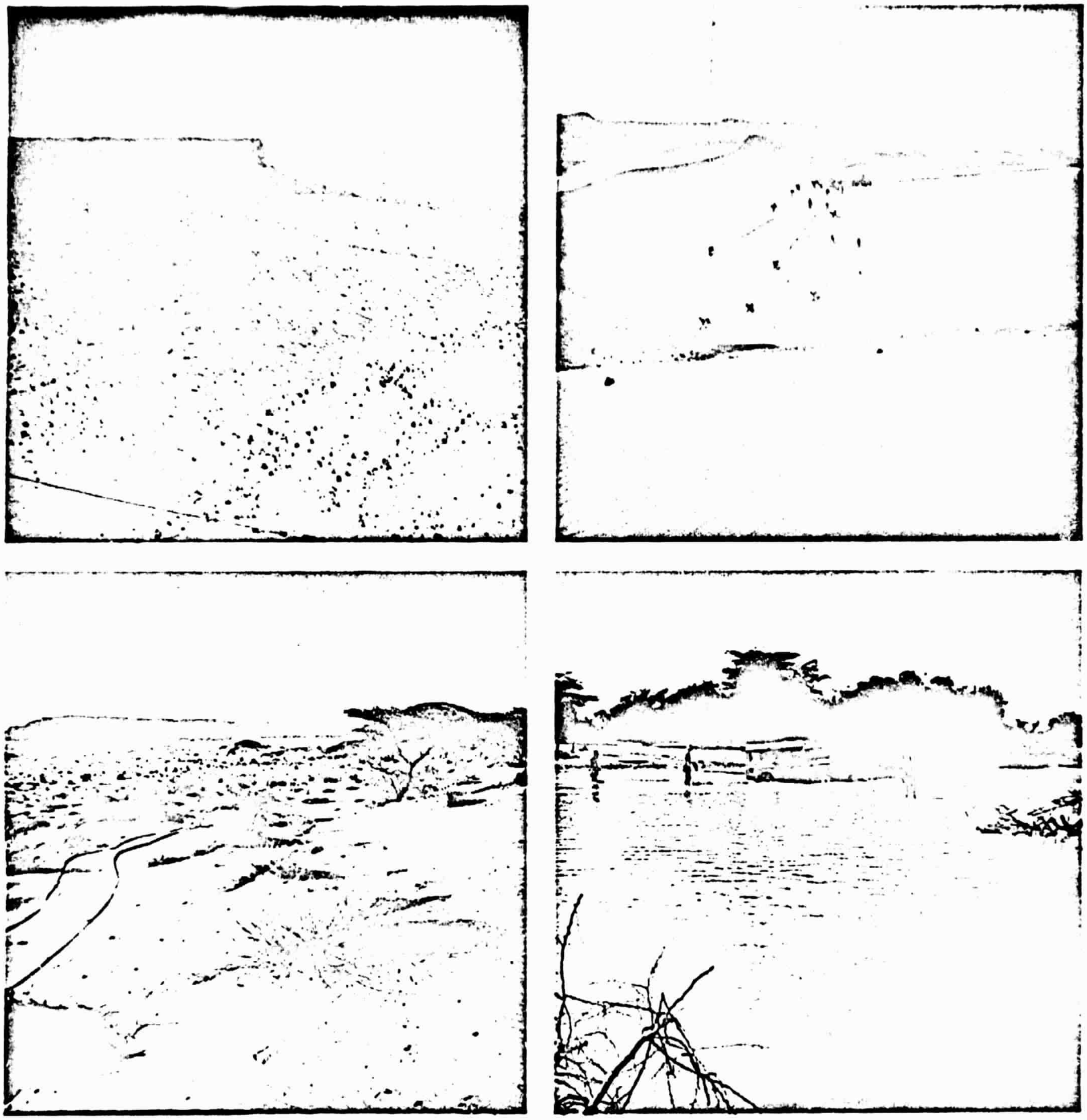
Plateau. A different kind of processing of the same initial image (upper right) leads to a clear differentiation between sand areas which are characterized by the same spectral characteristics. Dune belts and flying-sand deposits have a red tint in nature and can be clearly represented as black areas. Light sand areas, on the other hand, appear white. The two lower digitally produced image products give important information for photogeological interpretation. With the left image, one can obtain an exact boundary between rock series, consisting of sandstone and schist in the Tagant Plateau region. Other surfaces which appear dark in this processed image can only be interpreted by comparison with different processing methods. The lower right image seems to show a surface relief which was calculated from the relative contrast differences. By additional suppression of the brightness stages which are typical for the different surfaces, one can recognize and interpret the finest structures, at least the line structures, and surface patterns over wide regions.



A rough outline for a geological map (upper left) was put together on the "green table." This is the foundation for verifying and controlling operations in the field, together with other thematic map designs. After this, we developed thematic maps in final form and it was found that especially in geological-pedological problems and even for vegetation problems, experience with the Earth sciences is more valuable than computer decisions. The upper right images and the lower images show the geological maps, the vegetation maps and the ground maps. The geological map contains 14 units which were determined from textures, gray tones and color tones. The seven steps of the vegetation map extend from arid dunes and cliff formations to cultivation areas in the region of dams and palm forests. The color surfaces in the ground map show the properties of flooded regions through clay to the bases of cliffs, using eight steps.



The c 'or computer processing from the southeastern region of the Tagant has no similarity with our ideas about how the Earth's surface appears. The purpose of this processing is to obtain extensive surface differentiation. The interpreter must be knowledgeable of the fact that the finest color differences can correspond to completely different ground phenomena. Different red tones, for example, can indicate clouds or open water areas. They can also correspond to the many kinds of sand deposits or rock units of the Tagant Plateau. Compared with IR false color images shown on the left, the further color processing on the right gives a differentiation, especially in the regions with no vegetation, and fine details are lost.



The high plateau rises from the desert-like low plain and the drop-off is often perpendicular. From an aircraft (upper left), one can see how usually there are dense bushes and trees at the bases of cliffs, which gradually become vegetationless sandy areas. In front of the western Tagant Plateau (in the background in the upper right image), the drifting dunes often reach heights of up to 30 m. The vegetation does not exist here. The sand-covered high surface (lower left) with its grass vegetation and bush vegetation is used as a grazing area for camels. When we try to enter this region, there are often tire failures because they have to run over hard acacia thorns which are often over 10 cm long. The light acacia forest (lower right) is encountered often in the flooded regions, as well as in the rocky high valleys of the Tagant Plateau. After the rains, the open areas dry out and grain is planted here.

A synthesis of all of the individual formations available or which have been developed shows the cartographic representation which has been evaluated for land use. The results obtained from visiting the area, the literature data and the detailed interpretations of the satellite photographs, are combined here. The map represents a means of making decisions for different disciplines: agricultural exploitation without artificial irrigation and using the natural irrigation system, agricultural use using traditional irrigation methods without large investment costs (for example, rain field planting with earth dams for holding back water or foundtain irrigation of palm and vegetable gardens, or agriculture using the natural water reduction from flooded regions). One can also consider agricultural exploitation using modern irrigation methods (drilled fountains and dams). The evaluation scale extends from regions which can only be used for migration grazing up to regions with many possible uses.

WHERE IS A FOUNTAIN ADVANTAGEOUS?

The work plans of the National and International Development Aid Organizations contain a wide spectrum of programs. This extends from the planning of large or small water regions for irrigation and energy production to the development of new land for agriculture and population centers, the building of roads, exploration of raw materials, and the complete transformation of entire countries.

The bilateral collaboration of the Federal Republic of Germany has to be coordinated with new projects within the development - political concept of the federal government, and the guidelines for technical and financial collaboration.

The first step of such a project is a proposal to the Federal Ministry for Scientific Collaboration (BMZ) which is formulated by the government of the development country through the foreign office.

After this,project requests are examined as to purpose, extent and whether they can be realized. This detailed examination is primarily carried out by the Association for Technical Collaboration (GTZ) at the request of the BMZ. Financial collaboration is considered and carried out by the credit institution for redevelopment (KW).

In order to develop decision criteria for complete project selection, during project examination one has to use basic information for the area in question. Satellite images represent important decision aids during this phase. However, this requires a corresponding conversion of the ground science information in these images into a generally understandable form, a thematic map.

The satellite evaluation for agricultural development of the Tagant region in the Islamic Republic of Mauretania is an example of this.