

ARO 18405-12-G-5

2

AD-A161 453

TITLE

Desert Studies - A Global View

TYPE OF REPORT (TECHNICAL, FINAL, ETC.)

Final

AUTHOR (S)

John F. McCauley, Carol S. Breed, and Maurice J. Grolier

DATE

August 23, 1985

U. S. ARMY RESEARCH OFFICE

P.O. Box 12211
Research Triangle Park, NC 27709

CONTRACT / GRANT NUMBER

DRXRO-GS-18405

INSTITUTION

U.S. Geological Survey
2255 No. Gemini Drive
Flagstaff, AZ 86001

DTIC FILE COPY

NOV 21 1985

APPROVED FOR PUBLIC RELEASE;
DISTRIBUTION UNLIMITED.

11 18-85 219

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM	
1. REPORT NUMBER ARO 18405-12-65	2. GOVT ACCESSION NO. AD-A161453	3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle) Desert Studies - A Global View		5. TYPE OF REPORT & PERIOD COVERED Final; April 5, 1982 June 30, 1985	
7. AUTHOR(s) John F. McCauley, Carol S. Breed, and Maurice J. Grolier		6. PERFORMING ORG. REPORT NUMBER	
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Geological Survey 2255 No. Gemini Dr. Flagstaff, AZ 86001		8. CONTRACT OR GRANT NUMBER(s) ARO MIPR 155-84	
11. CONTROLLING OFFICE NAME AND ADDRESS U. S. Army Research Office Post Office Box 12211 Research Triangle Park, NC 27709		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS	
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		12. REPORT DATE August 23, 1985	
		13. NUMBER OF PAGES 20	
		15. SECURITY CLASS. (of this report) Unclassified	
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE	
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.			
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report) NA			
18. SUPPLEMENTARY NOTES The view, opinions, and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.			
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) hyperarid Badan-Jarain Desert Taklimakan Desert deserts Sudan (northwest) radar map units Peru Eastern Sahara sand sheets northwest China imaging radar sand dunes Egypt (southwest) caliche shallow groundwater authigenic CaCO₃ radar backscatter Western Desert			
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Results of work on summary reports of the surficial geology and geomorphology of Coastal Peru, Western Desert of Egypt/Sudan, and deserts of China (including the Taklimakan, Badan Jarain, and Hohsi Corridor) are outlined. Sections of summary reports on these hyperarid regions have been published as journal articles, interim technical reports, and abstracts. A summary report on Eolian Geology of Coastal Peru (Grolier and McCauley) is in draft form and will be submitted for publication in late 1985. Final text and maps for the summary report on the Western Desert of Egypt/Sudan have been delayed by the failure of the NASA Shuttle Imaging Radar-B			

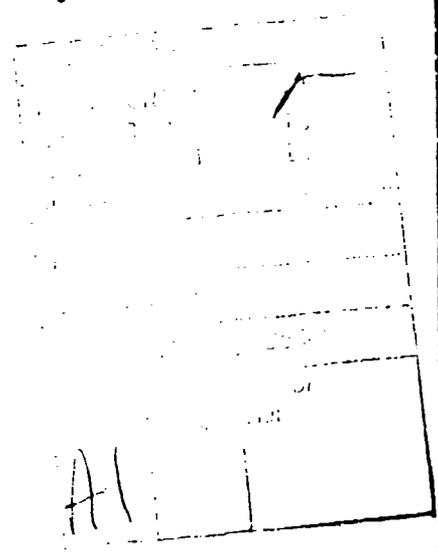
20. ABSTRACT (continued)

mission (October 1984; now rescheduled for March, 1987) and by delays in provision of Large Format Camera photography and Landsat Thematic Mapper imagery. Nonetheless, significant new findings have been described in interim published reports on the Western Desert. These include the discovery of a buried paleofluvial terrain, overprinted by eolian erosion and deposition, which controls the topography and trafficability of much of southwest Egypt and northwest Sudan (McCauley and others, 1982).

A new model for the Western Desert relates a series of superposed river networks, concealed beneath a centimeters-to-meters thick veneer of windblown sand sheets and dunes, to the composition and distribution of surficial and subjacent geologic units, including soil parent materials (McCauley and others, 1982, 1985, in press, and in preparation). The buried river networks can be identified and located in the nearly featureless terrain by using a "sandwich" of Landsat and radar images in concert with a satellite navigation device. Using this system, and a backhoe supplied by USAID-Cairo, riverine gravels and sands were found at depths of 1-3 m, as was shallow groundwater. The groundwater is associated with channels of Quaternary age, 1-2 km wide, inset within the larger, older alluvial valleys, and buried under the sandplains of southern Egypt and northern Sudan, where today there is no surface water. New regional maps relating the surface materials to the subjacent radar map units are now being constructed to accompany the summary report.

A key finding has been the role of groundwater carbonate deposition in recording the sequence of Quaternary fluvial episodes and climatic fluctuations in this region, as well as the present-day influence of the caliche deposits on the radar responses of interfluve, valley fill, and inset channel units (McCauley and others, 1985 and in press; Schaber and others, 1985 and in press).

—Preliminary results of field reconnaissance, Landsat, and Shuttle Imaging Radar (SIR-A and SIR-B) studies of deserts in Northwest China show evidence there, too, of radar signal penetration through dry sand to underlying bedrock and alluvium (Guo and others, 1985). Techniques devised to interpret radar response in the hyperarid Eastern Sahara thus appear to be transferable to other extremely dry core deserts. Field samples, maps, and ground photos collected in the Badan Jarain, Hohsi Corridor, and Taklimakan Deserts (Breed, 1984) are now being analyzed for a summary report that will update interpretations based on earlier satellite, and literature surveys of these formerly inaccessible parts of China.



CONTENTS

	Page
STATEMENT OF PROBLEM.....	1
MAJOR RESULTS.....	1
REPORT ON COASTAL PERU.....	2
REPORT ON WESTERN DESERT OF EGYPT	2
REPORT ON NORTHWEST CHINA.....	7
WORKSHOP ON DESERT PROCESS.....	8
PUBLICATIONS.....	9
PARTICIPATING SCIENTIFIC PERSONNEL.....	11
BIBLIOGRAPHY (CITED REFERENCES).....	19

ILLUSTRATIONS

Figure

1. Index map and aerial photographs of Coastal Desert, Peru.....	12
2. Index map and ground photographs of Western Desert, Egypt and Sudan.....	13
3. Comparison of Shuttle Imaging Radar (SIR-A) and Landsat-1 MSS Band 7 imagery of Western Desert near Egypt-Sudan border.....	14
4. Comparison of SIR-A and Landsat MSS imagery of Western Desert near Bir Safsaf, Egypt.....	15
5. Index map and ground photographs of Alashan Plateau, northwest China.....	16
6. Comparison of SIR-A and Landsat MSS imagery of dunes, Badan Jarain Desert, China.....	17
7. Comparison of SIR-A and Landsat MSS imagery of Shan Gejin area, China.....	18

Best Available Copy

PROJECT DRXRO-GS-18405

FINAL REPORT

DESERT STUDIES - A GLOBAL VIEW

STATEMENT OF PROBLEM

The surficial geologic and geomorphic characteristics of hyperarid desert regions, typified by parts of the Middle East, Northwest China, and coastal Peru, are poorly known to much of the U.S. scientific community. We use the term hyperarid to mean many times more arid than the driest parts of the U.S.; for example, the Yuma Desert on a recent aridity index (Henning and Flohn, 1977) is about a 10, while both the Western Desert of Egypt and coastal Peru are 200's. The hyperarid "core" deserts have little or no vegetation or surface water and are inaccessible except where foreign governments provide logistic support. The existing literature on these regions is widely scattered, generally antiquated, and almost invariably lacking in adequate photographic documentation. Geologic understanding of the sources and distribution of sediment on their surfaces and in the shallow subsurface is of a reconnaissance nature at best and existing maps are poor. In general, these regions have only a superficial resemblance to the deserts of the American Southwest, which are semiarid to arid, geomorphically young, and usually much smaller and more varied. As a result, planning for movements or developments of any kind in the core deserts may be jeopardized by faulty analogies with U.S. deserts.

The task of the Desert Studies Project is to provide up-to-date information about several foreign deserts, with particular emphasis on the poorly known hyperarid regions, based on field, laboratory, literature, and satellite data collected over the past decade by the U.S.G.S. Desert Studies Group in Peru, the Middle East (Egypt/Sudan, Tunisia, Yemen, Lut and Great Kavir of Iran), Central Australia, northwest India and northern China. The data include hundreds of field samples of surficial geologic materials (including soils), detailed field observations documented by thousands of aerial and ground photographs, extensive literature in French, German, and Spanish as well as English, and regional coverage by Landsat and other satellite imagery. Although much of this information was collected in the course of projects for outside agencies, the data bases for them have been incorporated into the Branch of Astrogeology's ongoing studies of geologic processes that shape desert surfaces. The objective of the Desert Studies Project is to synthesize these data for general scientific use, and to apply the results of completed and ongoing work to problems that are critical to a better understanding of the differences among deserts, but that are beyond our current Survey mission. The product of this project is to be a series of separately authored reports on the surficial geologic and topographic characteristics, and the processes by which they have evolved, in selected core deserts, particularly those undergoing present-day hyperaridity and "eolian takeover" (McCauley and others, 1977).

MAJOR RESULTS

The first report in the series will cover the eolian geology of the Coastal Desert of Peru. This report (Grolier and McCauley, in preparation) is

in draft form and will be submitted for publication by November, 1985. The second report, on the Western Desert of Egypt and northwest Sudan, has several completed sections that have been published as journal articles and abstracts, submitted as interim technical reports, or are currently in review (see Publications). It lacks a regional map and summary text for the most critical area, along the Egypt-Sudan border, due to the recent failures of the Shuttle Imaging Radar-B (SIR-B) and Large Format Camera (LFC) missions to acquire the planned coverage before the end date of this contract, and the equally slow provision of the Landsat Thematic Mapper coverage. LFC and Thematic Mapper imagery are now being received in Flagstaff, and completion of the map and summary text for the Western Desert is expected before Jan. 1, 1986. Parts of the third report, on the deserts of northwest China, have also been submitted as interim technical reports (see Publications). The summary text and preparation of maps for this region will be postponed until after detailed field work is accomplished following the SIR-B reflight in early 1987. This work as now planned is a cooperative USGS - Desert Research Institute of Lanzhou - Remote Sensing Center of Beijing effort. The following sections summarize progress to date on problems of desert geology in Peru, Egypt, and northwest China (reports 1, 2, and 3 under the Desert Studies Project).

REPORT ON COASTAL PERU

The report on eolian geology of the Coastal Desert of Peru, authored by M.J. Grolier and J.F. McCauley, is a compilation and interpretation of data from field work and aerial surveys by the authors in the course of USGS and NASA-sponsored expeditions in 1970, 1971, 1973, and 1978. Some of the data related to Mars analog studies were published in NASA-USGS Interagency Reports; these early reports did not include a synthesis of the local or regional geomorphology (Grolier and others, 1977; McCauley and others, 1977). The text for the summary report includes a detailed analysis of the regional and local topography that controls sand flow regimes, and documents a new model for the origin and distribution of coastal ergs (sand seas), isolated occurrences of very large, complex dunes, and yardangs (wind-eroded bedrock hills) (fig. 1). Type examples of the extremely complex coastal desert landforms are amply illustrated with numerous low-altitude aerial and ground photos keyed to high-altitude aerial mapping photos and topographic maps. This chapter will be the first completed in the Desert Studies Series, with publication anticipated in 1986.

REPORT ON WESTERN DESERT OF EGYPT

Our original plan was to compile results of completed work in Egypt into a regional synthesis that would be the first summary report in the series. However, shortly before the start of this project in 1982, we were invited to analyse Shuttle Imaging Radar (SIR-A) images of southwest Egypt and northwest Sudan. Our analysis revealed pictorial evidence of large fluvial networks, buried beneath the widespread sand sheets and dunes in the hyperarid core of the Sahara (McCauley and others, 1982). This evidence for a previously unknown, subjacent fluvial terrain required a radical re-evaluation of the geologic framework and geomorphic evolution of the Western Desert.

Most previous workers had assumed this now-barren, hyperarid, and extremely flat region to be an "eolian peneplain", and our previous field experience showed it is mostly a monotonous sand plain broken by low ("grazing") outcrops without an apparent pattern (Fig. 2). Reconstruction of "fossil" drainages that issued from the Gilf Kebir Plateau, near the border of Egypt with Libya and Sudan, (Breed and others, 1982) identified at least one, large, south-flowing master stream that disappears beneath an eolian disconformity at the sandplain near the border. By penetrating the sand sheet and dunes to a depth of as much as 5 meters, SIR-A revealed a dense array of south- and west-flowing streams at least 100 km south of the Gilf Plateau; these segments are parts of even larger systems that must have been responsible for pediplanation of this part of North Africa after recession of the Eocene seas and before the onset of Plio-Pleistocene aridity.

The new concepts of the geologic evolution of the Western Desert that emerged from this work required us to shelve the previously planned outline for the summary report on this region and to begin a wholly new synthesis of our data that would incorporate these new concepts. As a result of these findings, our group was invited to contribute to the SIR-A Imaging Team report a preliminary interpretation of the radar response from both surface and subsurface features in desert regions (Breed and others, 1982b). A major product of this work is a paper in Science (McCauley and others, 1982) that offers a new interpretation of the surficial geology of the southern part of the Western Desert and provides a framework for the revised Egypt report.

To test preliminary interpretations, a three-week field expedition to the Western Desert was funded by JPL in concert with the USGS and the Geological Survey of Egypt (Sept./Oct. 1982). Numerous hand-dug test pits were dug through the featureless sand sheets where the radar pictures showed river valleys, using roughly coregistered Landsat and radar pictures for navigation purposes. The pits revealed pedogenically reddened sandy alluvium and river gravels beneath an eolian veneer as much as 1.5 m thick. Rolled Stone Age artifacts were found in several pits, indicating that these river valleys were probably migration routes for early Man during episodic but brief periods of running water in the late Quaternary. Many trains of barchanoid dunes 3 to 5 m high were shown to be invisible to the radar because they do not interrupt the continuity of subjacent terrain units (fig. 3). Thus the penetration capability of Shuttle "L" Band radar, although doubted by some experts, was convincingly demonstrated from field observations. The validity of radar map units (McCauley and others, 1982); to be used as a basis for new maps to accompany the Egypt chapter, was tested and confirmed for key areas in southern Egypt and northern Sudan; characteristic composition, grain size, and degree of mobility were established for each type of surface and subjacent unit encountered, and we began to apply these data to problems of source materials, mode, and direction of transport (McCauley and others, 1985). During this field season we also accomplished a jeep reconnaissance across the Qattara Depression and the region south of El Alamein, obtaining much new ground data, including more than a thousand photographs, of this little-known northern part of the Western Desert and the adjacent WWII battlefields.

During July 1982, with a view toward expediting delivery of new maps for the Egypt report, McCauley accepted a one-month assignment in Cairo for USAID, to coordinate a final planning document on Project 263-0105, Mineral, Petroleum and Groundwater Assessment. The AID project was designed to provide

a geologic data base for Egypt, including new 1:1,000,000 and 1:500,000 scale geologic maps and extensive computer compilations of geophysical data. At the same time, our group was accepted as part of the investigator team for the NASA SIR-B mission to be flown in October, 1984. Planning for this mission was extremely time-consuming, but we considered it to be worthwhile, for it established coverage of Egypt - Sudan as the top priority for the experiment, with 8 swaths of radar imagery, each 50 km wide, to be acquired across the areas of the Western Desert.

A major limitation of our field methods in 1982 had been the inability to locate key sites to within better than 1-2 km in the essentially featureless sand plains that conceal almost all trace of the "radar river" networks (figs. 3, 4). In March 1983, a satellite navigation system was purchased with NASA funds and a second post-SIR-A expedition was made to Egypt and Sudan. Travel and field expenses were paid by USAID, Cairo; salaries of USGS personnel were covered by ARO; logistic support was provided by the Geological Survey of Egypt (GSE). The objective of the 1983 field work was to improve our navigational capability in nearly featureless terrain and to locate with improved accuracy small buried "radar rivers" as well as the banks and channel bars of the larger ones. The USGS Image Processing Center in Flagstaff, Arizona, prepared new map bases of specially processed, geometrically corrected Landsat images that match the current AMS Series 1404, 1:500,000 maps of Egypt and Sudan. Digitally enhanced radar images then registered well with these other base materials. Surface features on the corrected Landsat images, and subsurface features on the radar images, were then located in the field to about a quarter of a second of arc by satellite "fixes." This system permits us to map simultaneously both the surface (eolian) and the subjacent (fluvial and colluvial) terrains at a given locality, and thus to begin to produce a new type of geologic/geomorphic map for the summary report on the Western Desert.

Exploration focused on several large and small "radar rivers" of potential economic significance. Twenty-five large but shallow (<3 m) pits were dug by GSE laborers near the Egypt-Sudan border. Twenty-five km south of Bir Safsaf, damp sand was found in the center of one of the buried channels at a depth of less than 1 meter. A complicated sequence of evaporites was also found, as well as rounded stream gravels. Petrologic analysis shows strikingly different characteristics among the surface materials, indicating the presence of distinct stratigraphic units within the Selima Sand Sheet that mantles the region (fig. 1). These differences are probably related to different modes of deposition by wind, water, or a combination of these agents. As a result of these analyses, we have restricted the term "sand sheet" to sediments of demonstrable eolian origin (Breed and others, in press, a). Throughout the region, windblown sand unconformably overlies alluvium and colluvium of fluvial and mass-wasting origin. The regional extent of the "eolian unconformity", which we recognized earlier in the Gilf Kebir locality (Grolier and Schultejann, 1982), is a key to understanding the present topography and geomorphic evolution of this (now) extremely arid region. Electrical resistivity profiles and drill logs in areas where "radar rivers" exist on SIR-A images also clearly show channel-like subsurface anomalies. Converging lines of evidence from field, satellite, and geophysical surveys thus indicate that the present topography of the Western Desert is mainly controlled by these ancient river networks in a very subtle fashion. The results of the 1983 field and laboratory work were presented to symposia at

ERIM, at JPL, and at an International School of Climatology course on the climatic aspects of desertification in Erice, Italy (Breed, 1983; Breed and others, 1983).

In 1983 McCauley was invited to become a Co-investigator on the USGS Large Format Camera Experiment, and arranged to acquire high-resolution (to about 8 m) photographic coverage of most of Egypt and parts of Sudan, Chad, and Libya on Space Shuttle Flight 14, scheduled to fly in August, 1984. Existing (1983) aerial photography of the Western Desert at 1:103,000 scale was acquired from DMA with the help of Dr. Jack Rinker, ETL, and Mr. Bert Sharp and Mr. Buzz Johnston, DMA; it proved useful for relating large-scale patterns on the images from space (Landsat, radar) to features on our ground photographs.

An ongoing problem that has hampered studies of the surficial geology of the Western Desert is the widespread but seemingly random distribution of thick deposits of caliche a few centimeters to meters below the unconsolidated surface sands. In many places the carbonate material forms a dense calcrete almost as impenetrable as bedrock. A hard caliche layer 1 to 3 m thick commonly underlies eolian sand sheet deposits in the vicinities of the buried river valleys. Previous attempts to dig through the caliche, using hand labor, were not successful, and so the distribution and fluvial character of the underlying sediments were not fully understood. During the February and March 1984 field season near the Egypt-Sudan Border, we made a series of trenches across two key "radar rivers" using for the first time a backhoe supplied by USAID-Cairo. Again using radar images co-registered to Landsat images and topographic maps, together with positional data from the satellite navigation device (Satnav), we located subsurface channels as narrow as 1 km and dug a series of 82 backhoe trenches across them to examine their sedimentary and morphologic characteristics.

Excavations with the backhoe through the caliche to the underlying clean, riverine sands substantiated our new model of the subjacent paleofluvial terrain and its relation to the eolian overprint. A key to this model is the role of caliche in the response of subsurface materials to the Shuttle Imaging Radar (SIR) signal (McCauley and others, 1985 and in press; Schaber and others, 1985 and in press a, b). Caliche formed in interfluvial soils has irregular surfaces that give a mottled-intermediate response, thus outlining the valleys on the radar images. Layers of alluvial fill within the valleys, though also calichified, are smooth-surfaced and give a uniform intermediate response. Sinuous, anastomosing runoff channels, incised into the calichified fill in the older, broader valleys, give a dark radar response because they contain only fine-grained alluvium with little or no carbonate cement (fig. 4). The inset channels are masked by thin (2 cm-1 m) sheets of windblown sand, and thus are totally invisible on the surface, on aerial photos, and on Landsat images, but are readily apparent on SIR-A images (fig. 4). We established that these inset channels are shallow aquifers; water was encountered in them at depths of one to three meters. Laboratory analyses indicate that the caliche is of groundwater rather than pedogenic origin (Machette, USGS Denver, pers. commun.). A groundwater origin for these widespread CaCO_3 deposits fits our model of the distribution and geomorphic evolution of the radar rivers, interfluvial terraces and inset channels, and has important implications for the sequence of climatic changes in the Western Desert.

As a byproduct of this work, Acheulean hand axes were discovered in situ at depths of 1 m or more in alluvium on terraces adjacent to the largest valleys -- the first tools of this age (250,000 years) found in a riverine environment in the Eastern Sahara. Aside from the archaeological and paleoclimatic significance of this find (described in Science News "News of the Week" in April, 1984) we established that these and younger tools are "index fossils" useful for determining the relative ages of successive fluvial episodes. In May 1984, we presented our new model for the Neogene geologic history of the Western Desert at an International Conference on Geological Problems of the Eastern Sahara in Whittier, CA (McCauley and others, 1985; Breed and others, in press (a)). Work continued on a summary of results for the Egypt report (McCauley and others, in preparation), and was begun on 3 interim technical reports: one that defines and interprets the radar responses of various types of subjacent materials (Schaber and others, in press (b), submitted with this report); another that describes and interprets the formation and distribution of aligned bedrock hills (yardangs) in the Kharga and Farafra regions of the Western Desert (Breed and others, in preparation); and a paper that summarizes the implications of the most recent buried drainage patterns for former human occupations (McHugh and others, in review).

On October 5, the Space Shuttle Challenger (STS 17, Mission 41G) carried the SIR-B (Shuttle Imaging Radar) sensor into orbit for a planned 8-day mission to obtain mapping-mode and multiple-angle imagery. Top priority coverage was assigned to the Western Desert of southwest Egypt and northwest Sudan; coverage of Coastal Peru, southern Africa, northwest China, and Central Australia was included to test the capability of the 23.5 cm wavelength radar to depict subsurface topography and geologic features, otherwise obscured by overlying sand, in hyperarid regions other than Egypt and Sudan. Because of technical problems with the TDRS relay and the SIR-B antenna, only 8 hours of data rather than the planned 45 hours were obtained, and swath widths were cut by 40%. A few useful SIR-B images were obtained over the Western Desert of Egypt, Sudan, and Libya, and over deserts of northwest China, southern Africa, and central Australia. The first processed data from SIR-B were provided to our group in late December 1984, and have been partly analysed for inclusion in the preliminary SIR-B team report (McCauley and others, in press).

Because the SIR-B mission was essentially a failure, a reflight of the SIR-B sensor, again with emphasis on desert studies, is scheduled for February 1987. The first scheduled flight of the Large Format Camera, on what was then designated STS-14, was scrubbed at the last second and the LFC was later flown on STS-17 where it was in operational conflict with the SIR-B. Results to date have been disappointing. Only a small fraction of the anticipated coverage over Egypt was acquired and the first negatives for the LFC pictures were not received in Flagstaff until August, 1985, 6 weeks after the end of our ARO contract. However, the color infrared LFC pictures are superior to other remotely sensed data for the Western Desert and are expected to provide some of the matrix needed to complete our regional maps.

In spite of these problems, during the course of this contract we have published or submitted as interim technical reports, 3 major journal papers, 6 shorter papers, and 10 abstracts interpreting the results of our work in the Western Desert. These reports correlate and contrast our interpretations with results of earlier studies, and provide a new model for the geologic evolution

and present day surficial characteristics of this core desert. Our approach to the geologic problems of the Western Desert differs significantly from that of earlier workers, who were mostly concerned with explaining the geomorphic context for late Quaternary human occupations. Although our work has provided new insights into the geoarchaeological record, these are an incidental byproduct of a wholly new, synoptic geologic framework for the Neogene evolution of this region. While awaiting the receipt of newer, high-resolution Thematic Mapper images and LFC photographs, we have used Landsat MSS imagery, specially processed at the USGS Computer Facility in Flagstaff, to prepare a black-and-white mosaic of most of Egypt and northern Sudan, to use as a preliminary base for regional maps. In late 1985 we will submit a new proposal to ARO for additional time to allow us to incorporate the delayed satellite and Shuttle data (Landsat Thematic Mapper, reflown SIR-B, and LFC) into our text and accompanying maps to complete the summary report on the Western Desert and to extend the work to adjacent areas of the Eastern Sahara (Libya, Chad).

REPORT ON NORTHWEST CHINA

The report on Chinese deserts is a joint effort incorporating field work by Huadong Guo (Academia Sinica, PRC) and by A. Walker (U.S.G.S., Reston, Va.), on the Alashan Plateau and other localities (Guo and others, 1985; Walker, 1982; Walker and others, in press). The new data are being used with the results of previous and ongoing remote-sensing surveys and recent field reconnaissance (Breed and others, 1979; Breed, 1984) to update earlier information on the Chinese deserts, based on remotely-sensed (satellite) data and literature surveys. From July 31-August 19, 1984, Breed attended a Symposium on Arid Lands sponsored by the American Association of Science (AAAS) and the Chinese Association for Science and Technology (CAST) at the Desert Research Institute in Lanzhou, China. Three days of formal talks were followed by a two-week expedition to desert regions of extreme northwest China, including parts of the Tengger, Kumuntag, Garbantunggut, Turpan, and Talkimakan sand seas and gobi plains. As a member of this group, Ms. Breed was the first Western geologist since 1949 allowed access to the Taklimakan Desert (Hotan-Qira area). She obtained several hundred aerial and ground photos, and samples of surficial geologic units typical of each desert area, as well as maps, reprints, and preprints of recent Chinese research. Part of the general introductory section to the summary report on the Chinese deserts has been submitted as an interim technical report (Breed, 1984). Field samples and photos of the Taklimakan Desert are now being analyzed for a brief journal article.

From Sept. 23-28, Mr. Guo Huadong of the Remote Sensing Center, Beijing, China, worked with our group on SIR-A and Landsat images of the Badain Jaran desert, Yamalik Dunes, and Shan Gejin areas (figs. 5-7). He prepared a paper with us (submitted herein as an interim technical report) that documents radar responses and penetration of the surficial cover in several localities in northwest China. Preliminary results indicate that the techniques and interpretive methods used successfully in the Eastern Sahara are also applicable to the hyperarid deserts of China (fig. 5, 6, 7), and verify the ability to use imaging radar to locate and map shallow subsurface topography and geologic units in arid regions, other than the Sahara (the aridity index for this part of China is 30, compared with 200 for Egypt/Sudan and 10 for the

Yuma Desert in Arizona). On the other hand, this paper demonstrates that radar imagery is unreliable if used as a sole source for determining dune morphology in sandy deserts. Comparisons of radar and Landsat images of dune fields in northern China show that the radar response from large (kilometer-wide) sand dunes is controlled by the direction of radar illumination relative to the orientation of dune slipfaces (avalanche slopes). Slipface orientations are the key to identifying dune types and degree of complexity (Breed and others, 1979), which are critical to determining trafficability in sandy deserts. Dune slipfaces also record the direction of effective (sand-moving) winds; e.g., whether a locality is dominated by a unidirectional wind regime or by multiple or seasonal winds. Multiple winds often produce very large dunes with primary and secondary sets of slipfaces. At the 50° incidence angle of SIR-A, only those slipfaces that are oriented at right angles to the direction of radar illumination return a bright to very bright response, whereas slipfaces oriented oblique or reverse to the direction of the radar signal are not imaged. As a result, patterns of bright spots on radar images can be responses from secondary slipfaces that represent only a minor component of the effective wind regime. Where no slipfaces are oriented toward the radar signal, the response from the dunes shows no definitive patterns but simply appears as a dark area on the radar image.

Mr. Guo will collaborate with our U.S.G.S. group in field studies, now being planned, as a follow-on to the reflight of SIR-B. Key participants will be Prof. Zhu Zhenda, Director of the Desert Research Institute, Lanzhou, and members of his staff, who have agreed to arrange logistic support. Arrangements are now being made through Dr. Edward Chao, Reston, VA, who is the USGS Agency Coordinator for geologic activities under the amended Earth Sciences Protocol and Related Activities under the Agreement for Science and Technology negotiated in October 1984 between the U.S. Government and the People's Republic of China (PRC).

WORKSHOP ON DESERT PROCESSES

In an effort to evaluate current methods of monitoring and interpreting surface geologic processes in arid regions, our Desert Studies Group brought together 27 specialists in desert geomorphology and surficial geology for a USGS-U.S. Army Engineer Topographic Laboratories (ETL) joint Workshop on Desert Processes in Flagstaff, September 23-28, 1984. The workshop included 3 days of formal presentations and discussions and a 2-day aerial and ground field trip in the Great Basin Desert of northeastern Arizona. A field guide to the area, which provides numerous examples of current problems in desert geology, was prepared for the Workshop. Recommendations for interdisciplinary and interagency research in desert processes and interpretation of desert landforms, based on the Workshop results, have been summarized in a report submitted for publication as a USGS Circular.

PUBLICATIONS

1982: 4 papers, 2 abs. published

- Breed, C. S., McCauley, J. F., and Grolier, M. J., 1982, Relict drainages, conical hills, and eolian veneer of Southwest Egypt -- applications to Mars: *Journal of Geophysical Research*, v. 87, no. B12, p. 9929-9950.
- Breed, C. S., McCauley, J. F., Schaber, G. G., Walker, A. S., and Berlin, G. L., 1982, Dunes on SIR-A images, *in* Cimino, J., and Elachi, C., eds., *Shuttle Imaging Radar-A (SIR-A) Experiment*: JPL Publ. 82-77, p. 4-52-4-87.
- Grolier, M. J., and Schultejann, P. A., 1982, Geology of the southern Gilf Kebir Plateau and vicinity, Western Desert, Egypt, *in* El-Baz, F., and Maxwell, T. A., (Eds.), *Desert landforms of southwest Egypt: a basis for comparison with Mars*: NASA CR-3611, p. 189-206.
- McCauley, J. F., Schaber, G. G., Breed, C. S., Haynes, C. V., Grolier, M. J., Issawi, B., Elachi, C., and Blom, R., 1982, Subsurface valleys and geomorphology of the Eastern Sahara revealed by Shuttle Radar: *Science*, v. 218, no. 4576, p. 1004-1020.
- McCauley, J. F., Schaber, G. G., Breed, C. S., and Grolier, M. J., 1982, SIR-A images reveal major subsurface drainages in the Eastern Sahara (abs.): NASA TM 85127, p. 311-313.
- Schaber, G. G., McCauley, J. M., Breed, C. S., Grolier, M. J., Elachi, C., Blom, R., Issawi, B., and Haynes, C. V., 1982, Space Shuttle Radar: dramatic evidence of sand penetration in the Eastern Sahara of Egypt and Sudan (abs.): *Proceedings, ERIM Conf. on Remote Sensing in Geologic Exploration*, Dec. 6-10, 1982, Ft. Worth, TX, p. 39-40.

1983: 2 abs. published, 2 papers submitted for publication

- Breed, C. S., 1983, Subsurface imaging with SIR-A in the Egyptian Desert (abs.): *Summaries, 17th International Symposium on Remote Sensing of Environment, ERIM, Ann Arbor, MI, May 9-13, 1983*, p. 11-12.
- Breed, C. S., Schaber, G. G., McCauley, J. F., Grolier, M. J., Haynes, C. V., Elachi, C., Blom, R., Issawi, B., and McHugh, W. P., 1983, Subsurface geology of the Sahara in Egypt and Sudan discovered by Shuttle Imaging Radar: *Spaceborne Imaging Radar Symposium, Jan. 17-10, 1983, JPL Publication 83-11*, p. 10-12.
- Breed, C. S., and McCauley, J. F., Remote monitoring of geometeorological controls on desert surface processes -- the USGS Desert Winds Project, *in* Ypersele, J. P. (ed.), *Climatological aspects of desertification: Proceedings of the International School of Climatology, Erice, Italy, October 1983*, (in press).
- Breed, C. S., and McCauley, J. F., Use of dust storm observations on satellite images to identify areas vulnerable to severe wind erosion, *in* Ypersele, J. P. (ed.), *Climatological aspects of desertification: Proceedings of the International School of Climatology, Erice, Italy, October 1983*, (in press).

1984: 5 papers, 4 abs. published; 2 abs. submitted for publication

- Breed, C. S., McCauley, J. F., and Grolier, M. J., 1984, Multiprocess evolution of landforms in the Kharga region, Egypt -- applications to Mars (abs.): *NASA Technical Memorandum 86246*, p. 225-227.

- Breed, C. S., McCauley, J. F., and Schaber, G. G., 1984a, Shuttle Imaging Radar provides framework for subsurface geologic exploration in Egypt and Sudan (abs.): Summaries, International Symposium on Remote Sensing of Environment, ERIM, April 16-19, 1984, Colorado Springs, CO, p. 159.
- Breed, C. S., McCauley, J. F., and Schaber, G. G., in press (a), Stratigraphic studies of "radar river" deposits in the Western Desert, Egypt (abs.): Conference on African Geology, Whittier College, CA.
- Breed, C. S., 1984, Geomorphic aspects of China's desertification problem and de-desertification efforts, in McKell, C. M. and Levey, L. A. (eds.), Arid Lands in China, Delegation Trip Report: American Association for the Advancement of Science, Washington, D. C., p. 10-14.
- Breed, C. S., McCauley, J. F., Breed, W. J., McCauley, C. K., and Cotera, A. S., 1984, Eolian (wind-formed) landscapes, in Smiley, T. L., and others (eds.), The Landscapes of Arizona: The Geological Story: University Press, Chapter 16, p. 359-413.
- Breed, C. S., 1984, Landforms shaped by desert winds: American Association for Advancement of Science Symposium on Desertification Processes in Arid Lands, Lanzhou, China v. 4, no. 4, p. 2-10 (in Chinese).
- Elachi, C., Roth, L. E., and Schaber, G. G., 1984, Spaceborne radar subsurface imaging in hyperarid regions, 1984: IEEE Transactions on Geoscience and Remote Sensing, v. GE-22, no. 4, p. 383-388.
- McCauley, J. F. and Breed, C. S., 1984, Comparisons of the drainage networks of the Eastern Sahara with those on Mars (abs.): Geological Society of America, Annual Mtg., Reno, Nevada, p. 587.
- McCauley, J. F., Breed, C. S., Helm, P. J., Billingsley, G. H., Mackinnon, D. J., Grolier, M. J., and McCauley, C. K., 1984, Remote monitoring of processes that shape desert surfaces: the Desert Winds Project: U.S. Geological Survey Bulletin 1634, 19 p.

1985: 2 abstracts, 1 paper published; 1 abstract, 1 paper in press; 2 papers in review

- Breed, W. J., Breed, C. S., McCauley, J. F., and Billingsley, G. H., in review, Guide to air and ground field trip for a Workshop on Desert Processes, Flagstaff, AZ, Sept. 23-28, 1984; U.S. Geological Survey Open-File report, 82 p.
- Guo, Huadong, Schaber, G. G., Breed, C. S., and Lewis, A. J., 1985, SIR-A radar response from sand dunes and subsurface rocks of Alaskan Plateau in north central China: Remote Sensing Research, Rept. for Project UN/TCD CPR/80/T01, ERSAL, Oregon State Univ., p. 55-78.
- McHugh, W. P., Preparing for the SIR-B mission: Archaeological results and implications of the 1984 USGS-EGSMA expedition to the Nubian Desert, southern Egypt (in review).
- McCauley, J. F., Breed, C. S., and Schaber, G. G., 1985, Late Tertiary and Quaternary river systems of the Eastern Sahara as mapped on Shuttle Radar and Landsat images (abs.): NASA Technical Memorandum 87563, p. 471-473.
- McCauley, J. F., Breed, C. S., Schaber, G. G., in press, The radar rivers revisited: field studies in preparation for SIR-B, in Preliminary report of the SIR-B mission: JPL Publication, 6 p.
- McCauley, J. F., and Rinker, J. N. (Eds.), in review, Report of a Workshop on Monitoring and Interpreting Desert Surface Processes: U.S. Geological Survey Circular, 22 p. (approx.).

- Schaber, G. G., Breed, C. S., McCauley, J. F., and Billingsley, G. H., 1985, Physical controls on SIR-A signal penetration and subsurface scattering in the Mars-like Eastern Sahara (abs.): Lunar and Planetary Institute, Houston, TX, p. 732-733.
- Schaber, G. G., McCauley, J. F., and Breed, C. S., in press (a), The role of mineral precipitates in moderating Shuttle Imaging Radar signal penetration and subsurface scattering in the hyperarid Eastern Sahara: application to climatic history of Mars (abs.): Bulletin, American Astronomical Society, DPS meeting.
- Schaber, G. G., McCauley, J. F., Breed, C. S., and Ohlhoef, G., in press, Space Shuttle Imaging Radar: physical controls on signal penetration and subsurface scattering in the Eastern Sahara. (in press: Geophysics).

PARTICIPATING SCIENTIFIC PERSONNEL

Participants:

John F. McCauley, Geologist
Maurice J. Grolier, Geologist
Carol S. Breed, Geologist
Debbie Cook, Physical Science Technician
Kathy Doyle, Physical Science Technician

Gerald G. Schaber, Geologist, Alta Walker, Geologist, George Billingsley, Geologist, Paula Helm, Mathematician, W. P. McHugh, Archaeologist, G. Ohlhoef, Physicist, and Diana Elder, Physical Science Technician, contributed significantly to the Desert Studies Project but were supported from other funding sources. Ms. Elder, supported by the Minority Participation in Earth Sciences program, received her B.S. in Geology from Northern Arizona University, Flagstaff, while working on this project.

Figure 1. Index map and aerial photographs of Coastal Desert, Peru: top photo is oblique view of Pampa Lechuza, east of Pisco, showing numerous well-streamlined yardangs and dark lag surface of plain, with wind-fluted cliffs in background. Bottom photo shows Bahía de Caballitas dune field, south of Paracas Peninsula. This dune field is the source or "sandsheet" of the largest erg (sand sea) in Coastal Peru. It has a very sharp and straight eastern boundary resulting from combined effects of a change in direction of the coastline and the wind pattern developed over a 200 m high ridge to the south. Dunes have developed inland from part of beach where supply of sand is greatest, but are lacking inland from rocky beaches (bottom of photograph) where the sand supplies are meager, as well as inland from the 200 m high coastal ridge, where wind turbulence and eddies favor sand removal rather than accumulation. Vertical aerial photograph supplied by el Servicio Aerofotografico Nacional del Peru.

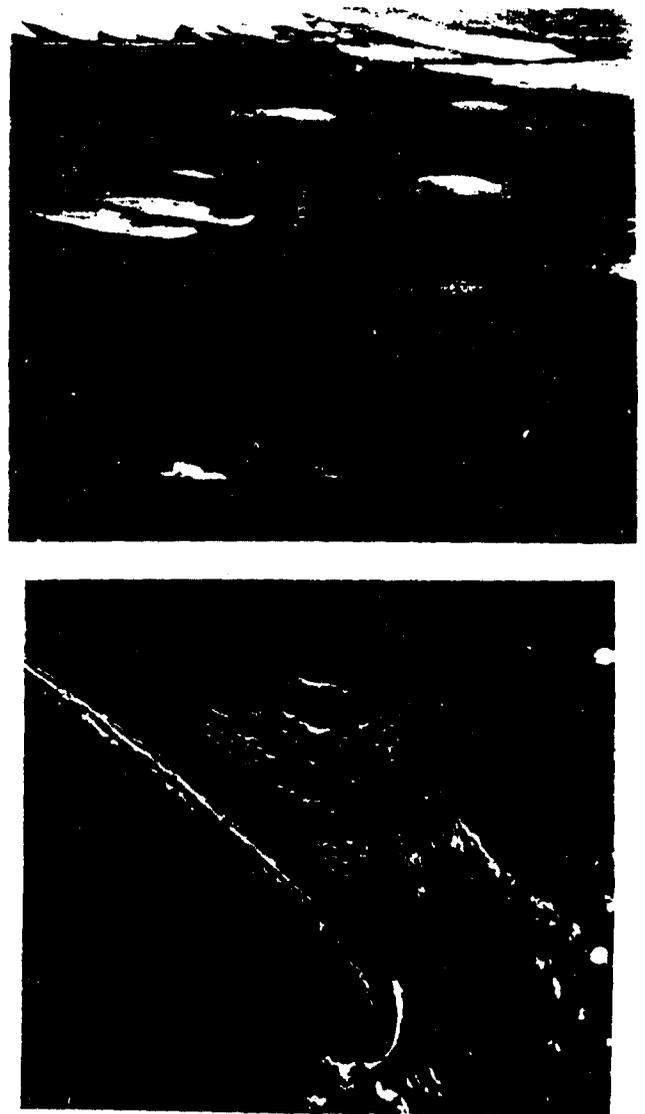
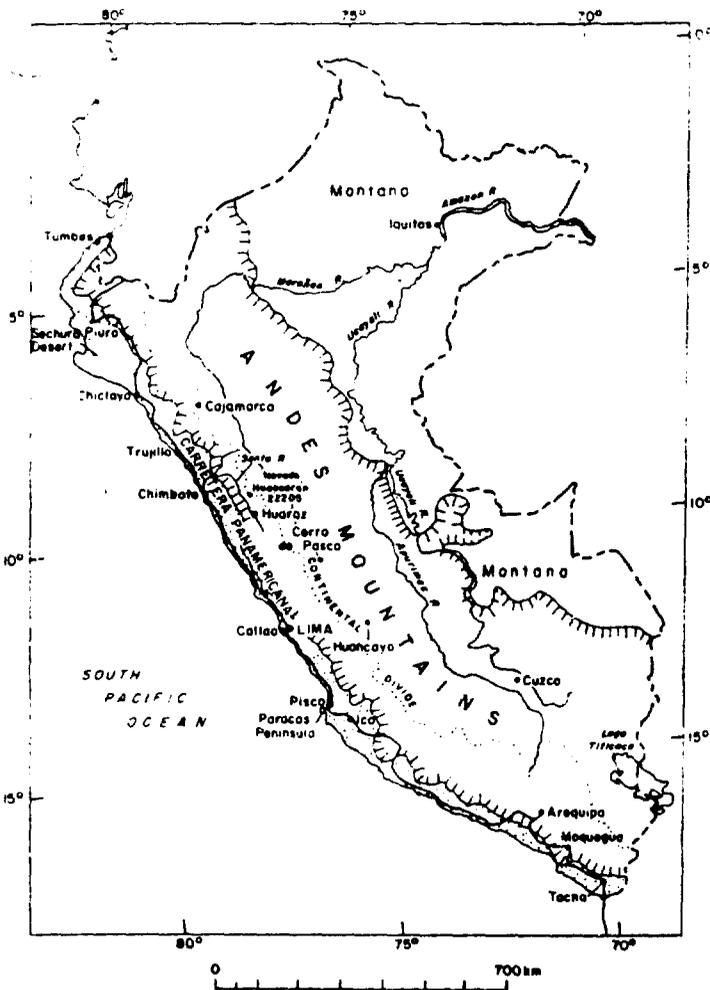


Figure 3. Comparison of Shuttle Imaging Radar (SIR-A) image (top) and part of a Landsat-1 MSS Band 7 image (bottom) of the Western Desert near the Egypt-Sudan border (fig. 2). Series of overlapping sand sheets and trains of active barchans (curved arrow) and relict parabolic dunes (straight arrow) on Landsat image are invisible to radar because the 24 cm signal penetrates the dry surficial sands of this region. Subparent geologic parent materials and relict fluvial topography (including river channels incised in bedrock -- arrow) are clearly evident on the radar picture (top). Locality B marks center of old, large "radar river" valley, about 20 km wide, concealed by sand sheets in Landsat image. Segments of a narrow channel incised in bedrock east of locality A (dark arrow) are discernible on Landsat but mostly overrun by dunes; entire channel can be mapped on radar image. Images are 100 km long.

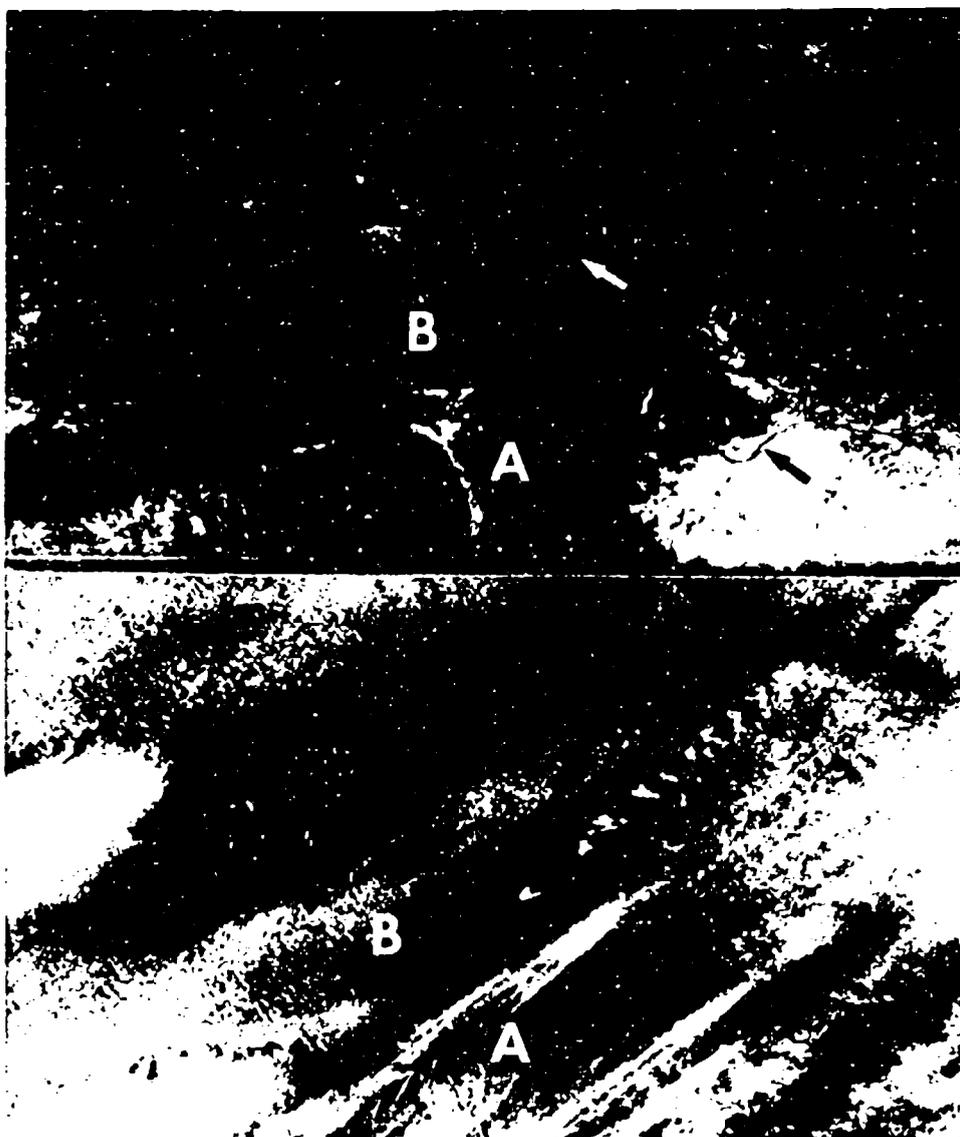


Figure 4. Comparison of SIR-A (top) and Landsat MSS band 7 (bottom) images of Western Desert south of Bir Safsaf, Egypt (fig. 2). Small (km-wide) radar-dark sinuous channels (A) are hidden from view on Landsat by cm-to-meter thick sand sheet. Water was found in several of these channels at depth of 1 to 3 meters. Images are 55 km long.

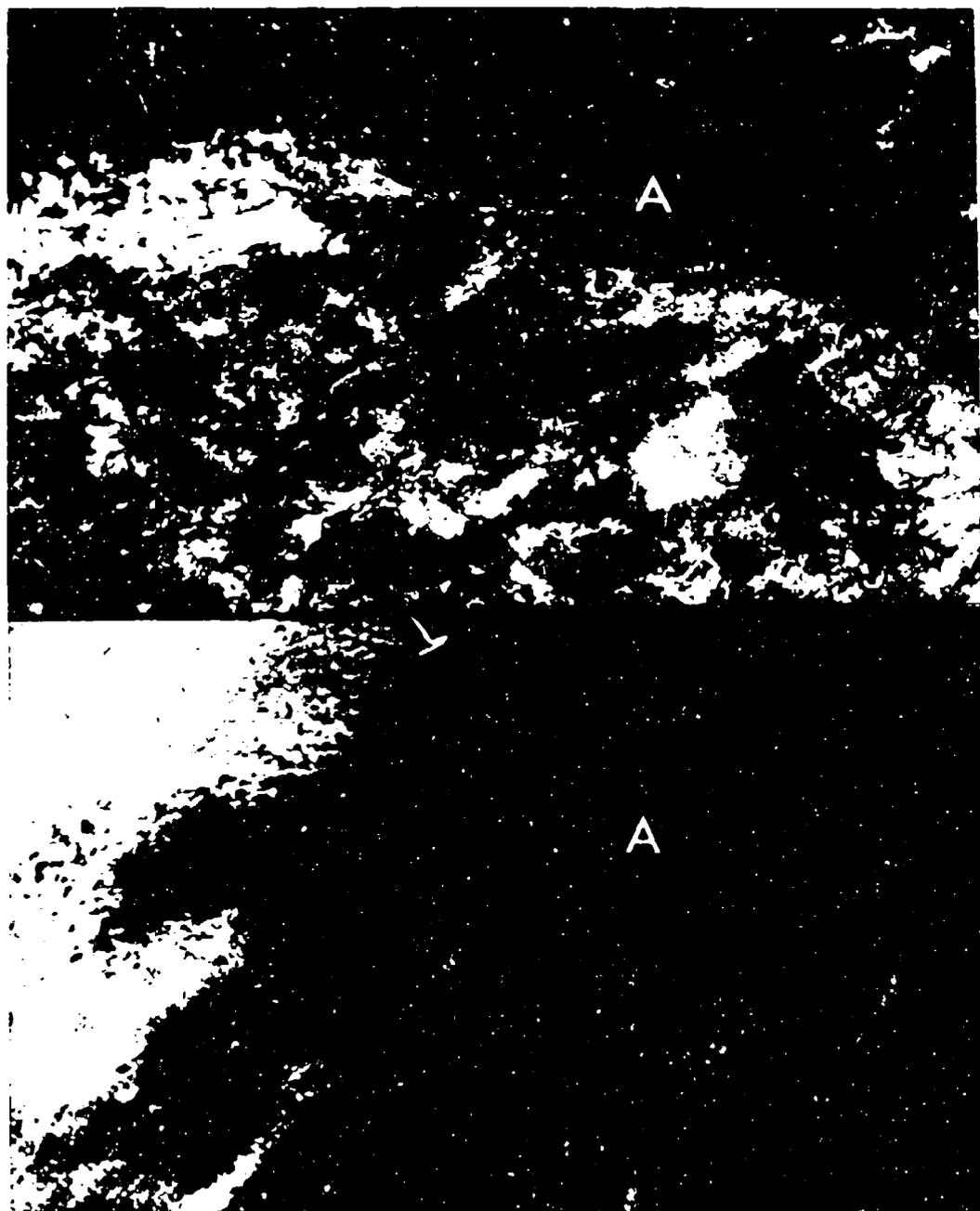
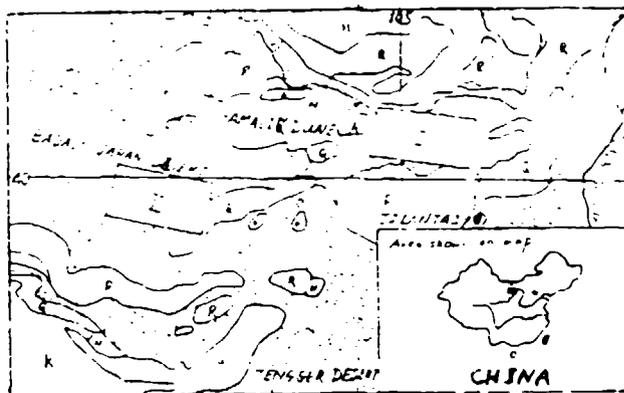


Figure 5. Index map of the Alashan Plateau, northwest China with ground photographs of Yamalik Dunes; R--Bedrock, N--Neogene, Q--Quaternary; I -- Yamalik Dunes; II -- Yapulai Shan Dunes; III -- Badain Jaran Desert; IV -- Hungar Yulin; V -- Shan Gejin. In foreground of top photo is a stony plain with vegetation and exposed outcrops that give an intermediate-bright return on radar imagery; barchanoid dunes in background have slopes oblique to the radar signal and give a very dark response on the radar images. Star line (bottom photo) have some cliff faces normal to the radar signal, and these provide bright radar returns. From Gao and others, 1985.



(Scale: 1:4,000,000)

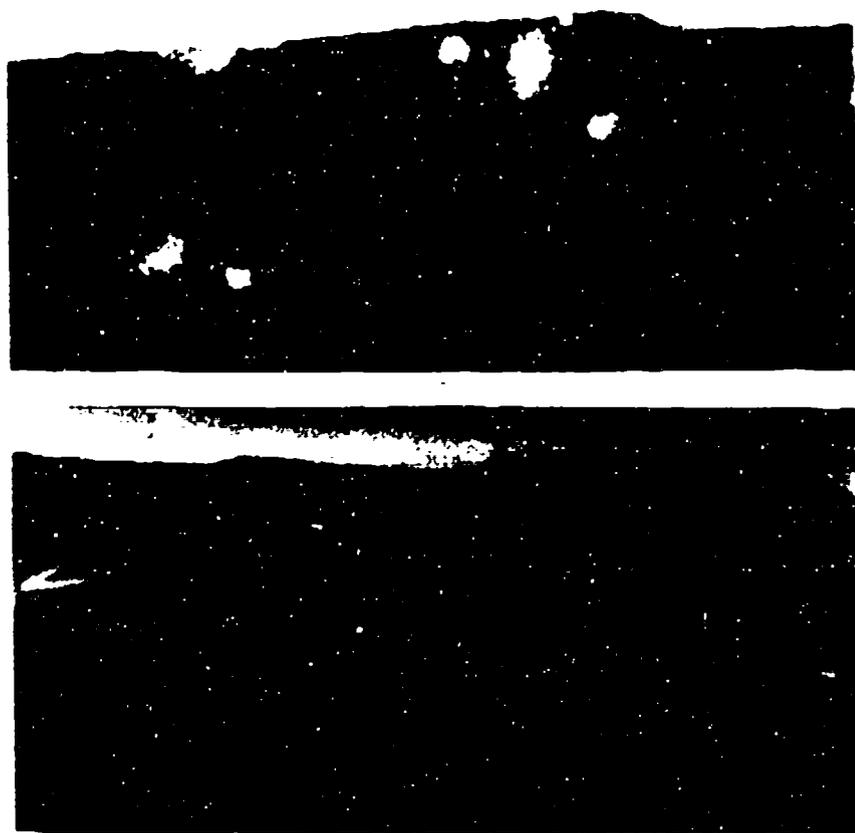
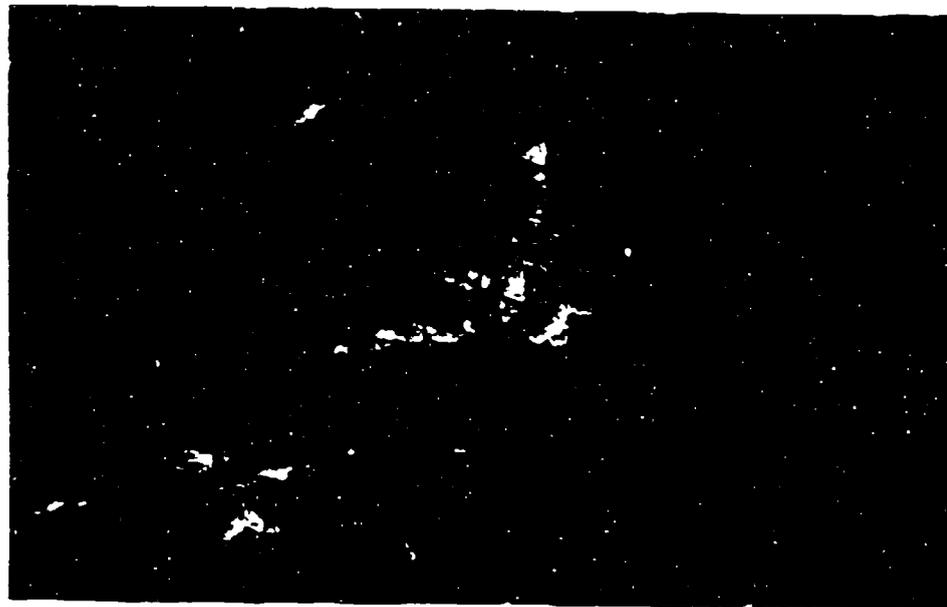


Figure 6. Comparison of SIR-A (top) and Landsat MSS (band 7) imagery (bottom) of large (km-wide) dunes in the Badan Jarain Desert, China (area III on Index Map, fig. 5). Landsat shows true southeast-facing morphology of the major dune avalanche slopes (slipfaces). SIR sensor, oriented oblique to the major slipfaces, receives bright response only from lesser, south-facing slopes probably produced seasonally by secondary winds. Thus radar, if used alone, can give erroneous interpretation of direction of migration of dunes and thus of prevailing effective wind. Images are 60 km long. (From Speed and others, 1982).



Figure 7. Comparison of SIR-A (top) and Landsat imagery (bottom) of the Shan Gejin area, China. (Area V on Index Map, fig. 5), showing radar penetration of dry surface sand; radar image shows bright return from bedrock concealed by sand sheet on Landsat (from Guo and others, 1985) images are 50 km long.



BIBLIOGRAPHY (CITED REFERENCES)

- Breed, C. S., 1983, Subsurface imaging with SIR-A in the Egyptian Desert (abs.): Summaries, 17th International Symposium on Remote Sensing of Environment, ERIM, Ann Arbor, MI, May 9-13, 1983, p. 11-12.
- Breed, C. S., 1984, Geomorphic aspects of China's desertification problem and de-desertification efforts, in McKell, C. M. and Levey, L. A. (eds.), Arid Lands in China, Delegation Trip Report: American Association for the Advancement of Science, Washington, D.C., p. 10-14.
- Breed, C. S., Fryberger, S. G., Andrews, S., McCauley, C. K., Lennartz, F., Gebel, D., and Horstman, K., 1979, Regional studies of sand seas using Landsat (ERTS) imagery: Chapter K in McKee, E. D., (Ed.), A study of global sand seas: U.S. Geological Survey Professional Paper 1052, p. 305-397.
- Breed, C. S., McCauley, J. F., and Grolier, M. J., 1982a, Relict drainages, conical hills, and eolian veneer of Southwest Egypt -- applications to Mars: Journal of Geophysical Research, v. 87, no. B12, p. 9929-9950.
- Breed, C. S., McCauley, J. F., and Schaber, G. G., in press (a), Stratigraphic studies of "radar river" deposits in the Western Desert, Egypt (abs.): Conference on African Geology, Whittier College, CA., 1984.
- Breed, C. S., McCauley, J. F., Schaber, G. G., Walker, A. S., and Berlin, G. L., 1982b, Dunes on SIR-A images, in Cimino, J., and Elachi, C., eds., Shuttle Imaging Radar-A (SIR-A) Experiment: JPL Publication 82-77, p. 4-52-4-87.
- Breed, C. S., Schaber, G. G., McCauley, J. F., Grolier, M. J., Haynes, C. V., Elachi, C., Blom, R., Issawi, B., and McHugh, W. P., 1983, Subsurface geology of the Sahara in Egypt and Sudan discovered by Shuttle Imaging Radar: Spaceborne Imaging Radar Symposium, Jan. 7-10, 1983, JPL Publication 83-11, p. 10-12.
- Breed, C. S., Whitney, M. I., and McCauley, J. F., Wind erosion of bedrock and surficial deposits in the hyperarid Kharga region, south-central Egypt (in preparation).
- Elachi, C., Roth, L. E., and Schaber, G. G., 1984, Spaceborne radar subsurface imaging in hyperarid regions, 1984: IEEE Transactions on Geoscience and Remote Sensing, v. GE-22, no. 4, p. 383-388.
- Grolier, M. J., Ericksen, G. E., McCauley, J. F., and Morris, E. C., 1974, Desert landforms of Peru; a preliminary photographic atlas: U.S. Geological Survey Interagency Report 57, 146 p.
- Grolier, M. J., and McCauley, J. F., in preparation, Eolian geology of Coastal Peru.
- Grolier, M. J., and Schultejann, P. A., 1982, Geology of the southern Gilf Kebir Plateau and vicinity, Western Desert, Egypt: Chapter 14 in El-Baz, F., and Maxwell, T. A., (Eds.), Desert Landforms of Southwest Egypt: a basis for comparison with Mars: NASA CR-3611, p. 189-206.
- Guo, Huadong, Schaber, G. G., Breed, C. S., and Lewis, A. J., 1985, SIR-A radar response from sand dunes and subsurface rocks of Alashan Plateau in north-central China: Remote Sensing Research, Report for Project UN/TCD CPR/80/TO1, ERSAL, Oregon State University, p. 55-78.
- Henning, D., and Flohn, H., 1977, Climate aridity index map, presented at the United Nations Conference on Desertification, U.N. Environment Programme (UNEP), Nairobi, Kenya.

- McCauley, J. F., Breed, C. S., and Schaber, G. G., 1985, Late Tertiary and Quaternary river systems of the Eastern Sahara as mapped on Shuttle Radar and Landsat images (abs.): NASA Technical Memorandum 87563, p. 471-473.
- McCauley, J. F., Breed, C. S., Schaber, G. G., in press, The radar rivers revisited: field studies in preparation for SIR-B, in Preliminary report of the SIR-B mission: JPL Publication, 6 p.
- McCauley, J. F., Breed, C. S., Schaber, G. G., and Issawi, B., Paleodrainages and Neogene Geology of the Western Desert, Egypt and Sudan (in preparation).
- McCauley, J. F., Grolier, M. J., and Breed, C. S., 1977, Yardangs of Peru and other desert regions: U.S. Geological Survey Interagency Rept.: Astrogeology 81, 177p.
- McCauley, J. F., Schaber, G. G., Breed, C. S., Haynes, C. V., Grolier, M. J., Issawi, B., Elachi, C., and Blom, R., 1982, Subsurface valleys and geomorphology of the Eastern Sahara revealed by Shuttle Radar: Science, v. 218, no. 4576, p. 1004-1020.
- McCauley, J. F., and Rinker, J. N. (Eds.), in review, Report of a Workshop on Monitoring and Interpreting Desert Surface Processes: U.S. Geological Survey Circular.
- McHugh, W. P., Preparing for the SIR-B mission: Archaeological results and implications of the 1984 USGS-EGSMA expedition to the Nubian Desert, southern Egypt (in review).
- Schaber, G. G., McCauley, J. F., and Breed, C. S., in press (a), The role of mineral precipitates in moderating Shuttle Imaging Radar signal penetration and subsurface scattering in the hyperarid Eastern Sahara: application to climatic history of Mars (abs.): Bulletin, American Astronomical Society, DPS meeting.
- Schaber, G. G., Breed, C. S., McCauley, J. F., and Billingsley, G. H., 1985, Physical controls on SIR-A signal penetration and subsurface scattering in the Mars-like Eastern Sahara (abs.): Lunar and Planetary Institute, Houston, TX, p. 732-733.
- Schaber, G. G., McCauley, J. F., Breed, C. S., and Ohlhoeft, G., in press, Space Shuttle Imaging Radar: physical controls on signal penetration and subsurface scattering in the Eastern Sahara. (submitted to Geophysics).
- Science News, 1984, News of the Week: Shuttle Radar is key to Sahara's Secrets: v. 125, no. 16, April 21.
- Walker, A. S., 1982, Deserts of China: American Scientist, v. 70, no. 4, p. 366-376.
- Walker, A. S., Olsen, J. W., and Bagen, in press, Geomorphological investigation of the Badain Jaran Desert from space: Proceedings, International Symposium on Exploration and Utilization of Natural Resources in Arid Lands, Urumchi, PRC, 5 August 1985.