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Delineation and Analysis of Drainage Pattern from Satellite Images of Sahl Al Matran Area, Northwest Saudi Arabia

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ABSTRACT. The potential importance of groundwater in Saudi Arabia is presented. Space borne remote sensing devices have been used to collect data and to investigate the drainage pattern of Sahl Al Matran Area, in the northwestern part of Saudi Arabia, between Al Wajh and Umm Lajj cities.

Enhanced Landsat Thematic Mapper images, together with aerial photos, have been used in the visual identification of thematic features. Digital image processing and lithographies were prepared. Distinct drainage pattern types occurring in the study area are characterized.

Drainage analysis was carried out in order to reveal the efficiency of the drainage network expressed as the drainage type, orientation, density, integration and uniformity.

Drainage angularity in the area is clearly related to the main fault systems of the area.

Key Words: Sahl Al Matran, Saudi Arabia, Landsat TM, Drainage pattern.

Introduction

A quantitative analysis of the drainage pattern was traditionally carried out on the basis of topographic maps frequently supplemented by field work. This approach is often inaccurate and time-consuming. Application of remotely-sensed data, aerial photographs, and satellite imagery can significantly improve the efficiency, detail and accuracy of drainage mapping. Remotely-sensed data are especially useful for these studies not only due to their synoptic character but also because they can frequently reveal invisible hydrographic features and hidden spatial patterns. Detection is furthermore facilitated when infrared and microwave (radar) electromagnetic radiation is applied to the investigated area.

It is commonly accepted that one of the best geomorphic characteristics relevant to hydrology is the drainage pattern. Understood as "the configuration or arrangement in plane view of the natural stream courses in an area" (Gary *et al.*, 1972), it "permits disposal of the water in the drainage basin and reflects the influence of such controlling factors as initial slope, lithologic uniformity, inequalities in rock hardness, structural control, degree of erodibility and infiltration – runoff ratio" (Alwash & Yousif, 1986). It is well known that the way the water drains from a given area depends upon the parent rock and soil formation, topography (slope length and inclinations) as well as climatic conditions. Drainage pattern is one of the most important identifiers of landforms. It reflects geological conditions and informs about the present and past drainage regime and climatic conditions.

The launching of Landsat for the acquisition of synoptic, sequential images from which useful data can be obtained for investigations in such disciplines as agriculture, geology and hydrogeology, constituted a turning point in underground water investigation (Boeckel, 1973). Since then, new vistas have been opened whereby the various earth resources including water could be better estimated, assessed and optimally utilized (Rango & Solmonson, 1978).

During the last decade, the Faculty of Earth Sciences, King Abdulaziz University has been carrying out various research and applied projects utilizing space-borne remote sensing devices and conventional geologic work for providing highly valuable basic information about various areas in the Kingdom of Saudi Arabia within the framework of multidisciplinary projects. Some examples of such studies are: Alwash, Zaidi and Terhalle, 1986; Alwash and Yousif, 1986; Alwash, Bodechtel and Zilger (1986); Bokhari, 1988; Alwash and Bokhari, 1989; Alwash and Bokhari, 1990; Bokhari, 1991; Alwash, 1992; Bokhari, 1993; Alwash & Bokhari, 1993; Bokhari, 1994; and Alwash & Bokhari, 1994. Specialized algorithms have been developed to visualize specific geologic features by enhancing both the radiometric and the spatial information (Zakir *et al.*, 1986).

A recent study of Sahl Al Matran Quadrangle, as part of a larger more extensive project, was undertaken, to investigate the coastal region between Al Wajh, Umm Lajj and Wadi Ḥamd. This project is in compliance with and direct support of the Kingdom's priorities of the current Development Plan. Specific contributions to the Development Plan includes: enhanced geomorphological framework of the Western Arabian Shield, evaluation of areas of potential geologic hazards, and developing strategies for water resources development and management.

Location

The Sahl Al Matran quadrangle (1:250,000-scale) is in the northwestern Hijaz region of Saudi Arabia between latitudes 26°00′ and 27°00′N and longitudes 37°30′ and 39°00E (Fig. 1). The quadrangle is situated astride the northern edge of the Arabian

Shield and is covered by Paleozoic sandstone over most of its northern half. It encompasses an area of 16,555 sq km. The southern half of the quadrangle is a rugged mountainous terrain of Precambrian hills (jabals) and incised wadis, whereas the northern half is a very gently northward dipping platform of Paleozoic sandstone, also deeply incised by wadis. The western part of the quadrangle is covered in part by Tertiary basalt that caps the sandstone in the northwest (Harrat al 'Uwayrid) and Precambrian rocks in the southwest (Harrat Hurayrah). Altitudes in the quadrangle range from about 500 m in Wadi al Jizl to more than 1,600 m atop Jabal ad Dukhan (Hadley, 1987).

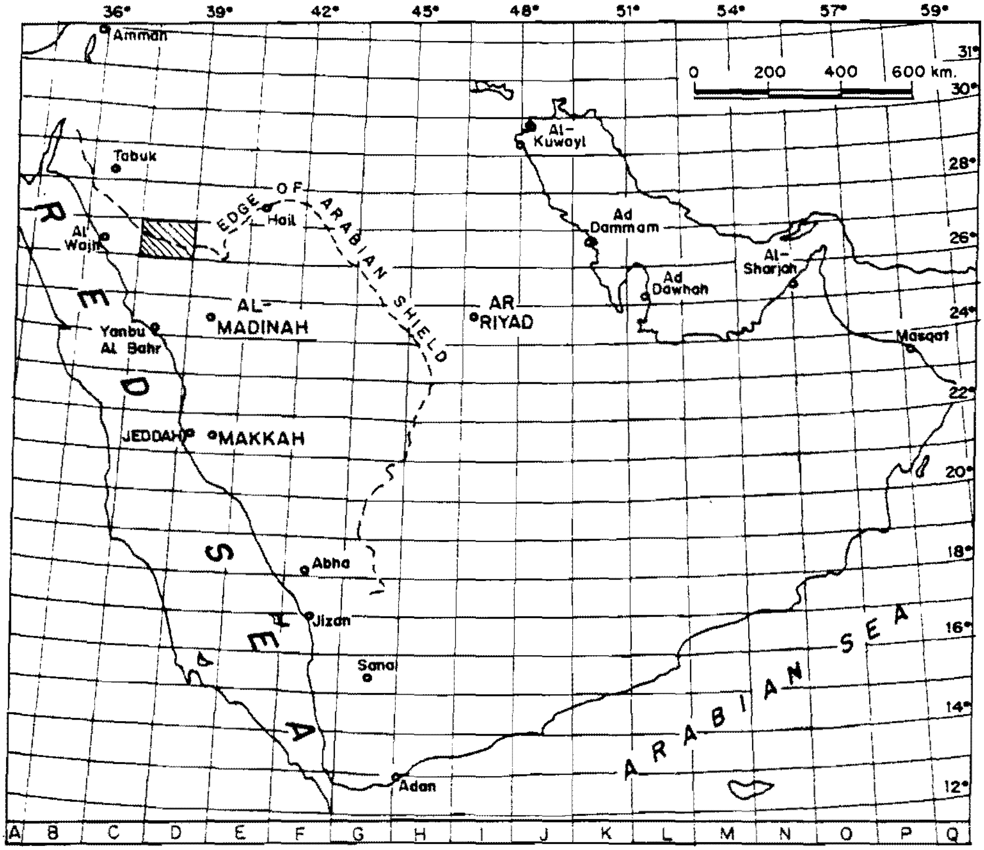

FIG. 1. Index map of Saudi Arabia showing location of the Sahl Al Matran quadrangle (patterned). Scale 1:5,000,000.

Previous Investigations

Significant geologic work in the Sahl Al Matran quadrangle which was started by a reconnaissance field work (Brown *et al.*, 1963). Following this early work, a program of detailed geologic mapping and mineral resource study was begun in 1970 by the

Ministry of Petroleum and Mineral Resources. Geologic reports have been published on Precambrian stratigraphy, the stratigraphy of Paleozoic sedimentary rocks and techniques for mapping different rock units. Investigations related to mineral occurrences were reported. Blodget and others (1975) used enhanced Landsat imagery for mapping. It is clear from the previous investigations on this area that no study on the water resources was undertaken before.

Available Remote Sensing Data

The study area is covered by the two Landsat Thematic Mapper scenes, path 172/row 42 and path 171/row 42. CCT's ordered from EOSAT; of acquisition dates are February 9, 1991 (171/42) and January 1, 1989 (172/42) were used in the present study (Fig. 2). This selection had to be done considering the necessary combination of the two scenes for covering the whole study area, the required similar illumination

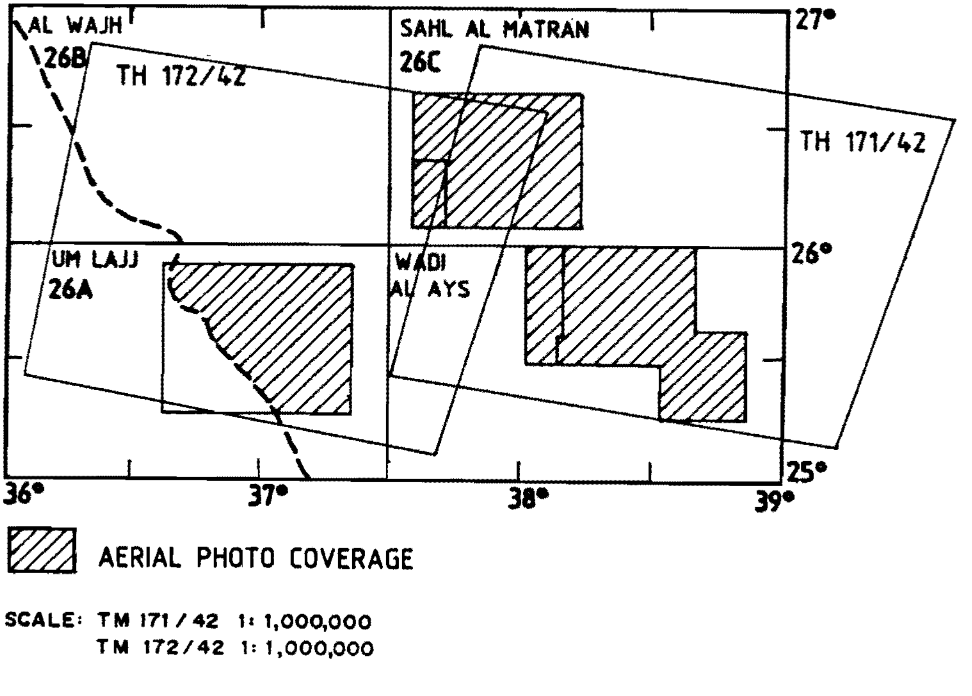

FIG. 2. Thematic mapper data coverage of the test area.
Scale TM 171/42 1:1,000,000
TM 172/42 1:1,000,000

conditions and superficial reflection characteristics and the good atmospheric transmission in Saudi Arabia due to relatively favorable weather conditions. Universal Transverse Mercator (UTM) projection was chosen for geometric correction of the data. This projection provides an accuracy similar to that in topographic maps up to scale 1:50,000.

The available black and white aerial photographs that date back to 1957 have a scale of approximately 1:60,000 and were flown with an overlap of 60%. The defined study area was covered by approximately 60 stereo pairs. Additionally, an uncontrolled mosaic of the aerial photographs was compiled on a scale of 1:100,000.

Digital Image Processing

Considering that the intention to apply the approach used for Sahl Al Matran area to other areas of high geomorphologic interest, a condition was laid down when developing the processing method, that it should provide good distinguishability in terms of geomorphologic classification for Saudi Arabian terrain in general. Also, because a map presentation of the satellite image was envisioned, an aspect which should not be underestimated, an aesthetic color combination was to be achieved.

By checking with other areas covered by the two Thematic Mapper scenes, the following approach proved to yield the best result:

a) registration of each TM scene, *i.e.*, a 2416 × 1867 pixel section of TM 171/42 and a 2340 × 2052 pixel section of TM 172/42, resulting in a merged file of 2496 × 2774 pixels with some overlap;

b) locating ground control points in the overlapping area, registration of the 2 sections, then applying cubic convolution and nearest neighborhood resampling; a geometric correction of scene 172/042 became necessary; because the geometric properties of the two scenes were not equal;

c) both sections were then combined with the help of a "stitch" program, yielding an image file of 2496 × 2774 pixels size;

d) the seam of the images, where they were put together, was then adapted with a "smoothing" low-pass filter;

e) the statistics of both images were computed, leaving out the seam area;

f) the low-pass filtered image was copied into the merged image;

g) gray levels were added to the western section of the merged image in order to overcome the spectral differences;

h) statistics of the assembled scene were calculated.

Then the first principle axis of all bands (besides # 6) was computed and stretched, before bands 5, 4 and 2 were fed into the computer as Red-Green-Blue (RGB) components, coupled with a stretching to 8 bit.

An Intensity, Hue, Saturation (IHS) transformation followed and a statistics computation of the principle axis and the stretched RGB combination were carried out. The saturation was enhanced, then filtered by using a 3 × 3 pixel sized addback-high-pass before introducing the complex processed principle axis component into the IHS transformation as intensity. A retransformation to the RGB system for photographic display completed the processing.

Preparation of Lithographies

Lithographies of the processed data were necessary for offset printing process already done at an earlier stage, directly after the optimum processing algorithm for the task under question has been defined in the iterative process. This includes the results and inputs provided by existing literature study, field comparisons, and especially the spectral radiometer measurements, as basis for the final, highly precise cartographic elaboration of the thematic maps. Only if the cartographic lining of the interpreted units or features is performed directly on an overly, fixed to the scale conformal lithographies via a precise pass-system, it is possible to directly combine interpretation and spectral data in the envisaged "satellite image map" without major time and cost consuming expenditures of correction work.

If, the cartographic eleboration would have been performed using a photographic enlargement [see part (a) above], the slight different optical characteristics of the different lens-systems devices would have resulted in significant deviations and incompatibilities between cartography and satellite image in the final map. The following method for conducting this work was applied by the research team. The method is based upon profound experience gained within former projects, and existing only at the Faculty of Earth Sciences (FES). The original transparency of each color processing was first scanned with a drum scanner. By appropriate hard- and software, the colors as displayed in the processing were split into 4 colors, which are required for the color offset printing process, namely:

yellow
cyan
magenta
black

On the output side of the computer, a laser drum plotter was connected, which allows formats of up to 1.40 m × 1.00 m to be worked with. Here, the 4 colors were displayed as black and white screened transparencies in the final printing scale. They will not be used directly in the printing machine, but will serve to produce printing plates of an aluminum/silver alloy, the real "lithographies".

An external agency possessing the appropriate devices of suitable quality was contracted to process such high geometric accuracy data like that of TM and SPOT. The necessary photographic processing including enlargements, however were carried out at the FES.

Mapping Drainage Pattern

Interpretation of the drainage network has been carried out on the transparent, black and white photographic enlargement of Landsat Thematic Mapper image derived from digitally enhanced and georeferenced scene 171/42 from January 1, 1989. Additionally, digitally processed false color composites specified in the aforementioned reports as well as prints of aerial photographs in the scale of 1:60,000 and an uncontrolled photometric were used in order to facilitate the interpretation procedure.

A drainage analysis usually begins with the study of drainage appearance on conventional cartographic documents or on preferably small to medium scale remotely sensed images. This approach permits to reflect drainage texture or drainage density and dissection. Purely visual as well as more sophisticated, qualitative and quantitative evaluations of drainage textures can be carried out. Fine-, medium-, and coarse-textured patterns are recognized and they expressed the amount of water runoff and therefore relative rock weathering resistance, erodibility and/or permeability.

A fine textured pattern usually indicates low permeable soils, impervious bedrocks and high surface runoff. On the other hand, a coarse-textured pattern characterizes more resistant bedrock, frequently permeable and covered with coarse, permeable soils. The amount of surface water runoff is low.

Another important criterion is known as drainage pattern type. Several distinct categories are recognized and described by geomorphologists and hydrographers (Choronicz *et al.*, 1992, Deffontaines *et al.* 1992) but only those of them which occur in the investigated area will be briefly characterized in this report :

Dendritic: or tree-like branching system is the most common drainage pattern occur on diversified landforms.

Angulate: or trellis pattern caused by the strong influence of geological structure of the area.

Rectangular: this pattern of rectangular shapes is formed frequently in slate, schist, gneiss and resistant sandstone in arid climate.

Trellis: this pattern is a result of differential erosion of deformed, interbedded soft and hard rocks.

Subdendritic: pattern of complex combination of several types indicates the influence of underlying rocks and tectonic development of the area for first-, second- and third-order drainage.

Barbed: this pattern is associated with different types of tectonic disruption. The lack of well developed drainage is typical for types of desert accumulation depressions covered with highly permeable, porous deposits.

Braided: very characteristic for large alluvial plans and extensive valley floors in arid lands where seasonal floods occur and channel clogging and overflowing is frequent.

Dichotomic: fan-like shape of this drainage is formed on complex alluvial fans, pediments and similar, uniformly sloping surfaces.

Results of the Drainage Pattern Mapping

The result of this stage of study was the interpretation overlay on a scale of 1:250,000. It contains two types of lines of different thickness symbolizing two classes of stream courses (valleys and wadis/sherms). These classes represent stream courses of the first and second order. This solution seems to be also justified for the sake of further analytical procedures and statistical analysis of data.

Additionally, the borders of very large valleys and areas of fluvial accumulation were cartographically represented with dotted lines.

The resulting drainage map (Fig. 3) was subjected to appropriate processing and morphometric analysis in order to reflect the hydrologic characteristics of the area. These investigations concerned with only selected parameters influencing the gravitational force acting on a drainage basin and therefore reflected as relief type, average slope and stream gradient. The main goal of these studies was to reveal the effi-

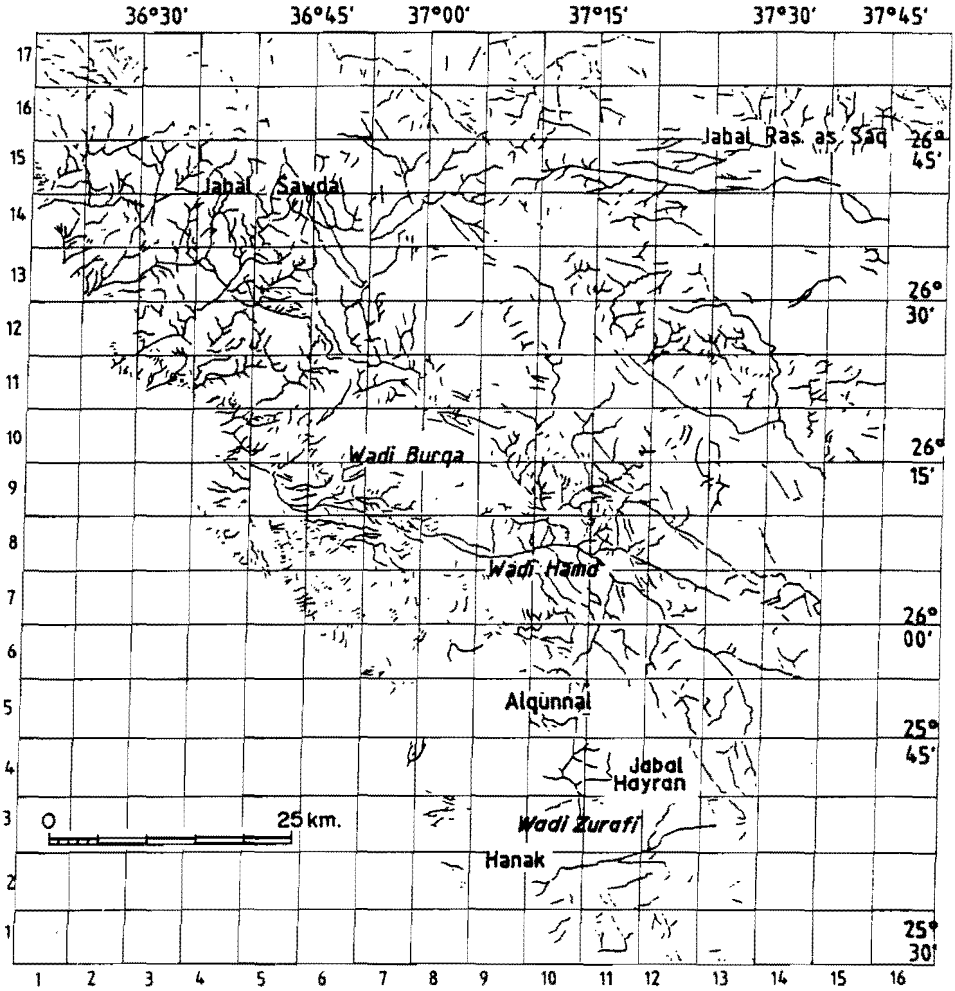

FIG. 3. Index digitized drainage pattern map of southeast Al Wajh area part of Sahl Al Matran quadrangle divided into (10 × 10 km) grid cells.
Scale 1:500,000

ciency of the drainage network expressed as the drainage type, orientation, density, integration and uniformity.

Analytical Procedure

The mapped drainage pattern was digitized with PC ARC/INFO software and Altek 31 digitizer. In order to simplify the analytical procedures, only stream courses were taken into consideration for further analyses (Fig. 3). Extensive fluvial accumulation plains as well as wide valleys were not digitized in spite of their frequently well established, directional character. However, over 4400 drainage lineations were spatially indexed with information referring to their lengths and directions calculated for 36 orientation classes.

Apart from drainage pattern digitizing, a simplified digital geologic map of the investigated area was elaborated from available 1:500,000 and 1:250,000 geologic maps (Fig. 4). Eight generalized principal rock units were distinguished and then served as an input for further analytical processing. These generalized rock units are :

1) QT (alluvial clastic deposits), Qes (eolian sand), Qsb (sabkha deposits), Qu (undifferentiated gravel, sand, silt and clay), Qg (gravel)
2) Qt (terrace deposits)
3) Qtb (basalt and andesite)
4) Tra (Raghama Formation)
5) rs (sedimentary rocks interbedded with and overlying the Shammer Rhyolite)
6) gm (monzogranite), gr (granite), gg (granite and granite gneiss), gp (granite or syenite)
7) sc (schist), am (amphibolite and hornblende schist), dg (diorite and granodiorite), ub (ultramafic rocks and gabbro), h (Hadiyah Slate), sr (Shammer Rhyolite)
8) Cs (Siq Sandstone), Cq (Quiweira Sandstone).

Twelve control points were used for geometric transformation which was performed in order to register digital file containing drainage and geologic data. The executing program is written in C language and the PC ARC/INFO. Simple Macro Language was used to prepare procedures devised to :

Calculate the predominant stream directions for 179 grid cells (10 × 10 km) and display the predominant stream directions within each cell (Fig. 5).

Calculate the drainage density ratio: stream length/cell area for all grid cells (Fig. 6). Drainage density is expressed in 8 classes :

1) less than 10 km/100 km^2
2) 10-20 km/100 km^2
3) 20-30 km/100 km^2
4) 30-40 km/100 km^2
5) 40-50 km/100 km^2
6) 50-60 km/100 km^2
7) 60-70 km/100 km^2 and
8) more than 70 km/100 km^2.

Construct azimuth frequency diagrams for eight principal rock units (Fig. 7-14).

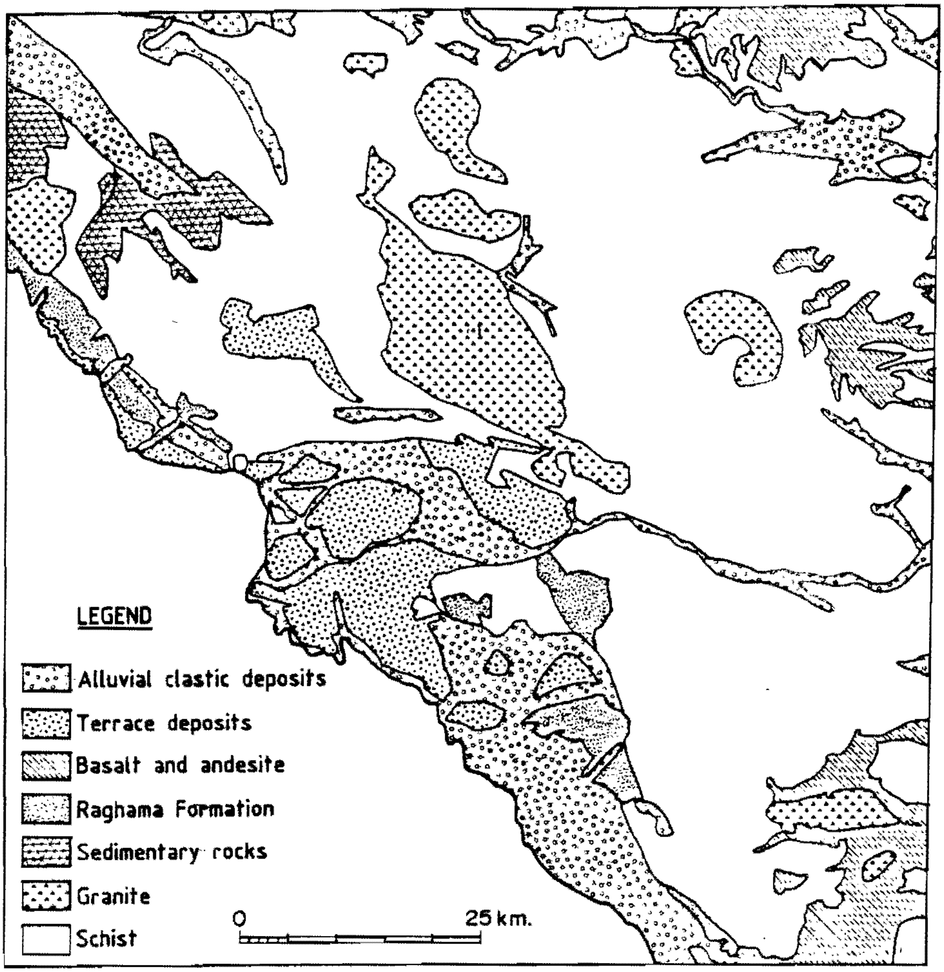

FIG. 4. Simplified geologic map digitized and compiled from available published maps. Scale 1:500,000

Conclusion of the Drainage Pattern Analysis

The results of this reconnaissance study may indicate that the drainage lineations generally show medium- and fine-textured pattern and multiple variations of dendritic and subdendritic drainage type. This reflects a fluvio-denudational morphogenetic character of the investigated area. Extensive areas covered with clastic alluvial and colluvial deposits are characterized with coarse-textured patterns and internal drainage types. In some places, located within large valley floors, braided drainage is developed. Dichotomic drainage pattern is associated with extensive alluvial and colluvial fans covering complex pediments (bajadas).

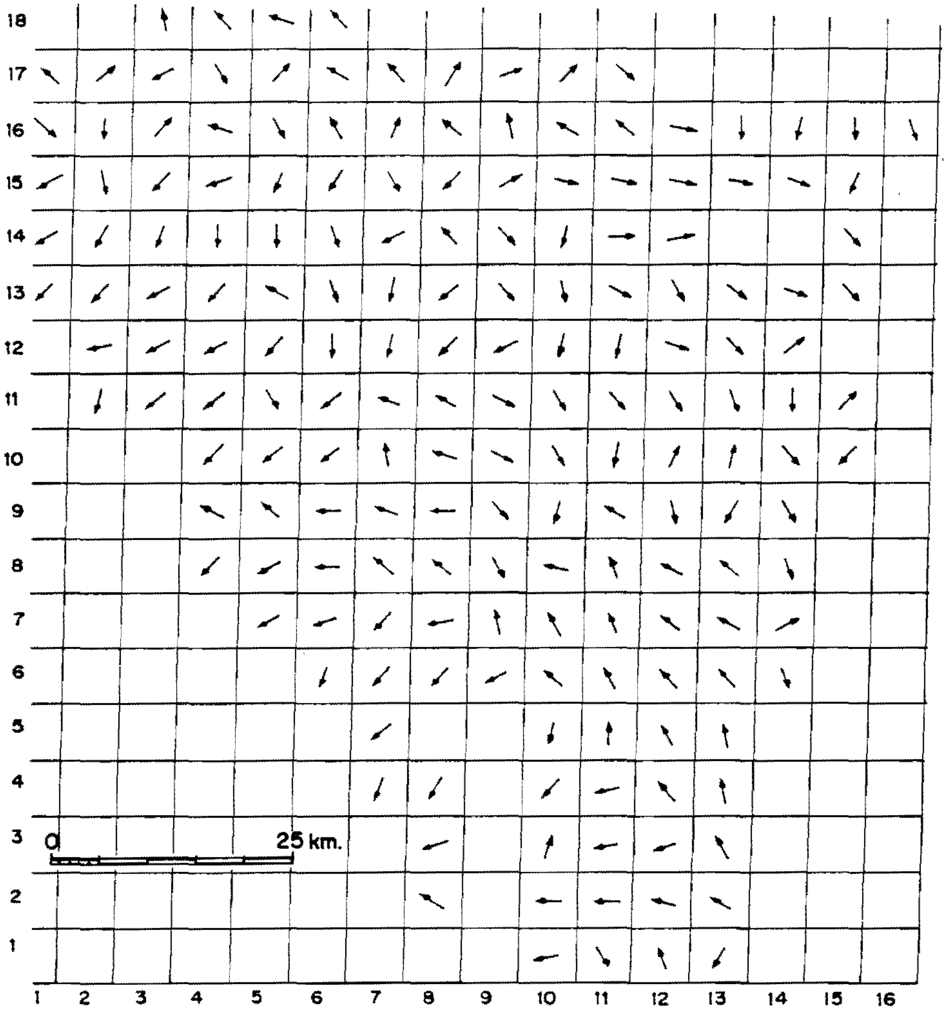

FIG. 5. Predominant stream directions in grid cells (10 × 10 km) calculated on the basis of the azimuthal/length drainage for all 179 cells.

Drainage angularity in the area is clearly defined and is related to the main fault systems of the area. The fold-faults pattern of the Arabian Shield together with certain stratigraphic relationships suggest that it was affected by two major systems or orogenic cycles. The second of which, or Najd orogeny, represents a younger period of mountain building. Its effects are seen in the long northwesterly trending left-lateral faults. The Najd orogeny seems to have involved at least two periods of igneous activity, interrupted by long quiet intervals and intermittent fault movements (Al-Sayari and Zotl, 1978). Morphologically it is expressed by the prominent escarpment

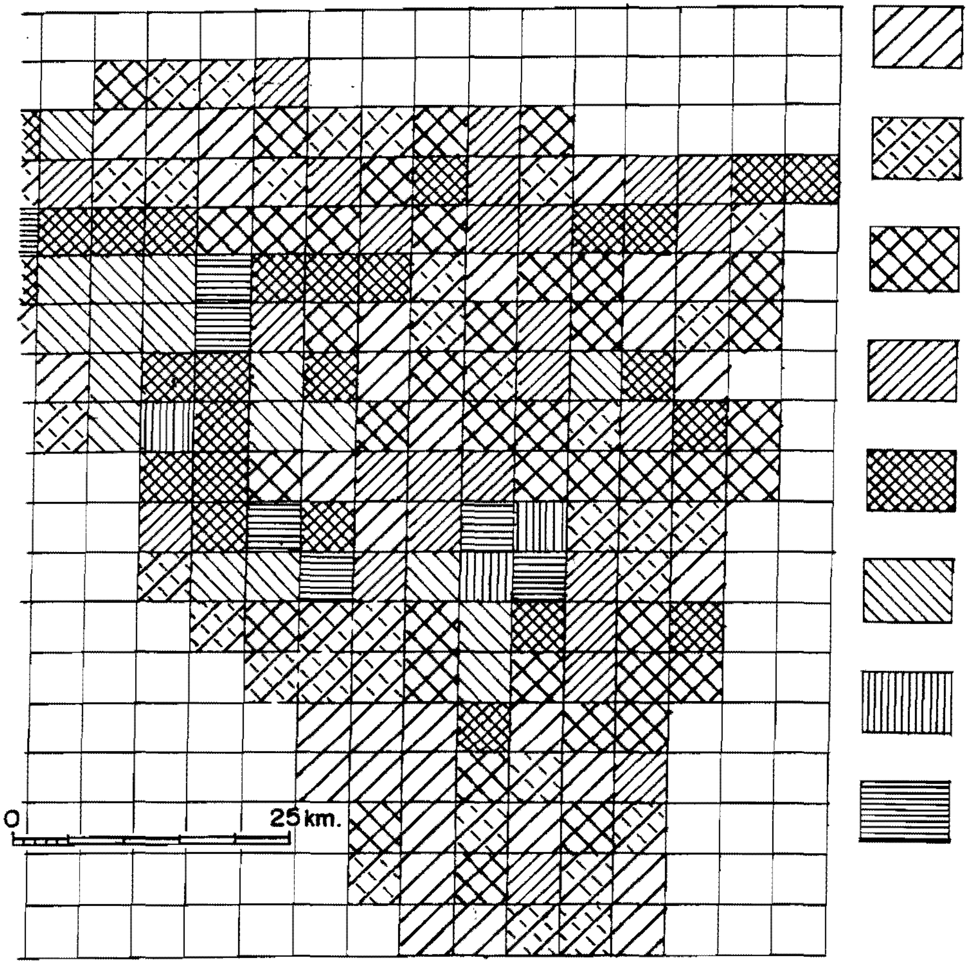

FIG. 6. Drainage density for particular grid cells (ratio stream length/cell area). For explanation of the legend please see text.

separating the mountains and foothills in the eastern part of the area from the Tihama coastal plain. Predominant orientation of drainage lineations drifting NW and SE coincides perfectly with the faults forming the Red Sea which appears to date mainly from the Miocene – by crustal thinning extending NW-SE and E-W sea floor spreading, a process that began in the late Oligocene at 30 Ma and has continued to the present (Styles and Hall, 1980).

It is worthy of noting that structural control of the drainage pattern can be traced over major physiographic units of the investigated area, *e.g.*, Tihama coastal plain covered with sedimentary materials deposited on horst and graben structures of Pre-

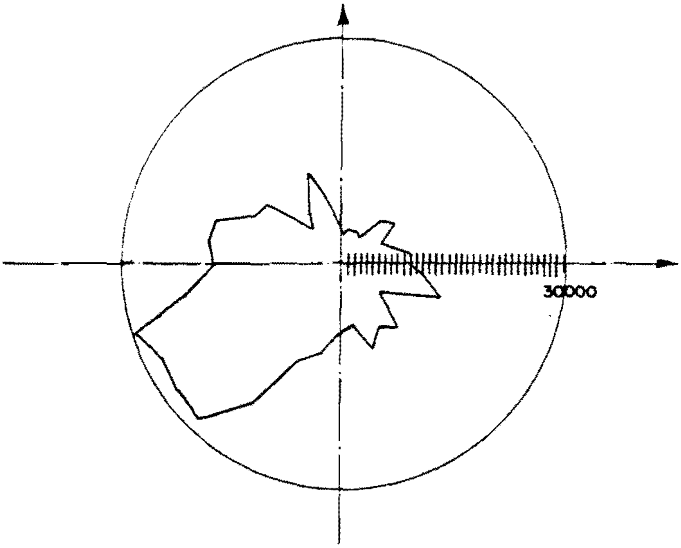

FIG. 7. Azimuthal frequency diagram for geological category # 1.

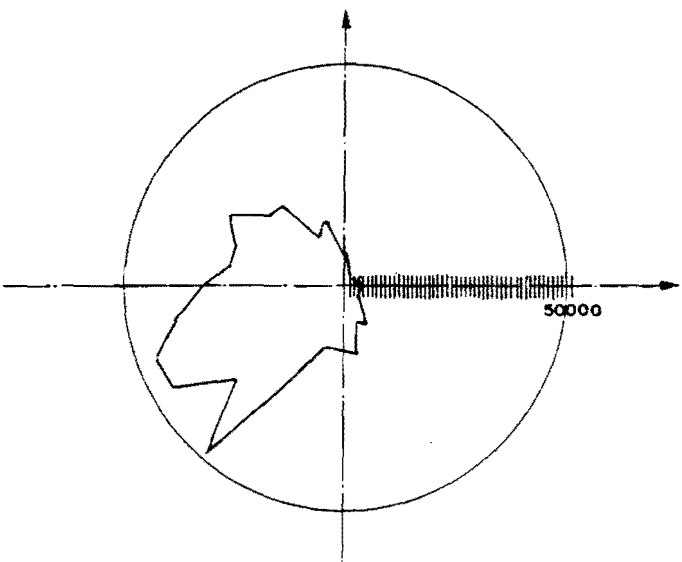

FIG. 8. Azimuthal frequency diagram for geological category # 2.

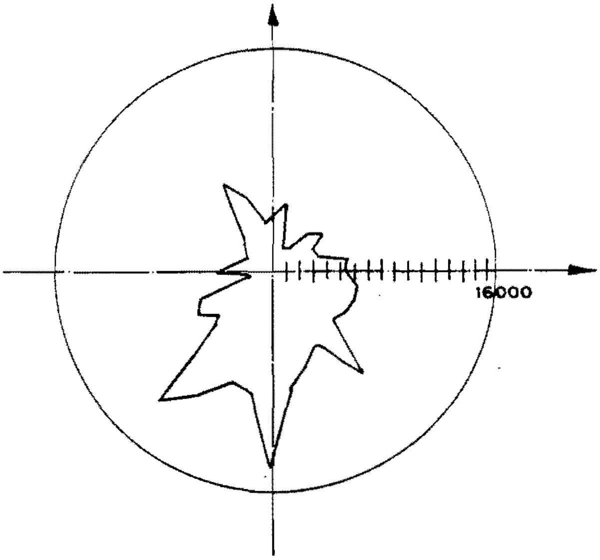

FIG. 9. Azimuthal frequency diagram for geological category # 3.

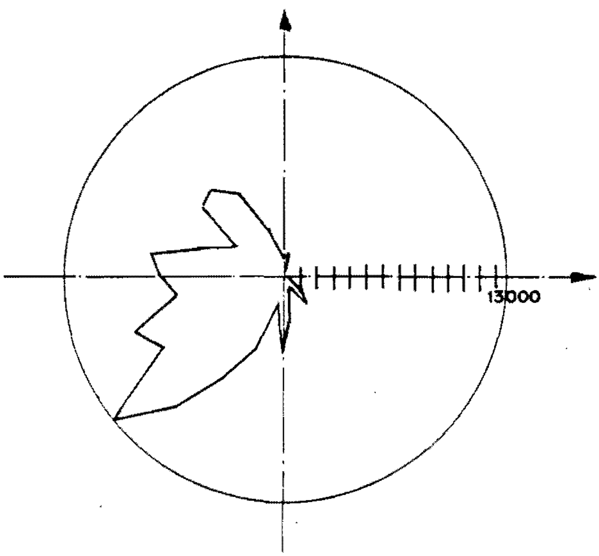

FIG. 10. Azimuthal frequency diagram for geological category # 4.

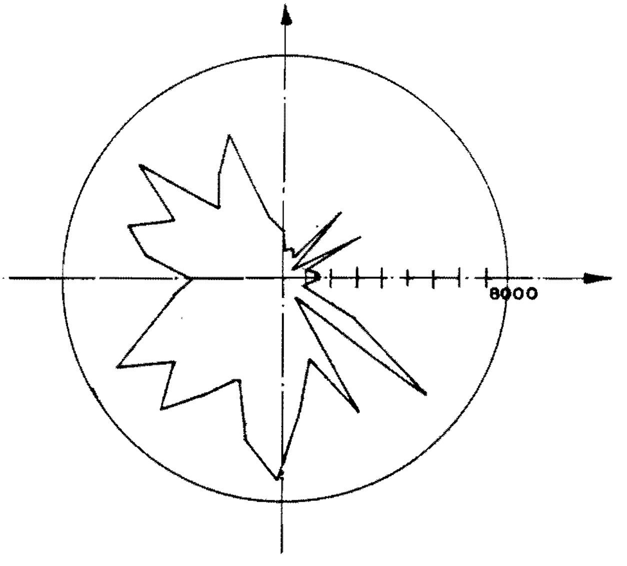

FIG. 11. Azimuthal frequency diagram for geological category # 5.

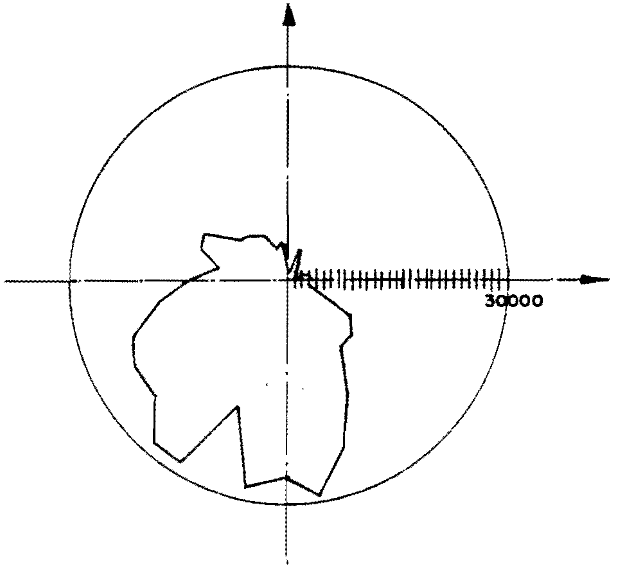

FIG. 12. Azimuthal frequency diagram for geological category # 6.

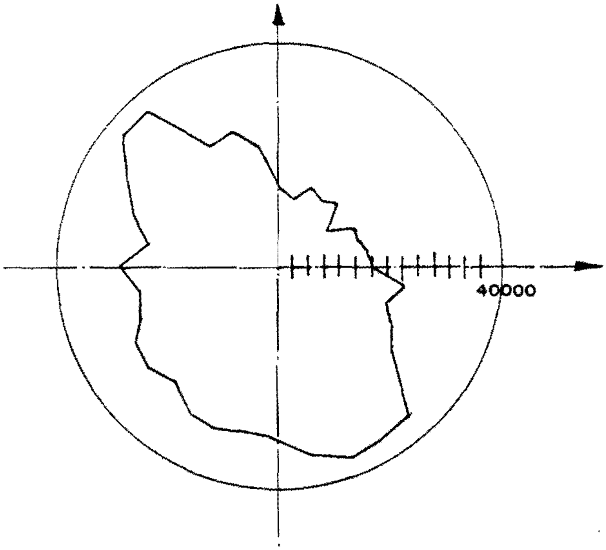

FIG. 13. Azimuthal frequency diagram for geological category # 7.

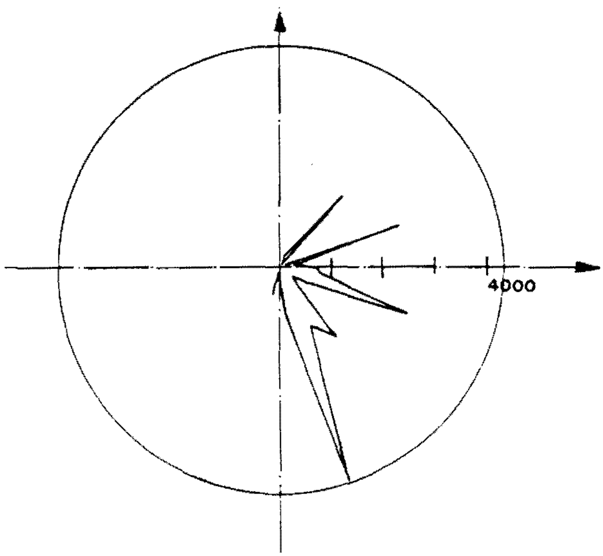

FIG. 14. Azimuthal frequency diagram for geological category # 8.

cambrian bedrock and faulted, jointed and fractured mountainous terrains located further to the east.

It may be concluded that the main controlling factors of the drainage pattern of the area are gravity or relief, lithology and directions of the fracture systems. Lithology is responsible for drainage density and structure influence drainage pattern type and its angularity.

Azimuth-length diagrams calculated for the whole Al Wajh-Umm Lajj area reflects very well the structural control of drainage lineations. Predominant northwestward and southeastward trending stream courses are strictly related to the aforementioned fault system. Cumulative length for both of these drainage lineations exceeds 380 km, approximately 200 km for northwestward trending streams and approximately 180 km for those of them trending southeastward (Fig. 15).

Westward and southwestward trending stream courses constitute other important orientations of the area's drainage lineations. Southwestward direction is especially remarkable on Tihama coastal plain where the cumulative length of all the stream courses trending in this direction is the highest from all 36 analyzed directions and exceeds 250 km. This fact confirms, what has already been mentioned, that the present physiographic character of Tihama coast plain is very strictly, morphogenetically related to fluvial and fluvio-denudative activity. As it may be observed on the azimuth-length diagram (Fig. 15), drainage lineations contained between north and east directions are by far less significant. None of the cumulative lengths calculated for these lineations exceeds 100 km.

All the aforementioned trends are clear in Fig. 5 which represents the predominant directions of stream courses calculated for each of 179 cells of the grid overlying the whole Al Wajh-Umm Lajj area with the special resolution of 10 × 10 km. Simple calculations carried out on these data reveal the following facts :

Northwestward and southeastward orientations are predominant and they characterize 37% of the grid cells;

Seaward trending drainage, *i.e.*, contained between West and South directions is characteristic for 31% of grid cells;

Only 5-6% of grid cells are characterized by northeastward orientation of predominant stream courses.

Another important landform identifier represented cartographically for every cell of the grid apart from the previously discussed predominant stream directions was drainage density (Fig. 6). Spatial distribution of this highly informative feature is correlated with lithological properties of the area and not with drainage orientation. In other words – the same drainage density may occur in the areas having different drainage orientation.

The highest drainage densities seem to characterize the regions covered with sedimentary rocks associated with terrace deposits of Tihama coastal plain and with differentially eroded metamorphic rocks of Jabal Hayran and Wadi Zurafi area.

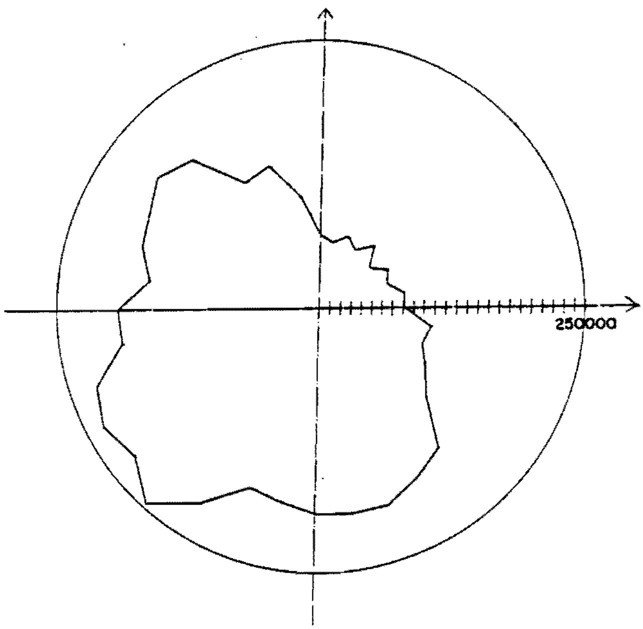

FIG. 15. Azimuth-length diagram for the whole area. The number 250,000 indicates the length (in meters) of the drainage locations within the predominant directional class.

TABLE 1. Frequency of drainage densities in the study area.

Drainage density	Number of grid cells
> 10 km/100 km^2	32
10 - 20 km/100 km^2	32
20 - 30 km/100 km^2	37
30 - 40 km/100 km^2	26
40 - 50 km/100 km^2	26
50 - 60 km/100 km^2	19
60 - 70 km/100 km^2	3
> 70 km/100 km^2	6

Table 1 shows numbers of grid cells with particular categories or drainage densities. As it may be seen 56.4% of grid cells has drainage density lower than 30 km/100 km^2 and only 5% of grid cells has drainage density higher than 60 km/100 km^2.

Further interpretation and statistical calculations were performed on the basis of this type of data :

The first was to reveal the orientation of drainage lineations characteristic for particular rock units, and the second was to confirm lithological conditioning of drainage densities (Fig. 8-14).

Azimuth-length diagrams (Fig. 7-14) calculated for each of the eight simplified geological rock units and drainage densities characterizing these categories reflect very clearly the aforementioned statement.

Alluvial clastic deposits (QT, Qu, etc.) are characterized in general by stream courses oriented seaward and therefore result from the wearing down the crystalline, metamorphic and sedimentary rocks of the area located further to the east of Tihama and for the formation of the coastal plain (Fig. 7). Cumulative length of these drainage lineations calculated for 4 predominant sea-ward directions exceeds 150 km (approx. 35 km for each of them). Similar results were obtained from terrace deposits (Qt) and sedimentary materials of the Reghama Formation (Tra). Maximal cumulative length of drainage lineations for these two geological categories was 50 km and 13 km respectively (Fig. 8 and 10).

Quite interesting is the azimuth-length diagram calculated for the metamorphic rocks (Fig. 13). It seems to reflect very well the structural control along NW and SE directions as well as the structural-denudational character of landforms differentially eroded by sea-ward oriented stream courses. It is also worthy to be noted that this rock unit has the highest value of drainage density (140 km).

As far as the highest drainage density/total area of the simplified rock unit is concerned, the following values were calculated for each of the eight distinguished rock units :

1 – 22502 m/100 km^2 (QT, Qes, Qsb, Qu, Qg)
2 – 42460 m/100 km^2 (Qt)
3 – 25423 m/100 km^2 (Qtb)
4 – 26706 m/100 km^2 (Tra)
5 – 38015 m/100 km^2 (rs)
6 – 27721 m/100 km^2 (gm, gr, gg, gp)
7 – 30576 m/100 km^2 (sc, am, dg, ub, h, sr)
8 – 46270 m/100 km^2 (Cs, Cq)

As to be expected, the highest value of drainage density is related to the highly fractured and jointed sandstones of *Siq* and *Quiweira* Formations (unit 8) as well as the erosion-prone terrace deposits (unit 2) and the easily-weathered sedimentary rocks (unit 5). Resistant basalt plateaux are characterized by low drainage density (unit 3).

It must be remembered that only sensu stricto stream courses were analyzed in the present study. This approach was justified in view of the available remotely-sensed data, reconnaissance character of the study, its scale, duration, and last but not least the physiography of the investigated area. However, it should also be remembered that probably more information could have been obtained if large wadis and extensive accumulation plains with well established directional orientation were also analyzed.

To sum up, Landsat TM data are excellent for fast, cost-effective reconnaissance mapping and analysis of drainage patterns.

References

Al-Sayari, S.S. and **Zotl, J.G.** (1978) *Quaternary Period in Saudi Arabia*, Vol. **1**, Springer-Verlag, Wien, pp. 1-18.

Alwash, M.A. (1992) Urban planning maps by use of aerial photographs and a SPOT/TM data merge, demonstrated with the city of At-Taif, Saudi Arabia, *Zeitshrift fur Photogrammetrie und Fernerkundug 5/92*, pp. 159-265.

Alwash, M.A. and **Bokhari, A.Y.** (1989) Multidisciplinary geoscientific investigations on the basis of remote sensing data and field work in the Madinah and Harrat at Rahat area, Saudi Arabia, *King Abdulaziz University Research Project 10/1409*, Jeddah, p. 142.

Alwash, M.A. and **Bokhari, A.Y.** (1990) Updating of Urban Planning by Use of SPOT/TM Data Merge, Demonstrated the City of Al Taif, Saudi Arabia, *Proc. 23rd. Int. Symp. Rem. Sens. Env.*, Bangkok, Thailand.

Alwash, M.A. and **Bokhari, A.Y.** (1993) Monitoring vegetation changes in Al-Madinah, Saudi Arabia, using thematic mapper data, *International Journal of Remote Sensing*, England, **14**(2): 1-7.

Alwash, M.A. and **Bokhari, A.Y.** (1994) Urban land-cover changes in Al Madinah Al Munawarrah using aerial photography and satellite sensor data. *The Asian-Pacific Remote Sensing Journal, Bangkok, Thailand (in press).*

Alwash, M.A. and **Yousif, M.S.M.** (1986) *Drainage and Drainage Lineation Analysis of Wadi Turabah, Central Arabian Shield, Kingdom of Saudi Arabia*, Verlag Von Dietrich Reimer in Berlin.

Alwash, M.A., Bodechtel, J. and **Zilger, J.** (1986) The application of high resolution MOMS-01 and thematic mapper satellite data for urban planning purposes: Example Jeddah, Saudi Arabia, *In: Proc. ISPRS Commission IV Symposium*, Edinburgh, Scotland, pp. 565-574.

Alwash, M.A., Zaidi, M.S. and **Terhalle, U.** (1986) Description of arid geomorphic features using landsat TM data and ground truth information (Wadi Fatima, Kingdom of Saudi Arabia). *CATENA. Vol.* **13,** No. 3, pp. 227-293.

Blodget, H.W., Brown, G.F. and **Moik, J.G.** (1975) Geological Mapping in Northwestern Saudi Arabia Using Landsat Multispectral Techniques, *National Aeronautical and Space Administration Technical Paper 1327*, 34 p.

Boeckel, J.H. (1973) ERTS-1 system performance overview, *third ERTS-1 Symposium, NASA Goddard Space Flight Center, Washington D.C.*, pp. 10-14.

Bokhari, A.Y. (1988) Hydrological investigation in the Western Al Madinah Quadrangle, Kingdom of Saudi Arabia on the basis of Landsat thematic mapper data, *Berliner geowiss. Abh. (C) and* **10,** pp. 113-35, 11 figs. 1 map, Berlin.

———— (1991) Hydrological investigation east of Al Madinah, Saudi Arabia, on the basis of Landsat Thematic Mapper Data, *Berliner geowiss. Abh. (C) band* **12,** pp. 79-105.

———— (1993) The drainage system around Al Madinah Al Munawwarah, Saudi Arabia as viewed from satellite data, *Journal of King Abdulaziz University (JKAU): Met., Env., Arid Land Agric. Sci.* **4:** 123-137.

———— (1994) Analysis of the Drainage Pattern in the Area Around At'Taif (Kingdom of Saudi Arabia) by the Use of Remote Sensing, *The Arabian Journal for Science and Engineering, King Fahd University of Petroleum and Mineral Resources (KFUPM)*, Dhahran, **19**(1): 59-70.

Brown, G.F., Jackson, R.O., Boque, R.G. and **Elberg, E.R. Jr.** (1963) *Geologic Map of the Northwestern Hijaz Quadrangle, Kingdom of Saudi Arabia*, US Geological Survey Miscellaneous Geologic Investigations Map, 1-204A, Scale 1:50000.

Choronicz, Jean *et al.* (1992) A combined algorithm for automated drainage network extraction, *Water Resources Res.* **28**(5): 1293-1302.

Deffontaines, Benoit, Chotin, Pierre, Ait-Brahim, Lashen (1992) Investigation of active faults in Morocco using morphologic methods and drainage pattern analysis, *Geologische-Rundshau*, **81:** 199-210.

Gary, M., McAfee, R. Jr., Wolf, C.L. (Ed.) (1972) *Glossary of Geology*, Amer. Geol. Institute, Washington D.C., p. 205.

Hadley, D.G. (1987) *Explanatory notes to the geologic map of the Sahl Al Matran Quadrangle*, sheet 26 C, Geoscience map GM-86C, Directorate General Mineral of Resources, Kingdom of Saudi Arabia.

Rango, A. and **Solmonson, V.** (1978) The Utility of Short Wave Length Remote Sensing Techniques for the Monitoring and Assessment of Hydrologic Parameters, *Proceedings of the 11th International Symposium on Remote Sensing of Environment*, ERIM, Ann. Arbor VI, Vol. **7,** pp. 55-66.

Styles, P. and **Hall, S.A.** (1980) A comparison of the Seafloor spreading histories of the Western Gulf of Aden and the Central Red Sea. In: *Geodynamic evolution of the Afro-Arabian rift system*, Rome, Italy, Accademia Nazionale dei Lincei, pp. 585-606.

Zakir, F.A., Chagarlamudi, P., Alwash, M.A. and **Divi, S.R.** (1986) *Third Progress Report on the Delineation of Tectonic Features Using Remote Sensing for Mineral Potential*, Report No. PR/3/ST691 Grant No. AR-6-91, KACST, Riyadh, Saudi Arabia.

تحـــديد وتحليـــل نمـــط الصـــرف المـــائي لمنطقـــة سهـــل المـطَران في شمـــال غرب المملكة العربية السعودية بوساطـة صـــور الأقمـار الصناعيـة

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المستخلص . يوضـــح هذا البحث أهمية دراســـات المياه الجـوفية في المملكـة العـربية السعـودية . وقـد استخدمت هذه الدراسة تجهيزات الاستشعار عن بعد لجمع البيانات وبحث نمط الصرف المـائي لمنطقة سهل المطران في المنطقة الشمالية الغربية من المملكة العربية السعودية ، بين مدينتي الوجه و أُملج .

وتضمنت هذه الدراسة الاستفادة من تقنية صور القمر الصناعي لاندسات ، بالإضافة إلى الصور الجوية في إعداد المعالجات الرقمية والليثوجرافيات ، موضحة حدوث نوعيات من نمط محدد للصرف المـائي في هذه المنطقة . وقد تم تحليل عمليات الصرف لبيان كفاية شبكة الصرف بالتعبير عن نوعية الصرف ، واتجاهه ، وكثافته ، وتكامله ، وتوحُّد شكله . وقد اتضح أن انحناءات مسارات الصرف مرتبطة بنظم الفوالق الرئيسة في هذه المنطقة .