Preparation of a Geologic Photo Map and Hydrologic Study of the Yemen Arab Republic

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The project report series presents information resulting from various kinds of scientific, technical, or administrative studies. Reports may be preliminary in scope, provide interim results in advance of publication, or may be final documents.

ILLUSTRATIONS

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1.0 SUMMARY

1.1 OBJECTIVES: The objectives of this experiment were to prepare a country-wide photogeologic map of the Yemen Arab Republic (YAR) at either 1:500,000 or 1:1,000,000 scale and a space photo map upon which it would be compiled, and to study Landsat imagery for possible sources of groundwater as indicated by geomorphic features and distribution of vegetation.

A longer-term objective was to study the regional fractures of the YAR in an attempt to solve some of the problems concerning Red Sea rifting--both past cycles and recent movements.

1.2 SCOPE OF WORK: Landsat image scales at 1:1,000,000, and 1:500,000 were studied visually, and geologic and hydrogeologic interpretations were drawn on overlays. Two field trips were made to the YAR to field check the accuracy of interpretations.

1.3 CONCLUSIONS: It is clear from this experiment that useful geologic and hydrologic interpretations can be made of at least some little known areas of the world that are difficult of access, at little cost, and in relatively short periods of time, using Landsat imagery.

Careful selection of imagery is required in order to carry out geologic studies, for sun angle, contrast, and cloud cover all affect interpretation of the imagery.

Repetitive seasonal coverage is necessary in studying hydrogeologic problems, and in the case of both geologic and hydrogeologic interpretation, appropriate field checks are required, especially to solve problems which become apparent during interpretation of imagery.

1.4 RECOMMENDATIONS: Inasmuch as visual interpretation of Landsat imagery has been deomonstrated to provide highly useful information, earth scientists in developing countries should be encouraged to make the maximum possible use of the technique. A minimum of equipment is required, thus expenditures for acquisition and maintenance are small. Furthermore, skilled earth scientists can apply the techniques in the field or in the laboratory, as seems best.

2.0 INTRODUCTION

Reliable geological information is a basic requirement for most development projects as well as for systematic geological and hydrogeological development programs. It is especially critical for ground water assessment and soils studies in support of agricultural activities, and for mineral exploration.

The YAR is basically an agricultural country with a limited minerals industry. Until recently the YAR was an exporter of agricultural products, but the only mineral commodity produced for export was common salt. New geologic information is important to the country's effort to build a broader mineral resource base.

Additional supplies of ground water are needed before the country can regain agricultural self-sufficiency, and more potable water is needed for a growing population. Not only must the water be found, but it must be properly utilized. This can be done only through a well-planned water-development program based on sound geological information.

The geology of the YAR is known only poorly. No systematic geologic work using modern techniques has been done in the country, and its mineral potential--which appears to be quite promising--remains to be tested. Until completion of the experiment described here, the most recent published geologic map covering the YAR was the southwestern part of the Geologic Map of the Arabian Peninsula, which was published by the U. S. Geological Survey in 1963 at the scale of 1:2 million. The southwest portion of the map was compiled from various sources, but principally from a 1:1 million-scale map by F. Geukens, which resulted from reconnaissance trips during the mid-1950's. Subsequently, a preliminary tectonic map of the Peninsula was prepared by G. F. Brown (1972) using field and other data obtained in the ensuing years, supplemented by the study of Gemini and Apollo space photographs. The space photo study indicated structural (and other) weaknesses in the geologic maps, strongly suggesting that systematic multispectral space imagery, properly utilized, could contribute significantly to a general upgrading of the geology.

This report describes the achievements of Project No. 21990, ID #199, an experiment in applications of Landsat data in the Yemen Arab Republic. The project was established by a Memorandum of Understanding between the National Aeronautics and Space Administration (NASA), Goddard Space Flight Center, and the U. S. Department of Interior, U. S. Geological Survey (USGS), dated June 28, 1975. According to the Memorandum, NASA was to provide a limited amount of repetitive imagery on a seasonal basis, and the USGS was to provide all other services. Both parties to the Memorandum have fulfilled their obligations to the project, the USGS achieving this by carrying on its activity as a part of a Participating Agency Service Agreement with the Agency for International Development, U. S. Department of State (USAID), which provides for a water and mineral survey of the Yemen Arab Republic.

Although D. F. Davidson of the USGS is listed as Principal Investigator for this project and prepared this report, all scientific work in the United States, and in the YAR was carried out by M. J. Grolier, W. C. Overstreet, and G. C. Tibbitts of the USGS and M. M. Ibrahim of the Mineral and Petroleum Authority, YAR, as is clearly shown by the listing of geological and hydrogeological maps and reports which is a part of this report.

3.0 ACKNOWLEDGMENTS

The scientists who carried out this project are pleased to acknowledge the courtesies and interest of His Excellency, Dr. Abdul Karim El-Eryani, Chairman, Central Planning Organization, YAR; and Aldelmo Ruiz, Director, USAID Mission to the YAR. Without their aid, this work could not have been done.

The U. S. Geological Survey scientists also wish to acknowledge special help received from our associate, Mohammad Mukred Ibrahim, Assistant Chief Minerals Geologist, Mineral and Petroleum Authority, who cleared all trips through local authorities; obtained access to private property from the owners of water wells; and obtained permission to sample well water, measure depths to the water table, and to collect other hydrological data.

James W. Aubel, U. S. Peace Corps Volunteer and geologist working with G. C. Tibbitts on the USAID water supply project in the YAR, guided the writers to many wells and helped in the collection of hydrological and related geological data.

Discussions in Sana'a with geologists, hydrologists, and other specialists on the staff of several foreign technical missions that are engaged in water development or hydrologic and geologic investigations in the YAR were enlightening. Amongst others, Grolier and Overstreet met with James Kahn, Tihama Development Authority; Dr. Joachim Thiele, Party Chief, Mission to YAR of the Bundesanstalt für Geowissenschaften und Rohstoffe, Federal Republic of Germany, Hanover, Germany, and Dr. Karl-Heinz Schultze; Micheal Glase, Hydrologist, Tipton and Kalmbach, Inc., Denver, Colorado, USA; Mikio Kurosaki, Hydrologist-in-charge for YAR, Tone Borning, Co., Ltd., Tokyo, Japan; John Chilton, Hydrologist, Land Resources Division, British Ministry of Overseas Development; Rudolf Schock, Department of Geography, University of Zurich; and Peter S. Walczak, Resident Oceanographer at Al Hydaydah, U. N. Food and Agricultural Organization.

4.0 OBJECTIVES

The objectives of the project were:

4.1 To prepare an improved, country-wide, photogeologic map of the YAR at a scale of 1:500,000 or 1:000,000 and a space photo map upon which it is to be compiled.

4.2 To study available Landsat imagery for possible sources of groundwater as indicated by geomorphic features, and distribution of vegetation.

4.3 To study, over a longer period of time, the regional fractures of the YAR in an attempt to solve some of the problems concerning Read Sea rifting--both past cycles and recent movements.

5.0 METHODS AND APPROACH

The work procedure followed during both the geologic and hydrologic analysis of the program consisted of selection of imagery, bibliographic search, image interpretation supported by interpretation of available topographic maps, and reconnaissance field checking.

Because of lack of time, the third objective of the experiment, the study of regional fractures of the YAR and their relation, if any, to Red Sea rifting, has not been achieved. It is anticipated that such studies will be carried out in the future, but probably by other investigators.

5.1 SELECTION AND PROCUREMENT OF LANDSAT DATA

The investigation was carried out in two separate albeit related steps: geologic analysis, and the hydrologic study. The scope of the investigation controlled the selection of the types of Landsat data that were procured. In the planning stage of the investigation, it was decided that there was no need to use computer-compatible tapes to enhance Landsat data, until specific geologic and hydrologic problems had been defined, and mineral prospects located. This decision seriously limited the search for reflectance anomalies due to oxidized sulfide ore deposits, either exposed or lying at shallow depth, but it had no adverse effect on the hydrologic reconnaissance of the country. Thus both geologic and hydrologic analyses were done by using prints and transparencies of Landsat images available from the USGS EROS Data Center, Sioux Falls, South Dakota.

Geologic analysis calls for radically different criteria in the selection of Landsat images than does hydrologic analysis. Winter coverage was selected for geologic analysis because the low angle of elevation of the sun at that season lengthens shadows of terrain elements enhancing topographic detail. Consequently, nine Landsat-1 images (Figure 1)(corresponding to the nine Landsat scenes) covering the YAR were selected for geologic analysis out of a total of 125 images available, because of the time of imaging. The imagery was acquired in the period November 18, 1972, to

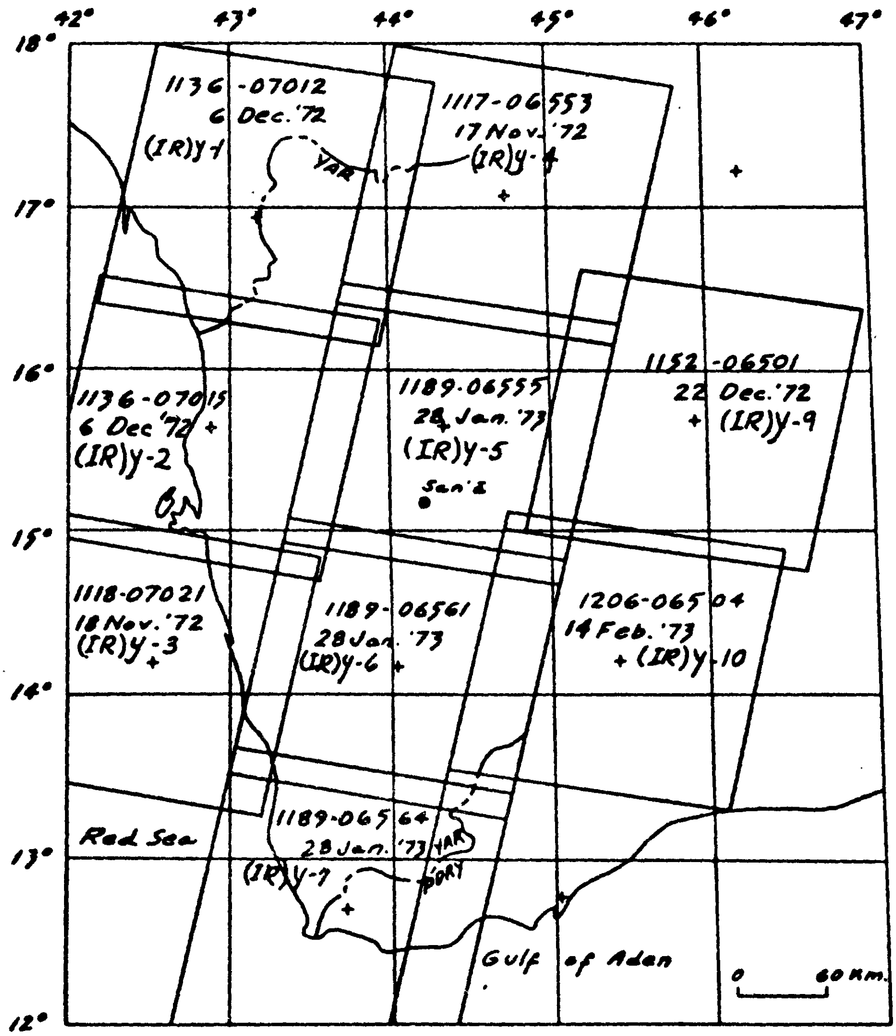

Figure 1.--Index map of the Yemen Arab Republic, showing the outlines of Landsat nominal scenes covering the YAR, and the identification number of the nine Landsat-1 images used as bases for geologic maps (Grolier and Overstreet, 1976, 1:500,000 scale). Dates indicate the date each Landsat image was acquired; the open-file report number is shown under the date.

February 14, 1973, and images were selected on the basis of freedom from clouds, and image quality. Geologic mapping was done on transparent overlays placed over false color infrared (IR) Cibachrome composite prints of bands 4, 5, and 7 at the scale of 1:500,000, and while the nine Landsat-1 images were being mapped geologically, they were assembled into a mosaic, which was to provide a planimetric base on which to plot geographic, geologic, and hydrological data. The mosaic is being processed for release as a publication.

In contrast to the relatively permanent character of landforms and rocks, and the slow rate of change brought about by most erosional and depositional processes, other processes, which control surface and groundwater conditions, and the growth of vegetation, are subject to seasonal changes, and longer-term climatic cycles, periods, or vagaries. The repetitive character of the Landsat system makes Landsat images taken at relatively short successive intervals of time ideally suited for analysis of the yearly and seasonal fluctuations in the hydraulic regimen of streams, and for monitoring the periodic growth and dormancy of vegetation. In addition, hydrologic observations must be timed, if they are to be meaningful, to some elements of the hydrological cycle that are suitable for short-term as well as long-term comparison. In this context, the Landsat images chosen for hydrologic analysis were timed to coincide as closely as possible with the two extremes of the yearly climatic cycle in the YAR:

(1) The end of the main rainy season in the late summer or early fall, and

(2) The end of the dry season in the spring.

The decision was made in the hope that those periods of the year would correspond to the periods of bankfull or flood stage, and flash floods on one hand, and low flow--if not base flow--on the other hand.

5.2 BIBLIOGRAPHIC SEARCH

The geologic and hydrologic literature covering the territory of the YAR is scattered in the scientific periodicals of several countries (mostly France, Germany, and the United States). An off-line computerized bibliographic citation list produced by Systems Development Corp., Santa Monica, California, was most useful at the state of the investigation in identifying reports published during the last 10 years.

5.3 IMAGE INTERPRETATION - GEOLOGIC ANALYSIS

Geologic mapping on infrared false-color infra-red Cibachrome prints of each of the nine Landsat-1 images enlarged to the scale of 1:500,000 was compared for accuracy against black and white positive transparencies at the scale of 1:1,000,000 of band 7, the band where terrain contrast between mafic and felsic rocks is greatest. Black and white positive transparencies of band 4 (at the same scale) in which solar radiation in the blue-green portion of the spectrum penetrates clear water down to several fathoms, were utilized to check the extent of coral reefs observed along the Red Sea coast. Even though albedo and color are ambiguous parameters for distinguishing geologic materials, 9 preliminary geologic maps of the YAR at 1:500,000 scale were produced in a period of 6 months (Grolier and Overstreet, 1976 a-i) that show far more geologic data than has been possible heretofore. This result was possible because of:

(1) The relatively small scale of the geologic map (1:500,000) which limited the amount of geologic detail shown;

(2) The marked contrast between some of the more widespread rock units in the country (i.e., limestone in contrast to volcanic rocks; young and unweathered volcanic rocks in contrast to older and/or weathered rocks, and alluvium and eolian sand);

(3) Relative lack of vegetation and lack of thick chemically weathered soils; and

(4) The unusually high regional relief (more than 3,000 m) which, in some places, allowed three-dimensional structural analysis on a monoscopic image. The high quality and photographic fidelity of the Cibachrome color prints made of each image were a great help in the geologic analysis.

The result of the geologic analysis has been the preparation and release of the nine 1:500,000-scale geologic maps mentioned above. The maps will serve as a basis for continuing study of the geology and potential mineral resources of the YAR.

5.4 IMAGE INTERPRETATION - HYDROGEOLOGIC ANALYSIS

The first step in the hydrologic investigation was to delineate the divides between small and major drainage basins. This was accomplished by geomorphologic interpretation of the terrain shown on the false-color mosaic, and by checking the accuracy of the interpretation against topographic maps at 1:250,000 scale (United Kingdom,

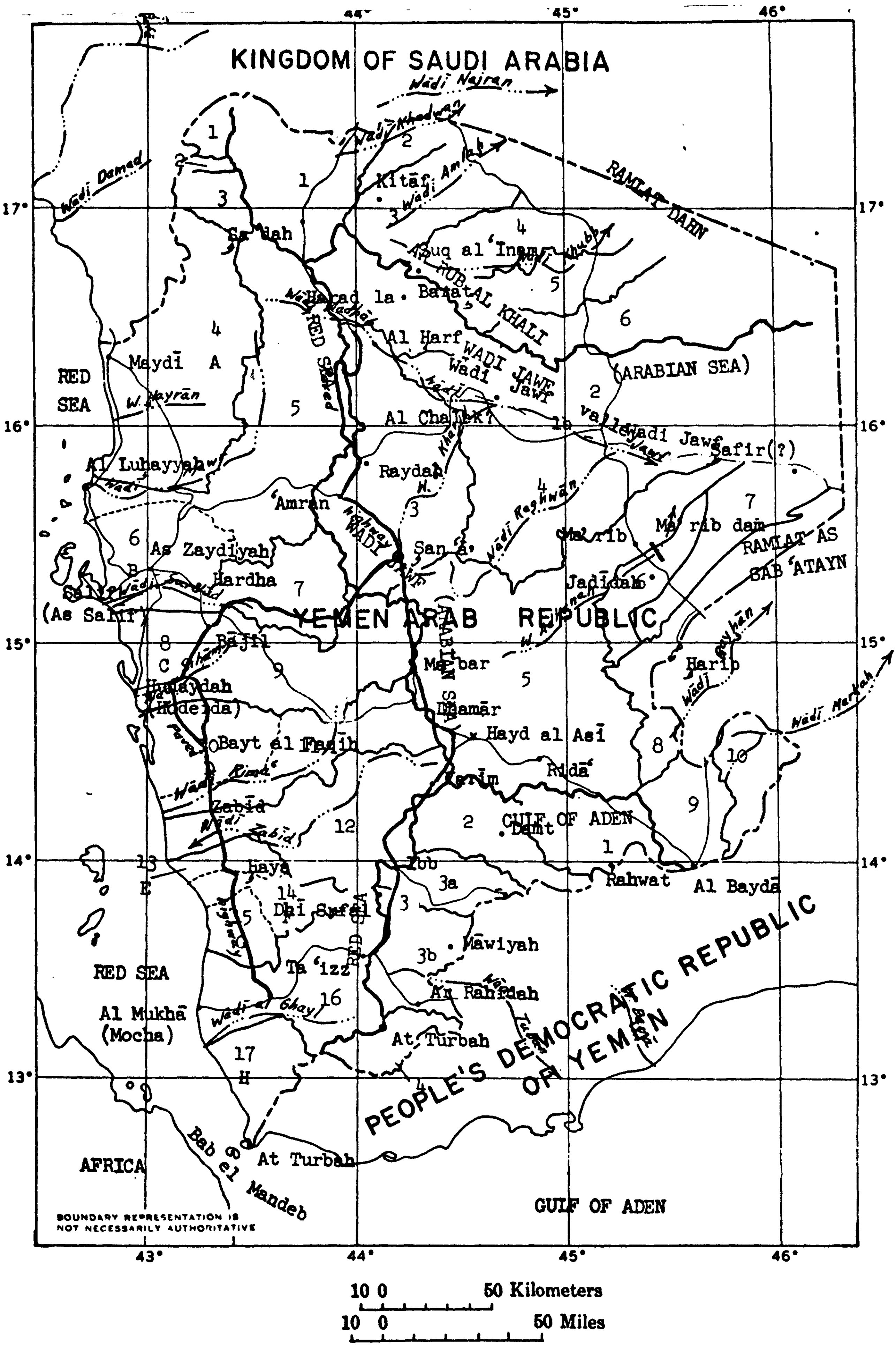

Figure 2 --Small-scale hydrologic map of the Yemen Arab Republic, showing four catchment areas and the major drainage basins within them.

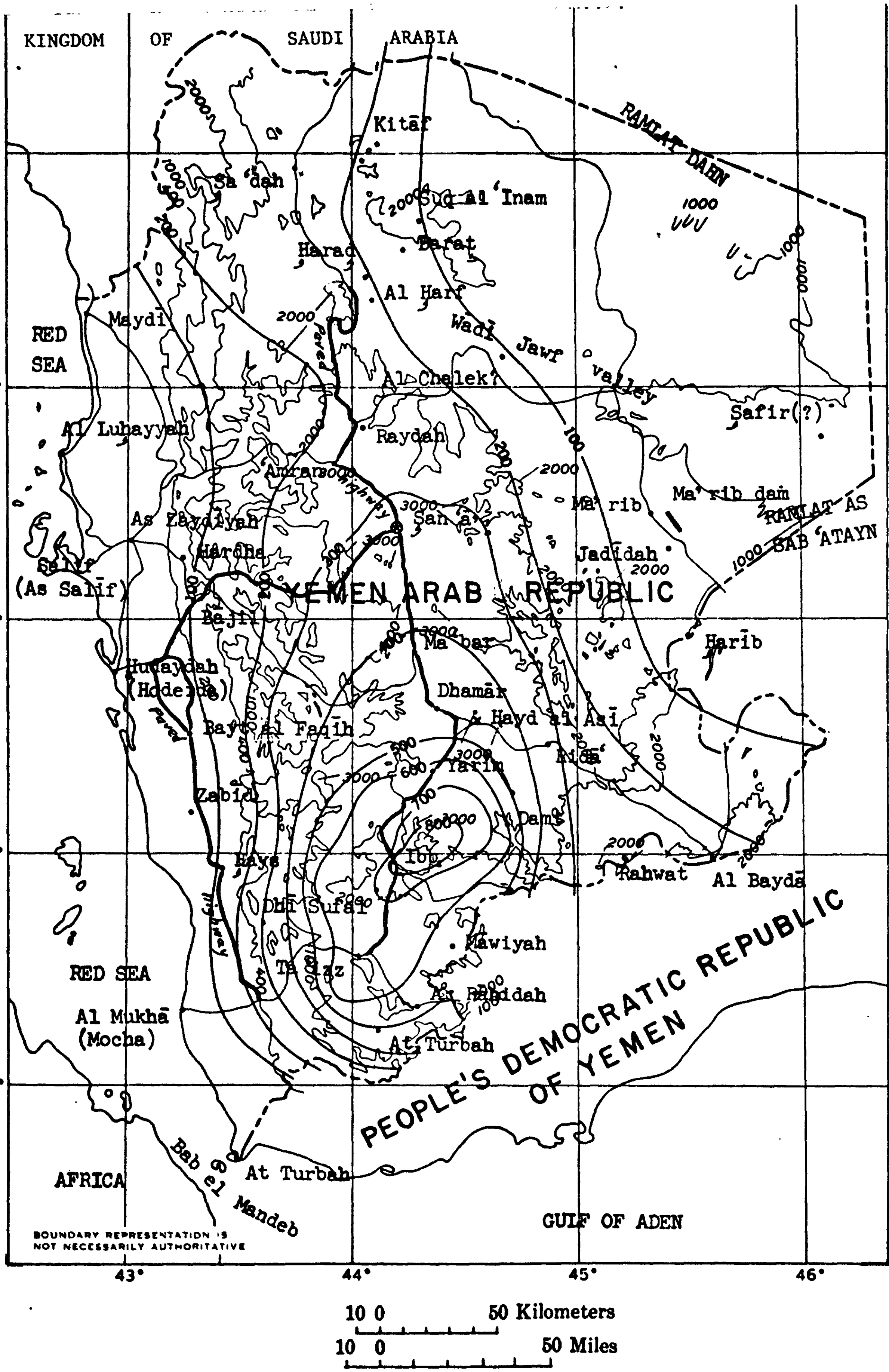

Figure 3 --Small-scale rainfall map of the Yemen Arab Republic, superposed on generalized topography. Topographic contour interval: 1,000 m. Note how altitude and distance from the coast control the areal distribution pattern of rainfall.

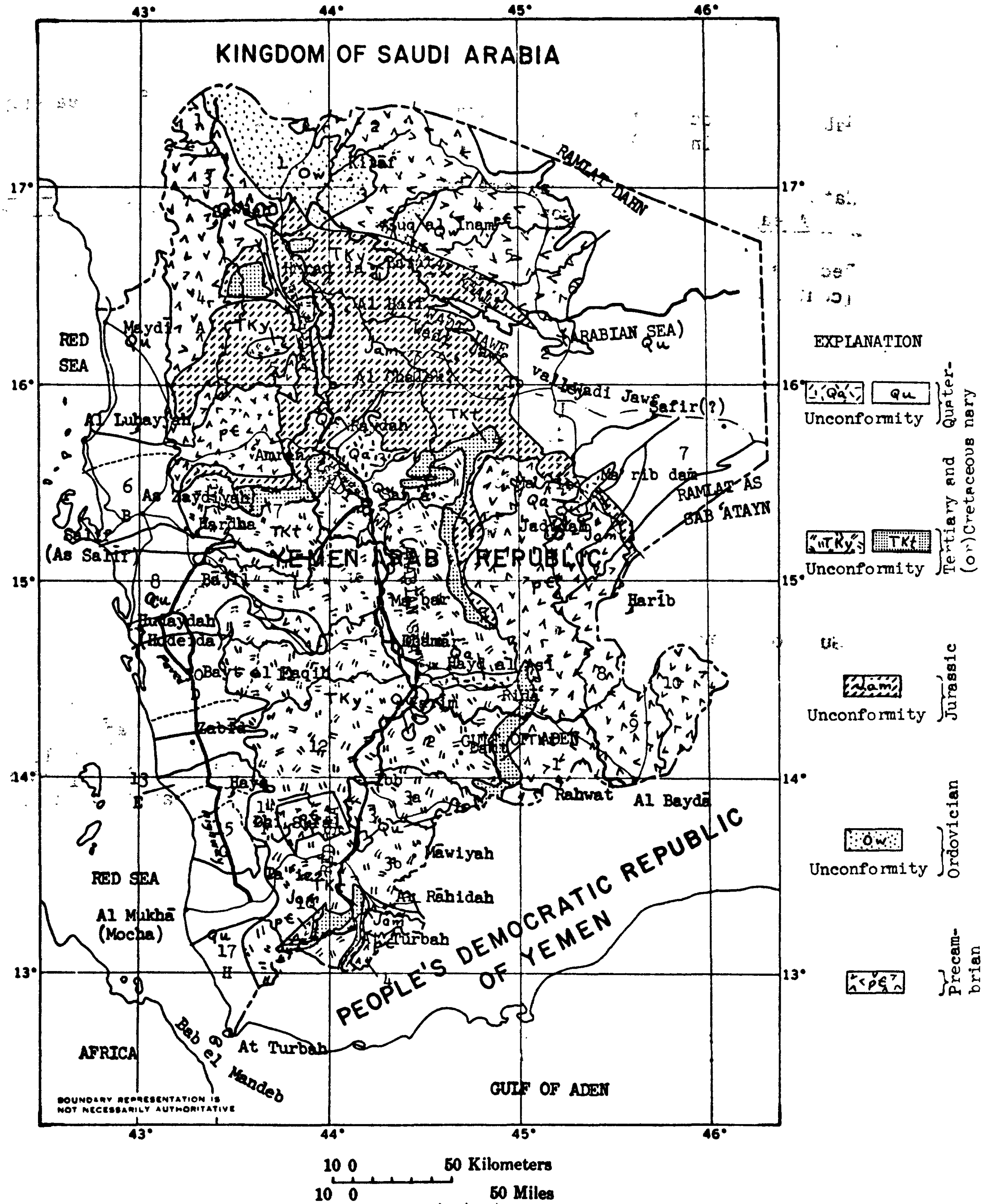

Figure 4.--Generalized geologic map of the Yemen Arab Republic.

Table 1. Catchment areas and drainage basins (in order of increasing rainfall) in Yemen Arab Republic (continued)

Catchment Area	Drainage basins (from North to South)	Remarks
Red Sea (continued)	5. Wādī Mawr	
	6. Coastal stream	
	7. Wādī Surdūd	
	8. Coastal stream	
	9. Wādī Sihām	
	10. Coastal stream	
	11. Wādī Rima'	
	12. Wādī Zabīd	
	13. Coastal stream	
	14. Coastal stream	
	15. Coastal stream	
	16. Wādī al Ghayl-Wādī Rasyān	
	17. Coastal stream	
Gulf of Aden	1. Wādī Hamrā-Wādī Ḥārib and Saylāt Sīh	
	2. Wādī Banā	
	3. Wādī Tubān	)The lower parts of
	a) Upper	)these basins are
	b) West-bank tributary	)located in the People's)Democratic Republic of
	4. Gulf of Aden coastal streams basins	)Yemen

Table 1. Catchment areas and drainage basins (in order of increasing rainfall) in Yemen Arab Republic

Catchment Area	Drainage basins (from North to South)	Remarks
Ar Rub' Al Khali	1. Wādī Najran	The lower part of this basin is located in Saudi Arabia.
	2. Wādī Khadwan	
	3. Wādī Imara?- Wādī Amlah	
	4. Wādī Qu 'ayf- Wādī Silba	
	5. Wādī Khabb	
	6. Wādī Amwah-Wādī Khalīfayn	
Wādī Jawf (Arabian Sea)	1a. Wādī Madhāb	
	1b. Wādī Jawf valley	
	2. North-bank tributary basins of Wādī Jawf	
	South-bank tributary basins of Wādī Jawf	
	3. Wādī Khārid	
	4. Wādī al Furdah- Wādī al Jufrah- Wādī Raghwān	
	5. Wādī Adhanah	
	6. Wadi al Khania (Mangai)	
	7. Small unnamed wadi basins	
	8. Wadi Ḥarib	The lower part of this basin is located in the People's Democratic Republic of Yemen
	9. Wādī Bayḥān	The upper and lower parts of these two basins are located in the People's Democratic Republic of Yemen
	10. Wadi Markhah	
Red Sea	1. Wādī ad Dafā- Wādī Hanaba	The lower part of these three basins is located in Saudi Arabia
	2. Wādī Damad	
	3. Wādī Jīzan(Qizan)- Wadi Ma' bār	
	4. Coastal stream	

Ministry of Defence, Mapping and Charting Establishment, 1974). Where regional relief is low and did not allow visual identification of divides on the mosaic, boundary lines were transferred from the topographic maps to the mosaic. A reduced version of the resulting hydrologic map of the YAR (figure 2), outlines four catchment areas and the major drainage basins.

The second step was to transfer the 400-m, 1-km, 2-km, and 3-km contours from the topographic sheets to an overlay of the 1:500,000-scale mosaic. The rainfall map of the YAR (a reduced version of the map is figure 3 of this report) was superimposed on this overlay. A second overlay showing the geology of the country (a reduced and generalized version is figure 4 of this report) was also prepared, and the superposition of the two overlays on the drainage basin map made possible the description of the relationships among altitude of watershed, precipitation, rock types, and shape, size, and location of drainage basins.

The next step was to identify, locate, and describe those drainage channels where surface water could be observed. Lastly, areas supporting vegetation also were identified as a basis for inferring other hydrological conditions. Only two of the four bands available for each scene were used in this analysis: Band 7 was utilized because there is little or no reflection of incident solar radiation from water in this spectral region, and thus the water appears dark in a positive black and white print or transparency. Band 5 was used because, within the red region of the spectrum, chlorophyll and carotene absorption of incident solar radiation reduces the magnitude of reflectance, and vegetation appears dark gray on a positive black and white print. Band 6, which is useful to identify wet and saturated soil (Deutsch and others, 1973) was not used, because the two principal objectives of the analysis are identification of streamflow and vegetation.

Vegetation and water are directly mappable on black and white transparencies or prints of bands 5 and 7. Nevertheless, two-band false-color composites were prepared for each scene, using Diazo color foils in order to enhance contrast by addition of color. By superposing the two bands upon each other, using foils suitable for additive color techniques, water and vegetation appear on the false-color composite in the dark hue of the colored band in which their reflectance is least. This part of the analysis was accomplished at a scale of 1:1,000,000, to conform to available laboratory equipment.

The vegetated areas of the YAR are important to a report otherwise devoted to water resources because during their growing season plants are excellent indicators of the presence of water. Where possible, natural vegetation and agricultural crops were distinguished, but lumped together where the size of cultivated fields is below the resolution of the Landsat imaging system, and the geometric pattern characteristic of cultivation could not be detected. Even where a definite pattern of cultivation does not emerge from the analysis of a Landsat image, some inferences can still be drawn from the environment in which plants grow. "Light forest" in the mountains can be generally inferred from the characteristically diffuse color value superposed on an otherwise drab, rugged terrain. Yet, there is no way at the scale of this visual analysis to state the percentage of terraced irrigated fields planted with gat (Cathay edulis), or with sorghum, which is included with trees and succulents growing wild in the "light forest." Similarly, vigorous seasonal plant growth in alluviated valley floors appears differently depending on site location, which in turn may reflect one of the many cultural, ecological, or economic patterns of human activities. In the valleys or wadis near the divides between catchment areas (where precipitation is relatively high because of altitude, and human density is also high), spectral evidence of vigorous seasonal plant growth implies agricultural crops. At lower altitudes in the Yemen highlands, particularly in the basins of wadis draining Precambrian crystalline rocks, where aridity is greater than in the mountains, and human density may be low, seasonal plant growth, particularly spot vegetation at times of low flow, may imply that phreatophytes are growing in alluvium, drawing water from a shallow zone of saturation.

The hydrogeologic analysis described here has led to the preparation of a report (Grolier, Tibbitts, and Ibrahim, unpub., data) which identifies specific areas that should be investigated because of their potential as sources of ground water in the YAR.

6.0 RECONNAISSANCE FIELD CHECKING

Two field trips were made in connection with this program. The first trip, which included reconnaissance from the air and on the ground, was made between June 16-July 13, 1975. During this trip it was possible to check the accuracy of the preliminary geologic maps (Grolier and Overstreet, 1976), and to appraise several known mineral prospects. A low-altitude reconnaissance of the country by plane was made during the first week in the field; it helped relate erosional, textural, and tonal patterns to specific rock types, clarify stratigraphic relationships, and prepare for the ground reconnaissance. Laterite, which occurs in the Asir region of Saudi Arabia, was sighted for the first time in the extreme northern part of YAR from the plane. Darkening of limestone along contacts with lamprophyric dikes, which had been observed on Landsat-1 images, was confirmed from the plane and later verified on the ground. Field checking on the ground was limited to a reconnaissance along the major road network of YAR: Sana'a-Taizz-Mocha, Al Hydaydah, Sana'a; to a round trip Sana'a-Sadah-Sana'a; and to a few side trips around Sana'a, Taizz, and Sadah because of difficulties or access to other areas.

The second trip, February 1-29, 1976, afforded an opportunity to collect rock and water samples in regions not visited during the first reconnaissance. It allowed close observation of several late Tertiary piercement domes on the Tihama near Al Luhayyah, sampling of several water wells, and of Precambrian rocks exposed in the southeastern part of the YAR, along the road between Ridah and Al Baydah. Rock and water samples collected during the second trip have not been analyzed as of this writing.

7.0 EQUIPMENT UTILIZED

Because the philosophy behind this experiment was to make the maximum use of Landsat imagery at least possible cost, only the simplest of equipment was used.

The geologic analysis of enlarged Landsat images on Cibachrome prints required large light tables installed in a darkroom. One of the advantages of a Cibachrome photographic print is that it is translucent in strong light in a dark environment. Desktop stereoscopes were used frequently to take advantage, wherever feasible, of the side-lap existing between scenes imaged on adjacent orbital paths. Ozalid reproduction equipment and a laboratory where false-color transparencies using Diazo foils were made were also used. Diazo false-color transparencies were prepared in the early stages of the investigations, and were referred to frequently during geologic analysis.

8.0 CONCLUSION

All participants in the Yemen experiment have concluded that useful geologic and hydrogeologic interpretations of Landsat data can be made in countries such as the Yemen Arab Republic. Factors which led to the success of the project include the following: the YAR is largely arid and geologic features are well exposed; access to many areas of the YAR is very difficult because of the physical nature of the country; opportunity, though limited, was provided for field checking in problem areas; and some repetitive imagery was made available for the experiments. The last factor of course, was of vital importance to the hydrogeologic study.

A further conclusion is that useful studies can be made with only the simplest kinds of equipment. Thus, properly trained scientists in countries similar to the YAR should be able to carry out studies of importance to their countries without making heavy investments in complex equipment.

9.0 RECOMMENDATIONS

Because this experiment has demonstrated conclusively that visual interpretation of Landsat imagery can provide information highly useful in geologic and hydrogeologic studies, the National Aeronautics and Space Administration and user agencies should encourage earth scientists in developing countries to make the maximum possible use of the technique. A minimum of equipment is required, thus expenditures for acquisition and maintenance are small. Furthermore, the techniques can be applied in base or field offices as seems best.

10.0 LIST OF REPORTS RESULTING FROM THE EXPERIMENT

Grolier, M. J., and Overstreet, W. C., 1976 a, Preliminary geologic map of the northwestern region, Yemen Arab Republic, Landsat-1 image no. 1136-07012: U. S. Geol. Survey Open-file rept. 76-737 ((IR)Y-1), scale 1:500,000.

Grolier, M. J., and Overstreet, W. C., 1976 b, Preliminary geologic map of Tihama and the Red Sea escarpment, north of Bajil, Yemen Arab Republic, Landsat-1 image no. 1136-07015: U. S. Geol. Survey Open-file rept. 76-738 ((IR)Y-2), scale 1:500,000.

Grolier, M. J., and Overstreet, W. C., 1976 c, Preliminary geologic map of Tihama between Zabib and Hydaydah, Yemen Arab Republic, Landsat-1 image no. 1118-07021: U. S. Geol. Survey Open-file rept. 76-739 ((IR)Y-3), scale 1:500,000.

Grolier, M. J., and Overstreet, W. C., 1976 d, Preliminary geologic map of region east of Sa'dah, Yemen Arab Republic, Landsat-1 image no. 1117-06553: U. S. Geol. Survey Open-file rept. 76-740((IR)Y-4), scale 1:500,000.

Grolier, J. J., and Overstreet, W. C., 1976 e, Preliminary geologic map of North Yemen, region north of San'a, Yemen Arab Republic, Landsat-1 image no. 1189-06555; U. S. Geol. Survey Open-file rept. 76-741 ((IR)Y-5), scale 1:500,000.

Grolier, M. J., and Overstreet, W. C., 1976 f, Preliminary geologic map of the San'a, Qa'tabah, Ibb, Zabib, and Bajil area, Yemen Arab Republic, Landsat-1 image nol 1189-06561: U. S. Geol. Survey Open-file rept. 76-742 ((IR)Y-6), scale 1:500,000.

Grolier, M. J., and Overstreet, W. C., 1976 g, Preliminary geologic map of the Ta'iz region, Yemen Arab Republic, Landsat-1 image no. 1189-06564: U. S. Geol. Survey Open-file rept. 76-743 ((IR)Y-7), scale 1:500,000.

Grolier, M. J., and Overstreet, W. C., 1976 h, Preliminary geologic map of the northeastern region, Yemen Arab Republic, Landsat-1 image no. 1152-06501: U. S. Geol. Survey Open-file rept. 76-744 ((IR)Y-9), scale 1:500,000.

Grolier, M. J., and Overstreet, W. C., 1976 i, Preliminary geologic map of the southeastern region, Yemen Arab Republic, Landsat-1 image no. 1206-06504: U. S. Geol. Survey Open-file rept. 76-745 ((IR)Y-10), scale 1:500,000.

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United Kingdom Ministry of Defense; 1974, The Yemen Arab Republic and neighboring areas 1:250,000: United Kingdom Ministry of Defense, map prepared for the Yemen Arab Republic.