JSC-09053

NASA TECHNICAL MEMORANDUM

NASA TM X-58142
June 1974

SKYLAB 4 VISUAL OBSERVATIONS PROJECT REPORT

(NASA-TM-X-58142) SKYLAB 4 VISUAL
OBSERVATIONS PROJECT REPORT (NASA) 249 p HC
$8.[illegible]
CSCL 22A

N76-1656[illegible]

Unclas
G3/43 08[illegible]36

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

LYNDON B. JOHNSON SPACE CENTER

HOUSTON, TEXAS 77058

NASA TM X-58142

SKYLAB 4 VISUAL OBSERVATIONS PROJECT REPORT

Edited by

J. L. Kaltenbach, W. B. Lenoir, M. C. McEwen,
R. A. Weitenhagen, and V. R. Wilmarth
Lyndon B. Johnson Space Center
Houston, Texas 77058

t No. SA TM X-58142	2. Government Accession No.	3. Recipient's Catalog No.
le and Subtitle SKYLAB 4 VISUAL OBSERVATION PROJECT REPORT		5. Report Date June 1974
		6. Performing Organization Code JSC-09053
7. Author(s) J. L. Kaltenbach, W. B. Lenoir, M. C. McEwen, D. A. Weitenhagen, and V. R. Wilmarth, Editors		8. Performing Organization Report No.
9. Performing Organization Name and Address Lyndon B. Johnson Space Center Houston, Texas 77058		10. Work Unit No. 951-16-00-00-72
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		13. Type of Report and Period Covered Technical Memorandum
		14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

The Skylab 4 Visual Observations Project was undertaken to determine the ways in which man can contribute to future Earth-orbital observational programs. The premission training consisted of 17 hours of lectures by scientists representing 16 disciplines and provided the crewmen information on observational and photographic procedures and the scientific significance of this information. During the Skylab 4 mission, more than 850 observations and 2000 photographs with the 70-millimeter Hasselblad and 35-millimeter Nikon cameras were obtained for many investigative areas. Preliminary results of the project indicate that man can obtain new and unique information to support satellite Earth-survey programs because of his inherent capability to make selective observations, to integrate the information, and to record the data by describing and photographing the observational sites.

17. Key Words (Suggested by Author(s)) Astronaut Training Astronaut Performance Project Planning Mission Operations Photography Earth Resources Information	18. Distribution Statement

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 250	22. Price

ACKNOWLEDGMENTS

The editors wish to express their appreciation to the many individuals at the NASA Lyndon B. Johnson Space Center who provided immeasurable assistance in the preparation of the text and illustrations. Special thanks go to Cecille Haynie for her untiring work in editing this report.

Dedicated to
Colonel Gerald P. Carr, Dr. Edward G. Gibson,
and Colonel William R. Pogue,
the crewmen of the Skylab 4 mission whose
accomplishments made this report possible.

FOREWORD

The purpose of this Project Report is to provide a description of the operations of the project and an early, quick-look assessment of the potential results in the individual investigative disciplines. Part A, prepared by members of the NASA Lyndon B. Johnson Space Center Visual Observations Project Team, describes the background and preparations for the Skylab 4 Visual Observations Project, the equipment and reference materials used by the crewmen, the operation of the project during the mission, and the postflight debriefings. It is intended to provide an understanding of the framework within which the project was carried out.

Part B, prepared by members of the Skylab 4 Visual Observations Project Science Team, is based on the mission transcripts of the crewmen's descriptions of observations, the postflight crew debriefings, and a relatively brief study of the first photographs developed (approximately one-third of the total photographs). Despite the limited analysis completed to date, it is apparent that significant new information has been compiled in some disciplines even at this early stage. Some Earth features are better suited for quick analysis of the Skylab data; as a consequence, those reports can present more dramatic results than others at this time.

The Skylab 4 Visual Observations Project Science Report will be published with color illustrations in a NASA document in the near future. It will present the detailed results of thorough analyses of the photographs and related data and, for some studies, will include the results of field investigations. Although the assessments contained in the present document are preliminary, they should give an indication of what can be expected in the Science Report.

CONTENTS

PART C — RECOMMENDATIONS

PART A

BACKGROUND

1. SUMMARY

The Visual Observations Project Team[a]

The purpose of the Skylab 4 Visual Observations Project was to determine the contributions man can make in Earth observations programs of the future. Ground-based operations were conducted by the Science Team that was composed of scientists from 16 disciplines and by the Visual Observations Project Team at the NASA Lyndon B. Johnson Space Center that specialized in mission operations. To support the project, the Visual Observations Book and the general map package were prepared to provide in-depth background for these phenomena and features identified premission as worthy of scientific study and capable of helping define man's capabilities. In addition to these sites selected preflight, the crewmen were free (within a limited time line) to make observations of features they considered significant. As a result of crewmen initiative, many unanticipated findings were made, such as the extent of icebergs in the South Atlantic, the visibility of the Falkland Current, the ability to study ocean surface phenomena in sunglint, and the ability to monitor snow-melt patterns.

Binoculars and cameras were the primary visual observations instruments used on board Skylab 4. Available camera and lens combinations included wide, medium, and narrow fields of view. More than 2000 photographs were taken during the 850 observations. Observations and photographs were made over the entire range of possible Sun angles (from local twilight to local noon) and viewing angles (from high oblique to vertical).

High Sun angles (more than 50° from the horizontal) were found to be best for making color discriminations, whereas low Sun angles (less than 20° from the horizontal) were best for detection of topographic relief. In general, viewing near the nadir is most desirable; however, oblique views are best for discerning the regional framework. Useful visual observations were made for areas as far away from the satellite point as 500 kilometers. The crewmen could perceive subtle color differences that were not detected in the handheld photography postflight. The time available over any single feature (30 to 40 seconds) permitted either observation and description or photographing, but both operations could not be fully performed.

The use of sunglint was found to be an extremely productive method for observing the surface texture of the oceans and rivers of the Earth. Many ocean current boundaries were easily observed because of color contrast and the presence of plankton blooms. The boundary features and the current rings caused by the confluence of the Falkland Current and the Brazil Current were

---

[a] The members of the Visual Observations Project Team are listed in table 4-III of this report.

observed for more than 3500 kilometers. Before the mission, these features were virtually unknown for this ocean region. In addition, the identification of cold-water eddies in major ocean currents is an important new data source for the study of ocean properties and the air and sea energy exchange.

In the Southern Hemisphere, the crewmen observed the harvesting and subsequent replanting of cereal crops. These observations indicate that a space-based crewman can classify areas with bare soil, bright-green young plants, mature green crops, and crops being harvested. Recording these vegetational patterns and variability within croplands can be accomplished through as much as 75-percent cloud cover. Crop damage was not discernible, but the extent of flood conditions could readily be resolved. In areas of sparse vegetation (such as arid lands), the conditions of the foliage could not be detected. In general, low-contrast areas (e.g., ancient, arid cities such as Addis Ababa) were much less discernible than high-contrast areas (e.g., newer cities such as Dallas). Contrast is best perceived in features near the nadir that are illuminated by high Sun angle.

Geologic observations were made in a study of volcanoes, sand dunes, global tectonics, and the geology of the southwestern United States and northwestern Mexico. A preliminary analysis of the sand-dune data indicates that man in space has the potential to contribute observations on the distribution, colors, shapes, and sizes of dunes and the relationship of the dunes to topographic features, wind directions, and other sand bodies. Information on the color variation, distribution, and wind conditions of the dunes is important for preparing desert classifications and studying the processes that contribute to the formation of deserts.

This mission afforded an excellent opportunity to complete observing and photographing sea ice development in the Gulf of St. Lawrence. The observational data supported by many photographs have provided information on the rapid variability in ice features in very short time intervals, on the morphological change as new ice forms and old ice thickens, and on the overall extent and character of the ice sheet from beginning to maximum coverage. This information can be used directly for ship routing, relating weather to ice extent, and studying the thermodynamics of ice and seawater.

Of the many meteorological phenomena described and photographed, those unresolvable in meteorological satellite images are particularly important to supplement synoptic images to understand such features and to predict meteorological conditions. Determining cloud dimensions, determining wind conditions for extratropical cyclones, studying the formation of jet stream cirrus, and studying the effects of cold air advection over warm water are examples in which better photographic resolution allows further analysis. Important observations and photographs made by the Skylab 4 crewmen have aided the discovery of outward-tilting eyewalls in some tropical storms. This important result requires new thinking in tropical-storm studies. Computer models of tropical storms must include the possibility of sloping eyewalls; presently, they do not.

Photographs and observational data of manmade and natural atmospheric pollution indicate that observations of such features from space can be useful. Descriptions and photographs of many different sources of atmospheric contamination were made that permit postflight analysis of the size, shape, extent, and textural variations of the pollutant as well as wind conditions. As a result of further detailed analyses, source features, atmospheric conditions, diffusion, and other parameters possibly can be related to the occurrence and distribution of the pollutants.

The major limitations on the results of this project were the extremely tight crew time line and the lack of preflight training in rapid site recognition and observation.

Recommendations were made by the Science Team members and the crewmen concerning more comprehensive mission planning and crew training. Suggestions related to the onboard equipment were also offered by the crewmen and the Science Team.

2. PROJECT ORIGIN

The Visual Observations Project Team[a]

Data acquired from manned and unmanned satellites have been used to perform scientific studies of the oceanographic, atmospheric, and terrestrial phenomena of the Earth. The Earth resources experiment package (EREP) expanded these studies through the collection of new and unique information from multispectral sensors with increased spatial and spectral resolution capability. Skylab also provided an opportunity to add another dimension in data acquisition; the skills of the crewmen were used to identify, describe, interpret, and photograph many features and processes pertinent to Earth investigations.

To optimize the collection of scientific data during the 84-day Skylab 4 mission, a Visual Observations Project was established as part of the Skylab experimental program. The primary objectives of this project were as follows:

1. To determine crewmen's capabilities in the visual identification of various types of surface, air, and water phenomena of the Earth that may be observed from the Skylab orbit.

2. To determine what visual observations, supplemented by photography, can accomplish in the support of scientific investigations.

3. To explore possible sources of data and to apply the findings to a number of disciplines.

4. To determine the type of crew training program necessary to perform the visual observations desired by the scientific investigators.

During the Mercury and Gemini missions, 70-millimeter Hasselblad cameras with color exterior film were available to the crewmen for taking handheld photographs of the Earth surface (experiment S005). As part of the premission training, the crewmen received general briefings on the types of features and phenomena of scientific interest. The crewmen used their judgment in selecting additional areas to photograph. During the Mercury and Gemini missions, most scientists were not aware of the value of space photography in the study of Earth environments.

Referring to Gemini photographs, Lowman (refs. 2-1 and 2-2) discussed the advantages of space photography in the analysis of complex geologic areas such

---

[a] The members of the Visual Observations Project Team are listed in table 4-III of this report.

as New Mexico, Baja California, and the northwest Sahara Desert region of Africa.

The prime objective of the Apollo Program was lunar exploration, although the Earth-orbital portions of these missions, particularly the entirely Earth-orbital Apollo 7 and 9 flights, provided an opportunity to obtain handheld photographs of the Earth. The Apollo 7 crewmembers received brief premission training and, as the crewmen did on previous missions, used their own judgment in selecting areas and features to be photographed. The Apollo 9 mission was the first in which the photographic sites were selected during the mission by a team of scientists (ref. 2-3) as part of the S065 multispectral photography experiment.

The Skylab Program, consisting of three manned missions (table 2-I), provided the opportunity to acquire sophisticated Earth resources information with the EREP microwave, infrared, and optical sensors. Operation of EREP was limited to certain predetermined groundtracks because of the spacecraft maneuvering and attitude constraints.

TABLE 2-I.- SKYLAB PROGRAM

Mission no.	Crewmen	Lift-off date	Splashdown date	Days in space
[a]1	Unmanned	May 14, 1973	--	
2	Conrad Kerwin Weitz	May 25, 1973	June 22, 1973	28
3	Bean Garriott Lousma	July 28, 1973	Sept. 25, 1973	59
4	Carr Gibson Pogue	Nov. 16, 1973	Feb. 8, 1974	84

[a] Skylab workshop launched. The workshop operated unmanned between manned missions.

The Skylab 2 crewmen received premission briefings on the geologic, meteorologic, and dim-light features and on short-lived-event phenomena. The onboard data package consisted of an atlas that pictured geologic features, geographic areas, and environmental subjects and of photographs of cloud formations that illustrated atmospheric phenomena for which space photographs would be valuable. The crewmen used these guides in obtaining scientifically useful handheld photographs and observations of Earth features.

The Skylab 3 crewmembers received similar premission briefings on environmental and Earth science; however, a handbook illustrating the specific types of scientific observations and photographs to be obtained for tornadoes, volcanoes, hurricanes, ocean upwellings and circulation patterns, air contamination, and vegetation patterns was prepared for the crewmen to review before lift-off. The onboard data package consisted of the same atlas used by the Skylab 2 crewmembers and a world map package.

Midway through the Skylab 3 mission, the crewmen requested additional work in their time line and, in response to this request, the detailed instructions for observing and photographing 58 specific sites were provided. Based on this information and that contained in the onboard data package, observational data for 35 sites and a total of 1292 photographs of various Earth features were obtained. The crewmen reported difficulty both in locating many of the sites with the onboard maps and aerial photographs and in performing the desired visual observations for most sites.

On the basis of the Skylab 3 experience, a Visual Observations Project was planned for the Skylab 4 mission to determine what photographic and observational data could be acquired by the crewmen when supported by multidisciplinary scientific training before lift-off and by a comprehensive set of procedures, maps, and photographs onboard.

REFERENCES

2-1. Lowman, Paul D., Jr.: Geologic Orbital Photography: Experience From the Gemini Program. Photogrammetria, vol. 24, 1969, pp 77-106.

2-2. Lowman, Paul D., Jr.; and Tiedemann, Herbert A.: Terrain Photography From Gemini Spacecraft: Final Geologic Report. Goddard Space Flight Center, Jan. 1971.

2-3. Lowman, Paul D., Jr.: Apollo 9, Multispectral Photography: Geologic Analysis. Goddard Space Flight Center, Sept. 1969.

3. PREMISSION PREPARATIONS

The Visual Observations Project Team[a]

CREW TRAINING

A Visual Observations Project Science Team, which consisted of 19 scientists representing 16 disciplines, was assembled to brief the crewmen on the scope and purpose of selected scientific investigations and on the types of observational data and handheld photographs required to support and extend these studies (table 3-I). The crew received 17 hours of training according to the schedule listed in table 3-II. Because the Visual Observations Project began late in the Skylab 4 crew training program, only 1 hour of briefing could be provided for each major subject. From discussions with the Science Team, the crewmen gained insight into the significance of observational data and awareness of the type of photographs to be obtained for specific studies.

FLIGHT DATA FILE

The flight data file consisted of the Visual Observations Book, the general map package, and the Earth orbital slider map. The goal of the Flight Planning Branch in preparing the file was to make it as informative and precise yet as compact and useful as possible. The flight data file met the specifications given in table 3-III.

Visual Observations Book

The Visual Observations Book was the primary onboard data source. Prepared by the Flight Planning Branch at the NASA Lyndon B. Johnson Space Center (JSC), with special assistance from the Science Team, it was published on October 26, 1973. Although it was not available during the training phase, the Visual Observations Book would have been an extremely valuable briefing aid. One week before the scheduled launch of Skylab 4, the book was reviewed during a final crew training session held with the Science Team on closed-circuit television. Procedures were clarified, errors were corrected, and several observation sites were added at that time.

---

[a] The members of the Visual Observations Project Team are listed in table 4-III of this report.

TABLE 3-I.- VISUAL OBSERVATIONS PROJECT SCIENCE TEAM

Principal Investigator	Affiliation	Discipline/application
William E. Shenk	NASA Goddard Space Flight Center Greenbelt, Md.	Meteorology
Peter G. Black	National Oceanic and Atmospheric Administration (NOAA), National Hurricane Research Laboratory Coral Gables, Fla.	Hurricanes/typhoons
Robert E. Stevenson	Office of Naval Research, Scripps Institute of Oceanography La Jolla, Calif.	Oceanography
George A. Maul	NOAA, Environmental Research Laboratory Miami, Fla.	Oceanography/currents
William J. Campbell	U.S. Geological Survey Tacoma, Wash.	Sea and lake ice
Darryl Randerson	NOAA, Air Resources Laboratory Las Vegas, Nev.	Air contamination
James C. Barnes	Environmental Research and Technology, Inc. Lexington, Mass.	Snow
David M. Carneggie	University of California Berkeley, Calif.	Vegetational patterns
Norman H. MacLeod	American University Washington, D.C.	Arid land patterns
Robert K. Holz	University of Texas Austin, Tex.	Land use patterns
William Muehlberger	University of Texas Austin, Tex.	Global tectonics
A. T. Joyce[a]	NASA Earth Resources Laboratory Bay St. Louis, Miss.	Cultural patterns
Murray Felsher[a]	Office of Technical Analysis, Environmental Protection Agency Washington, D.C.	Water pollution

[a] Provided crewmen briefings only.

TABLE 3-I.- VISUAL OBSERVATIONS PROJECT SCIENCE TEAM - Concluded

Principal Investigator	Affiliation	Discipline/application
Jules D. Friedman	U.S. Geological Survey Denver, Colo.	Volcanoes
Grant Heiken	NASA Lyndon B. Johnson Space Center (JSC) Houston, Tex.	Volcanoes
Leon T. Silver	California Institute of Technology Pasadena, Calif.	Continental shield areas
Richard H. Jahns	Stanford University Stanford, Calif.	Environmental geology
Edwin D. McKee	U.S. Geological Survey Denver, Colo.	Deserts
Carol S. Breed	U.S. Geological Survey Flagstaff, Ariz.	Deserts
David E. Pitts	JSC Houston, Tex.	Severe storms
J. T. Lee	NOAA University of Oklahoma	Severe storms

TABLE 3-II.- SCIENCE TEAM LECTURE SCHEDULE
FOR SKYLAB 4 CREWMEN

Lecture no.	Date, 1973	Time	Topic	Lecturer
1	Aug. 13	1:30 p.m.	Atmosphere	William E. Shenk
2		2:30 p.m.	Oceans: circulation and sedimentation patterns	Robert E. Stevenson
3	Aug. 17	1:30 p.m.	Hurricanes/typhoons	Peter G. Black
4		4:30 p.m.	Severe storms	David Pitts J. T. Lee
5	Sept. 15	8 a.m.	Deep ocean currents, upwelling, and chlorophyll bloom	George Maul
6		9 a.m.	Sea ice and associated phenomena	William J. Campbell
7		10 a.m.	Snow patterns	James C. Barnes
8		11 a.m.	Volcanoes: eruption features and associated phenomena	Jules D. Friedman

TABLE 3-II.- SCIENCE TEAM LECTURE SCHEDULE FOR SKYLAB 4 CREWMEN - Concluded

Lecture no.	Date, 1973	Time	Topic	Lecturer
9	Sept. 22	8 a.m.	Arid land patterns	Norman H. MacLeod
10		9 a.m.	Cultural patterns	A. T. Joyce
11		10 a.m.	Vegetational patterns	David M. Carneggie
12		11 a.m.	Regional relationships of land use patterns	Robert K. Holz
13	Sept. 29	8 a.m.	Air pollution patterns	Darryl Randerson
14		9 a.m.	Water pollution	Murray Felsher
15	Oct. 8	8 a.m.	Environmental geology, ore deposits, deserts	Richard H. Jahns
16		9 a.m.	Global tectonics	William Muehlberger
17		10 a.m.	Continental shield areas	Leon T. Silver

TABLE 3-III.- FLIGHT DATA FILE SPECIFICATIONS

Item	Dimensions, cm	Total weight, kg	Material
Visual Observations Book	20.3 by 25.4 (paper)	2.25	JCP[a] K-10 (text); Kodak RC-37 (photographs)
	21.6 by 26.7 (cover)	--	--
General map package	43.2 by 55.9	1.40	Kodak RC-37
Earth orbital slider map	47.9 by 49.5	.53	JCP E-20 (map); artist illustration board (reinforcement); [b]CEN-7 (transparency)

[a] Joint Committee on Printing.

[b] Cronar engineering negative.

Information in the Visual Observations Book was divided into the following major sections: atmosphere, tropical storms, snow mapping, ocean features, sea and lake ice, volcanoes, desert, African drought, cultural patterns, geology, vegetation patterns, water contaminants, air contaminants, and dim-light photography. A general discussion was included in each section to provide the crewmen with a brief background of the subject, an explanation of features and processes, and the scientific objective of the observation. The specific sites in each of the 14 sections were identified as handheld (HH) and numbered (table 3-IV). (The observational and photographic sites are shown by investigative areas in figure 3-1). When additional sites and phenomena were identified during the mission, the crewmembers received information (scientific objectives, descriptions of the site or the feature, and photographic procedures) on the teleprinter. An example of the information provided for the crewmen on the additional sites is shown in figure 3-2.

To facilitate use of the book, the data for each site were arranged in the following sequence: description, location, procedure, objective, and camera data (fig. 3-3). When available, photographs and drawings were used to show the area of interest or to give an example of the type of feature to be studied. The photographs that were included were obtained from the Gemini and Apollo Programs, the Skylab 2 and 3 missions, the Earth Resources Technology Satellite (ERTS) multispectral scanner, and various aircraft flights. Photographic support for the Visual Observations Book was provided by the Defense Mapping Agency (Aerospace Center) in St. Louis, Missouri. Each section of the book was tabbed along the top and each site was tabbed along the right edge. This method enabled the crewmen to use the site tabs for scheduled sites and the section tabs when particular phenomena were observed as "sites of opportunity."

The photographs in the Visual Observations Book were dry mounted back to back whenever practical so that the site descriptions and procedures faced the photographic examples. Three service support contractors required approximately 100 man-hours to complete the fabrication.

General Map Package

The general map package consisted of 17 geographical maps, a world coverage index map, world physiography maps, a seismology map, and a world natural-vegetation map. The maps were cut and bound with rings for launch stowage.

The 1:10,000,000-scale geographical maps were photoreduced from the 1:5,000,000-scale global navigation charts produced by the Defense Mapping Agency for general aircraft use. The index map was photoreduced from the Skylab Earth orbital chart and showed the coverage of each of the geographical maps. The world physiography and natural vegetation maps were photocopied from the 1971 edition of "The Times Atlas of the World."

The locations of the sites in the Visual Observations Book, with the exception of atmospheric and oceanographic phenomena, were shown on the

TABLE 3-IV.- VISUAL OBSERVATIONS SITES

Site no.	Description
	Atmosphere
HH01	Bénard cells in trade wind cumulus
HH02	Effects of islands on wind currents
HH03	Orographic influences on convection over mountains
HH04	Mountain waves (rotor clouds)
HH05	Convection in cold air passing over warm water
HH06	Jet stream cirrus
[a]HH06A	Strong jet stream formation
HH07	Squalls in the lee of a large lake
HH08	Cloud streets
HH09	Kármán vortices
HH10	Cumulonimbus buildup in intertropical convergence zone
	Tropical storms
HH15A	Prestorm squall line
HH15B	Cloud-free moat
HH15C	Cirrus streaks and waves
HH15D	Overshooting cloud tops
HH15E	Circular exhaust cloud
HH15F	Fine-scale eye structure
HH15G	Feeder band

[a] Sites added to the Skylab 4 Visual Observations Book during the mission.

TABLE 3-IV.- VISUAL OBSERVATIONS SITES - Continued

Site no.	Description
	Snow mapping
HH20	Snow patterns in Great Plains of U.S.
HH21	Mount Rainier and Mount Adams
HH22	Snow patterns in mountain areas of U.S.
HH23	Salt-Verde watershed
HH24	Kings River Basin
	Ocean features
HH30	Current boundaries
[a]HH30A	Current flow, southern Chile
HH31	Ocean water transparency and coloration
HH32	Upwelling water and plankton blooms
HH33	Current eddies
[a]HH33A	Cold eddies in warm water
HH34	Island wakes and vortices
[a]HH34A	Turbulent wakes behind Pacific islands
HH35	Seamounts and shoals
HH36	Internal waves
HH37	Coastal sediment plumes
[a]HH37A	River deltas
HH38	Lake circulation

[a] Sites added to the Skylab 4 Visual Observations Book during the mission.

TABLE 3-IV.- VISUAL OBSERVATIONS SITES - Continued

Site no.	Description
	Sea and lake ice
HH45	Sea ice (Gulf of St. Lawrence)
HH46	Lake ice (Lake Ontario)
HH47	Ice plumes and pack ice formation
HH48	Ice floes
HH49	Sea ice pressure ridges
	Volcanoes
HH55	Volcanic eruption clouds
HH56	Sierra Madre Occidental volcanic field
HH57	Hawaii shield volcanoes
HH58	Mount Lassen volcanic dome
HH59	Galapagos Island - volcanic activity
HH60	Afar Triangle and rift system of Eastern Africa
	Deserts
HH65	Dune field on the southern shore of Bagrash Lake in China
HH66	Dunes of the eastern Takla Makan Desert in China
HH67	Disrupted dunes in southern Takla Makan Desert in China
HH68	Individual star dunes of northeastern Algeria
HH69	Star dune chains in Algeria
HH70	Reticulate dune field in northeastern Algeria

TABLE 3-IV.- VISUAL OBSERVATIONS SITES - Continued

Site no.	Description
	Deserts - Concluded
HH71	Dune ridges in Mali
HH72	Dunes in the southern Peski Kara Kum region of the U.S.S.R.
HH73	Dunes in the northern Peski Kara Kum region of the U.S.S.R.
HH74	Dunes in the Peski Kyzl Kum region of the U.S.S.R.
HH75	Dunes of the Gobi Desert in northern China
HH76	Dunes of the eastern Gobi Desert
HH77	Disrupted dunes of the Namib Desert in South West Africa
HH78	Dunes of the northern Namib Desert in South West Africa
HH79	Dunes of Nama Land in South West Africa
HH80	Star dunes of the southern Empty Quarter in Saudi Arabia
HH81	Dune varieties in the Empty Quarter in Saudi Arabia
HH82	Kalahari Desert in southwestern Africa
HH83	Guajira Peninsula in Colombia
HH84	Bedrock structures in the Sahara Desert
	African drought
HH90	Inland delta of the Niger River
HH91	Soil erosion in Mali and Niger

TABLE 3-IV.- VISUAL OBSERVATIONS SITES - Continued

Site no.	Description
	African drought - Concluded
HH92	Interdunal vegetation
HH93	Saharan massifs drainage systems
HH94	Black Volta and White Volta River Basin
	Cultural patterns
HH100	Ozark Plateau and Ouachita province
HH101	Metropolitan development patterns
HH102	Plain of Nazca in Peru
[a]HH103	Nepal
	Geology
HH105	Philippine Fault in the circum-Pacific fault zone
HH106	Atacama Fault in the circum-Pacific fault zone
HH107	Alpine Fault in the circum-Pacific fault zone
HH108	San Andreas Fault in the circum-Pacific fault zone
HH109	Fault zones in Central America
HH110	Afar Triangle and rift system of eastern Africa
HH111	Northern Baja California, Mexico
HH112	Sierra Mazatan, Sonora, Mexico
HH113	Northwestern Sonoran coast fault zones
HH114	Sierra del Alamo

[a] Sites added to the Skylab 4 Visual Observations Book during the mission.

TABLE 3-IV.- VISUAL OBSERVATIONS SITES - Continued

Site no.	Description
	Geology - Concluded
HH115	Mexican earthquake areas
HH116	Alice Springs, Australia
HH117	Big Horn Mountains of Wyoming
HH118	Southern Chile and Argentina
HH119	Other major fault zones
[a]HH119A	Onshore extension of Romanche fracture zone
HH120	Germany-Italy region
HH121	Spain
HH122	Channeled Scablands of Washington
HH123	Colorado and Guadalupe River Basins
HH124	Bolivia
[a]HH124A	Pikelot Island
[a]HH124B	Ascension Island
HH125	Southeastern Arizona
HH126	Central Arizona linear features
	Vegetational patterns
HH140	Patterns in wheat production
HH146	Rangeland patterns
HH147	Forest fires and range fires

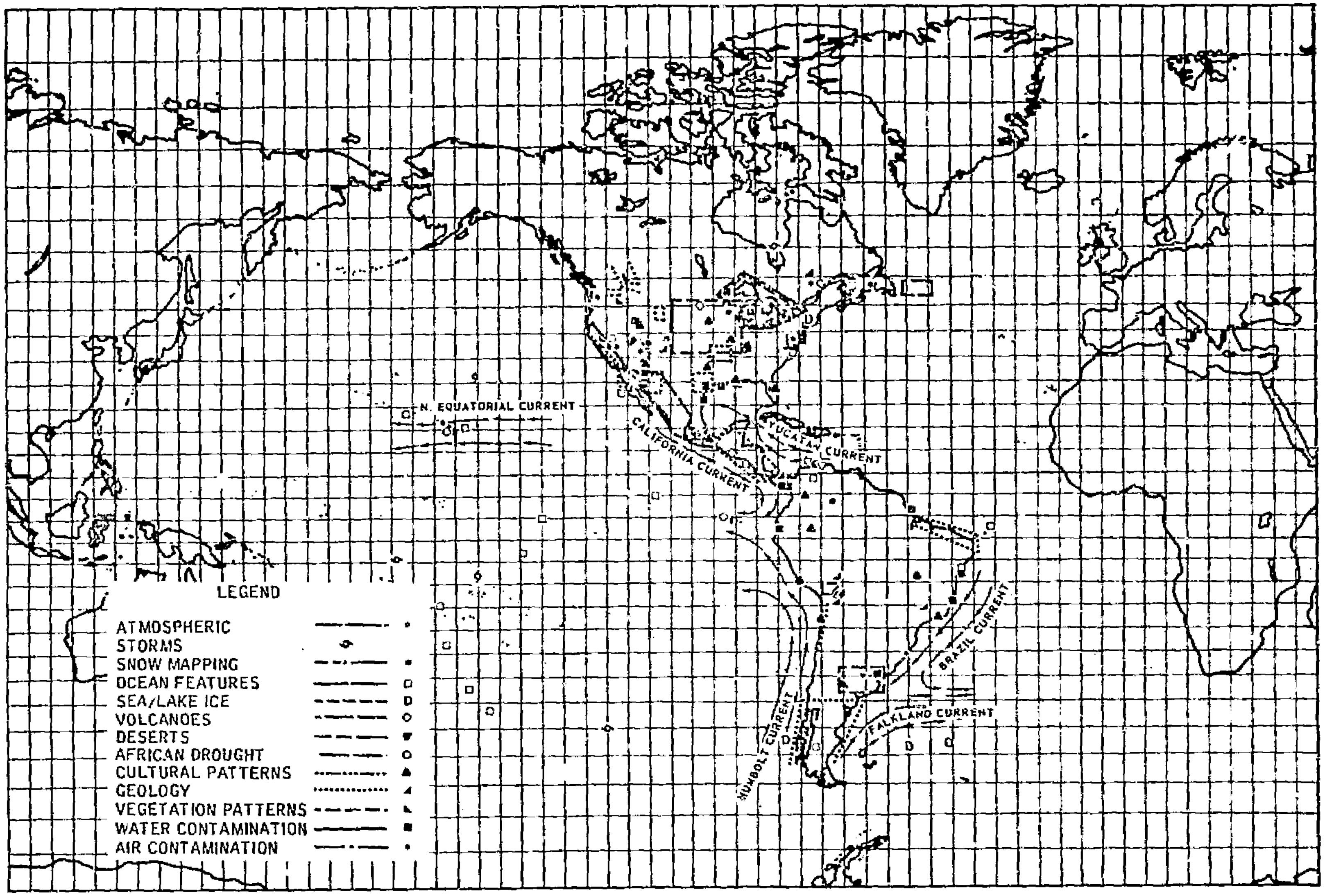
[a] Sites added to the Skylab 4 Visual Observations Book during the mission.

TABLE 3-IV.- VISUAL OBSERVATIONS SITES - Concluded

Site no.	Description
	Vegetational patterns - Concluded
HH148	Fire scars from 1973 forest fires
HH149	Insect and disease infestation
HH150	El Sudd Swamp in southern Sudan
HH151	Okavango Swamp in northern Botswana
HH152	Land use patterns in Malaysia
HH153	Northern Australia drought
[a]HH154A	Asian wetlands
[a]HH154B	Thailand resources
[a]HH154C	Florida green swamp
	Water contaminants
HH155	Urban area water contaminants
HH156	Oil slicks
	Air contaminants
HH163	Smoke plumes and smog
HH164	Jet and ship contrails
HH165	Duststorms
	Dim-light photography
[a]HH171	Low-light photography

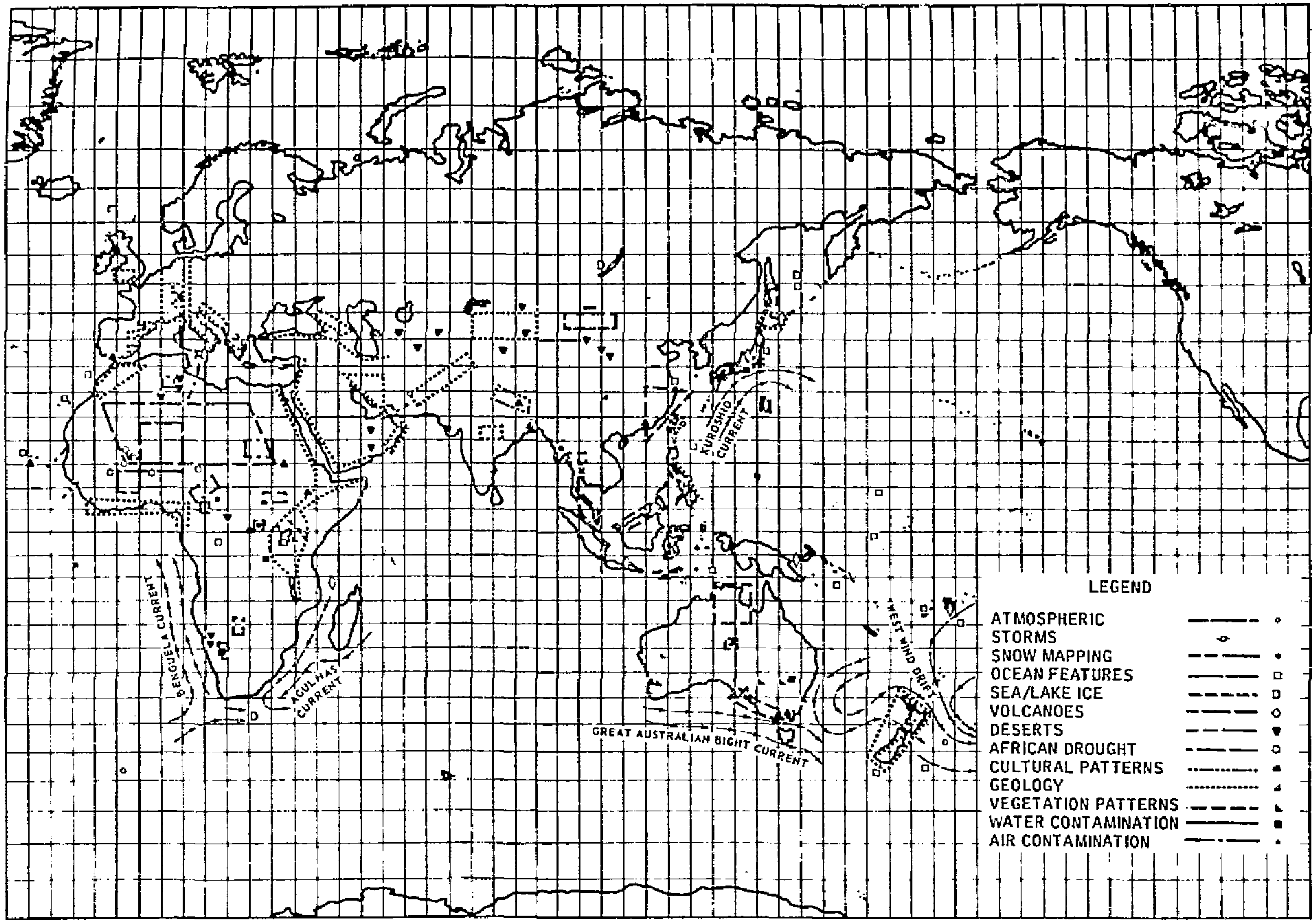
[a] Sites added to the Skylab 4 Visual Observations Book during the mission.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR



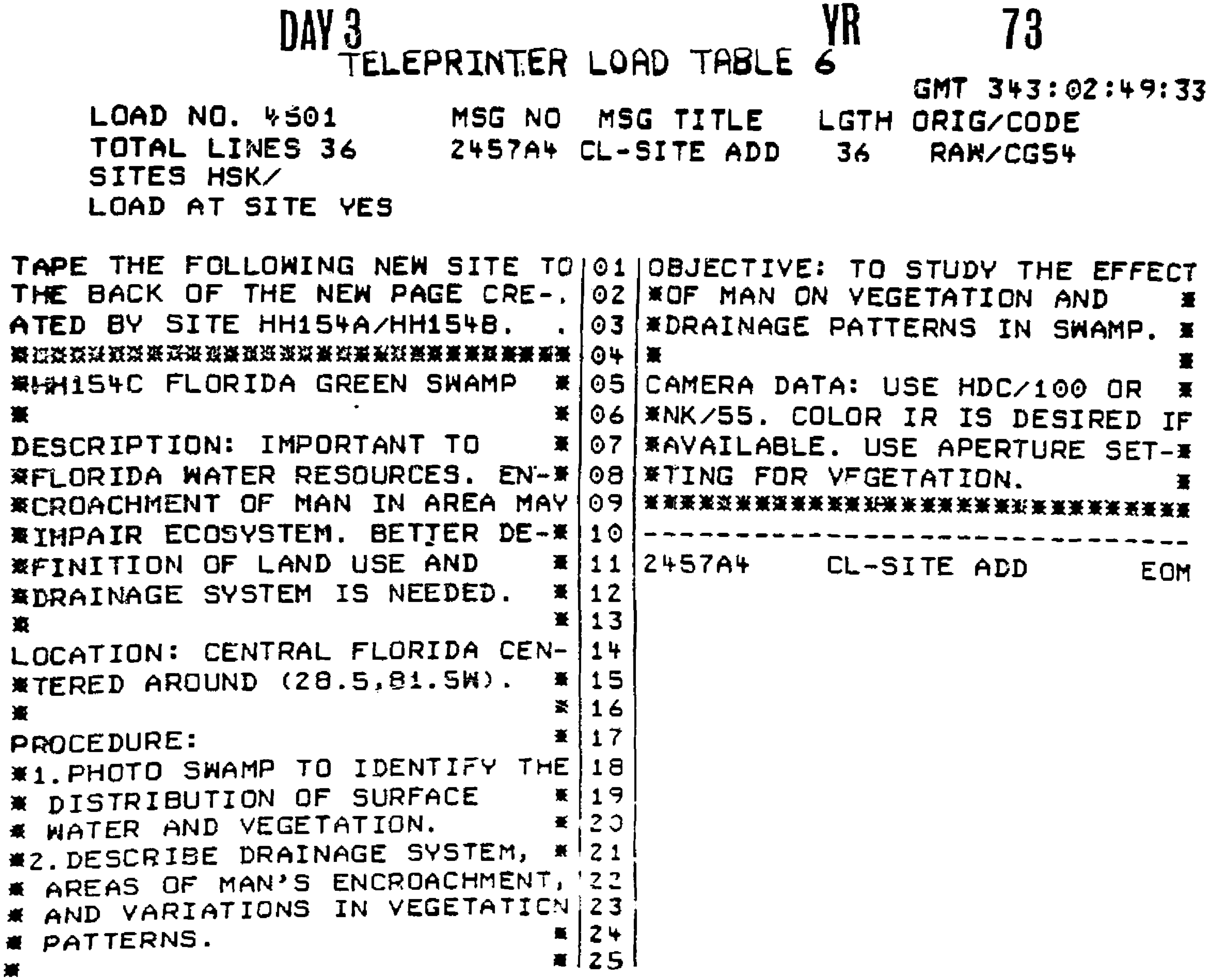
(a) Western hemisphere.

Figure 3-1.- Skylab visual observations sites (by investigative area).



(b) Eastern hemisphere.

Figure 3-1.- Concluded.



```
DAY 3                                        YR          73
           TELEPRINTER LOAD TABLE 6
                                                   GMT 343:02:49:33
LOAD NO. 4501         MSG NO  MSG TITLE    LGTH ORIG/CODE
TOTAL LINES 36        2457A4 CL-SITE ADD    36    RAW/CG54
SITES HSK/
LOAD AT SITE YES

TAPE THE FOLLOWING NEW SITE TO|01|OBJECTIVE: TO STUDY THE EFFECT
THE BACK OF THE NEW PAGE CRE-.|02|*OF MAN ON VEGETATION AND     *
ATED BY SITE HH154A/HH154B.  .|03|*DRAINAGE PATTERNS IN SWAMP. *
******************************|04|*                            *
*HH154C FLORIDA GREEN SWAMP  *|05|CAMERA DATA: USE HDC/100 OR  *
*                            *|06|*NK/55. COLOR IR IS DESIRED IF
DESCRIPTION: IMPORTANT TO    *|07|*AVAILABLE. USE APERTURE SET-*
*FLORIDA WATER RESOURCES. EN-*|08|*TING FOR VEGETATION.        *
*CROACHMENT OF MAN IN AREA MAY|09|******************************
*IMPAIR ECOSYSTEM. BETTER DE-*|10|------------------------------
*FINITION OF LAND USE AND    *|11|2457A4    CL-SITE ADD      EOM
*DRAINAGE SYSTEM IS NEEDED.  *|12|
*                            *|13|
LOCATION: CENTRAL FLORIDA CEN-|14|
*TERED AROUND (28.5,81.5W).  *|15|
*                            *|16|
PROCEDURE:                   *|17|
*1.PHOTO SWAMP TO IDENTIFY THE|18|
* DISTRIBUTION OF SURFACE    *|19|
* WATER AND VEGETATION.      *|20|
*2.DESCRIBE DRAINAGE SYSTEM, *|21|
* AREAS OF MAN'S ENCROACHMENT,|22|
* AND VARIATIONS IN VEGETATION|23|
* PATTERNS.                  *|24|
                             *|25|
*
```

Figure 3-2.- Example of the format used for new observation site information uplinked to the flightcrew during the mission.

HH140 PATTERNS IN WHEAT PRODUCTION

DESCRIPTION: Wheat is one of the major cereal crops of the world and illustrates typical farming vegetation patterns. The major wheat growing regions are shown in Ex. 11-1. SL-4 will be able to observe wheat in every phase of its developmental cycle. Winter wheat production in the northern hemishere (U.S. and Russia) will be in stages of planting, germination, and early growth. Its yield depends on snow cover to prevent loss due to freezing. In the southern hemisphere wheat will be in various states of maturity ranging from the harvesting (yellow) near the equator to the growing plants (yellow to green), at the higher latitudes.

LOCATION: There are five major winter wheat areas of the world:

P.1 (1) South Dakota - centered around 45 00'N, 100 00'W

P.1 (2) E. Montana - centered around 47 00'N, 105 00'W

P.1 (3) Kansas - centered around 38 00'N, 100 00'W

P.3 (4) Argentina - centered around 25 00'S, 60 00'W

P.13 (5) Australia - centered around 32 00'S, 145 00'E

PROCEDURE:

1. Photograph the winter wheat area to record snow cover patterns and growth cycles.
2. Describe the color patterns in the area and any changes that occur during the mission, particular any small scale color anomalies that may indicate stressed conditions.

OBJECTION:

To determine the usefulness of space observations in the study of crop conditions.

CAMERA DATA:

Use Hasselblad/100mm or Nikon/55mm. Color IR film is desired if available. Use aperture setting for GENERAL or VEGETATION, depending coloration.

Figure 3-3.- Example of the format used for handheld sites in the actual Visual Observations Book.

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

geographical maps. To aid in quick identification of a specific site on the map, the map page number was listed opposite the site location in the book.

The pages of the onboard general map package were dry mounted back to back to conserve space and to facilitate handling. To ensure good bonding, the photographic paper was roughened by sanding before the mounting procedure. Approximately 70 man-hours were required by the NASA personnel and two service support contractors to complete the map package. An additional 30 man-hours were spent annotating the visual observations sites on these maps.

Earth Orbital Slider Map

A shaded relief map at a scale of 1:40,000,000 was used with two transparent overlays. One overlay designated observation sites; the other marked respective orbital paths and times of approach. With ascending node data supplied daily by the Mission Control Center (MCC), the crewmen used the map to predict which visual observations sites would be sighted and the time of closest approach.

With North and South America on one side and Europe, Asia, Africa, and Australia on the opposite side, two parts of a map were attached to a cardboard reinforcement. The first overlay was superimposed over the map segments and taped down by the crewmen. The second, which had the schemes of the orbital paths, was taped so that it formed a full track and could slide freely. Two metal strips with tiny hingelike rollers were affixed to the left and right sides of the map to facilitate movement of the top overlay. Thus, the crewmen were able to identify observation sites in a specific orbit at a specific time.

4. OPERATIONS

The Visual Observations Project Team[a]

VISUAL OBSERVATIONS FLIGHT INSTRUMENTS

The Visual Observations Project equipment used by the crewmen included various types of cameras. The camera and film types used by the Skylab 4 crewmen are shown in table 4-I. The binoculars that were available on board are shown in table 4-II.

MISSION OPERATIONS

The JSC Visual Observations Team

The Visual Observations Project planning activities during the Skylab 4 mission were conducted in real time by the JSC Visual Observations Team (table 4-III). The JSC Team, which was responsible for the overall project operations, selected and scheduled observation (or handheld camera) sites, made recommendations on photography, maintained a status log of photographic accomplishments, and conducted weekly science conferences with the crewmen. To accomplish these tasks, the JSC Team consulted frequently with the Science Team members.

The two primary functions of the JSC Team were selecting and scheduling the visual observations sites. The selection process was accomplished through daily meetings of the JSC Visual Observations Team members. During a meeting, a preliminary list of observation sites was prepared for 3 days hence, a final list of sites for 2 days hence, and supporting information messages (called Visual Observations preadvisory data (PAD) messages) for sites scheduled the next day. This 3-day advance planning provided adequate lead time for incorporating the handheld camera sites into the flight plans and the crewmen time lines. Additional functions of the JSC Team included modification or addition of sites and consideration of daily reports from the Center for Short-Lived Phenomena, Smithsonian Institution, and of input from the Science Team for observation by the crewmen. Selection of the handheld camera sites during the mission was based on current accomplishments, calculated Sun angle, groundtrack availability, global weather conditions, and Science Team recommendations.

---

[a] The members of the Visual Observations Project Team are listed in table 4-III of this report.

TABLE 4-I.- ONBOARD CAMERA EQUIPMENT

Camera	Quantity	Lens focal length, mm	Field of view, deg	Nadir coverage (altitude 427.5 km), km	Film size and type
Hasselblad	1	100	29.2 by 29.2	223 by 223	70-mm CX[a]
Nikon	5	55	24 by 36	182 by 278	35-mm CX, BV,[b] IR[c]
		300	4.5 by 6.8	34 by 51	
Maurer data acquisition camera	1	5	80.2 by 117.5	720 by 1409	16-mm CX
		10	41.1 by 54.9	321 by 444	
		18	23.4 by 32.6	177 by 250	
		25	17.1 by 23.5	129 by 178	
		75	4.4 by 6.0	33 by 45	
		100	4.3 by 5.9	32 by 44	
Westinghouse color television	1	25 to 150 (zoom)	--	--	--

[a] Color exterior; SO 368, Ektachrome M5, color-reversal film, ASA 64.

[b] Very-high-speed-black-and-white film; 2485 high speed panchromatic with extended red sensitivity, ASA 6000.

[c] Color infrared; 2443, aerochrome IR color film, ASA 125.

TABLE 4-II.- BINOCULARS USED ON BOARD SKYLAB 4

Type	Magnification	Field of view, deg
Leitz binocular	10 × 40	7
Mark Systems stabilized image binocular, model 1610[a]	10 × 50	5
	20 × 50	2.5

[a] A switch on this model enabled the operator to choose between two magnifications and fields of view.

TABLE 4-III.- THE JSC VISUAL OBSERVATIONS PROJECT TEAM

Team member	Background and responsibility
John L. Kaltenbach Skylab project scientist	Image interpretation specialist with 20 years experience in use of photographic data in geology, cartography, and hydrology.
William B. Lenoir Scientist astronaut	Specialist in remote sensing of planetary atmospheres; served as backup science pilot for the Skylab 4 mission.
Michael C. McEwen Geologist	Trained Apollo lunar surface and orbital crewmen and coordinated JSC support of visual observations and handheld camera photography for final three Apollo missions.
Ronald A. Weitenhagen	Responsible for preparation of onboard data packages for the Skylab Earth Resources experiment package (EREP) and Visual Observations Project; additional activities include Apollo and Skylab crew training and related simulation programs.
V. R. Wilmarth Earth Observations Program scientist	Responsible for Skylab EREP scientific program; many years experience in terrestrial and lunar science programs.

Before the meeting, a list was prepared of all the possible handheld sites that would be available to the crewmen during the working portion of the day. From this list, the appropriate sites (usually fewer than 10) were selected, photographic specifications were determined, and those sites requiring visual observations PAD messages (sighting and observational data) were identified. Frequent telephone consultations were held with members of the Science Team to obtain their recommendations for future site selections or photographic procedures. During the Skylab 4 mission, on December 14, 1973, a meeting was conducted at JSC to assess accomplishments so that future team operations could be planned and end-of-mission reporting plans could be devised.

The JSC Team reviewed the voice transcriptions from the Skylab 4 crewmen daily and prepared them for shipment to the Science Team members. The JSC Team also prepared a daily status report that identified the handheld camera sites observed and photographed and that had a summary of and comments on the crewmen's observations. For each photograph, the camera and film type, frame number, f-stop, lens, and predicted quality of the photograph were listed. The Flight Operations Management Team received copies of this daily status log to include in their daily reports.

The weekly science conference with the crewmen was important to the visual observations activities. These conferences, which lasted approximately 10 minutes, were conducted to maintain a close working relationship between the crewmembers and the JSC Team, to provide the crewmen with assessments and highlights of their activities, and to review the plans for the following week. Because of the need to maintain their perspective of the value of their visual observation tasks, the crewmen welcomed these conferences.

Mission Control Center

The MCC was responsible for real-time control of all aspects of the mission. In addition, the staff in the Earth resources experiment package (EREP) Science Support Room (SSR) in the MCC supported the operations by preparing the teleprinter messages that were sent daily to the crewmen.

The EREP SSR staff in the MCC was composed of two groups responsible for preparing and submitting calculations that concerned possible observations sites and for preparing detailed PAD messages that concerned changes in or additions to the Visual Observations Book. The "Plan Operations" personnel in the SSR used the Activity Scheduling Computer Program to determine the time of closest approach of the spacecraft to the observation site, the optimum spacecraft viewing window, the approximate look angle from the spacecraft to the site, and the approximate Sun angle. With this information, "Truth Operations" personnel prepared the PAD messages, coordinated the scheduling of the observation sites, and formulated necessary changes in the Visual Observations Book to be uplinked to the crewmen.

The handheld camera sites were scheduled in the Crewman Detail PAD messages according to the format shown in figure 4-1. Sites were designated as scheduled or optional but time was allowed only for scheduled sites. Optional

```
1234 (OPT) 1239:21 HH30-12
     SA46 S190 HDC/100 (PAD)

1345 (SCH) 1350:47 HH59 SA34
     S2 NK/300

1527 (OPT) 1532:35 HH30A SA29
     WARD HDC/100 (PAD)

1912 (OPT) 1917:58 HH140-5
     SA23 S1 NK03/55/CX

2154 (SCH) 2159:00 HH148-7
     SA45 S190 HDC/100

2235 (OPT) 2240:13 HH149-1
     SA21 WARD 235,000,325
     NK02/300/IR (PAD)

2317 (OPT) 2322:46 HH120 SA20
     WARD
```

(a) Example of sites.

```
Crew on-station time for review of procedures
|
|     Optional or Scheduled
|     |
|     |      Time of closest approach to center of window
|     |      |
|     |      |         Site number
|     |      |         |
|     |      |         |         Sun elevation angle
|     |      |         |         |
|     |      |         |         |     Optimum window
|     |      |         |         |     |
2235 (OPT) 2240:13 HH149-1 SA21 WARD
     235,000,325 NK02/300/IR (PAD)
     |           |             |
     |           |             Additional information will be uplinked
     |           |
     |           Camera/lens/film, if required
     |
     Camera bracket angles, if required
```

(b) Explanation of format.

Figure 4-1.- Visual observations sites on the crewmen's detail PAD's.

site listings were supplied to the crewmen for information and guidance purposes should time to observe become available. The PAD messages were reviewed and accepted by the EREP Officer, Flight Activity Officer, Capsule Communicator (CAPCOM), and Flight Director before being scheduled in the daily flight plan.

Real-time discussions between the crewmen and the ground on the subject of visual observations were minimal. Usually, the crewmen understood the requirements and executed them; however, when questions arose, the crewmen related them to the CAPCOM during a convenient station pass. The CAPCOM would pass the query to the EREP Officer, who would contact a member of the JSC Team. Usually, the response would be uplinked on a teleprinter message the next day, although on several occasions a near-real-time response was given with a minimal time lapse. The EREP Officer/JSC Team interface was of critical importance, and future manned missions could benefit from further training and organization in this area.

The Skylab 4 Crewmen

The detailed PAD messages included information on visual observations sites. (Later in the mission, this information appeared in a separate message, the optional handheld camera site listing.) If additional observational data or background information were required, a visual observations PAD was also included. With this information and the flight data file, the crewmen could perform the scheduled observations at the appropriate time. In addition, they would try to observe or photograph as many of the optional sites as possible. The greatest amount of information was taken on a site-of-opportunity basis, in which a crewman who had a few free minutes would look out the window for a region or phenomenon of interest to the project. Then, based on his training and accumulated on-the-job experience, he would perform the appropriate observation and take the necessary photographs.

After observing and photographing a site, the crewmen's recorded debriefings were telemetered to ground stations. In addition to the information requested by the Visual Observations Book for a site, the time the photograph was taken, length of exposure, camera settings, film magazine, filters, estimated viewing angle, and Earth surface conditions were recorded. Transcriptions of these debriefings were extremely useful to the JSC Team in planning future sites. Coupled with the actual photographs, they are prime data for postflight analysis.

Visual Observations Project Science Team

Members of the Science Team participated in the mission operations [illegible] frequent telephone consultations with the JSC Team. The individual Science Team members received copies of the transcribed debriefings as soon as possible during the mission. Data from the transcriptions served to keep the Science Team members abreast of the proceedings in their respective areas of interest.

CREW DEBRIEFING

The Visual Observations Project crew debriefing, which required approximately 27 hours, was completed on March 20, 1974 (table 4-IV). In addition to the JSC Visual Observations Team members, the Science Team members, and the Skylab 4 crewmen, the debriefings were attended by the crewmembers for the Apollo-Soyuz Test Project (ASTP), the Principal Investigator for the Earth Observations and Photography Experiment for ASTP, and several members of the Flight Operations Directorate, who are involved in mission planning for the ASTP.

The debriefings, which consisted of a review and a discussion of each investigative area, were conducted jointly by the JSC Team and the members of the Science Team from the appropriate discipline. The purpose of the debriefing was to obtain additional information on specific features or phenomena observed or photographed by the crewmen. Before each debriefing, members of both the JSC Team and the Science Team outlined the agenda of the debriefing and prepared the appropriate photographic displays. The actual debriefings were conducted by the Science Team members and recorded professionally. Transcripts of the debriefing were provided to the Science Team members for use in preparing project reports. A meeting of the JSC Team and the Science Team members was held after the debriefing to define the scientific and operational highlights that resulted from the session.

The scope of the debriefing was limited to a review and evaluation of the Hasselblad 70-millimeter photographs and the transcriptions of the air-to-ground tapes that were recorded in real time during the mission. Because the Nikon 35-millimeter photographs were not available for this debriefing, additional discussions will be held with the crewmembers to resolve specific questions and to review results of the analysis of those photographs.

The informal debriefing provided the opportunity for the discipline scientist to examine in detail the photographic material obtained during Skylab missions with the crewmen and to resolve scientific and operational questions. Information on photographic procedures, viewing angles, use of cameras and film, relationship between the photograph and crewmen's observations, and a host of specific questions on oceanographic, atmospheric, and terrain phenomena were obtained.

In addition to the scientific value, the debriefing data will be used to provide guidelines for planning the Earth Observations and Photography Experiment for the 1975 ASTP mission.

TABLE 4-IV.- CREW DEBRIEFING SCHEDULE

Date, 1974	Time	Subject	Team member
March 12	8 a.m. to 12 m.	Geology	William Muehlberger Leon T. Silver
March 13	8 a.m. to 10 a.m.	Volcanoes	Jules D. Friedman Grant Heiken
	10 a.m. to 12 m.	Deserts	Edwin D. McKee Carol S. Breed
March 14	8 a.m. to 9 a.m.	General discussion	JSC Visual Observations Team
	9 a.m. to 12 m.	Vegetational patterns	David Carneggie
March 15	2 p.m. to 4 p.m.	Sea and lake ice	William J. Campbell
	5 p.m. to 5:30 p.m.	Air contamination	Darryl Randerson
March 18	10:30 a.m. to 12:30 p.m.	Snow mapping	James C. Barnes
	2:30 p.m. to 3:30 p.m.	Tropical storms	Peter G. Black
March 19	8 a.m. to 12 m.	Oceans	Robert E. Stevenson George Maul
March 20	1 p.m. to 3 p.m.	Cultural patterns	Robert K. Holz
	3 p.m. to 4 p.m.	African drought	Norman MacLeod
	4 p.m. to 5 p.m.	Dim-light features	L. Dunkelman

5. THE ROLE OF MAN IN SPACE

The Visual Observations Project Team[a]

Determining the role of the crewman in making Earth observations from space was a primary goal of the Visual Observations Project. This project used the crewmen's capabilities to act as discriminating viewers able to integrate preflight training and on-the-job experience. Results of the project confirm that man's abilities to observe, describe, reason, select, and modify provide distinct advantages in making many Earth observations.

During the Skylab 4 mission, some of the visual observations sites were scheduled in the crewmen's Flight Plan and others were recommended for observing and photographing but not scheduled. Approximately 75 percent of the observations, however, were planned and performed at the crewmembers' initiative in real time. Their choices were based on preflight training, observational experience earlier in the mission, recommendations from the Visual Observations Book, teleprinter messages, and conferences with the Visual Observations Project Team. The following discussion presents an assessment of man's unique capabilities in making visual observations of Earth features based on Skylab 4 mission experience. The examples given are discussed in greater detail in the preliminary reports that follow. In this section, however, the emphasis is placed on the application of man's abilities in general.

The human eye is extremely sensitive to numerous parameters, such as color, texture, size, and shape. Man is also able to compare different global areas; to detect regional differences in color, texture, and patterns; and to direct temporal changes in a given area. Such comparative data have application even though different conditions prevail in the regions. The crewman's ability to mentally remove the effects of different conditions of haze, viewing angle, and illumination is unique. Conditions such as haze and cirrus clouds that may seriously degrade single photographs are not always such a serious hindrance to continuous observation from a moving space platform. The "picket fence" effect permits observations around and under cloud cover. In addition, man's eyes are more capable of perceiving color and a much larger dynamic range than the film used in this project. However, man has less ability to accurately record and store his findings. In this regard, crewman ability and equipment capability complement one another well.

In manmade geometric field patterns, colors, sizes, and shapes can be detected and classified through as much as 75-percent cloud cover. However, in

---

[a] The members of the Visual Observations Project Team are listed in table 4-III of this report.

regions where land use patterns are less geometric, such as in the arid lands of Mali, such recognition and classification is much more difficult. Perception is also difficult in areas of low contrast, such as older cities constructed of local building materials. Cities constructed of materials foreign to the area are more easily discerned. Additional training may enable better recognition in the lower contrast areas as well.

Dynamic features such as ice and snow cover are also easily observed; significant changes in ice structure in the Gulf of St. Lawrence were noted on consecutive revolutions (approximately 90 minutes apart). Daily changes in snow cover (even hourly during a snowstorm) were observable, as were snow melting patterns.

The Skylab 4 crewmen have demonstrated that a trained observer can detect color changes in a crop growth cycle and can possibly establish optimum times to obtain additional remote-sensor information. Many of the cereal crops undergo a critical phase in development during which extensive remote-sensing measurements are desired to allow inference of future possibilities of that crop. Although this phase lasts approximately 10 days, its beginning stage is difficult to predict. The crewmen's ability to recognize that a field has entered this phase would be a significant contribution by itself.

It is man's capacity to reason that allows him to exercise judgment, perhaps the most important asset of a crewman. In response to in-flight experience (e.g., recognizing the significance of new features or phenomena), a crewman can modify procedures - or even objectives - to enhance the scientific value of the observations. Hypotheses based on observations can be discussed and validated with the ground team to enable new facts to be applied to the observational program during the mission.

The crewmen exercised judgment in observing and photographing many geologic areas that were not included in the preflight plan and had not been previously photographed or mapped. As an example, the Skylab 4 photographs of the volcanic fields in Bolivia and Chile are new sources of information. In addition, the occurrence of icebergs in the South Atlantic Ocean (e.g., the size, shape, and distribution) was documented because the crewmen used initiative. These data are especially important because information on icebergs in the South Atlantic has been sparse.

Observations of meteorological phenomena were almost entirely dependent on real-time judgment by the crewmen. Several of the anticipated phenomena, such as Kármán eddies over land, were not seen, but observations of unanticipated features (e.g., the bow-shock wave over Campbell Island) were new and scientifically important.

The space-based crewman has an excellent vantage point from which to scan a large field of view and to select the significant features for study. Rapid discrimination allows maximum possible time to observe a feature by locating it early and by viewing it from horizon to horizon. Increased viewing time permits more thorough observation and description and provides a better base for high-quality stereophotography.

Because many features change in appearance as the Sun angle and the viewing angle change, the crewman can select the optimum conditions for observing and photographing a particular feature. For example, in vegetation studies, a crewman can document observations made from horizon to horizon with photographs taken near the nadir, a position which optimizes the color contrasts important to crop studies. In geologic studies, he can document his observations with low-Sun-angle photography to enhance the appearance of the relief. The choices of what, when, and how to photograph an observational site are critical.

Man can easily observe and photograph a feature such as the Falkland Current, which meanders for thousands of kilometers in the South Atlantic Ocean, whereas it would be difficult to obtain similar information from automated satellites. Man's capability to integrate a total field of view rapidly and concentrate on the most significant feature is a considerable addition that man brings to Earth observations.

Man's presence greatly increases the flexibility of Earth observations from space platforms. The entire thrust of a program may be changed in real time when new observational information indicates the desirability of such a change. If necessary, the required changes can be incorporated into the plan and further modified, all within the same mission. Otherwise, each change could result in a major program alteration or a new mission.

An excellent example of program flexibility is the study of cold-water eddies in warm ocean currents. This phenomenon was discovered after the Skylab 4 crewmen were in orbit. The presence of man on board afforded the opportunity to modify planned oceanographic observations of eddies in the major ocean currents.

The previously mentioned capabilities of man were used in observing the sunglint phenomenon. Many large-scale surface features of the oceans were seen for the first time in sunglint, a rapidly changing phenomenon that is valuable for viewing surface texture. The ability to observe features in sunglint was not fully anticipated before the mission.

To take complete advantage of this phenomenon, the crewman had to recognize and identify the feature of interest in the sunglint pattern. The crewmen had approximately 5 seconds to observe a feature in sunglint, to decide the appropriate observational technique, and to perform that technique for the unexpected feature. Although the occurrence of sunglint is predictable, the features that will be visible in the sunglint are not.

This complex judgment capability separates man's work from that of satellite equipment. Certain features are more evident in the outer edges of the sunglint pattern than they are in the central area. A crewman is able to train himself to know exactly the optimum time for taking the photograph, whereas even the most sophisticated sensor package cannot respond to that type information.

The role of man as trained observer viewing the Earth from space is new. Working out the proper relationship between man as observer with remote-sensing instruments to direct and completely automated remote-sensing instruments has hardly begun. In this respect, the field of Earth observations can learn much from the field of astronomy. On Skylab, the Apollo telescope mount (ATM) was a sophisticated array of instruments for study of the Sun in wavelengths not detectable inside the atmosphere. In ATM operations, the crewmen functioned both as trained observers and technicians. Because the crewman had more complete real-time data available than the ground-based observatories, he decided when transient events (such as flares, point brightenings, and coronal transients) occurred and judged whether these events were significant enough to replace planned observations with studies of the transient. Many valuable ATM data were obtained by the crewmen's initiative. In addition, the crewman pointed the array at the desired feature, monitored the measurements of some of the experiments, and helped to troubleshoot malfunctions. Many of man's functions in spaced-based and ground-based astronomy will have counterparts in Earth observations.

In future Earth observations missions, such a combination of man and a semiautomated instrument package could greatly enhance scientific data return. The crewman contributes the aforementioned capabilities, and the instruments provide a high-resolution multispectral capability and a permanent record of the data gathered.

To realize fully the potential of manned observations, the mission planners must provide the crewmen with sufficient time not only to make the observation but also to prepare for it beforehand and to discuss it fully afterwards. At altitudes of 430 kilometers, the crewmen of Skylab could observe and photograph a site for approximately 30 to 40 seconds. During the debriefing sessions, the Skylab 4 crewmen indicated repeatedly that it was possible either to observe and describe or to obtain photographs; however, there was not enough time available to fully accomplish both tasks. In addition, mission constraints restricted the opportunities and time for observing and photographing the sites. In general, the opportunity to view many sites was limited to five passes or approximately 2 to 3 minutes. For the sites between latitudes 40° and 50° N and S, many more opportunities were available (because of the orbit intersections for a 50° inclination that occur within these latitudes) and, consequently, the information obtained was increased. Excellent examples of this occurred in the Falkland Current in the south and in the ice in the Gulf of St. Lawrence in the north.

An important conclusion of the Skylab 4 project activities is that, if more time is available for conducting visual observations, the type and amount of information returned will improve. The mission itself must be flexible enough to use fully the inherent flexibility offered by the presence of man. Preflight programing of tasks is mandatory, but flexibility must be retained for modifying the flight plans rapidly. This flexibility will provide the opportunities to observe, to photograph, and to study dynamic features such as hurricanes, volcanic eruptions, ice, severe storms, and crew-identified sites of opportunity.

PART B

PRELIMINARY RESULTS

PRELIMINARY RESULTS

During the 84-day mission, the Skylab 4 crewmen completed more than 850 observations of Earth features and phenomena and acquired approximately 2000 photographs to document these observations.

The preliminary results presented in the individual sections of this report were compiled by the Science Team members. These results are based on cursory analyses of five of the eight magazines of the 70-millimeter Hasselblad photographs, transcriptions of the crewmen's real-time descriptions, and information obtained during the crew debriefing sessions. (The 35-millimeter Nikon photographs were not available for analysis or inclusion in these preliminary reports.)

The major emphasis in this report is placed on the identification of significant observational data, the application of such data to scientific study, the description of man's role in obtaining these data, and recommendations of photographic equipment and viewing facilities for future manned orbital missions.

6. GLOBAL TECTONICS: PRELIMINARY REPORT ON SKYLAB 4 OBSERVATIONS AND HANDHELD PHOTOGRAPHY

W. R. Muehlberger,[a†] P. R. Gucwa,[a] A. W. Ritchie,[a] and E. R. Swanson[a]

The present model of mountain building involves the interaction of rigid plates of the crust of the Earth as they move in relation to one another. Pull-apart zones correspond to the midocean ridges; these areas are above sea level in Iceland (too far north for observation from Skylab) and extend the length of Africa from Mozambique in the south, through the East African rift valleys, to the Red Sea, Dead Sea, and Sea of Galilee in the north. This major fault zone was a site for visual observations and photography.

Transform faults, formed when plates slide past each other, are illustrated by the San Andreas Fault of California and the Alpine Fault of New Zealand. The third class of plate motion, in which one plate is pushed under its neighbor (subduction), is associated with ocean deeps, chains of volcanoes, and complex fault patterns as illustrated by Central America and, in a more complicated manner, by the Atacama Fault of Chile and the Philippine Fault of the Philippine Islands.

The major mountain chains of the world are the result of complex interactions of moving plates and the deformation of the edges of continental shelves. Visual observations of fault traces, related branch faults, and their regional pattern, combined with synoptic photography from space, should assist in evaluating present analyses as well as in integrating the results of ground observations in widely separated areas. The following paragraphs outline some preliminary results of this project that satisfactorily demonstrate that the mind and eyes of man are the best combination of sensors yet devised to make observations from space.

AFRICAN RIFT SYSTEM

The African continental crust has not behaved as two rigid plates during extension; rifting in Africa has centered on domal uplifts approximately 1000 kilometers in diameter. These uplifts are located where a rift divides into two major segments. Crustal extension is at a maximum at the center of these uplifts and decreases along their flanks. The Afro-Arabian rift system

---

[a] The University of Texas at Austin.

[†] Principal Investigator.

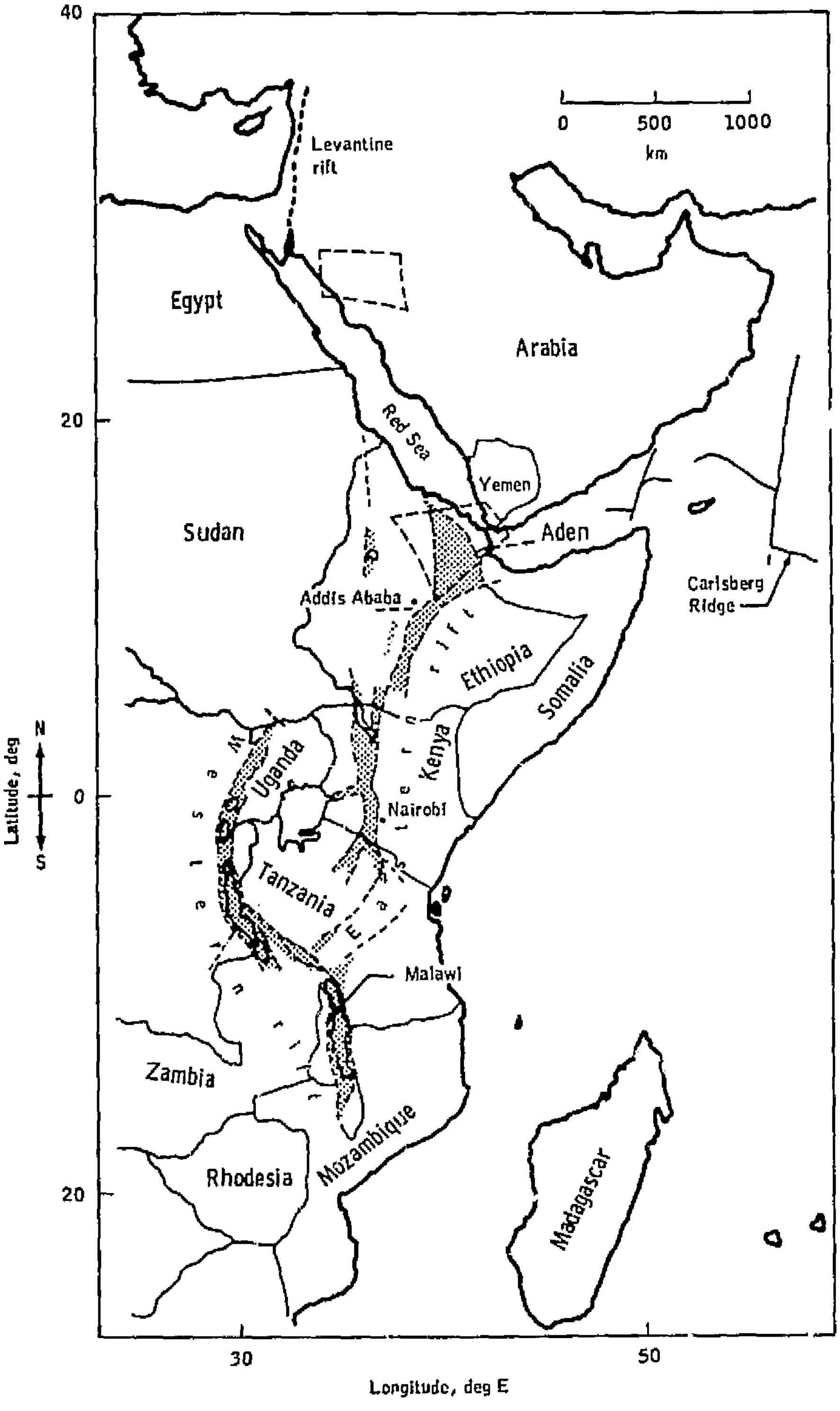


Figure 6-1.- Afro-Arabian rift system. Continental depressions are shaded. The area within the dotted line is shown in figure 6-2; the area within the dashed line is shown in figure 6-4.

(fig. 6-1 (ref. 6-1)) has an apparent spreading rate less than the 1 cm/yr that is interpreted for the Red Sea and Gulf of Aden rifts. Geological constraints allow a maximum crustal extension of approximately 30 kilometers in Ethiopia and approximately 10 kilometers in Kenya. Geophysical studies suggest that the eastern rift is underlain with thinned continental crust. The crust of the domal uplifts is underlain with low-density upper mantle that is presumably partly molten. Southward from the Red Sea, the decrease of volcanism in the eastern rift zone further supports the concept of decreasing continental separation from north to south.

The structure of the Afro-Arabian rift boundary can be interpreted as the result of the separation of Arabia from Nubia and Somalia along a spreading system that has been active since the end of the Cretaceous period (60 million years ago). The Gulf of Aden was created as Arabia rotated counterclockwise from Somalia. The gulf is floored with oceanic crust and contains a seismically active fault system that appears to be an extension of the Carlsberg Ridge of the Indian Ocean. Similarly, Arabia has rotated away from Nubia; this rotation resulted in the creation of the Red Sea, which is underlain, at least in part, with oceanic crust. Extension in the Sinai region was accomplished by left-lateral strike-slip motion along the Dead Sea Fault system and by normal faulting in the Gulf of Suez.

The Gulf of Aden and Red Sea rifts meet the northern terminus of the Afro-Arabian rift system in a complex junction of controversial origin in the Afar district of Ethiopia. The presence of faulted blocks of continental crust in Afar, such as the Danakil Horst, precludes an interpretation that all of Afar is underlain with oceanic crust.

The Skylab 4 photographs thus far received are mainly of the Red Sea region and show many significant features. Figure 6-2 is the first photograph from space to show the western scarp in Ethiopia. An explanatory map of the Afar area shown in this photograph is given in figure 6-3. The discontinuous, parallel set of linears, which are axial to the Afar rift (fig. 6-3), may relate to a change in the pull-apart character of the Afar region.

A question has arisen concerning the rotation of Arabia: Is all the displacement of the Arabian plate represented along the Dead Sea Fault? The Skylab 4 crewmen identified an anomalous area along the Red Sea margin of the Arabian Peninsula. As shown in figures 6-4 and 6-5, this area appears to be broken by faults both parallel and oblique to the coast. Many of the linear features are shown on published geologic maps as faults, but the photograph suggests much deformation internal to the Arabian plate that had not been previously recognized.

ALPINE FAULT ZONE OF NEW ZEALAND

The Alpine Fault of New Zealand has long been regarded as a textbook example of one of the great strike-slip faults of the Earth (fig. 6-6, (ref. 6-2)). A fault of this magnitude was expected to be visible from orbit,

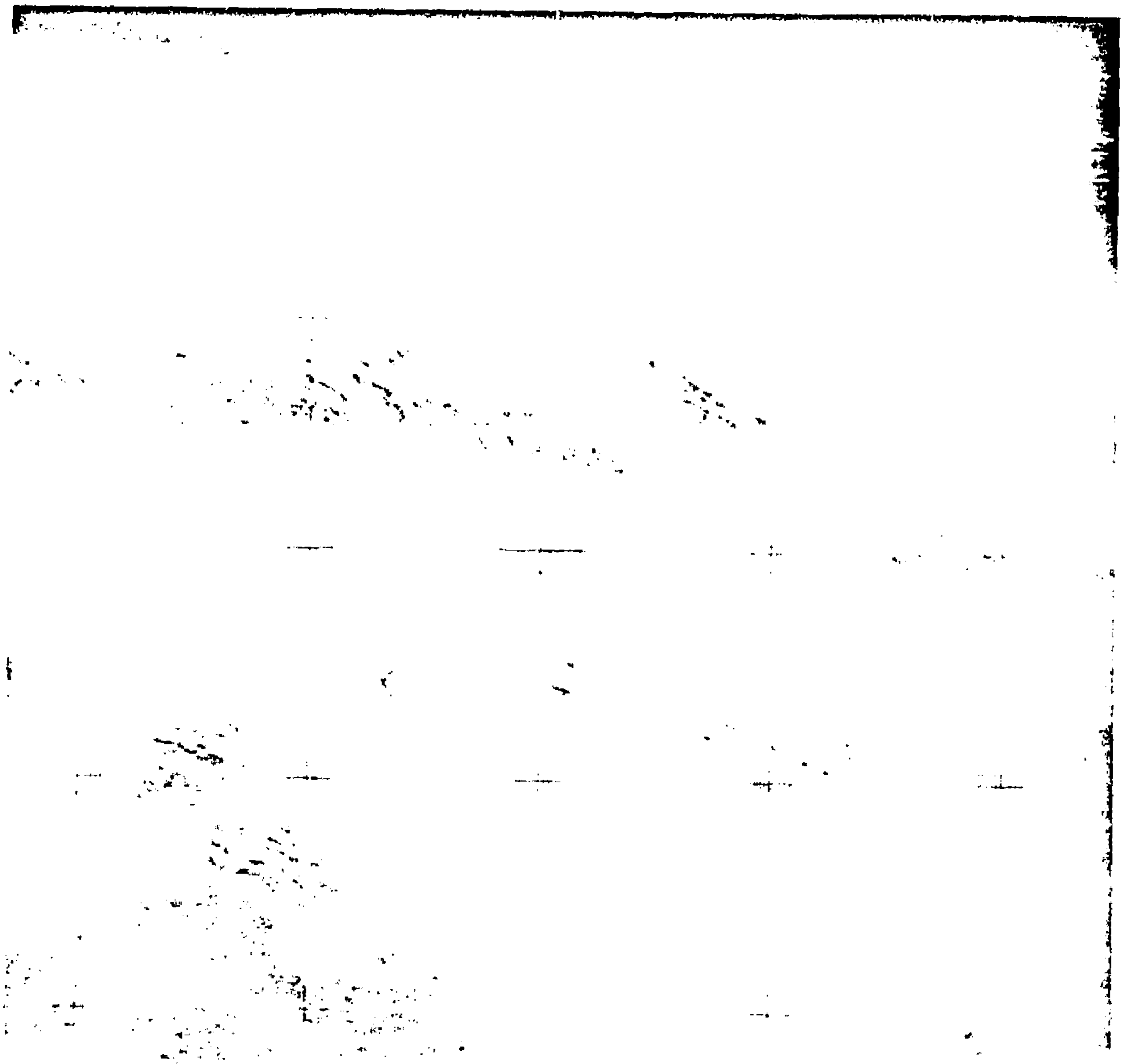


Figure 6-2.- High oblique view looking nearly west toward Ethiopia and across the Afar region of Africa (SL4-137-3585).

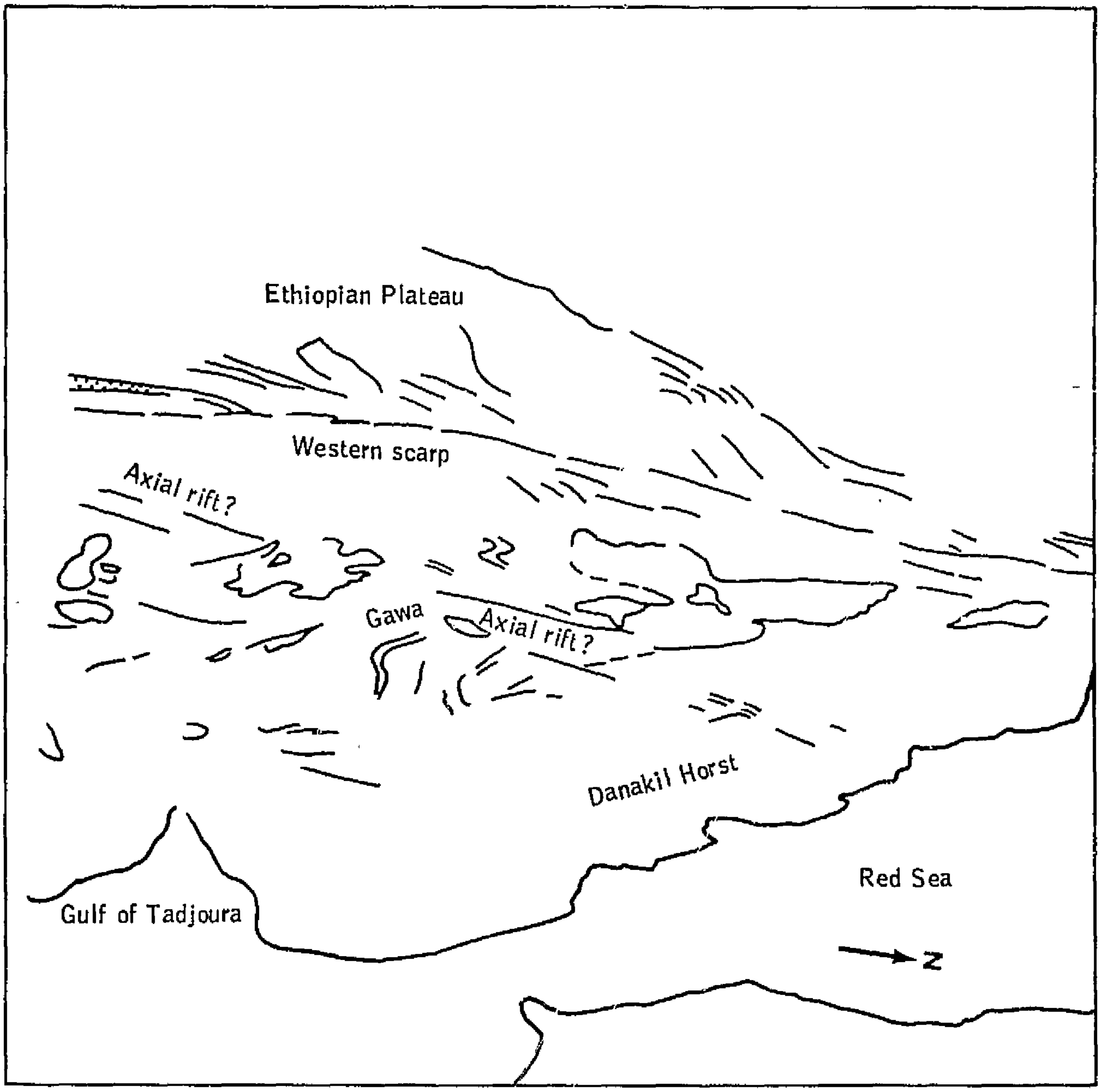


Figure 6-3.- Explanatory map of figure 6-2. The Danakil Horst is a basement block apparently separated from the Ethiopian Plateau during the opening of the Red Sea. The parallel, discontinuous set of linears (some are mapped as faults) axial to the rift may indicate a change in the pull-apart character of this region.

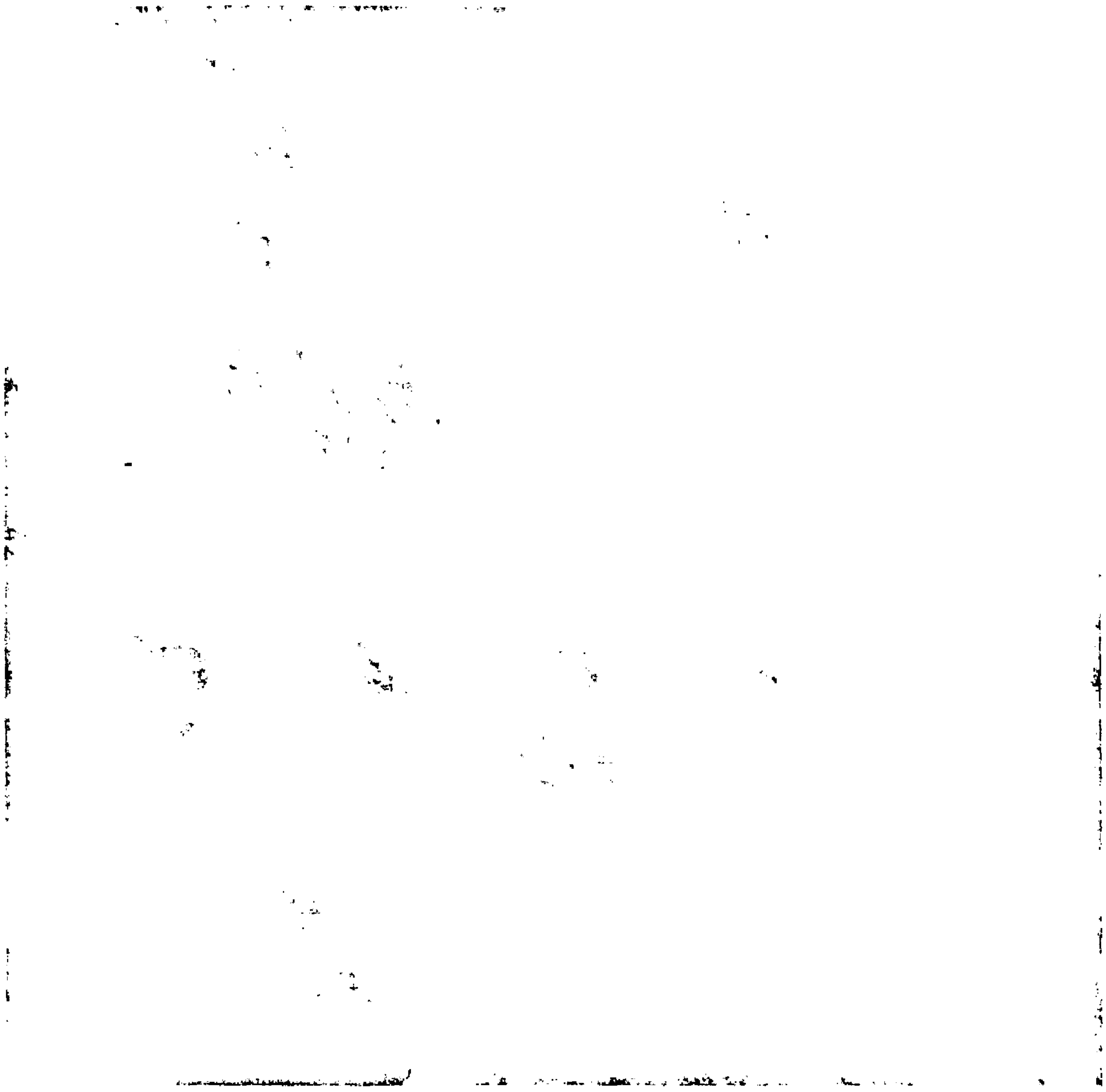


Figure 6-4.- Low oblique view of part of the Saudi Arabian Peninsula southeast of the Gulf of Aqaba (SL4-138-3751).

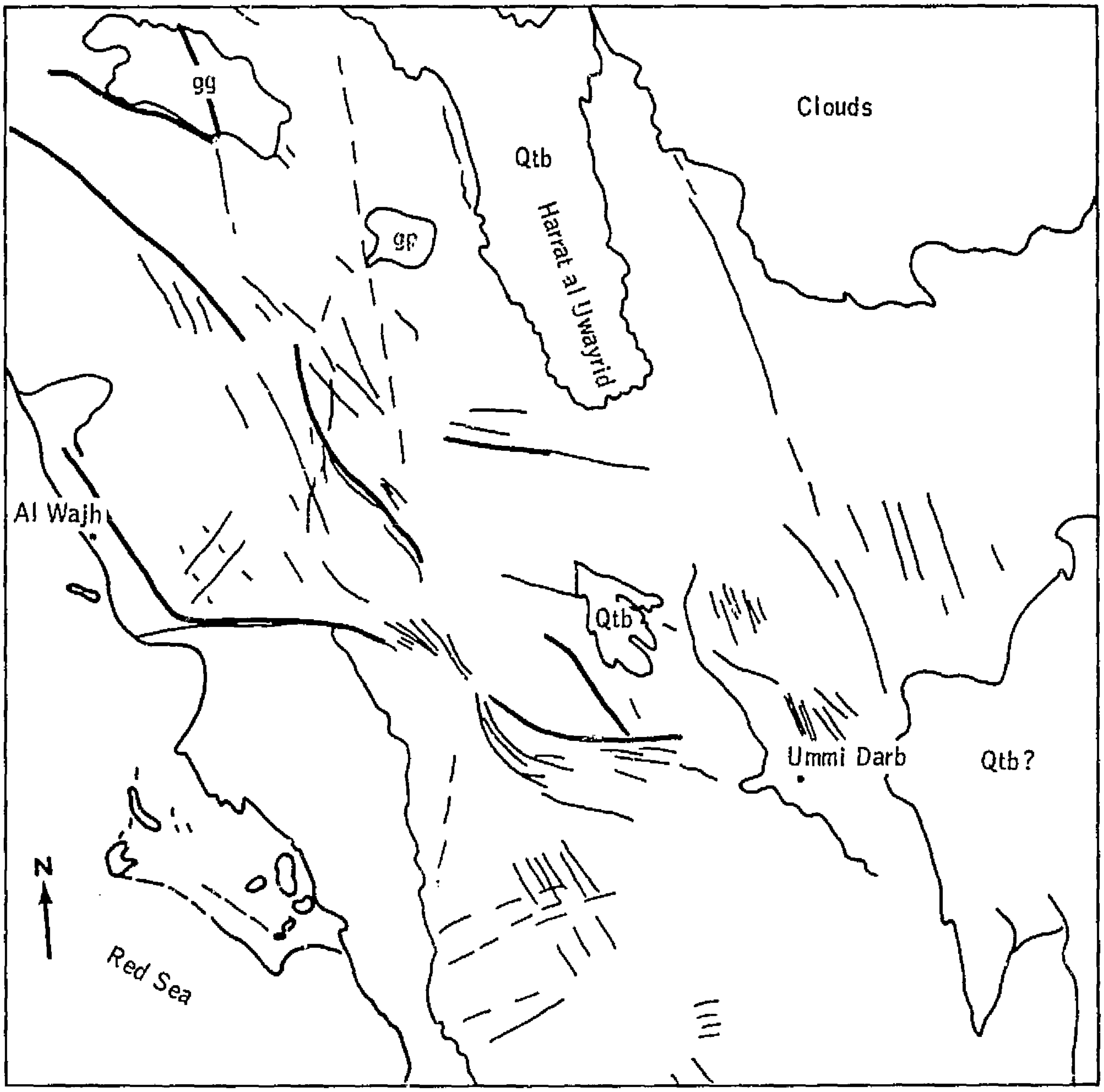


Figure 6-5.- Explanatory map of figure 6-4. The center of the drawing is approximately 26.5° N latitude, 37.5° E longitude. Mapped faults are shown by heavy lines; photolinears by light lines. "Qtb" is basalt and andesite, "gp" is peralkaline granite, and "gg" is granite. The Skylab 4 crewmen recognized this area as having anomalous trends compared with structures paralleling both sides of the Red Sea.

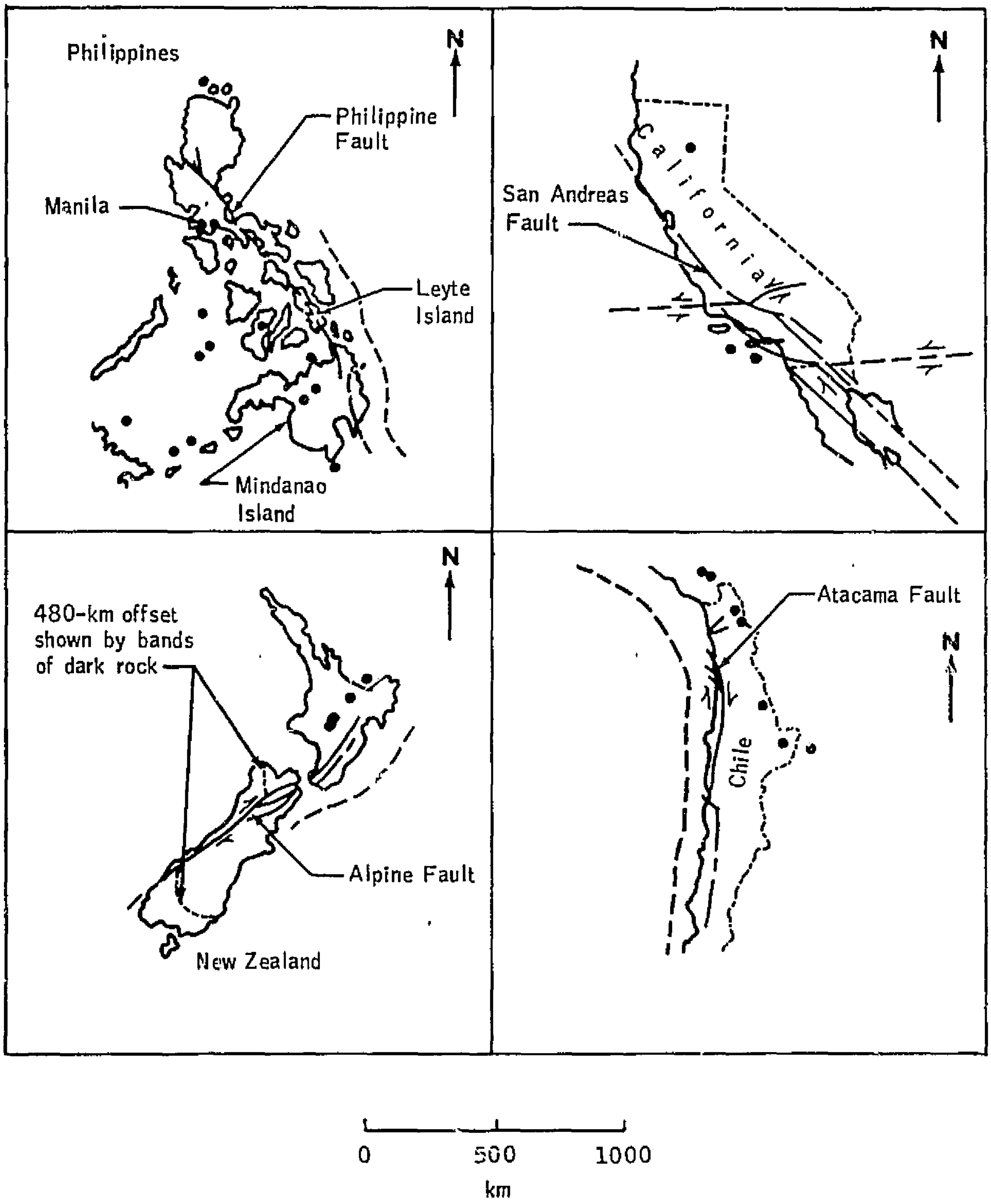


Figure 6-6.- Diagram showing the Philippine Fault, the San Andreas Fault, the Alpine Fault, and the Atacama Fault at the same scale. Active volcanoes are shown by darkened circles, major faults by solid lines, and [illegible] trenches by heavy dashed lines.

and the Skylab crewmen were expected to be able to observe and photograph it. In addition to documentation of the fault trace, documentation of the offsetting features on either side of the fault (which would indicate total offset) and observation of displaced river terraces, valleys, and stream courses (which would indicate recent movement) were also desired. The entire area of North and South Island was covered by approximately 60 photographs at varying Sun angles, view angles, and cloud cover. These photographs and the observations made by the crewmen have contributed much to the understanding of the geology of this region.

The Alpine Fault has a long history that includes a right-lateral strike-slip displacement of 450 kilometers, followed by a period that seems to be continuing and during which vertical uplift of the Southern Alps along the Alpine Fault occurred and faults that diverge from the Alpine Fault formed. The Skylab photographs show these diverging faults and the apparent resultant twisting of South Island.

A generalized map of New Zealand is shown in figure 6-7. The central part of South Island is shown in figures 6-8 and 6-9. The site photographed was described from orbit by the Skylab 4 commander (CDR) in the following manner:

> "The Sun angle was quite low; it was shortly after sunrise. I would estimate the Sun angle to be maybe 20 degrees. The Alpine Fault down New Zealand was very, very easy to see; quite clear. We were crossing the northern end of South Island, looking to the south, and you could see a fault line all the way from the very northern end of South Island until it disappeared under the clouds. The weather is just perfect, and the Sun angle is perfect. You should have some real good information here."

In addition to the Alpine Fault, linears can be seen in the photographs. They diverge at a small angle from both the northern and southern ends of the Alpine Fault. Those at the southern end are best seen in figure 6-10 and were described by the science pilot (SPT) as follows:

> "The rivers and water-erosion areas are very discernible on the west side and on the east, and there does appear to be a preferred orientation for these relative to the fault line. However, as far as identifying these as other faults, that's hard to say. You can identify these features; they're linear. But to call them a fault is, I find from observations from here, very difficult."

Shutter ridges, valleys closed by faulted spur ends, and offset stream courses were also observed by the SPT. These features are best seen in the area around the central portion of the Alpine Fault in figure 6-8. Displacement of these features is systematically right lateral, a fact indicating that recent motion has had some component of right-lateral movement. The stream courses, as they appeared from orbit, were described by the SPT:

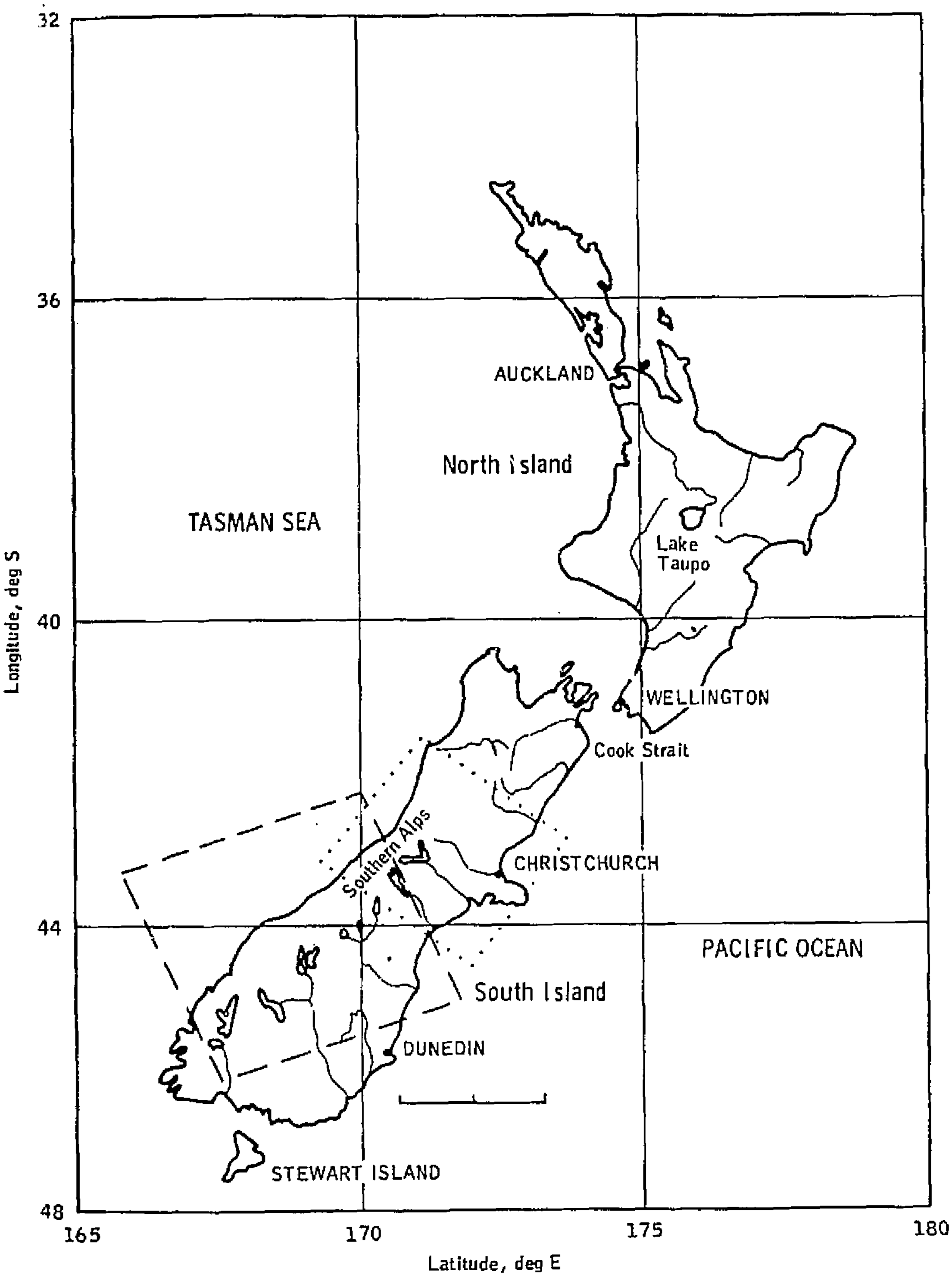


Figure 6-7.- Map of New Zealand. The dotted line indicates the area shown in figures 6-8 and 6-9; the dashed line indicates the area shown in figures 6-10 and 6-11.

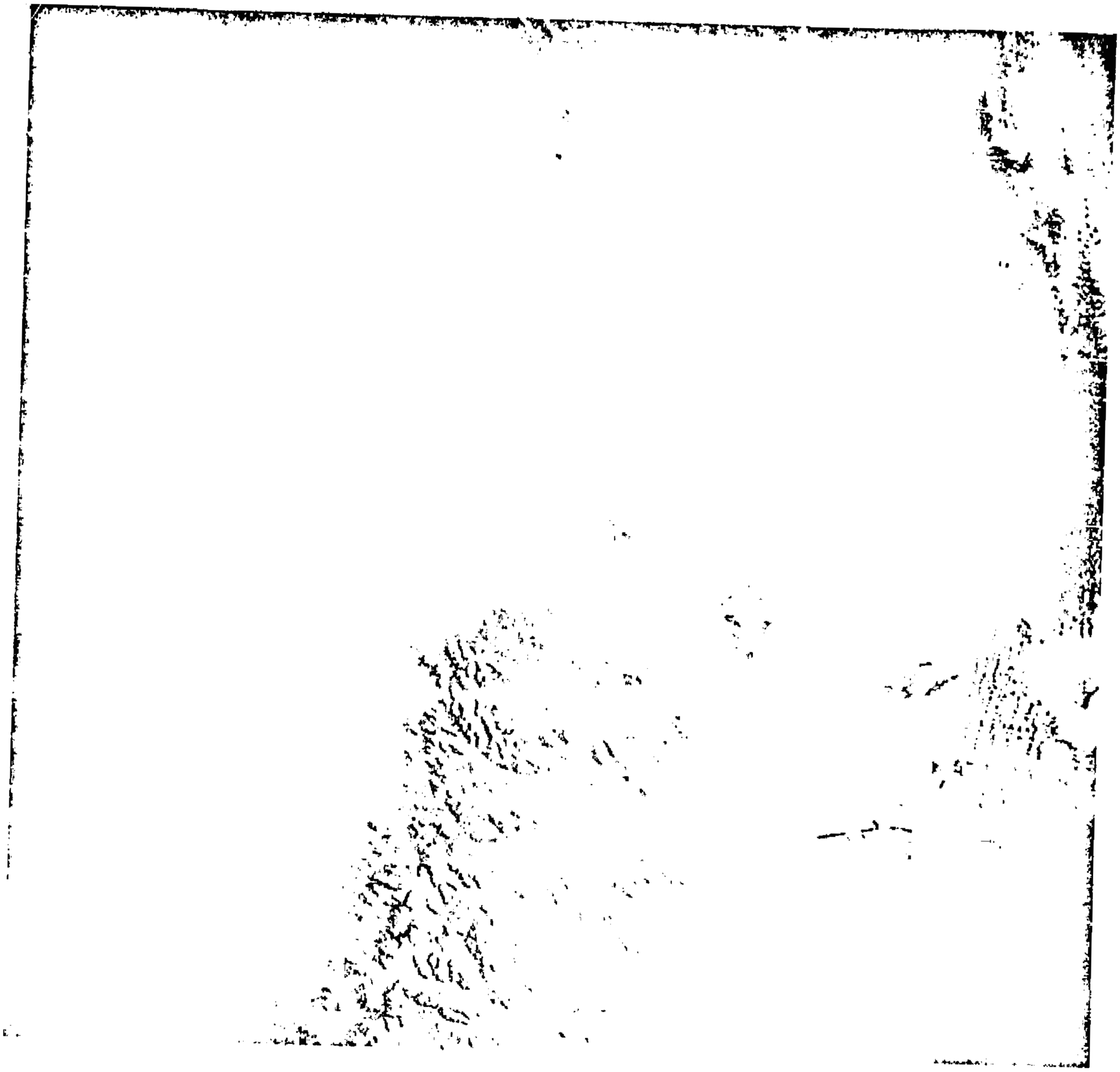


Figure 6-8.- Photograph of central South Island, New Zealand (SL4-137-3700).

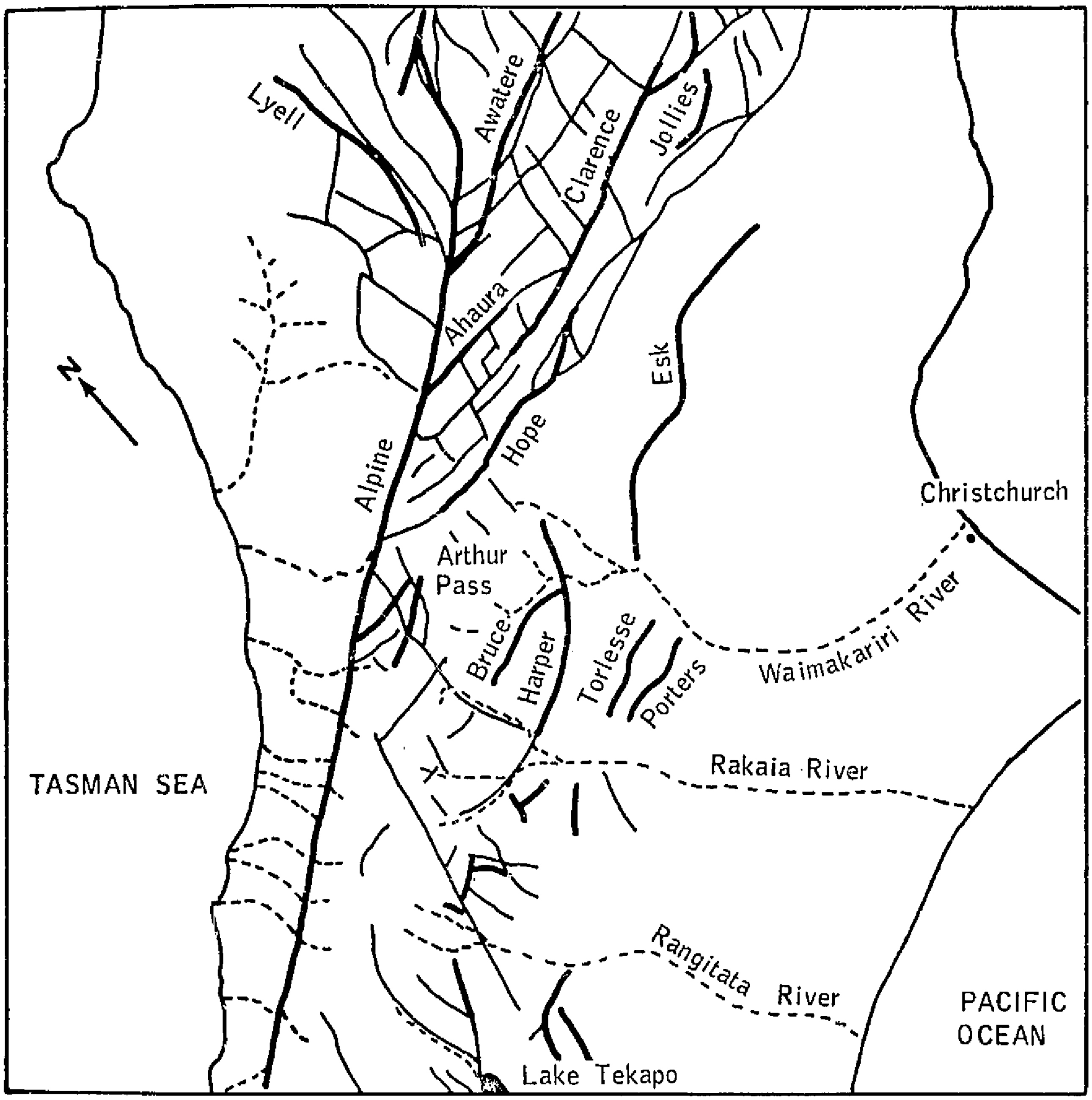


Figure 6-9.- Explanatory map of figure 6-8 showing linear features in central South Island, New Zealand. Heavy solid lines are mapped faults, light solid lines are photolinears (probable faults), and short dashed lines are drainage.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

Figure 6-10.- Photograph of southwestern South Island, New Zealand (SL4-136-3399).

> "I counted rather quickly up to around 50, I'd call, fairly major ravines or river channels leading out to the ocean, running from the fault zone itself, and their orientation could be very clearly delineated. I could not see where these picked up on the other side of the fault zone at all."

During debriefing, the SPT mentioned that he had also noticed that stream drainage there was generally offset right laterally. This observation is in accord with recent field mapping and seismic work.

Figures 6-9 and 6-11 show the distribution of linears as interpreted from two Skylab 4 photographs. Figure 6-9 shows the distribution of known faults, many of which are mapped discontinuously or are inferred. The coincidence of known faults with the photolinears suggests that many of these linears are indeed faults. The abundance of linears as seen from Skylab indicates that many more faults exist in this portion of New Zealand than have been mapped. These photographic interpretation studies combined with field work should produce rapid advances in the knowledge of the structure of New Zealand. Observations and photographs by the Skylab 4 crewmen of the Alpine Fault Zone demonstrate that significant advances can be made for an extensively studied area in recognizing both probable extensions and relationships between major fault blocks. It follows that this technique should be of even more value in remote regions.

ATACAMA FAULT ZONE OF CHILE

The Atacama Fault is a poorly understood linear feature that parallels the coast of northern Chile for over 100 kilometers (figs. 6-6 and 6-12 to 6-16). Here, on the western margin of South America, the Pacific Ocean floor is being thrust under South America along the Peru-Chile Trench. Before the beginning of underthrusting, approximately 200 million years ago, the western coast of South America was the site of sedimentary rock accumulation. Subduction (underthrusting) began, folded the older rocks, and produced magmas that formed a volcanic arc and associated batholiths. Later, a second volcanic arc began to form to the east of the earlier arc. Rising magma produced volcanic and intrusive rocks that form the foundation of the western cordillera of the Andes. Approximately 15 million years ago, explosive volcanic activity began, followed closely by the eruption of andesitic lavas that formed the volcanoes (some still active) that dominate the Andes (refs. 6-3 and 6-4).

In southern Chile, an actively subsiding graben, the central-valley graben, separates the rising coastal ranges to the west from the rising Andes to the east. In northern Chile, the tectonic setting west of the Andes is not so simple. Here, a poorly defined topographic depression, the Pampa del Tamarugal, is oblique to the coast and reaches the Pacific at Arica. This depression may be a northern analog of the central-valley depression in the south (ref. 6-5). The Atacama Fault, presently active, cuts the coast ranges to the west of this valley.

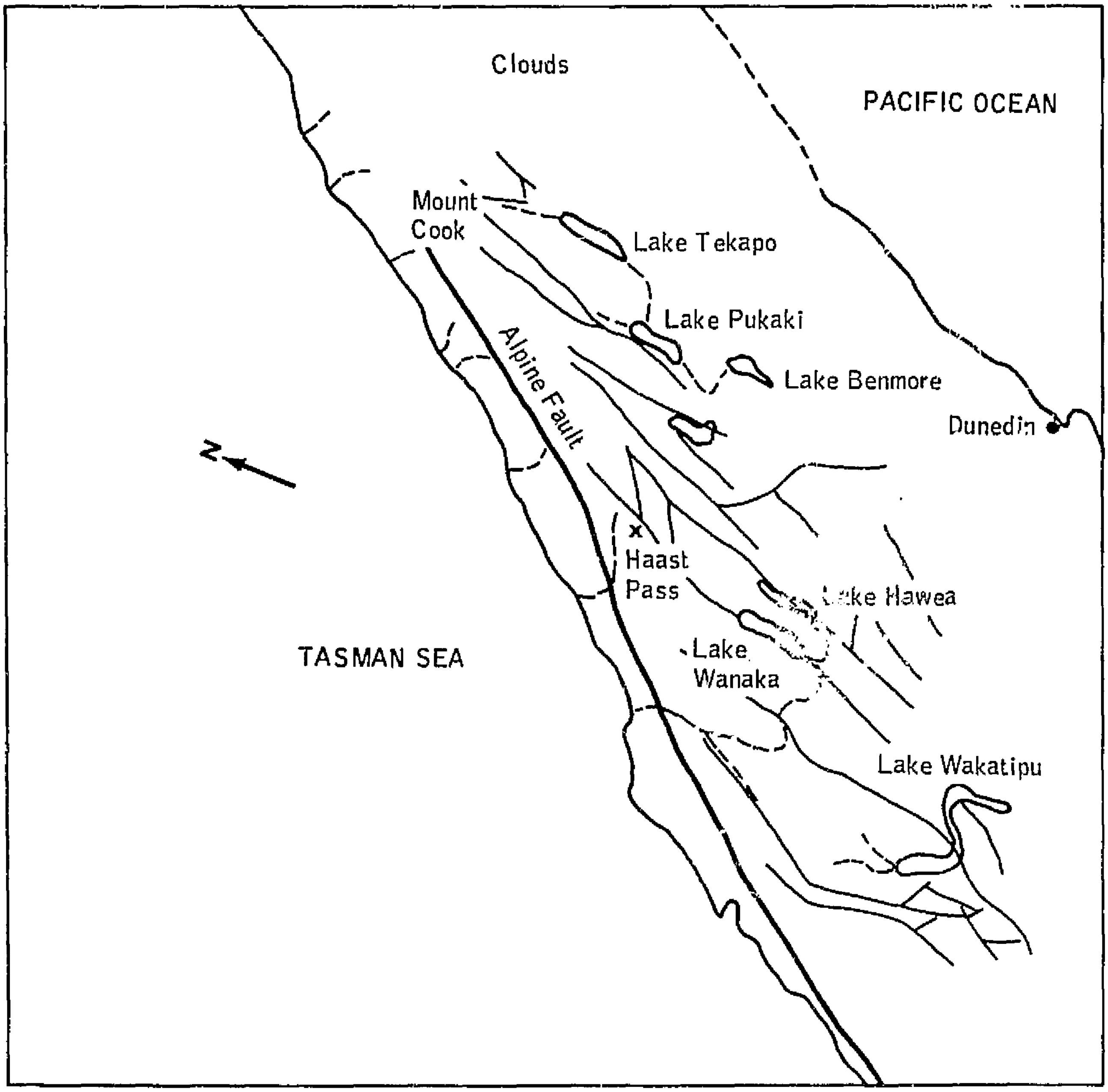


Figure 6-11.- Explanatory map of figure 6-10 showing linear features in South Island, New Zealand. Solid lines are interpreted as faults; short dashed lines are drainage.

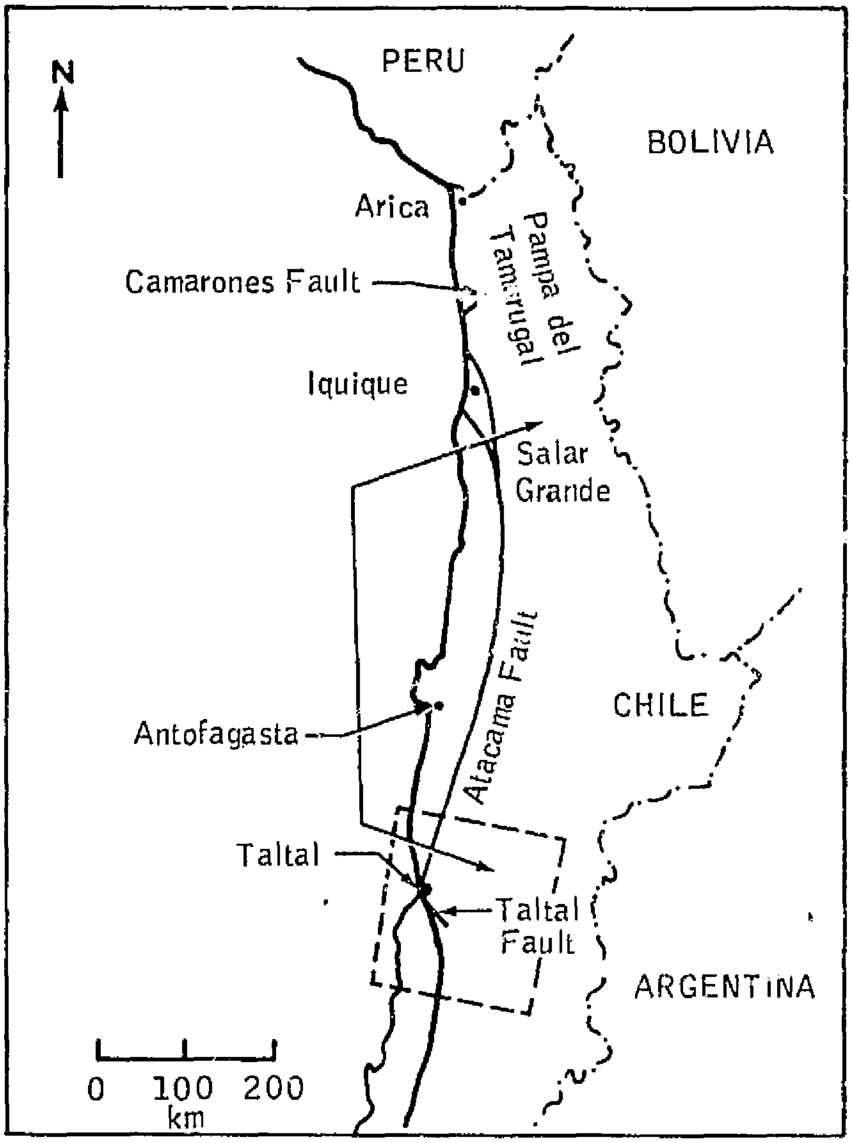


Figure 6-12.- Principal geographic features of northern Chile. Dashed line indicates location of figure 6-13; solid line indicates location of figure 6-15.

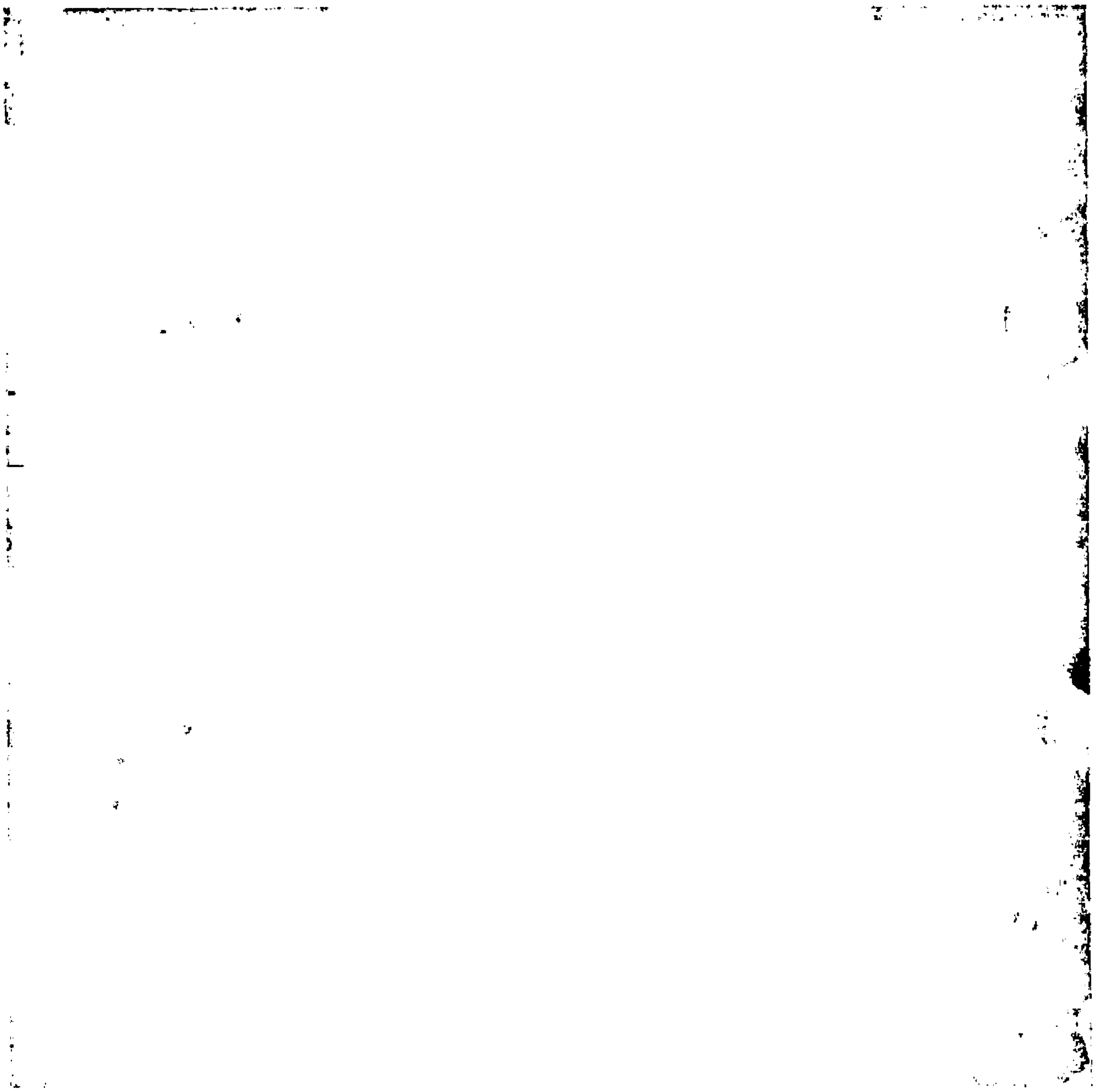


Figure 6-13.- Photograph of Taltal region, Chile (SL4-138-3794).

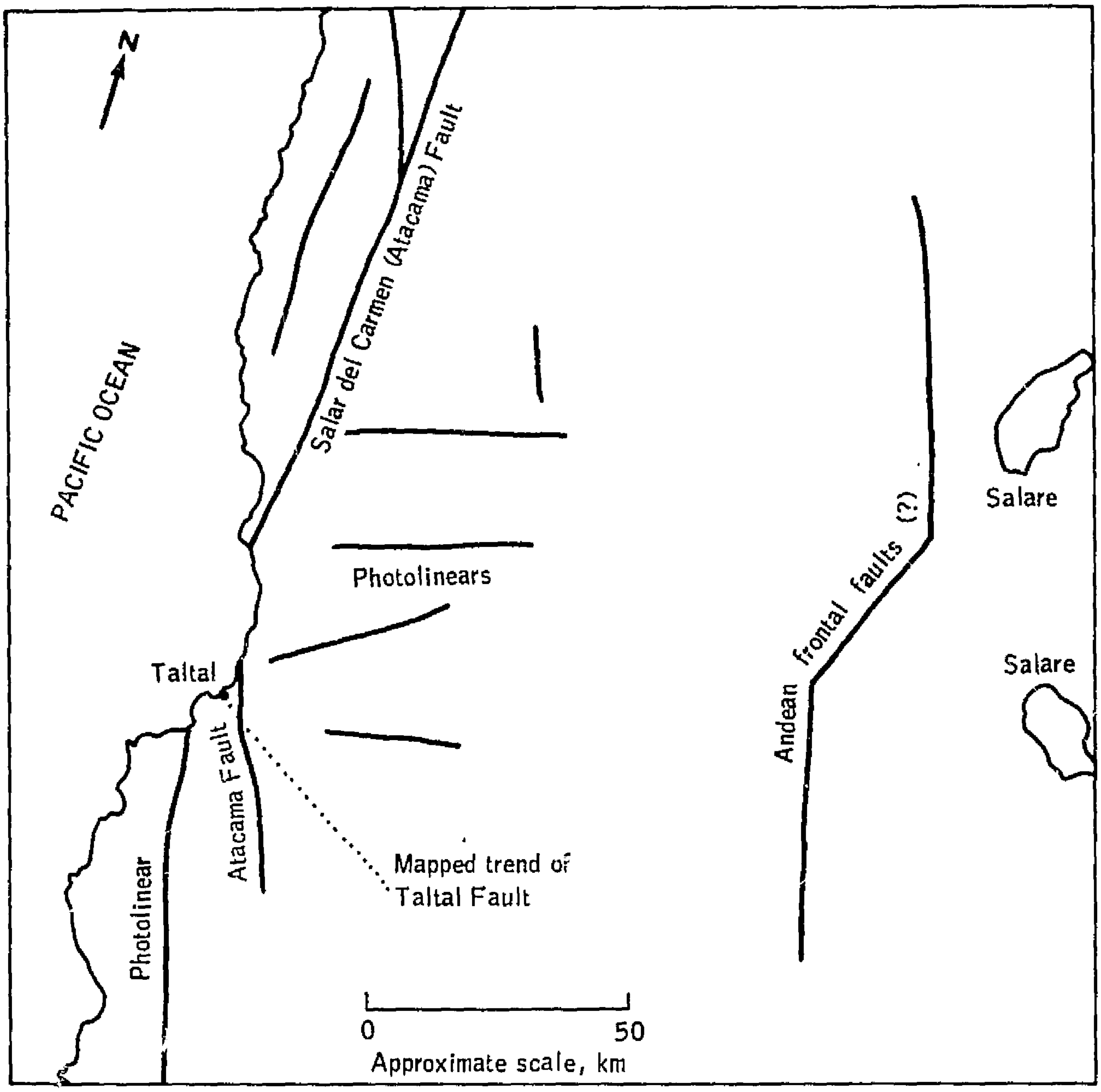


Figure 6-14.- Explanatory map of figure 6-13 showing complex structure in the Atacama Fault Zone.

Figure 6-15.- Photograph of central Chile (SL4-137-3711).

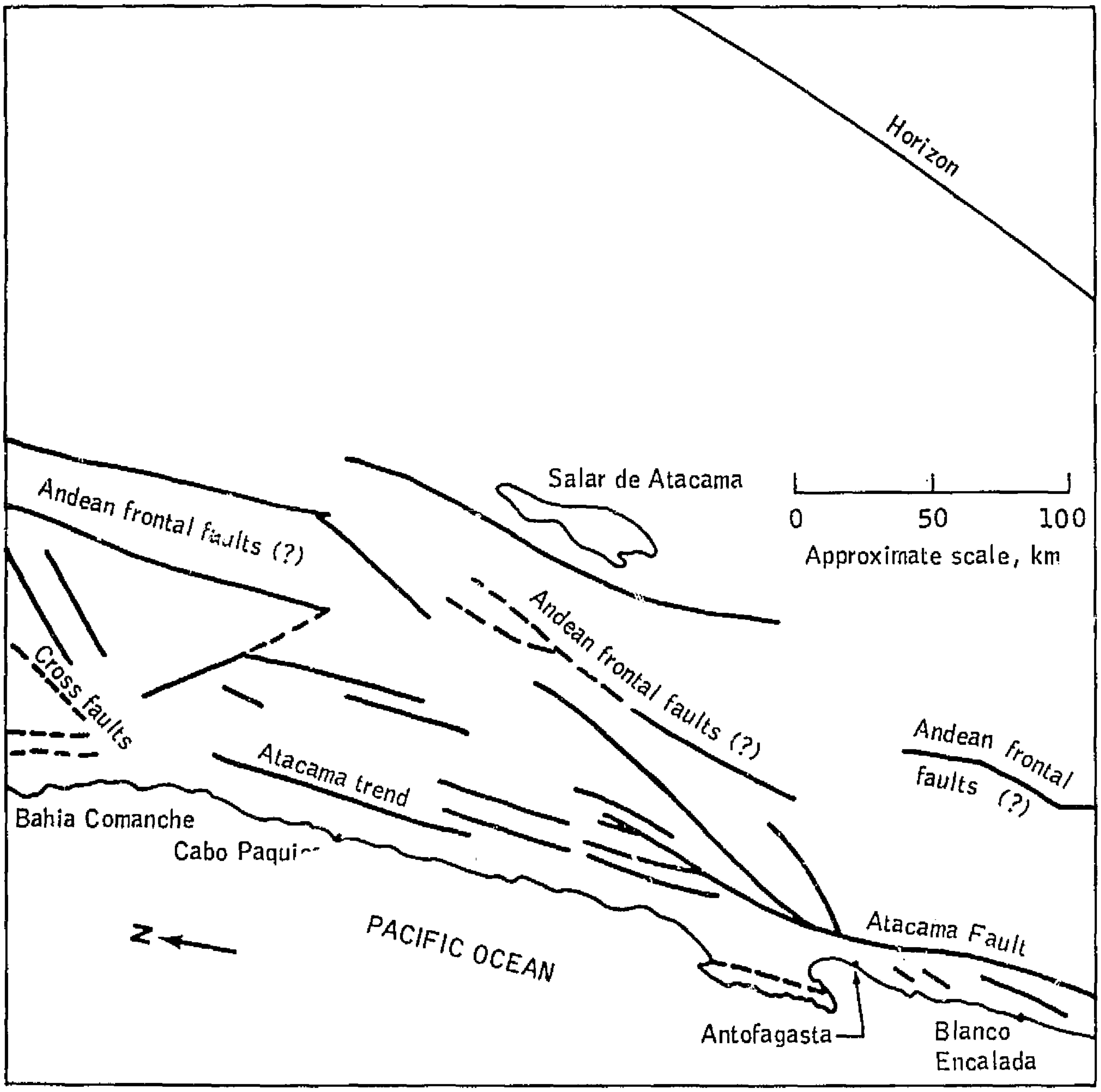


Figure 6-16.- Explanatory map of figure 6-15 showing the Atacama Fault and related faults. Dashed lines are poorly defined photolinears.

Historically, the Atacama Fault has been considered to be a right-lateral transcurrent fault, an analog of the well-known San Andreas Fault of California (fig. 6-6). Field evidence about the nature of the Atacama Fault includes (1) linearity of the fault over hundreds of kilometers, (2) rift topography with no consistent differential elevation across the fault, (3) dextral stream offsets near Salar Grande (fig. 6-12), and (4) widespread horizontal slickensides with rakes averaging 29° (ref. 6-6). The most recent activity along the Atacama Fault, however, has been normal, as indicated by small fault scarps in recent alluvium. Conjugate, northeast-trending, left-lateral, strike-slip faults break the Atacama Fault at several locations, most notably along the Camarones Fault and associated faults between Arica and Iquique (fig. 6-12). A left-lateral offset of the Atacama Fault also occurs along the southeast-trending Taltal Fault (fig. 6-14) farther south. The largest demonstrable recent lateral offsets are on the northeast cross faults: 0.4 kilometer of right-lateral stream offset along the Camarones Fault (fig. 6-12) and 1.5 kilometers of lateral offset along a parallel fault 10 kilometers to the east (ref. 6-6).

The intent of Skylab 4 observations of the Atacama Fault was to determine the exact nature of the fault and to map its position, direction and amount of movement, and interrelationships with other faults. Preliminary examination of Skylab 4 photographs has revealed the following information about the Atacama Fault area.

1. The Atacama Fault appears to be discontinuous, made up of a series of en echelon segments, particularly in the area immediately north of Antofagasta (fig. 6-12). Such discontinuity makes large-scale recent lateral movement along the Atacama Fault very unlikely.

2. Possible Andean frontal faults (figs. 6-13 to 6-16), previously unknown in northern Chile, can be seen in the photographs and were quite conspicuous to the crew. Such Andean frontal faults, probably normal, may mark the eastern side of a graben similar to the central-valley graben of southern Chile. The western side may be bounded by the Atacama Fault. Further study is needed on this point.

3. A large number of linears that have been unrecognized in field mapping can be seen crosscutting the Atacama Fault in the vicinity of Taltal (figs. 6-13 and 6-14). These linears may be additional cross faults displacing the Atacama trend. Analysis of the attitude of these features and their offsets should facilitate an analysis of the stress patterns of northern Chile.

Some of these observations independently confirm the results of extensive field work by Arabasz (ref. 6-2).

The crewmen were unable to observe the Taltal Fault even though they repeatedly searched for it, and they had difficulty in recognizing the Atacama Fault Zone. Recently gained knowledge and the Skylab observations attest to the fact that the Atacama Fault is not a simple, continuous, strike-slip fault zone, such as the San Andreas Fault of California, but is, instead, a strike-slip fault zone that today is being fragmented by faults of different trends and displacements.

CAUCASUS REGION, RUSSIA

From a geological standpoint, some of the most interesting photographs available to date, taken by the Skylab 4 crew, are those of the Caucasus region. Despite snow and cloud cover, these photographs show a set of north-northwest-trending linears; figure 6-17 is an example. Figure 6-18 is an explanatory map of the area shown in figure 6-17. Most of the published literature on the Caucasus region is in Russian, and the literature reviewed to date does not indicate the cross-trending linears. The greater abundance and closer spacing of the linears at the bends in the Caucasus Range and their near-right-angle relationship to the axis of the range make it appear that they represent offsets of the mountain system similar to those commonly seen along the bend of a single fold. Such features are expectable but have never been photographed or documented before.

OPERATIONAL RESULTS

Photographs do not capture everything that can be seen by the eye. In particular, the movement of the spacecraft permits the eye to integrate the terrain features as seen through a partial cloud cover, whereas the camera sees only a specific moment and clouds may dominate the scene. Thus, verbal descriptions of partly cloud-covered areas appear to be best for delineation of trends, objects, and so forth, although stereophotographic sequences might also penetrate the cloud cover and thus permit later detailed analysis of the terrain features. Further, the eye picks up textural details not visible on the photograph.

Low Sun angles enhance structures by shadowing, whereas high Sun angles enhance color differences. The Skylab 4 high-Sun-angle photographs of the Atacama Fault Zone aided in the discrimination thereof, whereas the earlier Apollo 7 photographs outlined the zone best by the shadowing and obliquity of view.

Oblique photographs are best for showing the regional framework but generally do not reveal details of geology unless viewing is oriented along a linear feature in proper lighting. The crewmen commented that sites must be within approximately 500 kilometers of the groundtrack to be adequately observed or photographed. Because of the short viewing time for any one geographic locality (30 to 40 seconds on Skylab), the choice between visual observation and photography must be made in advance.

The progressively developing abilities of the crewmen to recognize fault zones (e.g., their recognition of major fault zones in India and Brazil without prior briefing) suggest that a more intensive training program would have enabled them to work efficiently from the beginning of the mission, would have improved the quality and quantity of observations, and would have increased their understanding of the observed features.

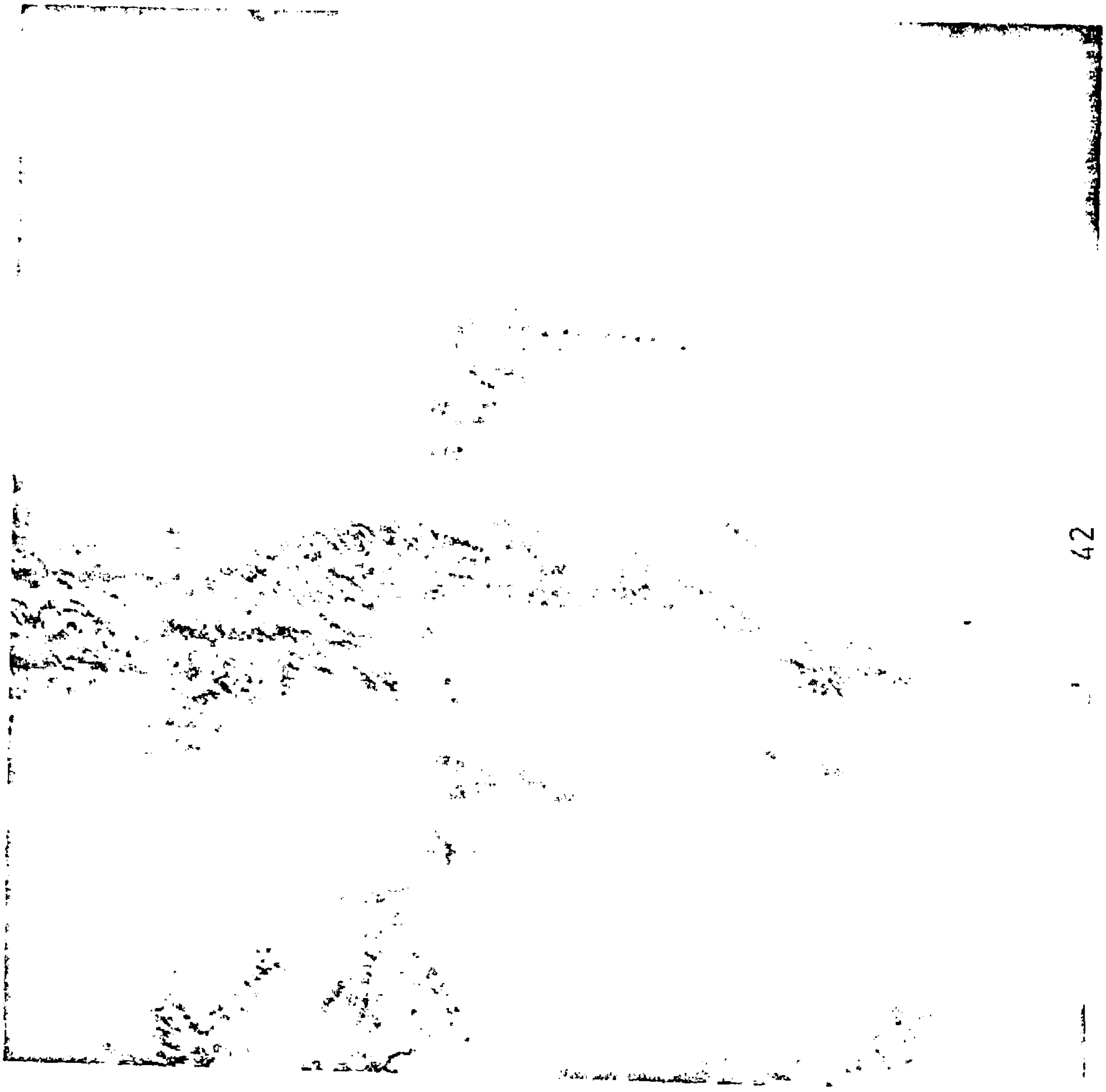


Figure 6-17.- Photograph of a part of the Caucasus Mountains (SL4-138-3872).

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

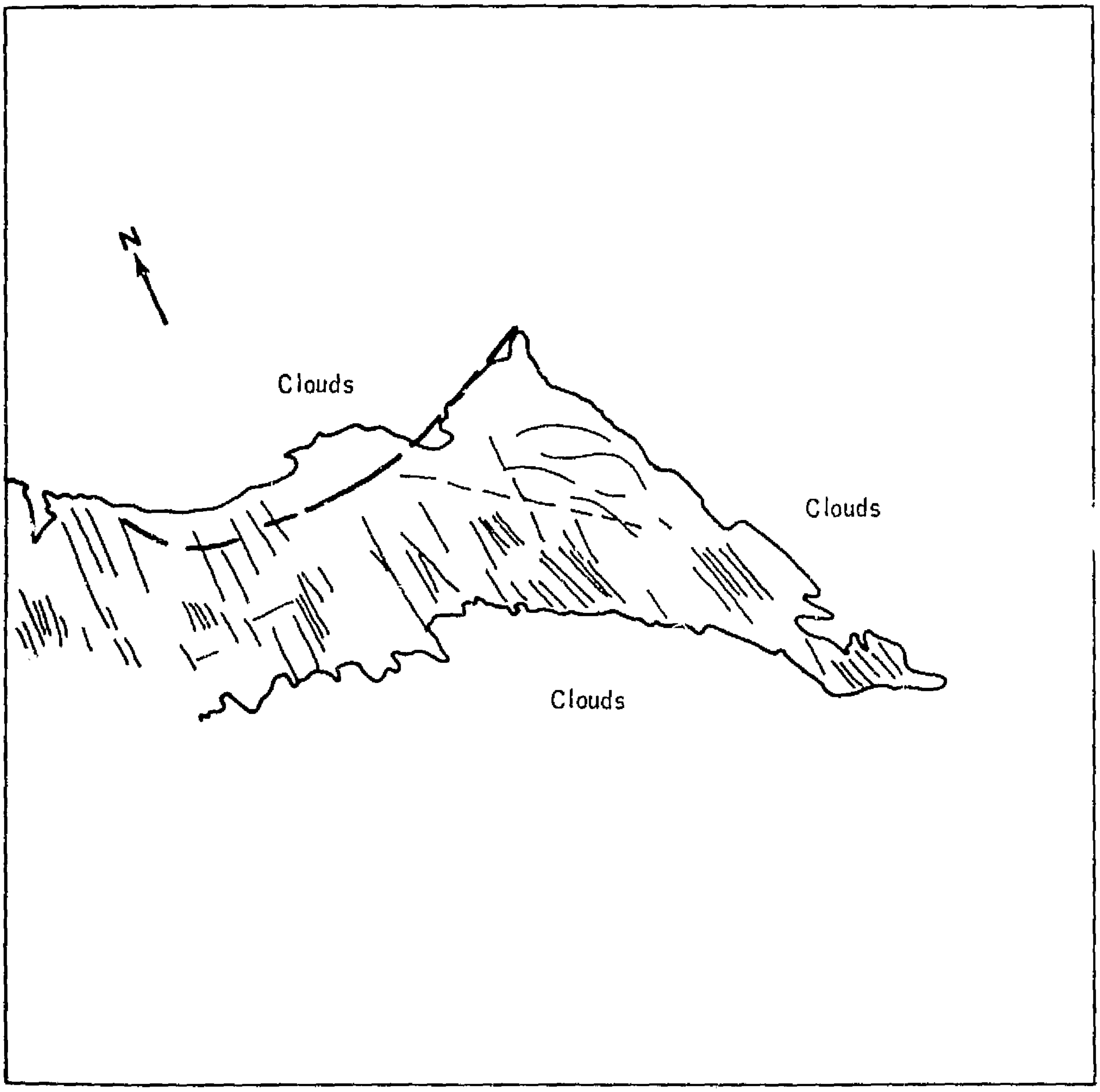


Figure 6-18.- Explanatory map of figure 6-17 showing linears (which cut across the range) that are interpreted to be cross faults. Heavy dashed line is a linear that coincides with a mapped fault.

The crewmen noted (1) a need for more briefing in rapid recognition of geographic localities, to eliminate the approximately 20-day orientation period, (2) a need for better maps and annotated photographs, (3) the inadequacy of the viewing station, (4) their observations were hampered by the need to select the camera and lens, and (5) the debriefing of each photograph further hampered observation. A correction of these inadequacies and obstructive factors would substantially improve the efficiency and effectiveness of visual observations. More verbal interplay between the crewmen and scientist during the mission is desirable to enable the crewmen to follow up on observations.

RECOMMENDATIONS

Stereopairs, either vertical or oblique, best show geologic features and are preferred over single photographs. Observation or photography should be planned in advance. If cirrus clouds cover an area, observation may be more useful than photographs; if the area is clear, photographs should be taken. The crewmen should have near-real-time communication with the ground to better apprise the Science Team of observations made and to receive recommendations on how to best follow up previous observations.

Maps could be improved by eliminating unnecessary cultural features and by enhancing those features visible from space; annotated photographs from previous Earth-orbital missions are the best base. Correct camera/lens/filter combinations should be predetermined, and lenses should be rapidly interchangeable. Fully automated cameras with remote-control capabilities would allow crewmen of future missions to observe the photographic objective at all times. Frame and magazine numbers, as well as time and position, should be automatically recorded to allow the crewmen the freedom to carry on observations. More training on the quick recognition of geographic position is needed to eliminate the approximately 20-day orientation period. This period could be substantially reduced by the use of existing space photographs to construct exercises on recognition of key areas and features.

The photographs studied thus far demonstrate that tropical (i.e., high humidity) regions require different film, filters, or camera settings than those currently used.

REFERENCES

6-1. Allen, Clarence R.: Circum-Pacific Faulting in the Philippines-Taiwan Region. J. Geophys. Res., vol. 67, no. 12, Nov. 1962, pp. 4795-4812.

6-2. Arabasz, Walter Joseph, Jr.: Geological and Geophysical Studies of the Atacama Fault Zone in Northern Chile. Ph.D. Thesis, Calif. Institute of Tech., 1971.

6-3. Baker, B. H.; Mohr, P. A.; and Williams, L. A. J.: Geology of the Eastern Rift System of Africa. Geol. Soc. Am. Spec. Paper no. 136, 1972, pp. 1-61.

6-4. Cristi, Jorge Munoz: Chile. Handbook of South American Geology, William Furness Jenks, ed., Geol. Soc. Am. Memoir no. 65, 1956, pp. 187-214.

6-5. James, David E.: Plate Tectonic Model for the Evolution of the Central Andes. Bull. Geol. Soc. Am., vol. 82, no. 10, 1971, pp. 3325-3346.

6-6. James, David E.: The Evolution of the Andes. Sci. Am., vol. 229, no. 2, Aug. 1973, pp. 61-69.

6-7. St. Amand, Pierre; and Allen, Clarence R.: Strike-Slip Faulting in Northern Chile (abs.), Bull. Geol. Soc. Am., vol. 71, no. 12, Part II, 1960, p. 1965.

7. PRELIMINARY REPORT ON GEOLOGIC INVESTIGATIONS OF SOUTHWESTERN NORTH AMERICA

Leon T. Silver,[a] T. H. Anderson,[a] Clay Conway,[a] and Jay Murray[a]

A brief geology experiment was part of the Visual Observations Project of the Skylab 4 mission. In general, the experiment was designed to determine the effectiveness of man as a scientific observer of Earth surface features from a space platform and, in particular, to investigate some basic scientific problems in southwestern North America. The crewmen made 110 verbal observations and took more than 300 photographs, with handheld (HH) cameras, of all designated study areas and some sites of opportunity over the region. To date, positive transparencies of all pertinent photographs from five of the eight Hasselblad data camera (HDC) 70-millimeter magazines and complete transcripts of the crewmen's relevant comments are available. The remaining three Hasselblad magazines and the Nikon 35-millimeter magazines are being processed. The results of the study of these data will be incorporated into the final report; however, the preliminary analyses indicate some important contributions to the understanding of major fault structures and will be discussed in this report.

OBJECTIVES

The objectives of the geologic portion of the Visual Observations Project were related to man's capabilities as a discriminating and organized observer, spontaneous experimenter, explorer, and discoverer from the vantage point of an Earth-orbiting space platform. This report is concerned with the extent and effectiveness with which the crewmen examined and photographed the designated study areas. The scope of this section is dictated by the limited opportunities thus far to examine and synthesize the total product and to return to the crewmen for further discussions.

EXPERIMENT PREPARATION

The Science Team member for the Visual Observations geologic studies and his colleagues prepared a series of 11 operational exercises and study areas in the southwestern United States and northwestern Mexico, each built around a base photograph from Apollo and earlier Skylab missions. These exercises were reorganized into seven study problems by the Visual Observations Project Team

---

[a] California Institute of Technology.

to the NASA Lyndon B. Johnson Space Center (JSC) and were then incorporated into the Visual Observations Book as specific handheld camera sites.

Preflight review of the Visual Observations Book with the Skylab 4 crewmen was limited to one afternoon session for all categories of visual observations experiments. However, some opportunities for in-flight communications to the crewmen were provided.

PRELIMINARY ASSESSMENT OF MISSION RESULTS

A number of important points reflecting the potential of visual observations and the techniques necessary to realize that potential can be derived from the in-flight performance and recorded comments of the crewmen and from the available photographs. A major preliminary observation is that human visual perception appears to equal or exceed most photographic techniques, including those of mapping cameras, in perceiving color and textural contrasts. Another important observation is that the return from visual observations can be greatly enhanced by adequate preflight crew training and preparation. The crewmen demonstrated interest and expertise in performing the experiment and their continued participation in the analysis of the results will be valuable.

Identification of Designated Sites

The crewmen quickly established the geographic location and identified the major geologic features in most of the designated sites (figs. 7-1 and 7-2). The fault systems of California (HH108) and of Baja California (HH111) were repeatedly observed and photographed. All the sites in Sonora, Mexico (HH112, HH113, and HH114) were examined and photographed. Some photographs of central and southeastern Arizona (HH125 and HH126) were obtained. In addition, the crewmen selected and geographically identified a number of additional photographic sites in the region that displayed useful geological information.

Verbal Commentary

The crewmen recorded comments primarily to identify the sites that were photographed, the Greenwich mean time of the photograph and the recording, the photographic conditions, and the camera settings. In general, descriptive and interpretative comments were subordinate. A listing of observations by geographical area is given in table 7-I.

Photographic Summary

The crewmen obtained intensive photographic documentation of all study areas and of other geological features of interest to them. For the specific study areas, the provisional count from the transcript is given in table 7-II.

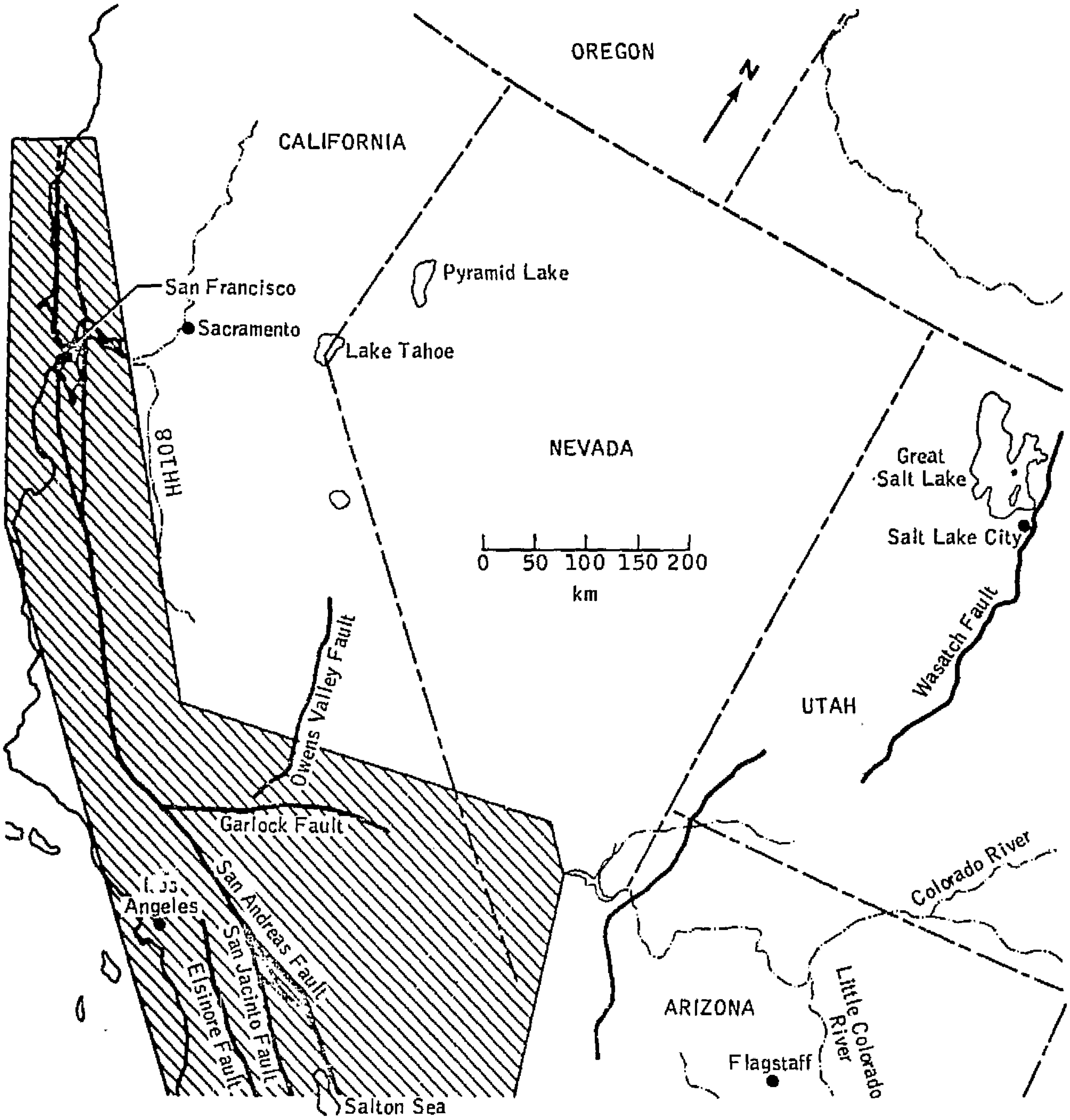


Figure 7-1.- Shaded areas represent study sites in California and Nevada (HH103).

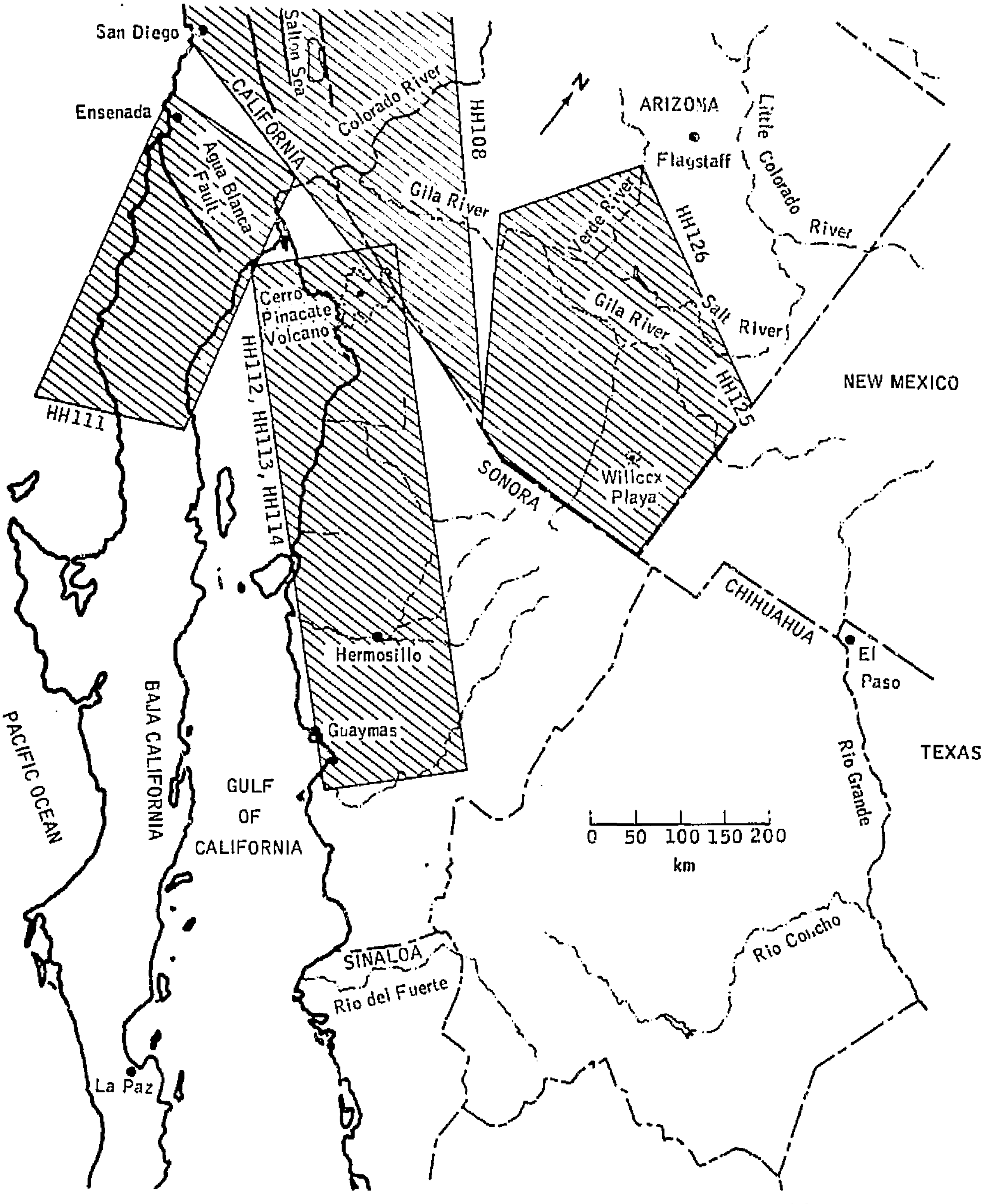


Figure 7-2.- Shaded areas represent study sites in Baja California and Sonora, Mexico (HH111, HH112, HH113, and HH114) and the southwestern United States (HH125, HH126).

TABLE 7-I.- REAL-TIME CREW COMMENTS ON VISUAL OBSERVATIONS SITES

Feature	No. of times mentioned	No. of observations of nearby sites
Baja California and the Gulf of California (HH111) . . .	33	6
Sonora, Mexico (HH112, HH113, and HH114)	12	10
Arizona (HH125 and HH126)	2	8
San Andreas Fault and related faults (HH108)	22	18

TABLE 7-II.- PHOTODOCUMENTATION OF MEXICO AND THE SOUTHWESTERN UNITED STATES

Feature	No. of frames taken
Baja California (HH111)	158
Sonora, Mexico (HH112, HH113, and HH114)	77
Arizona (HH125 and HH126)	8
San Andreas Fault and related faults (HH108)	72
Total	315

Many of these frames are sufficiently oblique and cover large enough areas that they may be useful in several investigations. A review of the available photographs has indicated that the coverage of the designated study areas will probably be almost 100 percent. Figures 7-3 to 7-5 plot the locations of 43 frames taken over Mexico and the southwestern United States. A comparison of the sites shown in these figures with the designated sites shown in figures 7-1 and 7-2 reveals how thoroughly the areas were photographed.

Examination of figures 7-3 to 7-5 indicates that relatively few photographs are redundant. Varying conditions of lighting and cloud cover justify much of the overlapping photography; almost every photograph shows specific and unique features.

Crew Debriefing

The 4-hour crew debriefing on geological observations was informative and productive. The debriefing transcripts are important documents and should be available for future mission planning. Although most of the questions were based on cursory studies, they were received and handled well by the crewmembers. The most effective discussions concerned the improvement of Earth-oriented visual observations studies in future space missions and special recommendations for the Apollo-Soyuz Test Project (ASTP). It is evident that as the analyses of photographs and commentary continue, additional exchanges with the Skylab 4 crewmembers will enhance the scientific yield from the Visual Observations Project.

ACHIEVEMENT OF EXPERIMENT OBJECTIVES

Scientific Results

The crewmen focused intensively on the various fault systems in their designated study areas. In the geology debriefing, the crewmen emphasized that their attention was drawn by the strong topographic expression of several of these faults, especially the San Andreas and San Jacinto Fault Zones in California (HH108) and the Agua Blanca Fault Zone in Baja California, Mexico (HH111). These faults can be identified in figures 7-6 and 7-7.

The Agua Blanca Fault Zone (figs. 7-8 to 7-11) was first identified by the Principal Investigator and his colleagues approximately 20 years ago. It clearly is one of the major regional structures related to the recent geologic history of Baja California and the Gulf of California. The eastward projection and the sense of relative motion of the two different branches are unresolved problems. The crewmen were asked to look for linear features that might be eastward extensions of the fault. They carefully scrutinized the regions east of San Matias Pass (figs. 7-10 and 7-11) in the Valle San Felipe and along the coastline of the Gulf of California. The crewmen observed no features that seemed to be possible extensions of the fault system. This confirmed the

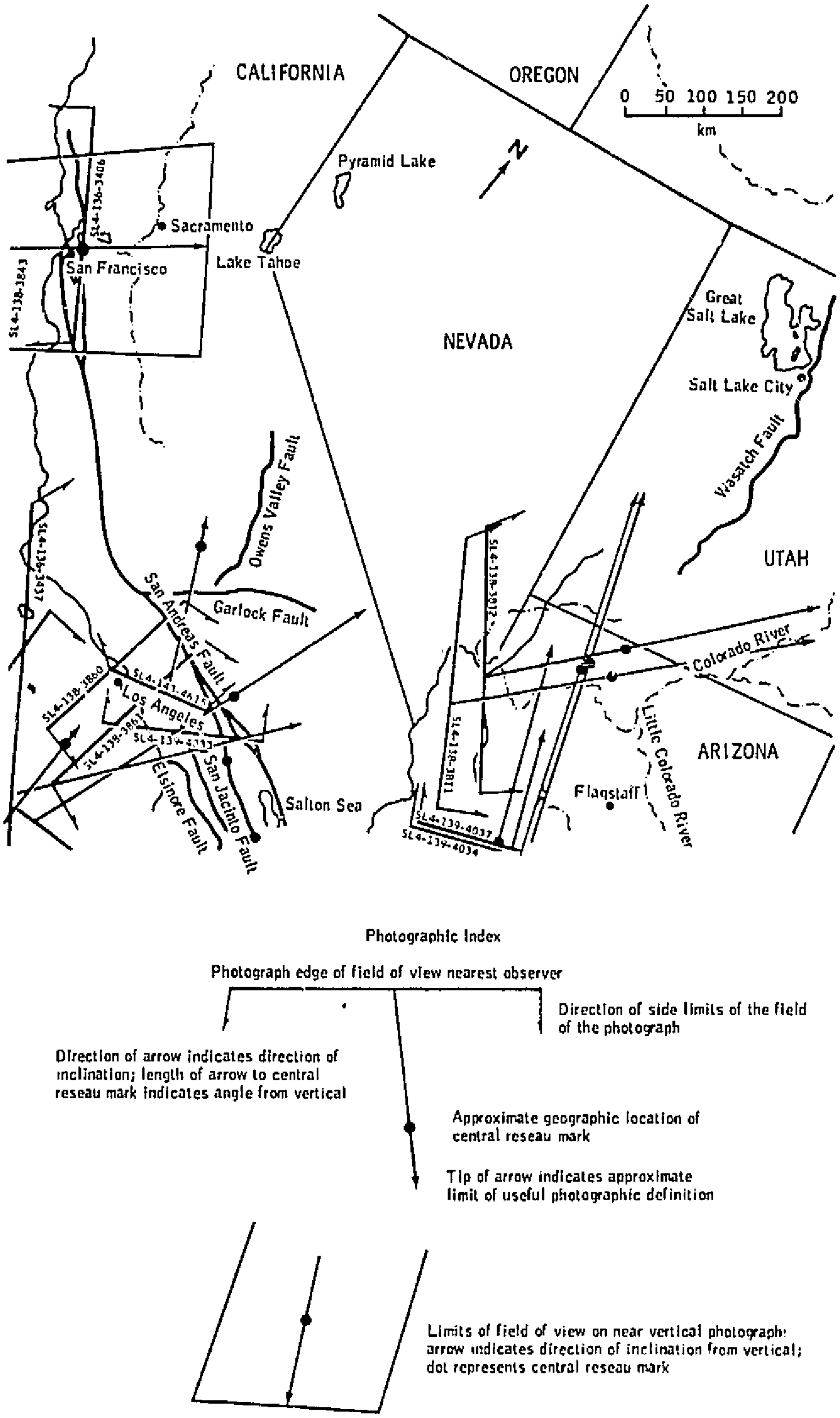


Figure 7-3.- Handheld photographic sites in the southwestern United States.

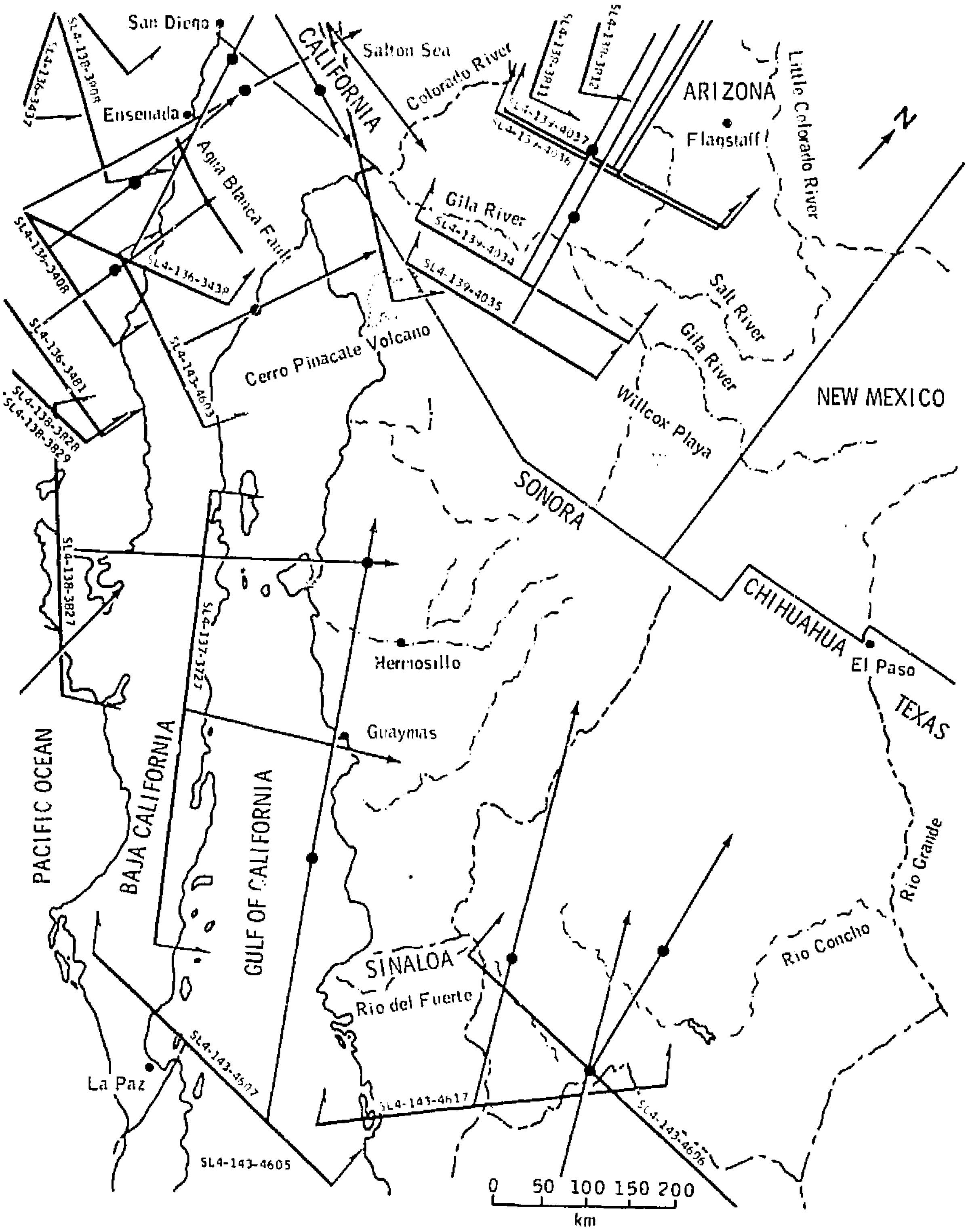


Figure 7-4.- Handheld photographic sites in the southwestern United States and Mexico. Explanation for symbols is given in figure 7-1.

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

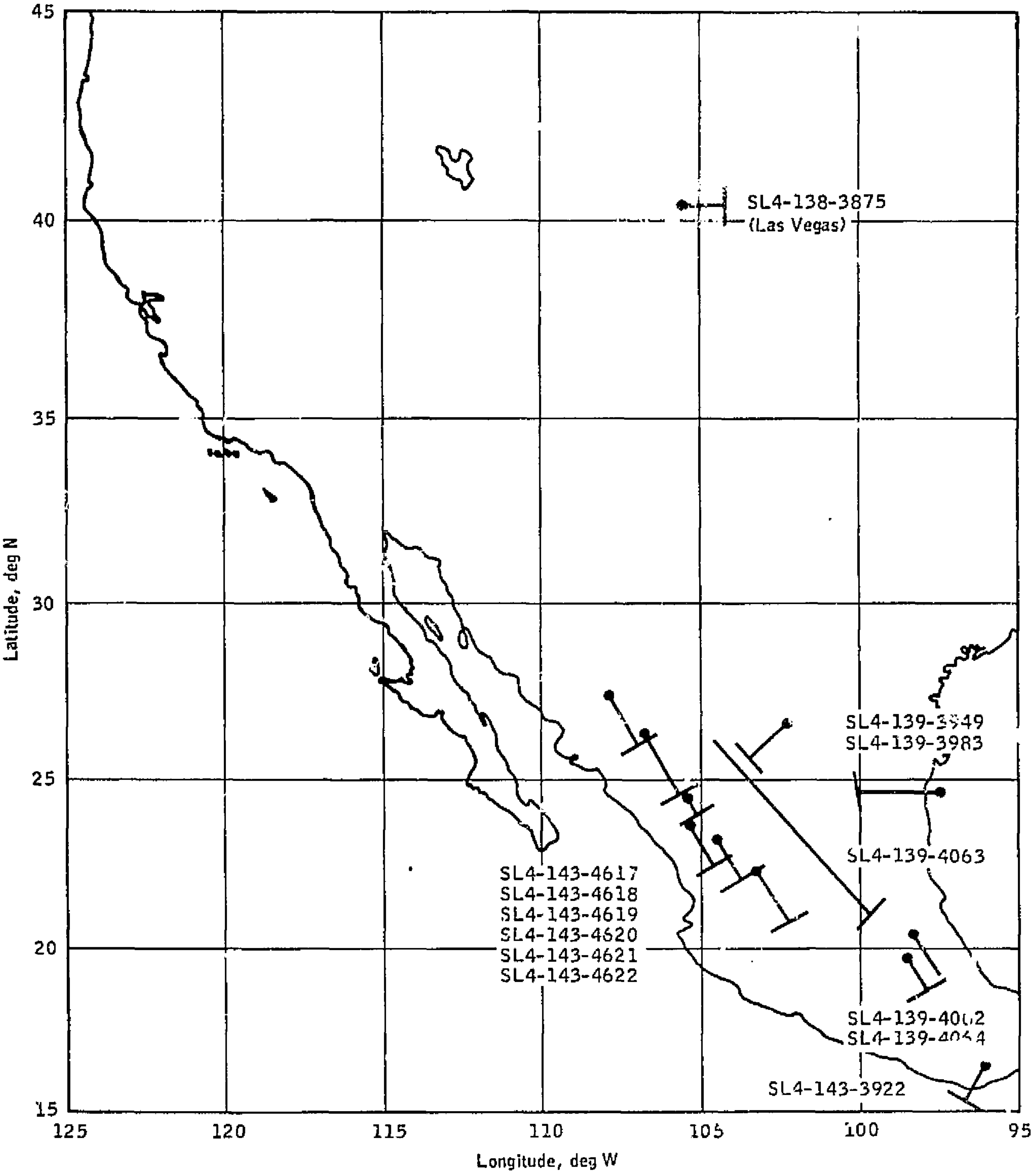


Figure 7-5.- Map of Mexico and the southwestern United States showing areas of photographs taken by the Skylab 4 crewmen.

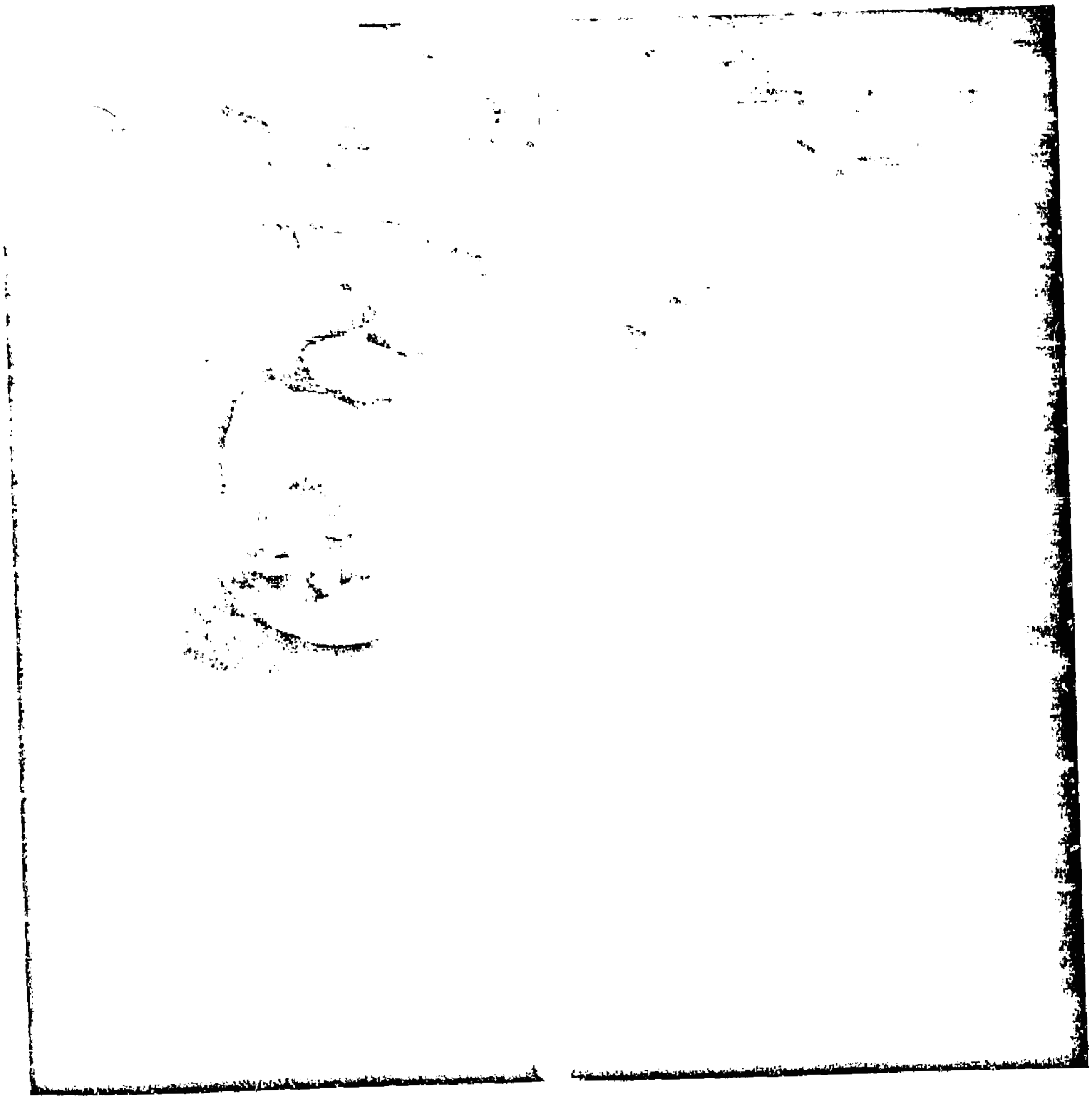


Figure 7-6.- Photograph of major fault zones in the southwestern United States and Mexico (SL4-136-3438).

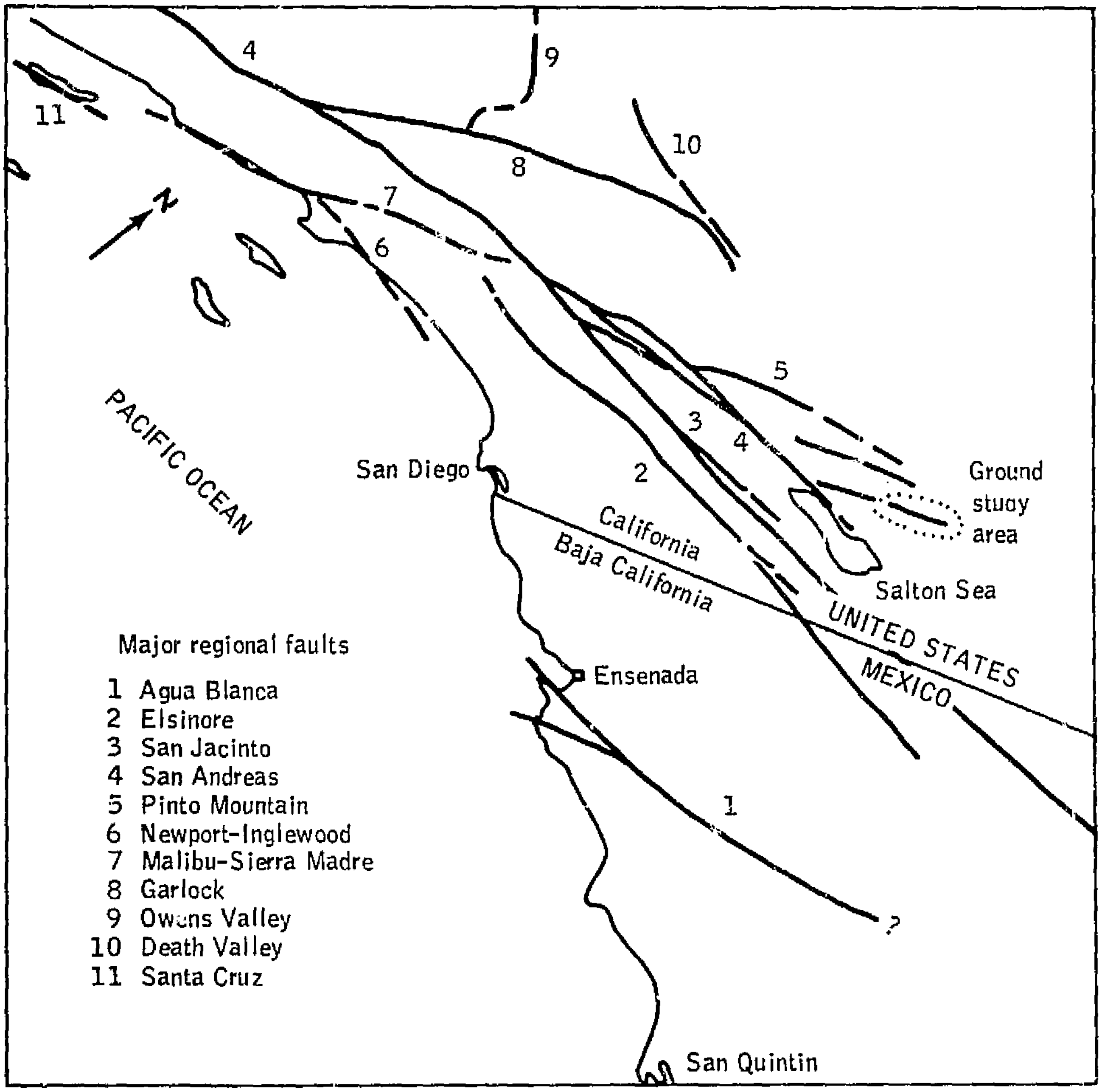


Figure 7-7.- Explanatory map of major fault zones visible in figure 7-6.

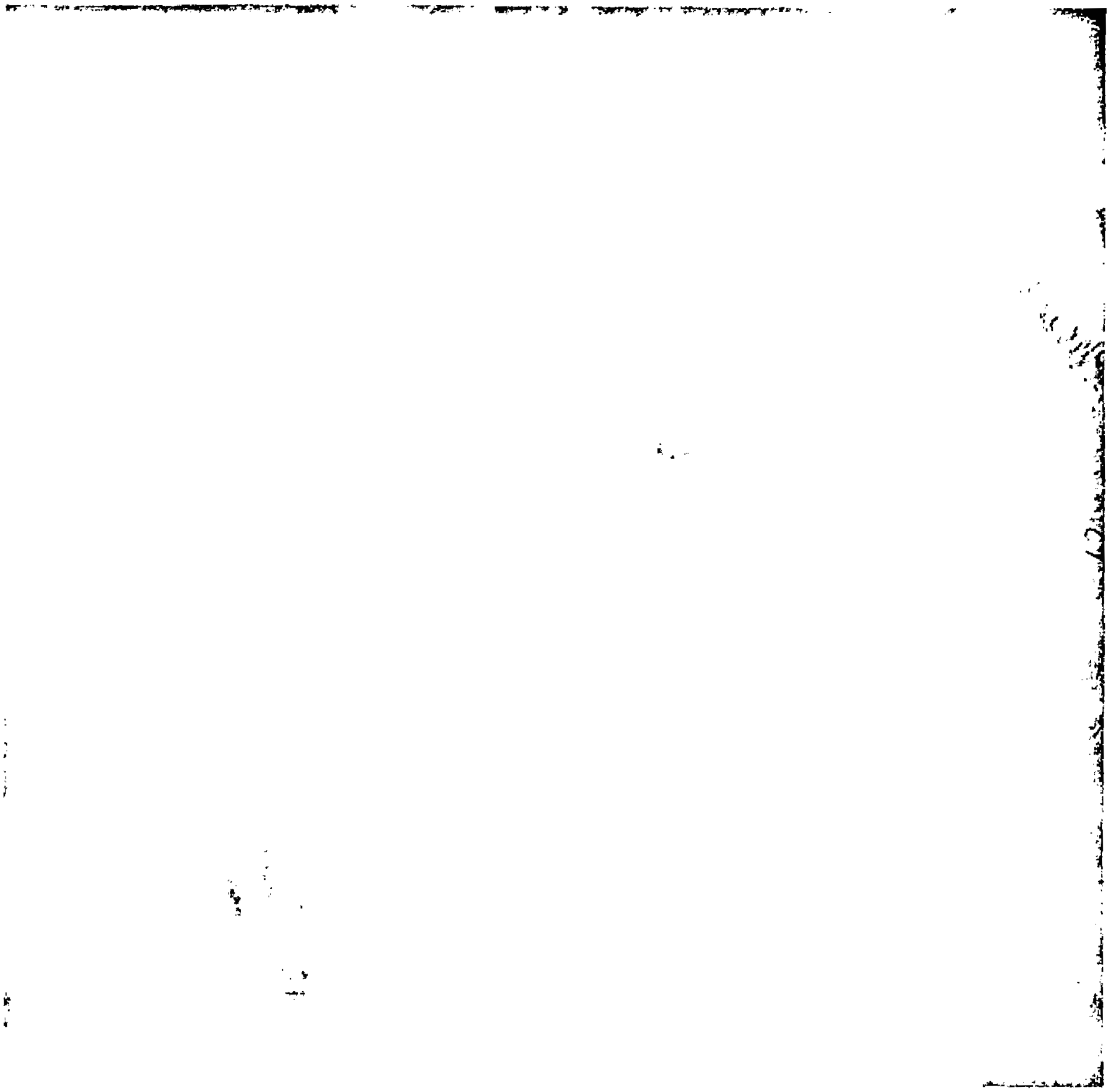


Figure 7-8.- The Agua Blanca Fault Zone in Baja California, Mexico (SL4-136-3480).

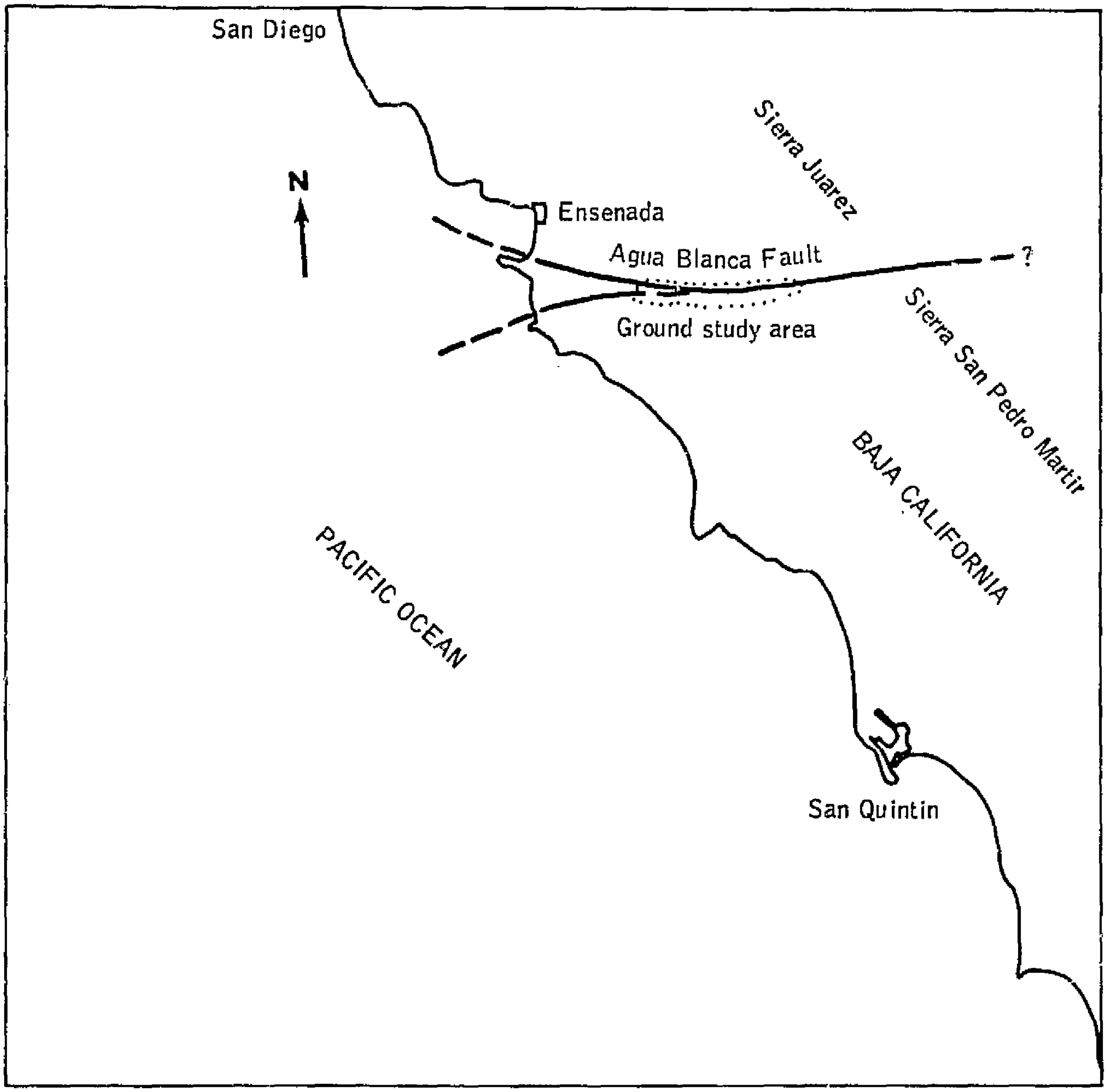


Figure 7-9.- Explanatory map of the area pictured in figure 7-8, showing the location of the Agua Blanca Fault Zone.

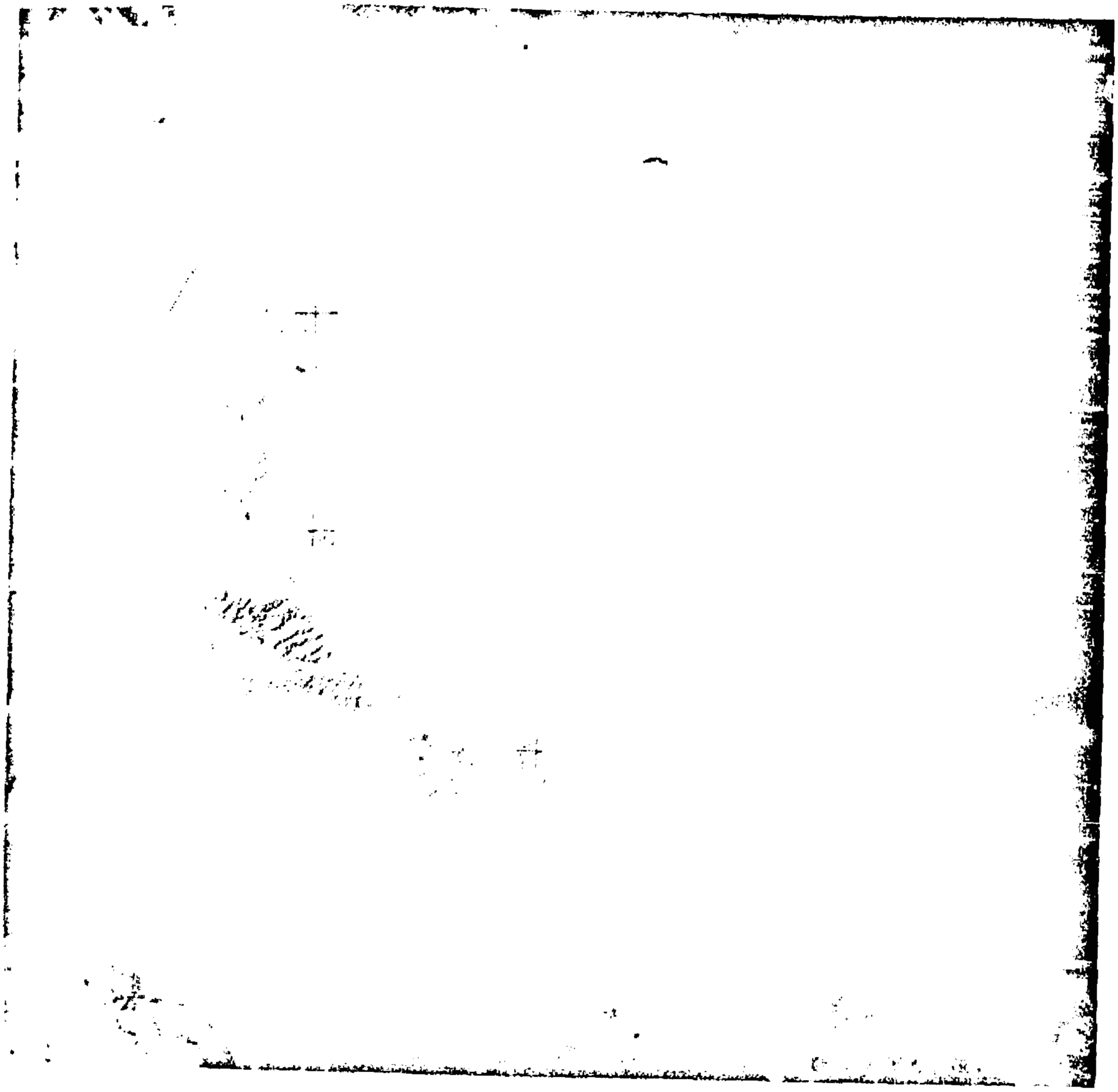


Figure 7-10.- Photograph of the area in which the crewmen searched for a possible eastward extension of the Agua Blanca Fault Zone (SL4-143-4603).

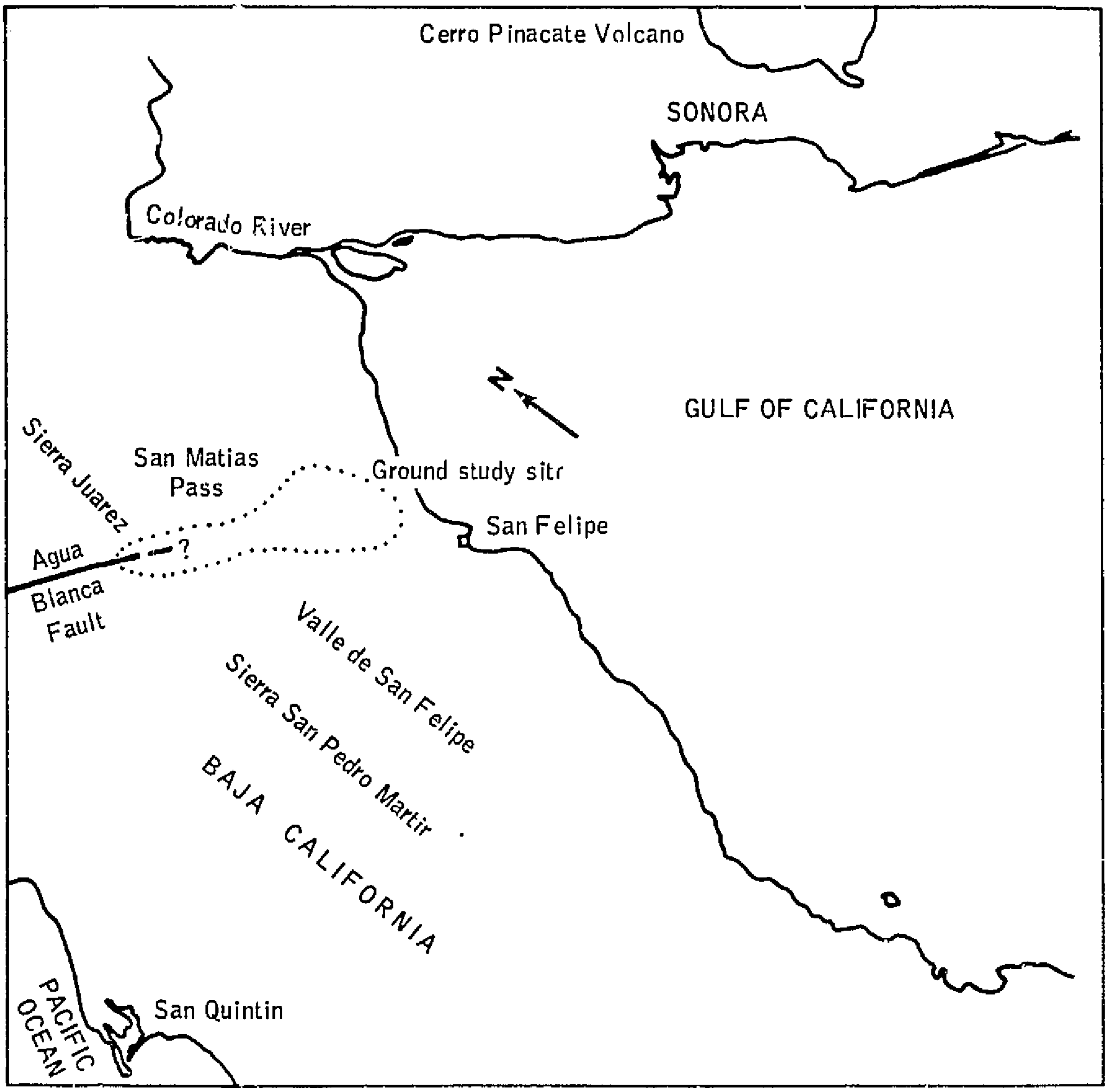


Figure 7-11.- Explanatory map of the area shown in figure 7-10. The site of planned ground studies is indicated.

results of the early studies of the area that were conducted when no maps or photographs existed. Further field studies based on the photographs and the observations of the Skylab 4 crew are planned.

The significance of these observations lies principally in the interpretation of the genesis of major regional faults. The Agua Blanca Fault would appear to have developed as a short-lived transform fault during the progression of the eastern Pacific rise from west of the California coast to its present position in the Gulf of California. Observations made by the crewmen are relevant to this hypothesis.

The photographs suggest a need for field investigations in a region east of the Salton Sea (fig. 7-6), where some evidence for displacement on an important east-west fault is seen. A ground study of this region is being planned (fig. 7-7).

Operational Aspects of the Visual Observations Project

The effectiveness of any program depends on the personnel involved; their interest, scientific training, observational powers, and preflight preparation are key aspects. The Skylab 4 crewmen demonstrated a high degree of interest both in the Visual Observations Project and in the geologic questions that concerned specific sites.

The scientific background of the Skylab 4 crewmen varied from sound for the commander and the pilot to outstanding for the science pilot. They clearly understood the nature of observational techniques and the associated inductive logic. For geological sciences, the crewmen lacked a basic familiarization with geologic phenomena; this could have been remedied by longer preparation for observational tasks.

The preparation of the crewmen for the Visual Observations Project was minimal. The crewmembers recognized this and, during debriefing sessions, discussed the need for a longer, more in-depth training program. The Visual Observations Book was extensive and detailed and was designed to keep the crewmen constantly aware of the contingencies that pertained to the observations.

The observational powers of the crewmen were exceptional. Combined with their interest and enthusiasm, these capabilities have produced some outstanding photographic studies. The quality of the transcribed comments, in comparison with that of the photographs, may reflect a lack of confidence by the crewmen in their command of the diverse scientific subject matter. The fact that the crewmembers quickly recognized and identified the geological features that they were trained to identify reinforces the belief that more extensive preflight preparation would have been beneficial.

The Skylab 4 crewmen used many new techniques for visual observations and photography; these techniques will be treated at length in the final report. The crewmen have stressed the importance of the fact that photography cannot match the effectiveness of the human eye in perceiving color, texture, and form of surface phenomena.

In the geology debriefing session of March 12, 1974, the Skylab 4 commander made the following comments:

> "Let me say just one thing to you. I think there is one fallacy we fell to, and that was the tendency to depend on the photographs. We've gotten back and we've looked at this photography now. It doesn't capture everything that's there and I think you guys understand that. I don't think we understood it as well as we should have before we left. Some of the stuff we have looked at just does not hold a candle to what you can really see with the old MK [Mark]-VIII eyeball. And this is something we are going to have to do in future programs, and that is either to get better photography or start training a little bit more towards being able to get verbal descriptions of what you're looking at, because these pictures just don't have all of it at all."

SOURCES OF INFORMATION

The preliminary results of the Skylab 4 geologic investigations are based on the examination of the following data.

1. The Visual Observations Book
2. Skylab groundtrack map (mission chart)
3. Transcriptions of real-time and recorded comments by the Skylab 4 crewmen
4. Data logs of handheld photographs prepared and updated on the ground during the mission
5. Summary and description of the completed visual observations and handheld photographs prepared by the JSC Science Team members
6. Scene identifications of handheld photographs according to geographic location
7. Video tapes of Earth-looking scenes (SL4-164, SL4-175, and SL4-186)
8. Handheld photographs from HDC magazines 136 to 139 and 143
9. Handheld and Earth resources experiment package photographs from the Apollo 6, 7, and 9 missions and from the Skylab 2 and 3 missions
10. Skylab 4 crew debriefing of March 12, 1974
11. Previous field studies by the authors

CONCLUDING REMARKS

The experiences of the Skylab 4 crewmen have made an excellent beginning in establishing the operational requirements for an effective Visual Observations Project, and scientists will profit from both the deficiencies and the successes of the Skylab 4 mission. A comparative analysis of photographic capabilities as opposed to human capabilities in Earth observations will aid in optimizing future visual observations techniques.

8. VOLCANOES AND VOLCANIC LANDFORMS

Jules D. Friedman,[a†] David G. Frank,[b] and Grant Heiken[c]

Before the Skylab 4 lift-off, the crewmembers were briefed on the scientific significance of volcanic features and on the types of dynamic volcanic processes, such as eruption clouds, that should be described and photographed. As an aid for this task, the onboard data package included a map showing the location of the volcanoes that were expected to be active during the mission and a list of volcanic landforms to be photographed. This report describes the results of a preliminary assessment of the Skylab 4 Hasselblad 70-millimeter photographs and of the transcripts of the crewmen's observations of terrestrial volcanoes and volcanic landforms.

During postmission debriefings, the crewmen provided a valuable assessment of the information contained in the 70-millimeter transparencies in relation to that perceived from orbit by the unaided eye or through binoculars. Color contrasts and shape variations seen by the crewmen from orbit may not be discernible in the transparencies. However, the transparencies have the advantage of availability for extended quantitative study. The crewmen commented that the level of detail seen from orbit was equivalent to that seen in the stereophotographs. The color of volcanic features recorded on film depends on a variety of factors (e.g., lighting conditions); therefore, the color shown in the photographs may or may not accurately reproduce that seen from Skylab. A Sun angle of 20° or less is optimum for viewing and photographing volcanic surface features and eruption clouds. The low Sun angle enhances low-relief features, whereas a high Sun angle and low phase angle provide optimum definition of color contrasts.

SIGNIFICANT OBSERVATIONS

The most significant volcanologic observations and photographs were obtained over the erupting volcano Sakura-zima in southern Kyushu, Japan, and the inaccessible Bolivian-Chilean-Argentine volcanic fields. Excellent photographs were also acquired of the Tibesti Massif in Chad and of the volcanoes in Oregon, Washington, Hawaii, and the neovolcanic axis of Mexico.

---

[a] U.S. Geological Survey, Denver, Colorado.

[b] U.S. Geological Survey, Tacoma, Washington.

[c] NASA Lyndon B. Johnson Space Center.

[†] Principal Investigator.

Sakura-zima, Japan

Among the most valuable photographs of volcanic activity made from Earth orbit are those obtained by the Skylab 4 crewmen that show the island of Kyushu, Japan, and the active volcanoes Turumi, Kuzyu, Aso, Kirisima, Unzen, Kaimon, and Sakura-zima. Sakura-zima (fig. 8-1), identified by the whitish eruptive cloud, is in Kagoshima Bay at the south end of Kyushu and consists of three overlapping stratovolcanoes. Activity has been recorded at this volcano since the year 708; recent eruptions have consisted mostly of pyroclastic activity at Minami-dake (South Peak) where 1 to 13 eruptions a day have occurred interspersed with the quiet release of fume clouds. The maximum elevation reached by the tephra clouds was 4 kilometers above the vent (ref. 8-1). An isthmus, formed in 1914 by lava flows, connects the island of Sakura-zima with Kyushu. Since the 1914 eruption, the activity has shifted to, and has been localized at, the summit of Minami-dake, as shown in figure 8-1. However, during Pleistocene time, the volcanic activity of proto-Sakura-zima occurred at a point 10 kilometers northeast of the present Sakura-zima volcano. The semicircular form of the northeastern shoreline of Kago-shima Bay may represent the outline of the older caldera formed before the present location of Sakura-zima. The Skylab photographs thus document the southwestward shift in the focus of volcanic activity now concentrated at the Minami-dake summit of Sakura-zima.

On January 7, 1974, the Skylab 4 crewmen observed that Sakura-zima was erupting and subsequently described and photographed (fig. 8-1) the entire eruption cloud. Control of the eruption cloud movement by winds was evident in the following description by the commander (CDR): "The smoke was flowing straight southeast from the volcano over the southeast corner of Kyushu. As soon as it reached the ocean, it began to diffuse and billow." The eruption cloud was not continuous but was a series of "puffs" possibly corresponding to paroxysms spaced a few seconds apart. After crossing the Osumi Peninsula and reaching the ocean, the cloud moved northeast and was dispersed by strong winds. The width of the fume pattern appears to be two to three times that of the white cloud.

On January 8, 1974, 24 hours after the initial description of the Sakura-zima plume, the CDR photographed the plume again (fig. 8-2) and described it as "diffused, covering a much larger area." The plume pattern was similar to that observed on January 7; the crewmen estimated the white or tan cloud was approximately 240 kilometers long.

In figure 8-2, the volcanic plume is continuous until it reaches the ocean where it turns northeast and is dispersed. The length of the visible cloud in the photograph is estimated to be 285 kilometers. The degree of dispersion is evident in the width of the cloud. Near the vent, the cloud is approximately 4 kilometers wide; at 172 kilometers, the cloud is 86 kilometers wide and is dispersed into 1- to 8-kilometer-wide parallel bands.

The Skylab photographs of the plume are significant for several reasons. First, they document the type and extent of a Sakura-zima eruption plume from Earth orbit. Second, they constitute synoptic data suitable for studying an

Figure 8-1.- North-facing oblique view of the island of Kyushu, Japan. The eruption cloud from the Sakura-zima Volcano (A) is moving southeast across the Osumi Peninsula and is then dispersed over the Pacific Ocean. Other caldera-stratovolcanic complexes in the photograph are Kaimon (B), Kirisima (C), Aso (D), and Kuzyu (E) (SL4-139-3942).

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

Figure 8-2.- West-facing oblique view of Kyushu Island, Japan, and Sakura-zima Volcano. The eruption cloud moves southeast across the Osumi Peninsula and is dispersed to the northeast over the Pacific Ocean (SL4-139-3972).

entire eruption cloud. The curling, twisting plume visible in these photographs demonstrates that previous models of tephra fall, following a parabolic or elliptical outfall pattern with a near-linear axis, may not always apply. This new information is significant. Third, analysis of the stereographic images shows that the eruption cloud did not penetrate the tropopause and therefore did not form a dust veil in the upper atmosphere. These results have provided information for relating the intensity of volcanic eruptions to contamination of the upper atmosphere. Information about the 1955 to 1960 eruptions of Sakura-zima (ref. 8-2) indicates the kinetic energy level of individual paroxysmal eruptions of the type observed by the Skylab 4 crewmen ranges from 0.3×10^{11} to 2×10^{11} joules (0.3×10^{18} to 2×10^{18} ergs). Based on the Skylab 4 photographs, this magnitude is probably too small to penetrate the tropopause and create a stratospheric dust veil.

Bolivian-Chilean-Argentine Volcanic Fields

Several Skylab 4 handheld photographs provide interesting and useful information on the topographic and geologic features of the isolated and inaccessible volcanic fields in the region from Salinas Grandes and Salina del Rincan, Argentina, to Lago Colorado and Lago Verde, Bolivia. (One of these photographs, figure 8-3, is representative of this South American volcanic region.) Four volcanic calderas, 10 to 15 kilometers in diameter, are visible in the photographs. Analysis of the photographs indicates that the floor of each caldera is characterized by a series of resurgent domes, lava flows, and cones. One of the largest calderas is cut by a broad graben, possibly indicating collapse of the caldera after the eruption of ash-flow tuff that appears to form the tablelands surrounding the calderas. The ash-flow tuff apparently covered much of this area and filled the prevolcanic mountainous terrain. Further analysis of the Skylab photographs will define the geologic relationship of calderas, fault systems, and volcanic flows in this part of the high Andes Mountains.

Island of Hawaii

In the photographs of the volcanic areas of Hawaii, prominent volcanic features such as the summit caldera on Mauna Loa, the extinct volcano Mauna Kea, the Kilauea caldera, and the pit crater at Halemaumau within the caldera are easily identified (fig. 8-4). Detailed features such as the extent and delineation of historic lava flows on Mauna Loa can be determined and are important factors in planning the study of volcanoes for future manned missions.

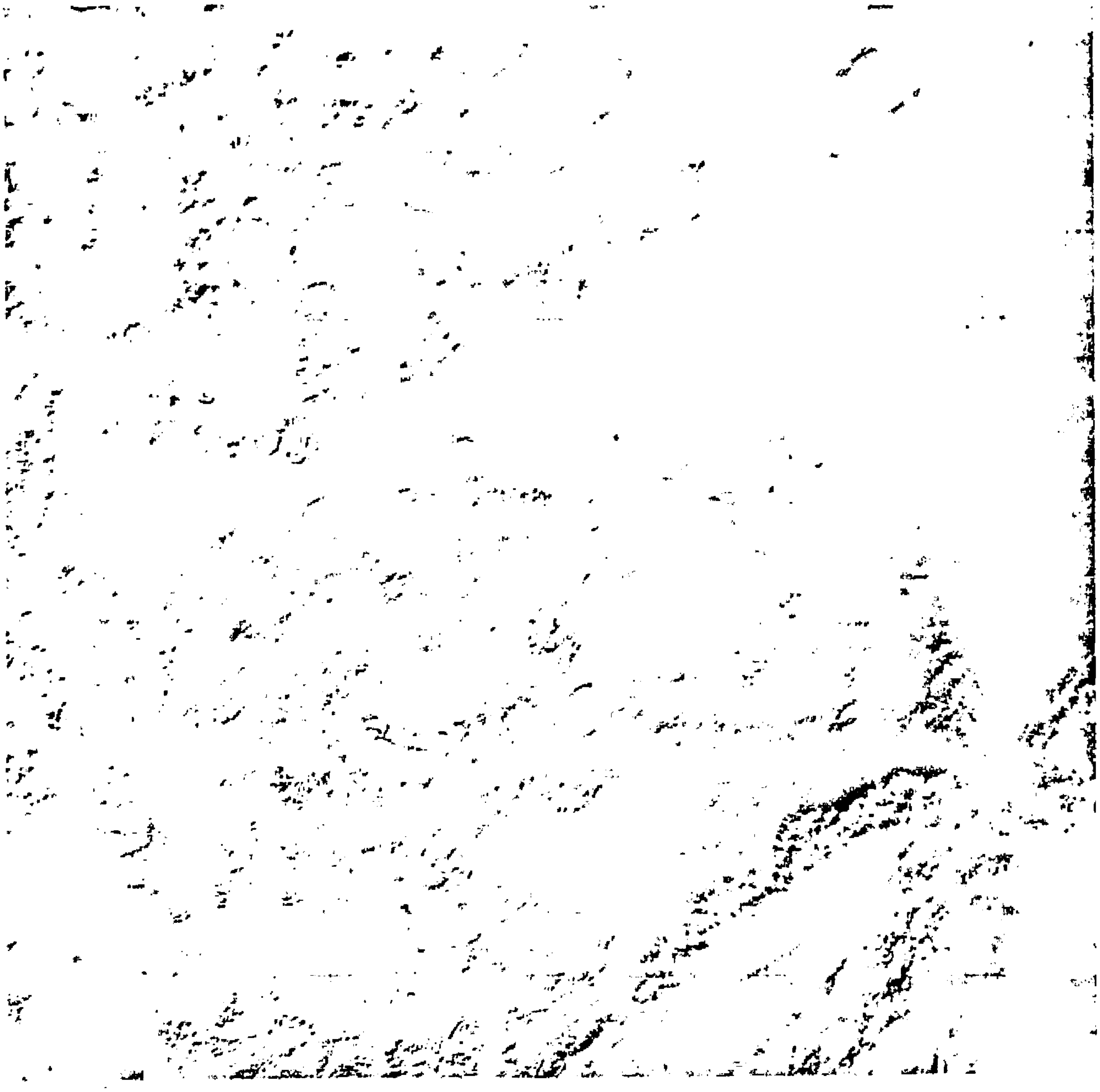


Figure 8-3.- Near-vertical view of the extensive volcanic fields near the junction of the borders of Bolivia, Argentina, and Chile. Features include a caldera approximately 15 km in diameter (A) surrounded by plateaus of ash flow tuff (?), rhyolite (?) flows (B), and stratovolcanoes (C) (SL4-137-3674).

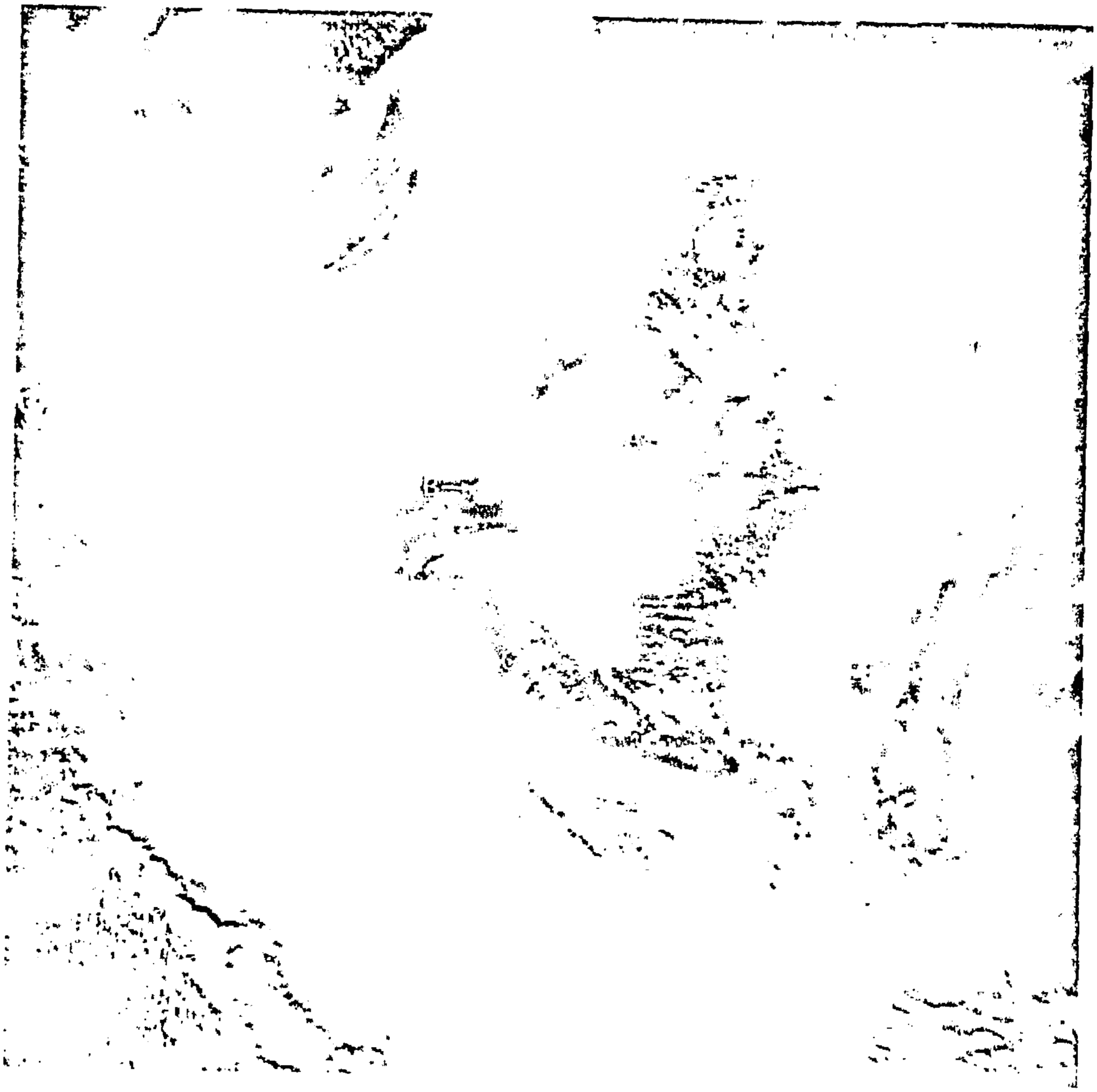


Figure 8-4.- The island of Hawaii and the recent volcanoes Mauna Kea (A), Mauna Loa (B), and Kilauea (C). Many lava flows are evident (SL4-139-3997).

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

Tibesti Massif, Chad

The photographs obtained by the Skylab crewmen have further explained the evolution of the Tibesti caldera and ash-flow tuff (ignimbrite) plateaus. One photograph (fig. 8-5) shows the vivid contrast between the reddish nonvolcanic bedrock and sedimentary deposits and the dark volcanic rocks. Distribution of the major rock units can be mapped from this photograph. Analysis of the photograph clearly reveals the dissection of the domelike carapace formed by the ash-flow tuffs and the nature of the older underlying rocks. The 14.5-kilometer-diameter Emi Kaussi caldera is a prominent landmark.

Volcanoes of Oregon and Washington

The Cascade Range from the Oregon-California border to Canada and the volcanic fields of south-central Oregon are shown in figures 8-6 and 8-7. In figure 8-6, the prominent stratovolcanoes of Crater Lake and Mount Hood are easily identified. The crewmen were not requested to identify and describe specific features such as the 2100-meter-diameter summit crater on Mount Rainier or the 80-meter-diameter summit crater on Wizard Island in the Crater Lake caldera; however, because of the snow cover, these features would have been difficult to detect.

The effect of snow cover in the identification of surface features is indicated in figure 8-6. In the Cascade Range, snow cover is extensive and, because of the contrast between the white snow and dark forests, the high peaks are enhanced. The Holocene (recent) lava flows from the Belknap Craters, Oregon (upper left) are covered by snow; however, they lack vegetation and their general structures and distribution can be determined. Older volcanic landforms that support forests are masked by snow. In south-central Oregon (fig. 8-6), snow cover is not extensive, and the basalt flows at Devils Garden, Lava Mountain, and Green Mountain (upper left center) as well as numerous small cones and domes (upper right) can be seen.

Mexican Volcanoes

Photographs of the eastern section of the east-southeast-trending neovolcanic axis of Mexico, from Mexico City to the Gulf of Mexico, were obtained by the Skylab 4 crewmembers. The most prominent peaks in one of these photographs (fig. 8-7) are the Pleistocene-Holocene stratovolcanoes San Nicolas and Pico de Orizaba, last active in 1687. Snow cover accentuates the summits of both peaks, although the craters are not apparent. The lower relief volcano almost midway between San Nicolas and Orizaba is La Malinche.

The valley northwest of Orizaba appears to be a dry lake basin containing broad, low craters similar in appearance to maar volcanoes. On the north rim of the valley north of Orizaba are twin calderas, 5 to 10 kilometers in diameter. Both are surrounded by dissected table lands that may consist of ash-flow tuffs. Color variations, which may indicate alteration or variations

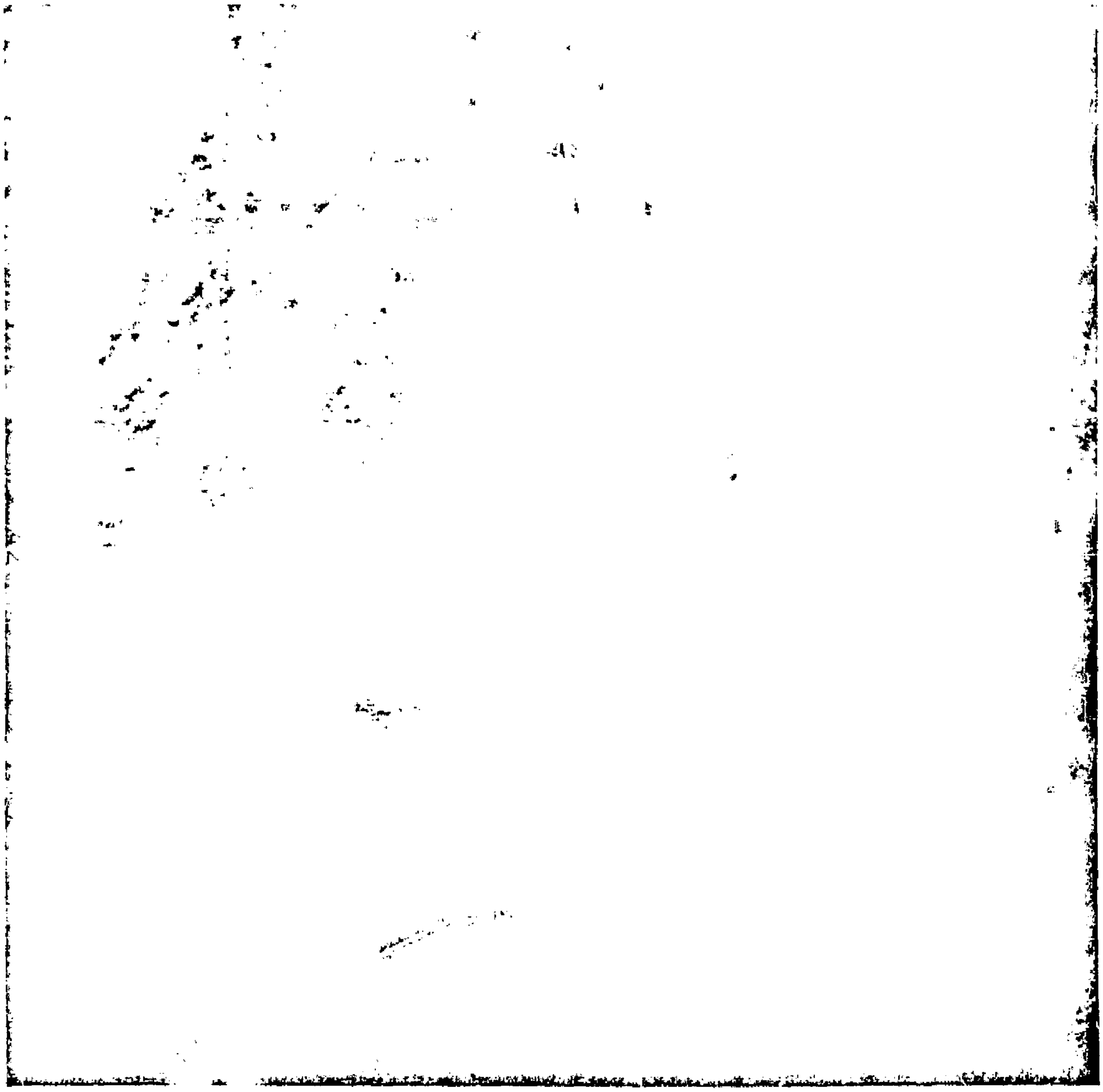


Figure 8-5.- The Tibesti Massif, Chad, a heavily dissected volcanic plateau (SL4-138-3789).

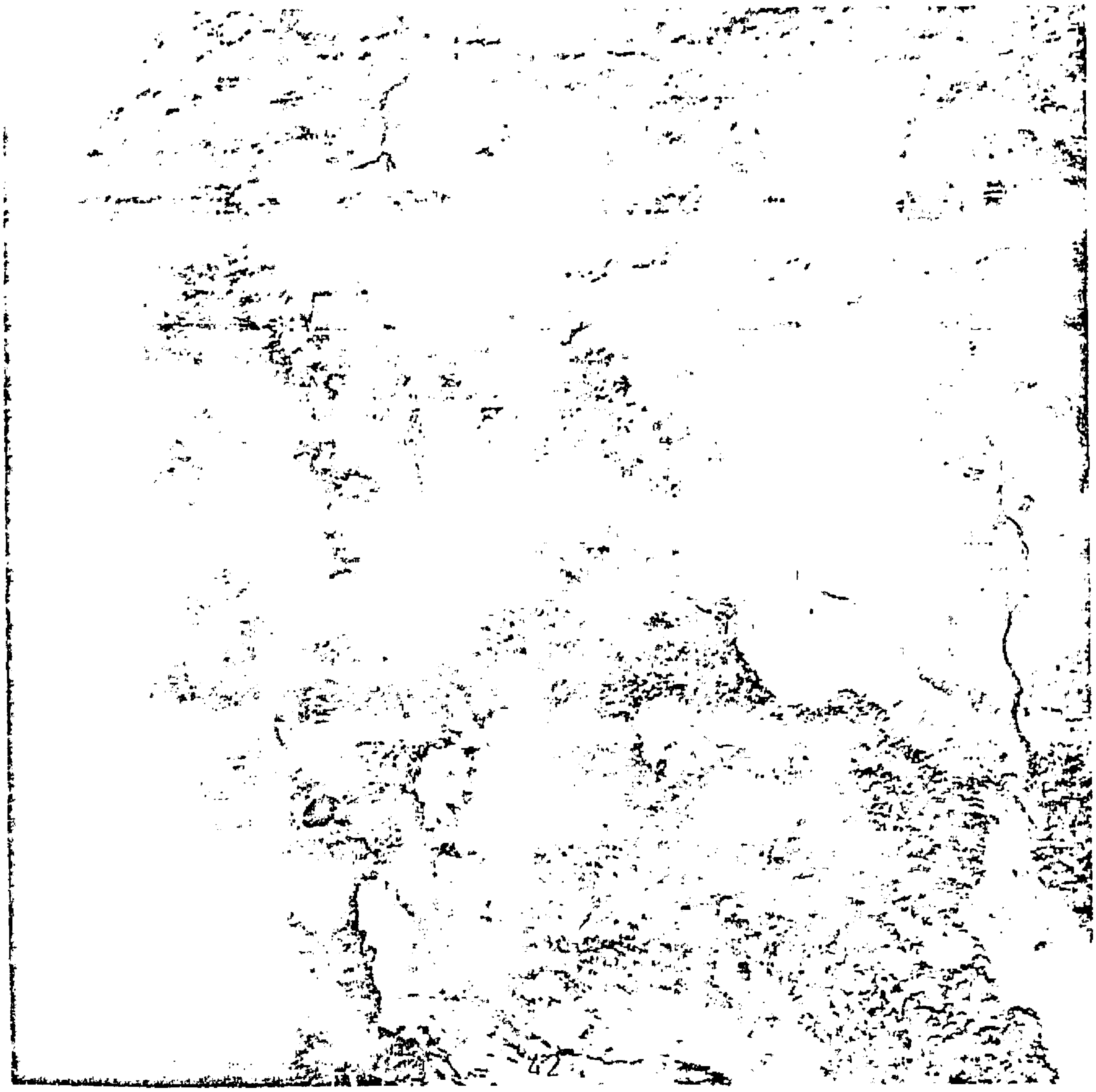


Figure 8-6.- Recent stratovolcanoes in the Cascade Range, Washington and Oregon. From north to south, labelled features are Mount Hood (A); Three Sisters (B); Devils Garden, Lava Mountain, and Green Mountain (C); and Crater Lake (D) (SL4-139-4048).

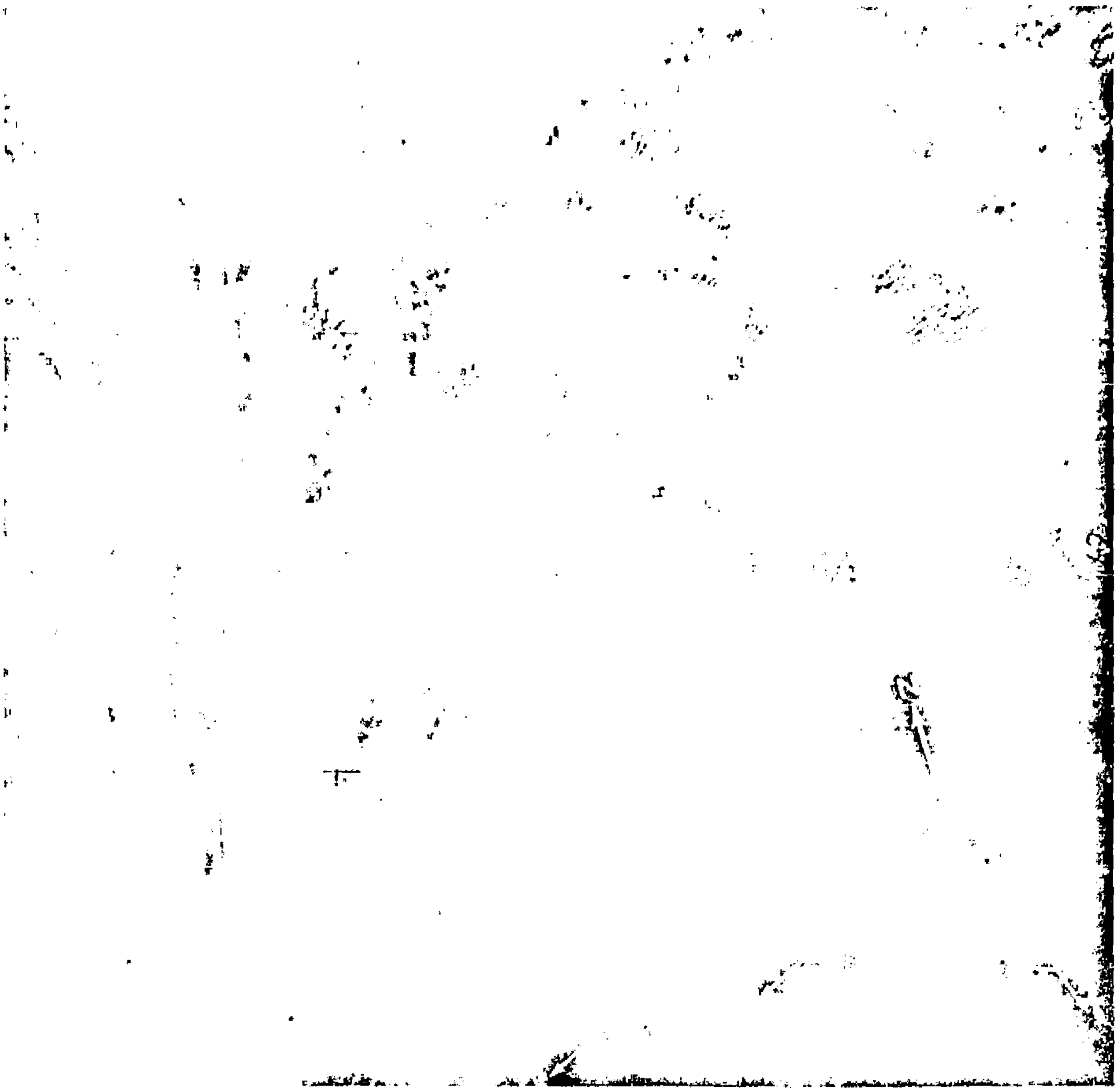


Figure 8-7.- Pleistocene-Holocene volcanoes between Mexico City and the Gulf of Mexico coast. The most prominent stratovolcanoes are San Nicolas (A), La Malinche (B), and Pico de Orizaba (C) (SL4-139-4064).

in composition, are noticeable on lava flows on the eastern slope of La Malinche. Although the nearby volcanoes Popocatépetl and Iztaccihuatl have been linked tectonically to a 50-kilometer-long fracture trending north-northwest, no evidence of structures related to the volcanoes was found in the photographs.

CONCLUSIONS

The following conclusions are based on a preliminary assessment of 70-millimeter Hasselblad photographs and crew descriptions and debriefings.

1. Some specific active volcanic processes, particularly eruption columns and clouds, were observed from Skylab 4. The crewmen have confirmed that subtle differences in color or density of eruption and fume clouds can be discerned best by the human eye.

2. Earth-surface features are best mapped with near-vertical rectifiable stereophotographs such as those obtained from the Earth resources experiment package camera systems; however, photographs from the Skylab handheld cameras have provided valuable new information on areas where it was not feasible to operate the experiment cameras.

3. The real-time judgment of the crewmen in selecting areas to photograph is of great value in volcanic studies.

4. Even though changes in the size, shape, and color of the eruption cloud from Sakura-zima occurred rapidly, they could not be detected while viewing the cloud during one orbital pass. The changes were readily apparent on subsequent passes.

5. Stereophotographs were very useful in studying volcanic landforms and eruption clouds. When the tropopause is penetrated by an eruption cloud, stereophotographs will be valuable in making dust-veil index assessments to determine the quantity of volcanic dust ejected into the upper atmosphere.

6. The crewmen confirmed that relief is seen best at Sun angles less than 20° and that colors are seen best at high Sun and low phase angles.

7. The crewmen confirmed that craters a few hundred meters in diameter are generally too small for the observation of structural or morphologic details. It is expected that lava lakes with surface temperatures well above 813 K (the Draper Point, the temperature at which red light first becomes visible against a darkened sky) should be visible from orbit. Dark rocks were especially difficult to identify in heavily vegetated areas, as in the coastal plain of Oaxaca, Mexico. Both spatial and color differentiations in volcanic features were easiest to detect in arid or high and dry plateau regions, as on the Mexican or Andean plateaus. Volcanoes on small distinctly shaped islands were also easily identified.

8. The ephemeral subaerial phase of submarine eruptions is extremely difficult to observe from Earth orbit; those submarine eruptions that occurred near Japan and Samoa were not observed by the crewmen.

9. A statistical study of surface colors of volcanic features in relationship to their composition and geomorphic or climatic province would be a valuable research project.

REFERENCES

8-1. Sakurazima Volcanic Activity. Japan Meteorological Agency. Event Information Report, Smithsonian Institution Center for Short-Lived Phenomena, 1974.

8-2. Kuno, Hisashi: Catalogue of the Active Volcanoes of the World Including Solfatara Fields. Part XI, Japan, Taiwan, and Marianas. Intern. Assoc. of Volcanology (Rome), 1962, p. 31.

9. PRELIMINARY REPORT ON DUNES

Edwin D. McKee[a†] and Carol S. Breed[b]

Eighteen sites in the major sand seas of the world were designated for visual observations and photography by the Skylab 4 crewmen. Most of the desert sites were chosen because they are difficult to study by conventional means. Reliable maps and aerial photographs are not available for some of these sites, and access to other sites is difficult because of geographic and political reasons. The sites chosen for handheld (HH) camera photographs include four in the Sahara and sub-Sahara of North Africa (HH68, HH69, HH70, and HH71); four in the Namib and Kalahari Deserts of South Africa (HH77, HH78, HH79, and HH82); two in the Empty Quarter of Saudi Arabia (HH80 and HH81); five in the Takla Makan and Gobi Deserts of China (HH65, HH66, HH67, HH75, and HH76); and three in the trans-Caspian deserts of the U.S.S.R. (HH72, HH73, and HH74). In addition to these 18 formally designated sites, other areas of eolian sand accumulation in North Africa, India, Mexico, and Australia were recommended as optional sites for obtaining visual observations and photographs.

NUMERICAL SUMMARY OF THE DATA

For a total of 26 sites in 8 major sand seas, the Skylab 4 crewmen recorded 40 visual observations of desert phenomena and obtained 65 color 70-millimeter photographs that are now being studied. Other photographs are being processed, and the analytical results will be included in the final report. In addition to the transcribed visual observations, valuable information was recorded at the debriefing meeting with the crewmembers on March 13, 1974.

PRELIMINARY RESULTS

More than 40 percent of the visual observations recorded while the crewmen were in orbit concerned the distribution, shape, size, and color of dunes and other eolian sand features and the relationship of sand bodies to other topographic features, surface elevations, and probable wind directions.

---

[a] U.S. Geological Survey, Denver, Colorado.

[b] U.S. Geological Survey, Flagstaff, Arizona.

[†] Principal Investigator.

The remainder of the recorded visual observations verified the presence of dunes in particular areas. Other comments consisted of notifications that the photographs were being taken.

Approximately 95 percent of the photographs examined to date are of excellent quality and contain information useful in testing ideas regarding the form, distribution, and movement of desert sand seas. Both the oblique views, which clearly indicate regional relationships, and the vertical views, which provide details of dune morphologies, will be useful. The near-vertical stereopair photographs may be of the greatest value. The color of sand areas as recorded in the photographs, although apparently not as vivid as the color remembered by the crewmen, provides an important new tool for studying the deposition of eolian sand in the specific sites designated for study. Unfortunately, no photographs were taken over the high-latitude deserts of the U.S.S.R. and none were requested of dune fields in Argentina, Alaska, Greenland, and the United States.

The comments of the crewmen during the 2-hour debriefing session are probably of equal value to those recorded during the mission because specific questions could be resolved while both the crewmen and the Science Team members were viewing the same landforms in color photographs. In several instances, the answer to one question led to another question, which resulted in additional data. For example, the discussion of desert sand colors led through a series of questions and answers and photograph viewing to a realization that, once the question of Sun angle is resolved, future observers in Earth orbit will have an excellent opportunity to make rapid comparisons of the surface colors of sand bodies in all deserts of the world. Such observations should help to determine whether latitude, or distance from the source of the sand, or relative age of sand deposits is the controlling factor in the production of red eolian sediments. Observations from space by crewmembers, supported by photographic documentation, may provide a new set of data related to this long-standing geologic problem of the origin of red beds in desert environments.

DISCUSSION OF RESULTS

For the study of sand seas on the Skylab 4 mission, the crewmen were asked first to obtain photographs and then to observe visually specific characteristics of sand bodies in selected localities within several deserts of the world. This approach tended to emphasize differences among the specific sites selected more than to emphasize the similarities of sand patterns. The results, however, provided information on the relationship of sand bodies to barriers and on the geographic distribution of dune types, sizes, and colors in various desert environments.

Observations by the crewmen both from space and during the debriefing have provided interesting and new data for specific sites. For example, the crewmen confirmed that the star dunes of eastern Algeria are very red; that the interdune areas of this region are composed of gray bedrock; that the dunes occasionally tend to build up in character, relief, and size as they go downwind; and that there appears to be no simple factor to explain the abrupt boundary at the southern margin of the dunes. These visually observed characteristics are verified in figure 9-1, which shows the individual star dunes and linear chains of star dunes in the Great Eastern Erg of Algeria.

In the eastern Empty Quarter of Saudi Arabia (fig. 9-2), individual star dunes and linear chains of star dunes are red, which is in contrast to the whitish-gray (composition undetermined) interdune surfaces. The characteristics of these dunes and interdunes were not recorded by the crewmen. According to the debriefing transcript, the similarities between the Algerian and the Arabian deserts were not noted, probably because of different Sun angles when viewing the two deserts but more likely because the crewmen were only requested to look for areas of transition among dune types in the Empty Quarter. Thus, they may have concentrated on the problem of transition at the expense of other observations.

Dune ridges in the inland delta of the Niger River, Mali, are illustrated in figure 9-3. The presence of old dune ridges at this site was visually observed but the presence of narrow, reddish, linear dunes crossing the old vegetated ridges at oblique angles was not mentioned. Both the commander and the pilot stated in the debriefing session that this area was a difficult one in which to make observations because of the high Sun angle and the low contrast of ground features. When shown a slide of similar narrow, reddish, linear dunes in the Simpson Desert of Australia (fig. 9-4), the crewmen immediately identified it as the dune area around the Niger River because of the linear forms. This was a very interesting observation because it demonstrated that the eyes of the crewmen had seen and that their minds had stored information concerning the similarity of the two widely separated deserts. However, this information was not recorded until their perceptions of these similarities were evidenced during the debriefing.

Regions that are inaccessible for ground exploration, such as the Namib Desert of South West Africa (fig. 9-5), can be observed by crewmen in Earth orbit. Several useful observations on the effect of topographic relief on the distribution of dunes and on color distribution in the Namib Desert were recorded from space and during the debriefing. Because reliable relief maps are not available for the Namib Desert, the observations and photographs returned by Skylab crewmen will provide the information for analyzing the basic geography of this region.

To summarize the results, the Skylab 4 crewmen established that large-scale patterns, colors, and topographic influences on eolian sand distribution can be seen and accurately described from space and that the human eye sees nuances of color that the camera cannot record. All the observations by the Skylab crewmembers support the preliminary classification of eolian landforms, based on Earth Resources Technology Satellite (ERTS) imagery. The observations of the crewmen will be used to evaluate the ERTS imagery classification system. Although all observations support the classification system presently in use, the Skylab 4 crewmen did not necessarily confirm the validity of the system because they were not asked to look for similarities of form and distribution of eolian sand bodies on a worldwide scale.

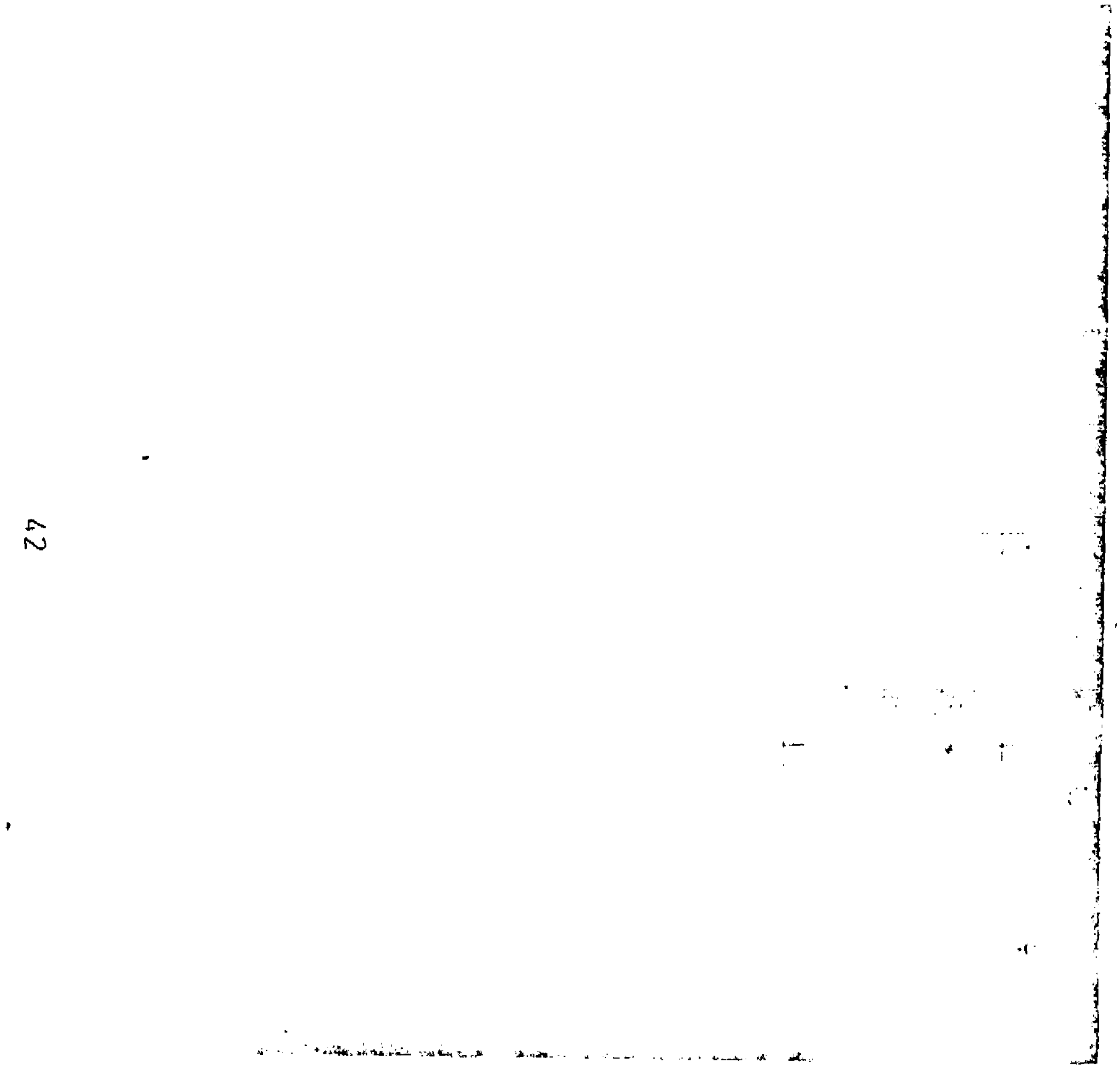


Figure 9-1.- Individual star dunes and linear chains of star dunes in the Great Eastern Erg of Algeria (HH69) (SL4-138-3885).

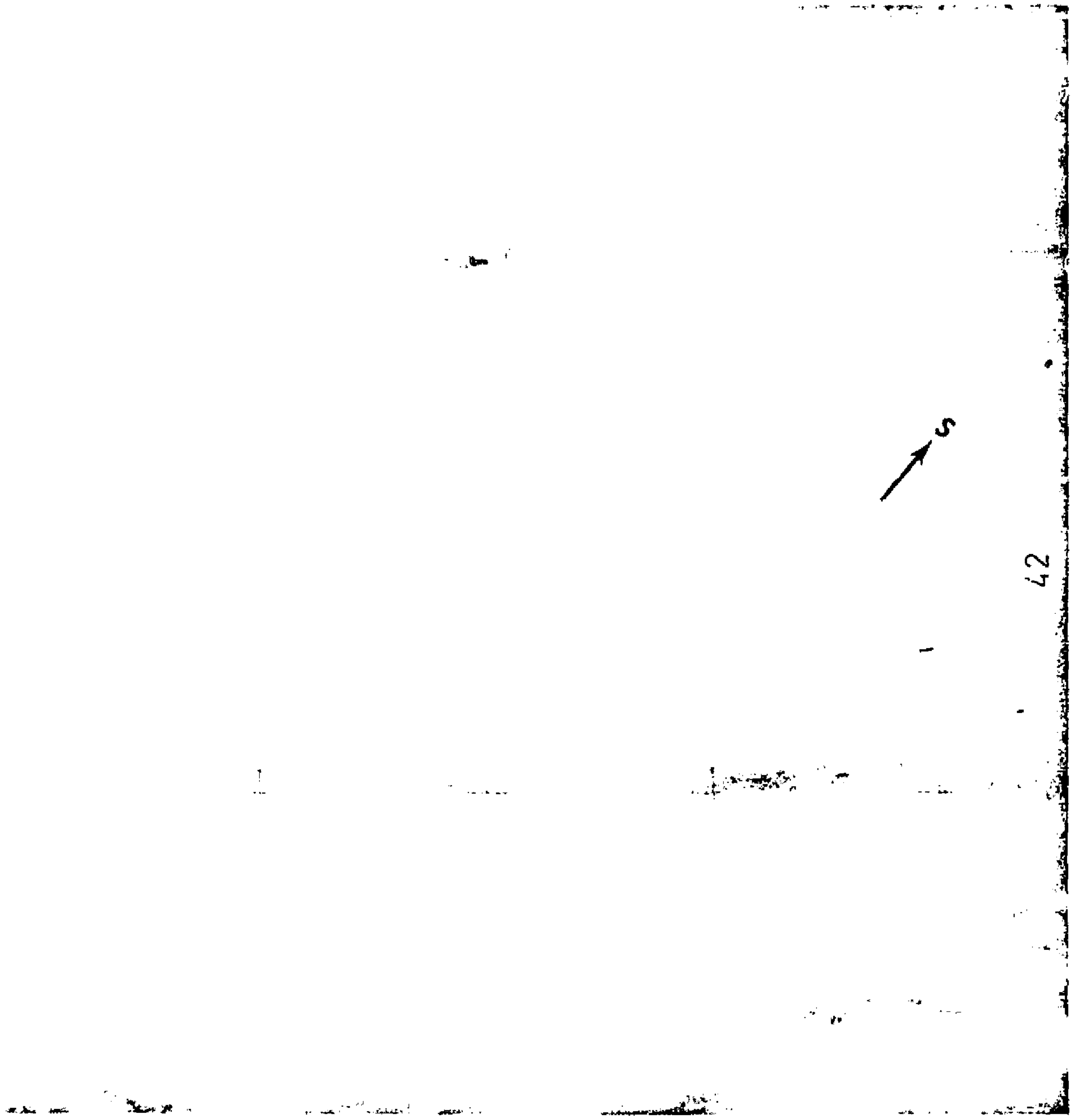


Figure 9-2.- Individual star dunes and linear chains of star dunes in the eastern Empty Quarter of Saudi Arabia (SL4-138-3744).

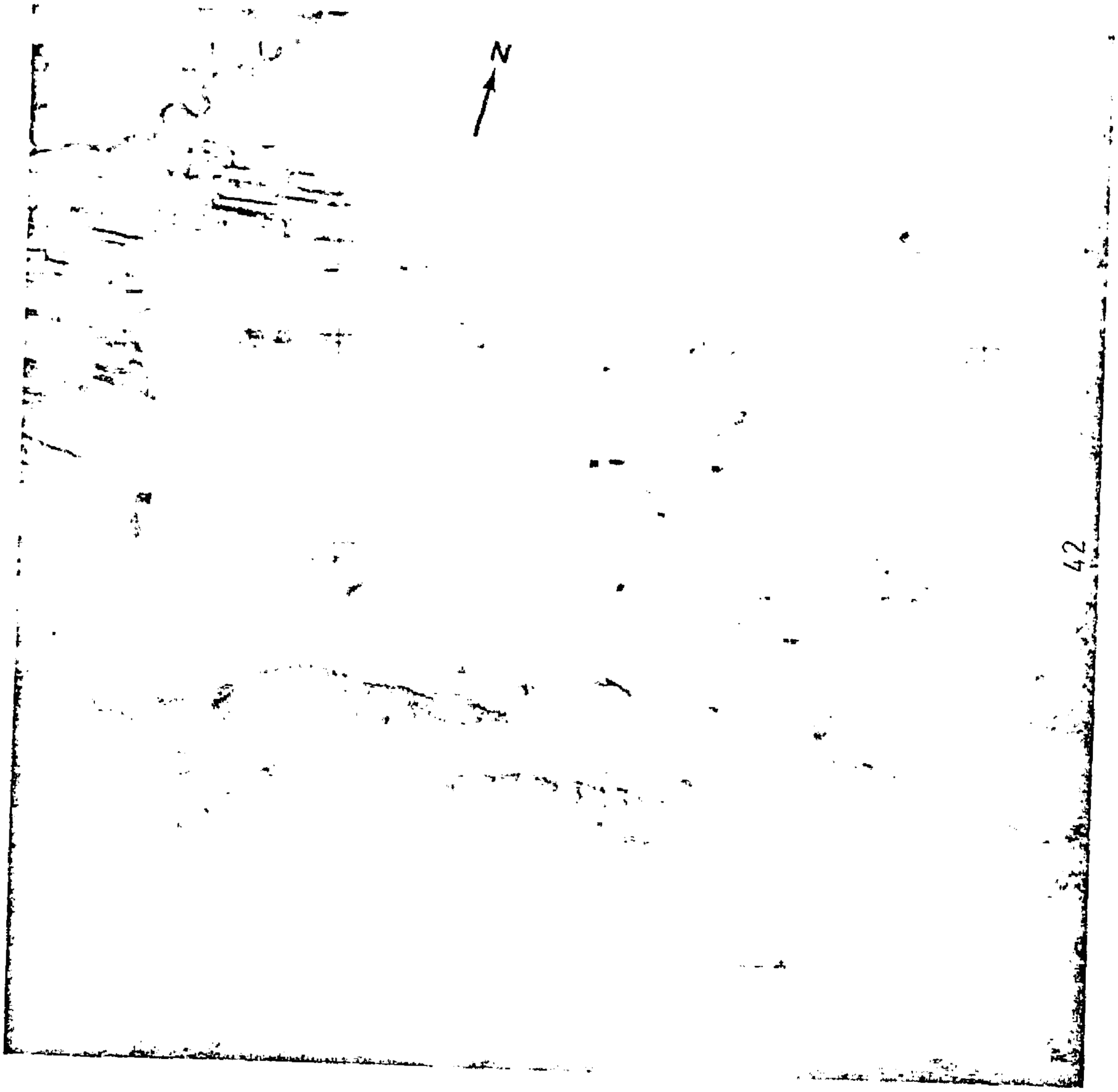


Figure 9-3.- Dune ridges in the inland delta of the Niger River, Mali (SL4-136-3380).

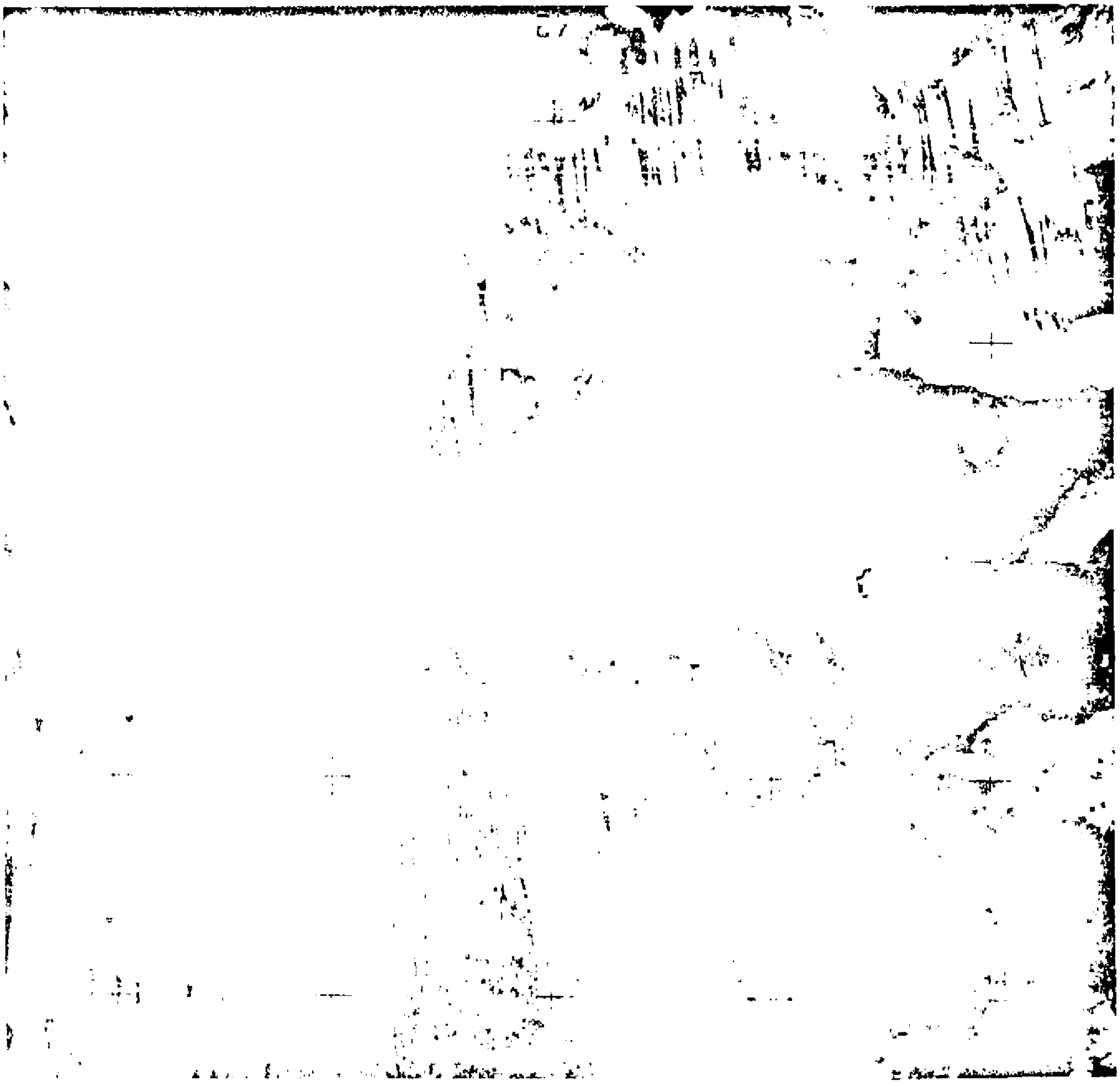


Figure 9-4.- Linear dunes in the Simpson Desert of Australia (SL4-143-4637).

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

Figure 9-5.- The Namib Desert of South West Africa (HH77 and HH78) (SL4-137-3693).

RECOMMENDATIONS

The visual observations expressed by the Skylab 4 crewmen for the first time during the debriefing session on March 13, 1974, are highly significant. From these observations, investigations can be made based on the experience and the knowledge gained during the mission. A space platform provides an excellent opportunity to make worldwide, almost simultaneous, visual observations of desert phenomena, particularly the distribution of color, patterns, and barriers. Furthermore, such observations can provide a data base for a new and informative comparative study of the sand seas of the world.

To use fully the capabilities of the human eye and mind, the brain must be able to quantify quickly what the eye sees. Several methods for developing this capability might be explored. First, colors as seen from space might be used to design a land color chart similar to the U.S. Geological Survey rock color chart. Such a chart could be posted beside the viewing window for immediate reference. Second, a pattern and size recognition chart could be prepared to enable quick, objective descriptions of landform patterns with their sizes, shapes, and spatial relationships as seen from Earth orbit. Third, the observers might be trained to make quick, verbal descriptions of various aspects of the surface of the Earth while viewing satellite photographs. The training should be supplemented by field trips to view typical desert phenomena both from the air and on the ground. Advance familiarity with known desert phenomena would allow the crewmen to focus their attention on the unknown phenomena that need further study.

In summary, the visual observations and photographs of the deserts of the world made by the Skylab 4 crewmen provide useful information about the specific sites selected. A future study is therefore suggested in which quick, synoptic visual observations would be recorded and documented by photographs.

10. VEGETATIONAL PATTERNS

David Carneggie[a]

Because man is dependent on vegetative resources for sustenance, adequate methods of conserving, managing, and using these important renewable resources are essential. In the past, vegetative resource information has been acquired through conventional ground-survey and aerial-survey techniques. In many instances, these techniques have been adequate for providing information regarding the type, quantity, quality, distribution, and availability of vegetative resources. In other instances, conventional inventory techniques have not provided information that was either timely enough or accurate enough for intensive management purposes. Within the last 7 years, manned and unmanned satellite systems have been used as a new tool for rapidly acquiring information about vegetative resources on a global basis. Man's role in acquiring timely vegetative resource information from orbiting satellites is evaluated in this section with respect to visual observations and photographic documentation made by the Skylab 4 crewmen.

PREPARATION AND TRAINING

Two training sessions were held before the launch of the Skylab 4 crewmen. The first session introduced the crewmen to the importance of making observations of vegetation. Primary emphasis was given to factors that cause problems and damage of economic importance to three important vegetative environments; namely, forest, rangeland, and agriculture. Early detection of damaging factors, such as fire, flood, insect, disease, et cetera, is important for minimizing economic losses; thus, it is important to learn the extent to which man in orbiting satellites can detect these damage-causing agents. Secondary emphasis was directed to observing change in vegetative appearance that results from normal plant development. The detection and the timing of these changes in appearance of crops and range forage, for example, may provide clues to the identity of vegetative type or condition. In many instances, the relative productivity of the vegetative crop, based on the timing of observed changes in plant development, may possibly be inferred.

A handbook of specific observations to be made throughout the world was provided for the crewmen. During the second training session before lift-off, the handbook was reviewed with the crewmen to clarify last-minute questions regarding observations of vegetative phenomena.

---

[a] University of California at Berkeley.

DATA INPUTS FOR VEGETATIVE ANALYSIS

Throughout the 84-day mission, the descriptions of forest, rangeland, and agricultural vegetation by the crewmen were transcribed and made available to the Visual Observations Project Team for their evaluation. Because the transcripts were made available periodically throughout the mission, observations made by the Skylab 4 crewmen could be compared to those made during previous missions. In many instances, more detailed questions were uplinked to the crewmen to test the limits of man's observational capability. Concurrent with the observations, both vertical and oblique photographs of vegetation within prescribed observation sites were acquired. For this report, only a few of the photographs taken on eight film magazines from the 70-millimeter Hasselblad camera were reviewed.

A 3-hour postmission briefing was conducted to review the transcripts of verbal descriptions made from space and the available photographs. The information derived from the postmission briefing, combined with the analysis of the available photographs and the transcripts, forms the basis for this preliminary report. The factors affecting man's ability to observe vegetation and characteristics and conditions of forest, rangeland, and agricultural vegetation that can be observed are discussed in the following paragraphs.

FACTORS AFFECTING VISUAL OBSERVATIONS OF VEGETATION FROM ORBITAL ALTITUDES

Some of the factors affecting man's ability to observe vegetation on the surface of the Earth from orbital altitudes include the characteristics of spacecraft windows, atmospheric conditions, time of day, viewing angle, rate of spacecraft movement past the object to be observed, type and color of vegetation, and distance between the object observed and the observer.

Spacecraft Windows

The observation windows in Skylab vary in size and thickness of glass. The crewmen expressed concern that observations of features that are viewed at an angle through the windows may have been affected by optical distortion and reflective properties of the different windows. It was not known to what extent the observation windows may have been tinted and to what extent this tinting may have varied from window to window. To remove any variable attributed to differences in window characteristics, future observation satellites should either have standardized observation windows or one specific window that is not tinted and is free from optical and reflective distortion.

Atmospheric Conditions

The crewmen indicate that agricultural patterns and variability within cropland can be observed through as much as 75-percent broken cloud cover. Presumably, observations are best achieved with a high Sun angle, which minimizes observation difficulty caused by cloud shadow. The crewmen could distinguish various amounts of haze over the surface of the Earth. A higher frequency of haze (haze effect) was observed over heavily vegetated areas in contrast to less vegetated areas. In many areas, haze increased during the day and became most acute during middle to late afternoon local time. The presence of haze did not affect the ability of the crewmen to discriminate vegetational types, but the haze was a factor in discriminating darker colors. The effect of haze on the ability to discriminate type and color of vegetation became more pronounced as the look angle increased from the vertical. Photointerpretation was affected more by the haze than visual observations. In viewing numerous photographic images taken from space, the crewmen expressed concern that haze had reduced detail and color discrimination that had been distinguishable by the eye. This finding is significant because it indicates that human eyes are superior to photographs in discriminating colors and discerning certain ground details through moderate to greater amounts of haze.

Time of Day

The crewmen considered noon local time as the optimum time for discerning and describing vegetation because the Sun angle was high and haze interference, which increases as the day progresses, was not yet a problem. No examples were recalled in which lower Sun angles were an aid to discriminating vegetation type or condition. Without exception, low Sun angles meant reduced ability to discriminate vegetation on the basis of color. Moreover, lower Sun angles did not enhance textural detail that could aid in discriminating vegetation type. Fires were easily detected during the periods of darkness, but the type of vegetation being burned or threatened could not be assessed. The effect of the time of day on observations of change in appearance of vegetation over a period of time remains a problem. Further analysis and questioning will be required to verify the extent of this problem in making these types of observations.

Angle of View

Although nadir observations are more easily made from Skylab, the crewmen felt that sufficiently accurate observations could be made at distances of 480 kilometers on either side of the flightpath. Oblique photographs showing land features at distances of 480 kilometers were generally poor and difficult to interpret primarily because of atmospheric effects on color film. Therefore, man may have an advantage over the camera for recording information about the vegetational resources as far as 480 kilometers from the flightpath.

When the look angle and the Sun angle were in a specified position, sunglint from water could be observed. An understanding of these angular relationships should be helpful in determining the proper look angle and Sun angle for discerning bodies of water. This observation may be particularly important in assessing availability and distribution of water in rangelands and in drought-affected areas.

Rate of Movement

Initially in the observations program, the rate of movement of the spacecraft over the ground was a problem in detecting details within the vegetative complex. With time, the crewmen became more familiar with the specified observation site. This familiarity enabled them to spend more time observing details concerning the vegetation. In certain instances, specialized optical viewing equipment with image motion compensating devices was used to extend the viewing period of pinpoint objects. In this manner, greater detail was described in contrast to observations made without the aid of optical devices.

Type and Color of Vegetation

Generally, forest, rangeland, and agricultural vegetation as seen from space were distinguished by the pattern created by conspicuous linear field boundaries and the variations between field blocks. The shape, size of field, pattern, and color were used in identifying agricultural land. Because textural detail could not be discerned, basic agricultural types such as cereal crops, truck crops, orchards, or vineyards were not distinguishable.

Within the wildland vegetational environments, it became increasingly difficult to distinguish between rangeland and forest. Generally, forested land appeared to be very dark green in the color photographs. The crewmen expressed the opinion that variations of forest types within forest land could not be detected. However, a greater range of color variation was discernible within rangeland environments. It was also difficult to determine whether vegetation existed in the semiarid and arid environment. Perhaps these findings demonstrate that space observers with a greater background in vegetative resources are required to answer many questions relating to the extent to which man can discern specific vegetative types within the much larger vegetational environments.

Darker colors in vegetation were more difficult to differentiate than lighter colors. The range of colors used to describe agricultural crops in various stages of development includes light green, much lighter green, nice brilliant green, good healthy green, deep green, dark green, very dark green, brown, dark brown, black, light tan, yellow, straw colored, and gold-tan. The lighter and brighter greens and the light tans and yellows were easier to detect and separate than the darker greens, blacks, and browns. Despite the difficulty in discriminating dark colors, the crewmen were able to agree on the color of an object. However, they also agreed that color standards should be developed for future space experiments to reduce the subjectivity associated with color descriptions. A color standard also would be useful for describing colors in haze conditions in which the observers have indicated that color discrimination is more precise with visual observations than photographic documentation. As indicated previously, the ability to discriminate colors is reduced with low Sun angle.

Orbital Altitude

It would be difficult to determine whether lower orbital altitudes would significantly increase the amount of detail discernible within the vegetative complex. The crewmen indicated that texture was not an important identifying characteristic in discriminating vegetative type or condition. However, it is significant that considerably greater detail can be observed with the use of binoculars. For example, one of the crewmen describing the terrain of northern Australia indicated that green vegetation could be seen only along the watercourse. Inspection with binoculars did, in fact, indicate that the green vegetation was an area of concentrated truck farming crops. This trade-off between what man can see with and without binoculars may be extended to imply that man could see much greater detail with the unaided eye from a considerably lower orbital altitude.

OBSERVABLE CHARACTERISTICS AND CONDITIONS WITHIN VEGETATIONAL ENVIRONMENTS

Agriculture

Croplands were the easiest vegetative environment for the crewmen to distinguish. The color. shape, and size of field and the linearity of field boundaries contributed to this ease of identification. During the Skylab missions, the crewmen concentrated their observations on wheat-producing areas in Argentina, Australia, and the United States. During the time period of the mission, wheat was being harvested in the Southern Hemisphere, whereas the autumn planting of wheat in the Northern Hemisphere had begun before the mission.

Both the photographs from space and the visual observations substantiate that the extent of snowfall and the relative amount of snow present on wheatfields in the Northern Hemisphere can be observed. Moreover, the crewmen could easily detect areas where early snowmelt could expose wheat plants to freeze conditions, thus killing the plants. These observations regarding snowmelt patterns are especially important in regions where snow cover is critical for the survival of the plant. Observations regarding the timing of snowmelt also can be correlated with local weather conditions that affect plant growth.

In the Southern Hemisphere, progressive drying of cereal crops followed by harvesting and replanting was observed. Observations of Argentina suggest that cereal crops became progressively drier during the mission, whereas in Australia (South Australia, New South Wales, and Victoria), cereal crops were already dry and a progressive trend toward greener fields associated with replanting was noted (figs. 10-1 and 10-2). During one observation period,

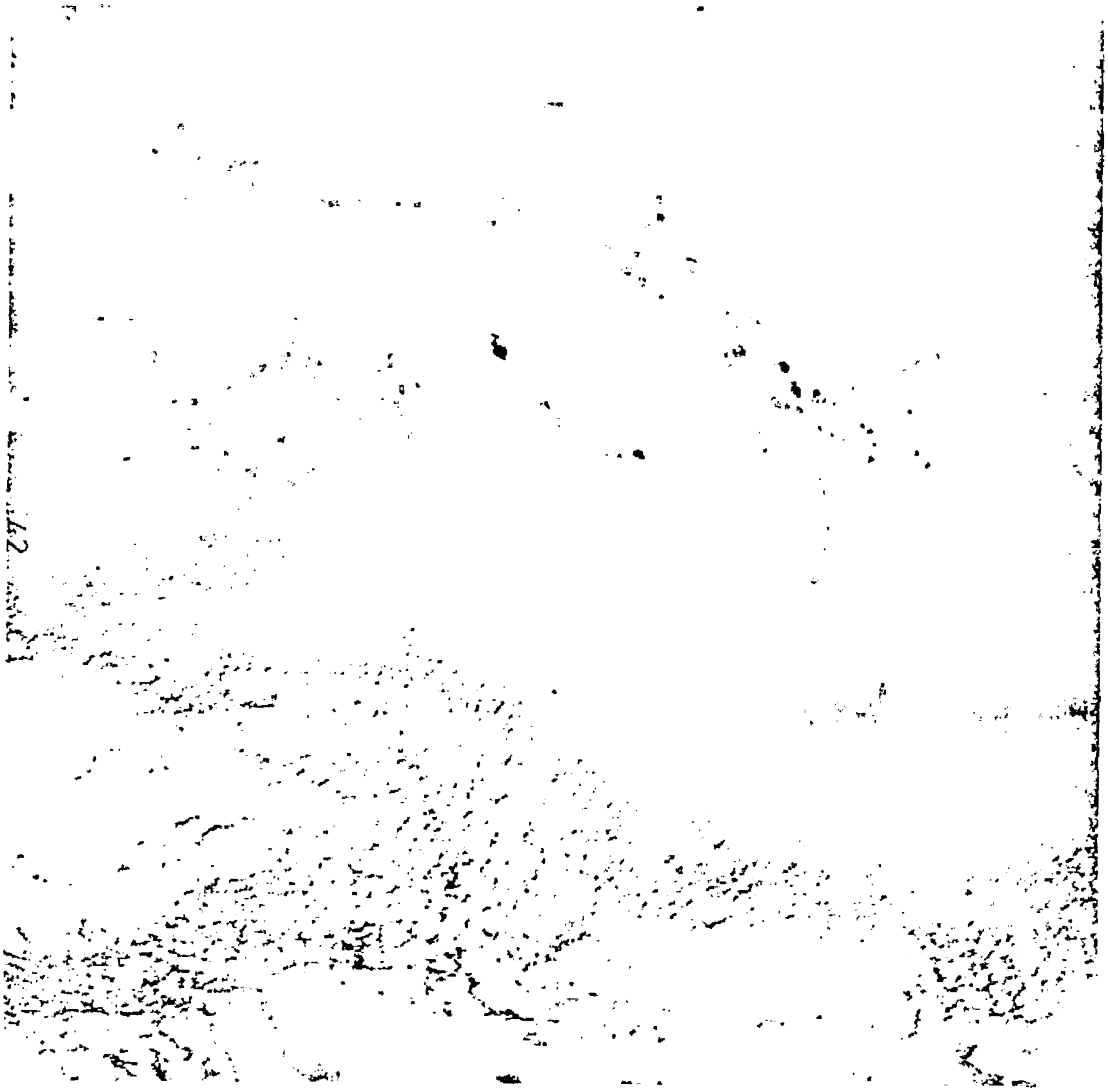


Figure 10-1.- Cereal crops in Australia (South Australia, New South Wales, and Victoria) (SL4-138-3835).

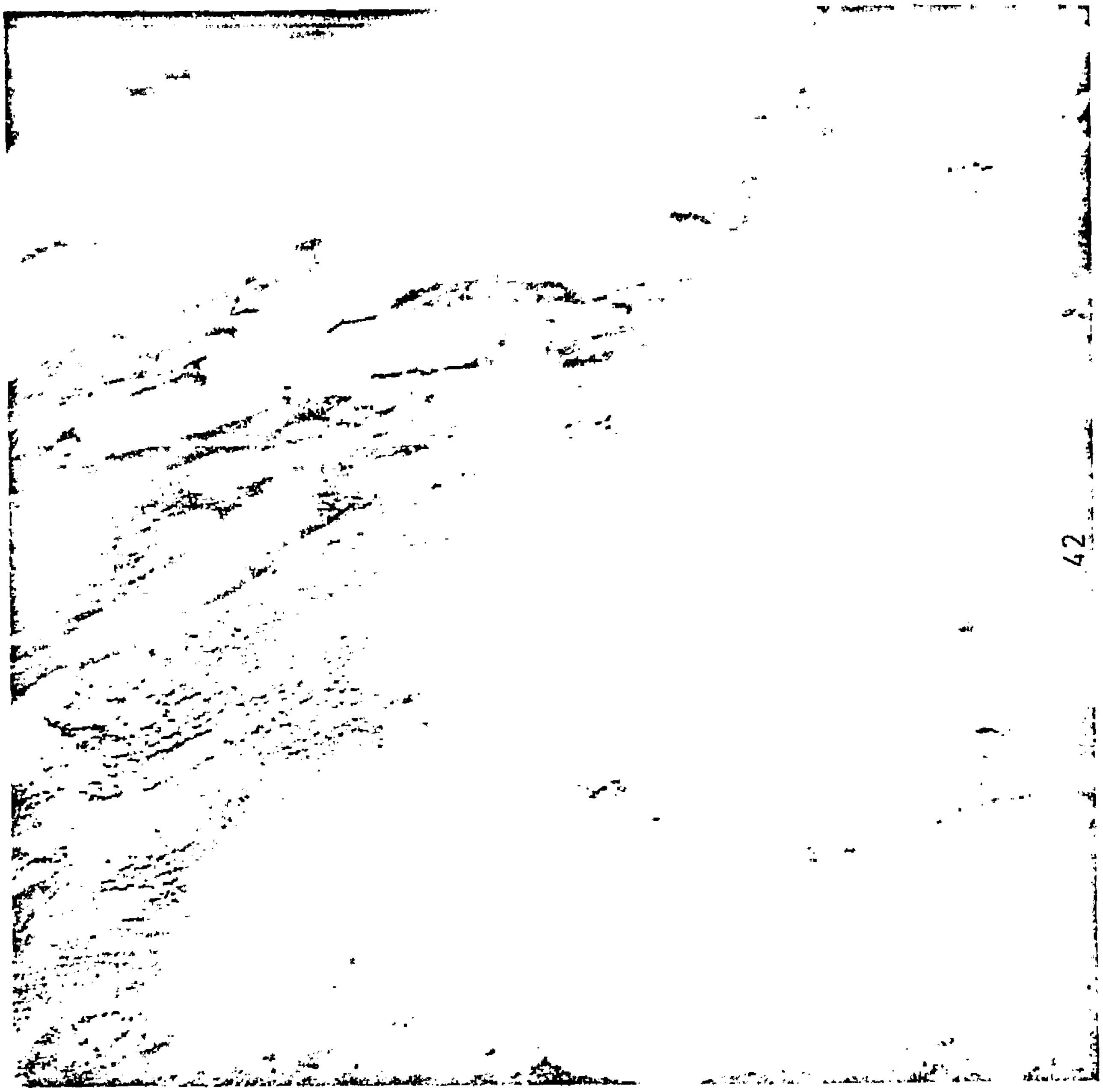


Figure 10-2.- Darker areas indicate replanting of cereal crops shown in figure 10-1 (SL4-143-4639).

the crewmen quantified the proportion of wheatfields that contained green mature plants, exposed soil, bright-green fields of juvenile plants, and dry plants or plants in harvest stage. Further analysis will be required to correlate visual observations with concurrently acquired photographs.

It is apparent, nonetheless, that space observers are capable of describing the variable stages of crop maturity within a region. Moreover, they can contrast stages of plant development between regions and continents. These types of observations are perhaps the most significant because they demonstrate that the human space observer can appraise the development and condition of cereal crops. This information can provide inputs for determining the availability and perhaps the productivity of cereal crops, such as wheat, on a global basis.

There is no evidence to reject or accept the hypothesis that human space observers can detect variation due to damaging agents such as insects or disease within large agricultural fields. The crewmen did not note any specific examples in which variation within fields could be associated with crop-damaging agents. They did, however, indicate that within very large fields (more than 3 square kilometers), the opportunity for detecting variation due to crop-damaging agents would be greater. Very large wheatfields, exceeding 4 square kilometers, can be seen in figure 10-3.

Several floods were observed. In each instance, the crewmen were able to observe the extent of the area and the type of land use affected. In the northern Sacramento Valley of California, in the Mississippi Valley, and in eastern Australia, agricultural land was inundated by floodwaters.

In summary, it appears that visual observations made from orbital altitudes will be most beneficial for assessing the rate and timing of various plant development stages of cereal crops. Other major crops, such as rice, that exhibit distinctive growth stages could also be monitored in terms of time of planting, maturity, and harvesting. Although variations within large fields may be attributed to crop-damaging agents such as insects, disease, and wind damage, these agents are not easily identifiable. However, areas affected by floodwater and fire can be easily assessed by human observers from space.

Rangeland

Within rangeland environments, the crewmen were able to detect fenceline boundaries. Such boundaries were obvious because of differing intensity of forage use on opposite sides of the fences. These fenceline conditions were clues for determining land use. However, in many rangeland areas where fenceline boundaries did not exist, it was less obvious that the land use was primarily for grazing. This was especially true in arid and semiarid rangelands characterized by sparse vegetative cover. Where vegetative cover was sparse, assessment of the presence of available forage or its condition (greenness or dryness) was difficult. Sufficient evidence is available, however, to conclude that space observers are able to detect the occurrence of ephemeral flushes of herbivorous vegetation when the vegetative cover exceeds 50 percent.

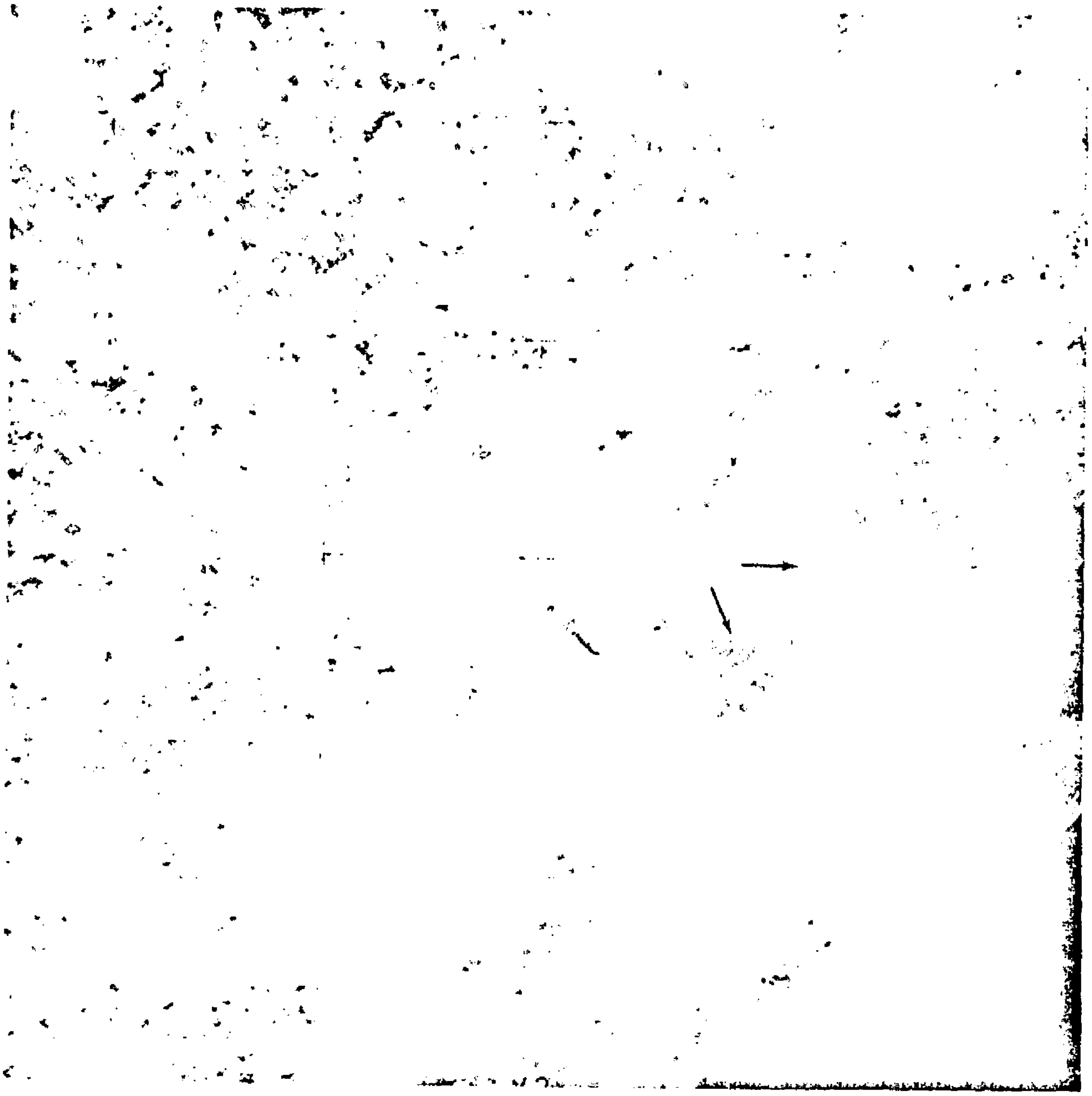


Figure 10-3.- Large wheatfields in Western Australia. Arrows indicate areas of old fire scars (SL4-137-3620).

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

A semiarid rangeland environment in western Australia is shown in figure 10-4. Grazing is the primary land use as evidenced by the distinctive fencelines marking paddock boundaries. The dark surface features are the perennial shrub cover. The lighter areas (primarily soil surface), which appeared reddish in the color photograph, contain sparse vegetative cover. The more heavily used paddocks appear lighter in color than the less heavily used areas. Within the paddocks, light-colored areas, which are the heavily used areas surrounding a watering area, can be detected. If the water supply for these areas is derived from open reservoirs, orbiting observers should be able to determine the presence or absence of water in such reservoirs. Exploiting sunglint in this determination would be valuable. An assessment of the availability and distribution of water is particularly important in determining whether rangelands can be grazed and the extent and severity of drought conditions.

Numerous range fires were sighted throughout South America, Africa, and Australia (fig. 10-4). In some instances, fires had been accidentally ignited or resulted from lightning. Most of the fires, however, were probably intentionally ignited, because fire is an important tool in many rangelands for controlling shrub invasion, for controlling the tsetse fly, and for improving forage quality. Where smoke did not obscure visual observations of the ground, the crewmen could usually determine the type of vegetation that was burning; namely, grassland, shrubland, forest land, or agricultural land.

Forest Land

The crewmen expressed difficulty in separating different forest cover types. Forest land was distinguished primarily by its dark-green color and complete canopy cover. Further evaluation is needed to determine whether conifers can be distinguished from hardwoods and whether commercial forest can be distinguished from noncommercial forest. There were no specific sightings of damaging agents such as disease or insects within forest land; however, variation caused by old fire scars could be observed (fig. 10-3). Additional questioning and evaluation will be required to determine the value of visual observations for acquiring forest land resources information.

Figure 10-4.- Semiarid rangeland in Western Australia. Lines between points A and B and B and C define fenceline boundaries. Point D indicates smoke from range fire; E indicates area of burn from range fires (SL4-137-3630).

11. PRELIMINARY RESULTS OF LAKE AND SEA ICE EXPERIMENT

W. J. Campbell,[a†] R. O. Ramseier,[b] W. F. Weeks,[c] and J. A. Wayenberg[a]

Although only a small fraction of the Skylab, aircraft, and ground reasurement data have been analyzed, the lake and sea ice experiment performed on the Skylab 4 mission was an unqualified success. The key design criterion for the experiment was the acquisition of sequential synoptic information on the behavior of sea ice in the Gulf of St. Lawrence and of lake ice on Lake Ontario. The Skylab 4 crewmen obtained handheld photographs of the primary mission sites, of sea ice in the Bering Sea, the Sea of Okhotsk, and James Bay and of icebergs in the South Atlantic Ocean. These photographs will also be beneficial in other floating-ice studies. Information obtained from the lake and sea ice experiment will be invaluable and fundamental in the interpretation of the Earth resources experiment package (EREP) data, aircraft remote-sensing data acquired from the four remote-sensing aircraft, ground measurements data acquired by a ship in the Gulf of St. Lawrence, and data obtained from hovercrafts and a helicopter in Lake Ontario.

The Skylab 4 crewmen have an immense amount of information that will aid in the interpretation of the Visual Observations Project data and in the interpretation of all other satellite, aircraft, and ground measurement data. The investigators will continue to collaborate with the Skylab 4 crewmen in the analysis and publication of these data.

GULF OF ST. LAWRENCE

Fortunately for the lake and sea ice experiment, the winter of 1974 was one of severe ice conditions in the Gulf of St. Lawrence. Considerable ice coverage of the Gulf occurred, and a variety of ice types was observed. The Skylab visual observations data provide excellent information on the rapid variability of ice dynamics that have been demonstrated to occur at very short time intervals. The great morphological changes that occur as the new ice forms and as older ice thickens also were accurately observed. For example, the ice distribution in the northwestern part of the Gulf of St. Lawrence on January 18, 1974, is shown in figure 11-1. At the time of the observation,

---

[a] U.S. Geological Survey, Tacoma, Washington.

[b] Department of the Environment, Ottawa, Ontario.

[c] Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire.

[†] Principal Investigator.

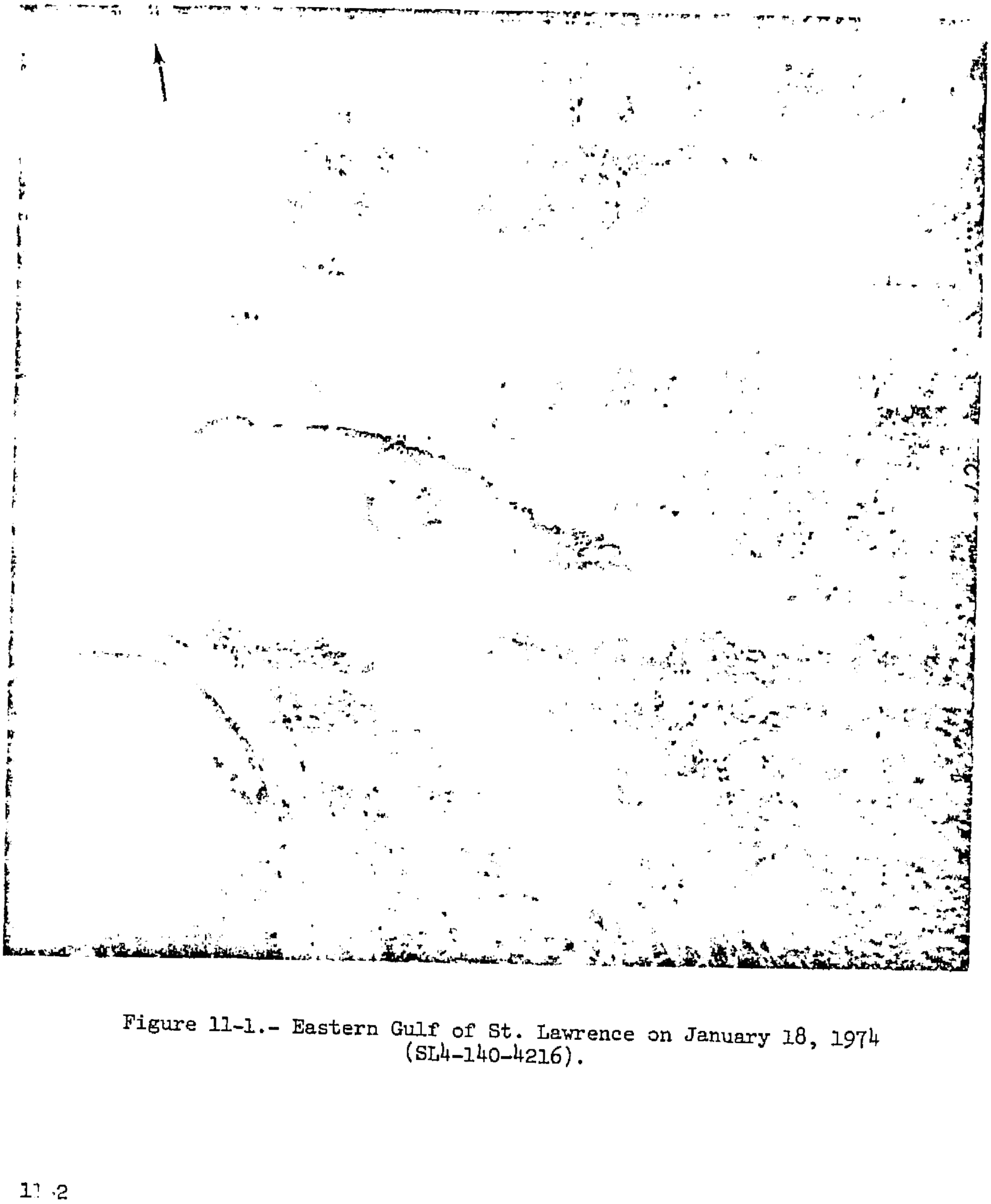


Figure 11-1.- Eastern Gulf of St. Lawrence on January 18, 1974 (SL4-140-4216).

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

the wind was from the north. On the northern shore of Anticosti Island, the advected gray ice can be seen with newly formed grease ice to the north. South of Anticosti Island, grease ice is forming in the wake, and interesting iceplume effects also occur.

The same area is shown 2 days later (January 20, 1974) in figure 11-2. Again, the wind was from the north and interesting iceplumes appear in the wake south of Anticosti Island. The ice has grown thicker in the entire region; along the north coast and to the east of Anticosti Island white ice has formed. Along the southern coast of Quebec, a zone of newly formed grease ice appears with gray and gray-white ice to the south. Therefore, four distinct forms of ice occur between Anticosti Island and the mainland to the north. The lead pattern in the white ice to the north and east of Anticosti Island indicates that a stretching deformation is occurring. The lead pattern to the northwest of Anticosti Island also shows that the ice is in a strong, stretching deformational mode. In the iceplume region south of Anticosti, floes of white ice are floating among the gray-white and gray ice. Ice dis-distribution in the entire Gulf of St. Lawrence can be observed in figure 11-3, which was taken one orbit after the photograph shown in figure 11-2. The edge of the icepack extends from the southwestern tip of Newfoundland to the Gaspé Peninsula. The ice edge is quite convoluted and irregular with a very complex morphological structure. The entire plumed ice region in the wake of Anticosti Island is visible in figure 11-3. The newly formed grease ice occurs along the entire northern edge of the Gulf from the Strait of Belle Isle to the northwest tip of Anticosti Island.

In all the photographs of the Gulf of St. Lawrence made in cloud-free conditions, the four forms of ice (grease, gray, gray-white, and white in the color photographs) can be clearly distinguished. The lead and polynya patterns are clearly discernible. The data clearly indicate that the ice morphology is very complex and that dynamic changes occur rapidly. When these data are analyzed in conjunction with the Skylab EREP, aircraft, and ground measurement data, perhaps a more complete description of the morphology and dynamics of the Gulf of St. Lawrence ice can be made.

LAKE ONTARIO

During the 1973 growth period, the ice extent in the Gulf of St. Lawrence was greater than normal, but the ice coverage in Lake Ontario was significantly less than normal. Actually, the amount of ice coverage was less than that evinced in recent years.

On January 8, 1974, Lake Ontario and the Thousand Islands region were ice free, and ground observations confirmed the absence of ice in the seaway in this area (fig. 11-4). Normally, at this time of the year, the ice would extend to or beyond the island chain (Main Duck and Gallou) located in the eastern end of Lake Ontario.

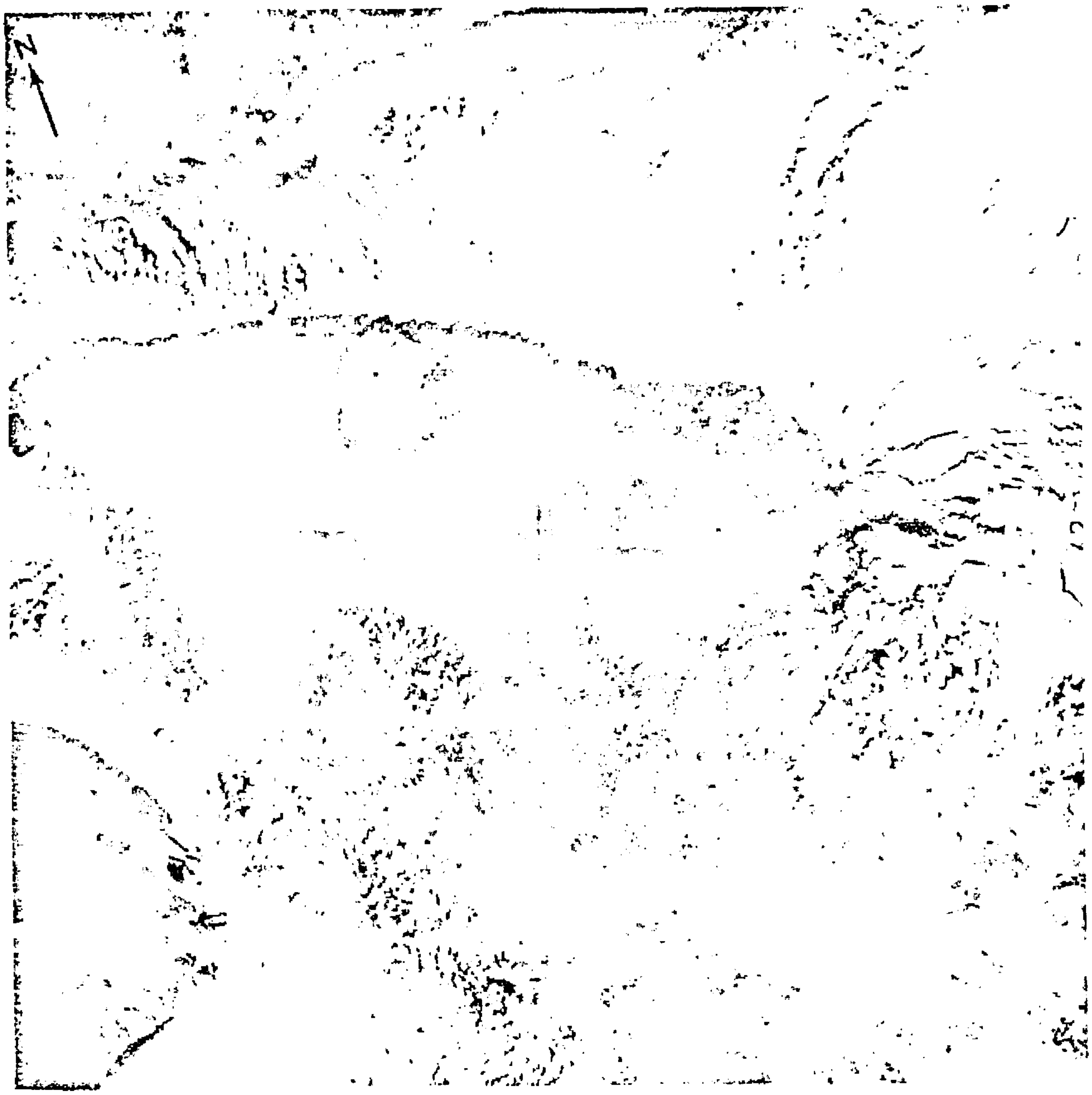


Figure 11-2.- Eastern Gulf of St. Lawrence on January 20, 1974, at 16:04 G.m.t. (SL4-141-4323).

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

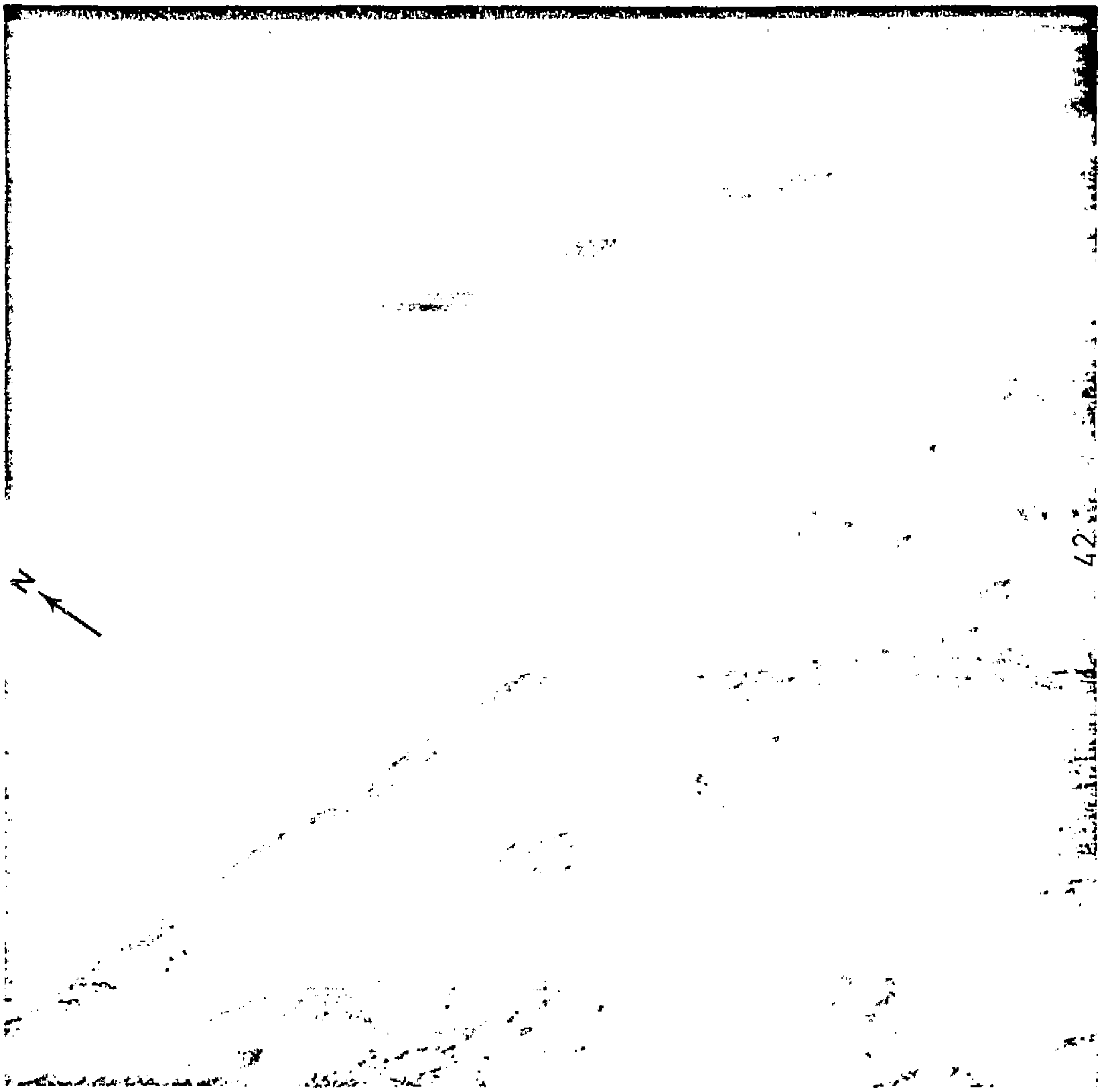


Figure 11-3.- Sea ice in the Gulf of St. Lawrence on January 20, 1974, at 17:40 G.m.t. (SL4-141-4331).

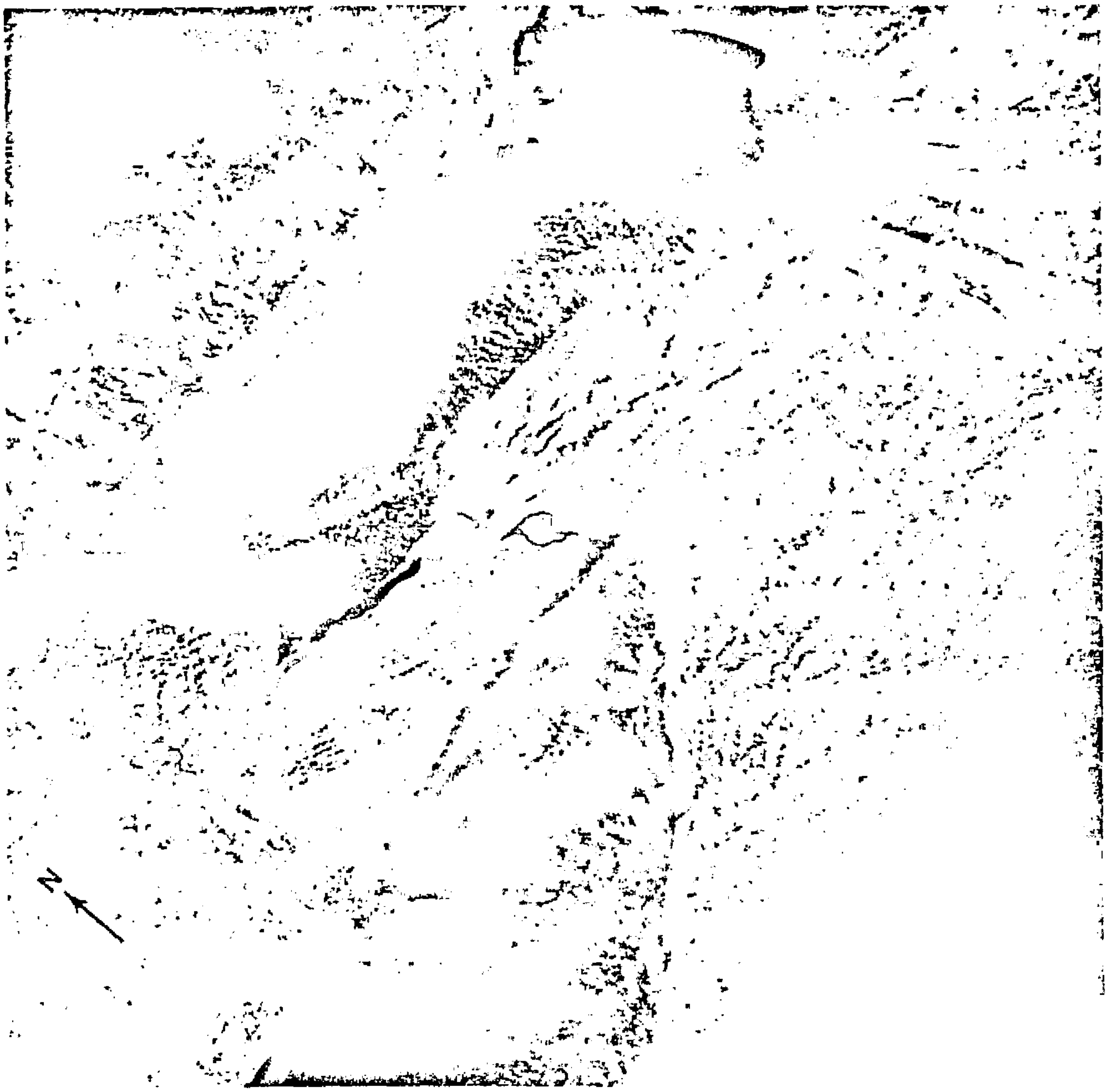


Figure 11-4.- Lake Ontario on January 8, 1974 (SL4-139-3989).

On January 13, 1974, the ice in the seaway had formed completely and had an opaque, white appearance (fig. 11-5). An intense cooling period occurred just before this visual observation was made. The ice formed in the seaway on January 12 and, by the time of this observation, ranged from 10 to 28 centimeters thick. A snow layer 3 to 5 centimeters thick covered approximately 85 percent of the ice area.

As shown in figure 11-5, black ice occurs westward from the opaque, white ice boundary on both sides of Wolfe Island, extends beyond the island chain, and fills the east end of the lake. This newly formed black ice was between 3 and 11 centimeters thick.

When compared to the dynamic sea ice of the Gulf of St. Lawrence, the lake ice of Lake Ontario could be classified as static. However, successive Skylab photographs of the edge of the cohesive ice cover provide valuable data on the rapidly changing ice extent. The extent of the ice cover has a direct influence on the temperature of the water entering the St. Lawrence River. During a cold period, a small area of ice coverage will cause the water entering the St. Lawrence River to be supercooled, which enhances the formation of frazil ice in the western end of the river; a large area of ice cover will prevent the formation of frazil ice. Morphological changes that occur in the ice cover downstream in the St. Lawrence River can be inferred from studies of satellite photographs of the ice edge dynamics.

OBSERVATIONS IN OTHER AREAS

Ice morphology and dynamics also were observed in James Bay, Canada. In the near future, hydroelectric dams now under construction will cause significant changes in the ice regime of this bay; therefore, the Skylab 4 data will provide valuable baseline information for assessing the extent of these changes.

The Skylab 4 photographs of the Bering Sea will help elucidate the complex behavior of the sea ice; comparison of these photographs with the data obtained a year earlier by the joint U.S.S.R. and U.S. Bering Sea experiment (BESEX) also will be useful.

The Japanese and Russian scientists are interested in the Skylab 4 observations of the Sea of Okhotsk where the sea ice has a morphology similar to that of sea ice in the Bering Sea.

Perhaps the most interesting Skylab 4 ice observations of other areas are those of Antarctic icebergs. The Skylab 4 crewmen obtained time-sequenced photographs of several very large tabular icebergs in the vicinity of South Georgia Island. One of these icebergs measured approximately 45 by 60 kilometers and may be the largest iceberg ever observed at such a low latitude (fig. 11-6). Recent research has suggested the feasibility of towing Antarctic tabular icebergs to selected areas and using them for water supplies. Skylab 4-type observations could provide many needed data on the distribution,

Figure 11-5.- Lake Ontario on January 13, 1974 (SL4-140-4097).

Figure 11-6.- Tabular Antarctic iceberg in the vicinity of South Georgia Island (SL4-142-4577).

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

size, and drift of icebergs in Antarctic waters. Because many icebergs are not of a size observable by meteorological satellites and because Earth Resources Technology Satellite images of a given area can be obtained only every 18 days, Skylab 4-type photography may be the best way to observe icebergs and to measure their drift trajectories.

CONCLUDING REMARKS

The Skylab 4 visual observations data are extremely useful to researchers in the floating ice discipline. The high information content in the data from the two main study areas and from other areas can provide needed information on a great variety of topics, such as ship routing in ice-infested waters, variability of ice extent as related to weather, icebergs as a fresh water source, and thermodynamic studies of ice/water interaction.

Although many aspects of floating ice can be studied by use of unmanned satellites, the Skylab 4 data show that man is necessary as a data-collecting tool for certain observation tasks. Because he has the ability to select and to focus on specific observation areas where there is a wide variety of activity, and because he can rapidly choose the period and extent of data collection, man is necessary for Earth observations from space. The Skylab 4 lake and sea ice experiment has accomplished its objectives, specifically because of the information obtained by the crewmen on the Visual Observations Project. Therefore, it is strongly recommended that future manned space programs, such as the Apollo-Soyuz Test Project and the Space Shuttle Program, should acquire visual observations and time-sequenced photographs of floating ice.

12. PRELIMINARY REPORT ON METEOROLOGY

William E. Shenk[a†]

On the Skylab 4 mission, handheld photographs were taken of numerous meteorological phenomena including thunderstorms, tropical cyclones, extratropical cyclones, intertropical convergence zones, mountain waves, convection in the cold air passing over warmer water, orographic convection, jet stream cirrus, island vortex and convection effects, sea breezes, cloud streets, air pollution, and other small-scale atmospheric circulations. There are many stereographic image pairs that can provide quantitative information on the vertical dimension. The photographs, the descriptions by the crewmen, and other data provide excellent sources of information for the study of these meteorological phenomena. Specific examples of the value of the photographs for some of the phenomena are discussed in this preliminary report.

EXTRATROPICAL CYCLONES

The high resolution and image contrast of the 70-millimeter color photographs provide an opportunity to see the details of the cloud structure associated with extratropical storms that normally cannot be seen in available meteorological satellite images. A well-organized cloud pattern associated with an extratropical cyclone is shown in figure 12-1. This cyclone, located near latitude 40° S (approximately 3200 kilometers east of New Zealand), exhibits a spiral configuration that is usually a sign of an occluded storm. The low Sun angle and oblique photographic angle enhance the details of the cloud structure within the main frontal band. There is considerable evidence of convective activity, both in the frontal band and near the end of the spiral, not far from the storm center. Most of the convective activity in the band is near the rear edge and, therefore, near the occluded or cold front. The convection near the center is probably produced by a cold pool of air in the middle troposphere and a warm sea-surface temperature sufficient to cause a relatively steep lapse rate. Given the same midtropospheric temperatures, if the cyclone were further south over much colder water, the likelihood of this convection would be less.

An oblique photograph of another extratropical storm over the South Atlantic is shown in figure 12-2. The oblique view provides a look at the clouds from the side. Inferences can be made regarding the vertical and horizontal wind fields from the cloud structure of the cumulonimbus buildups

---

[a] NASA Goddard Space Flight Center.

[†] Principal Investigator.

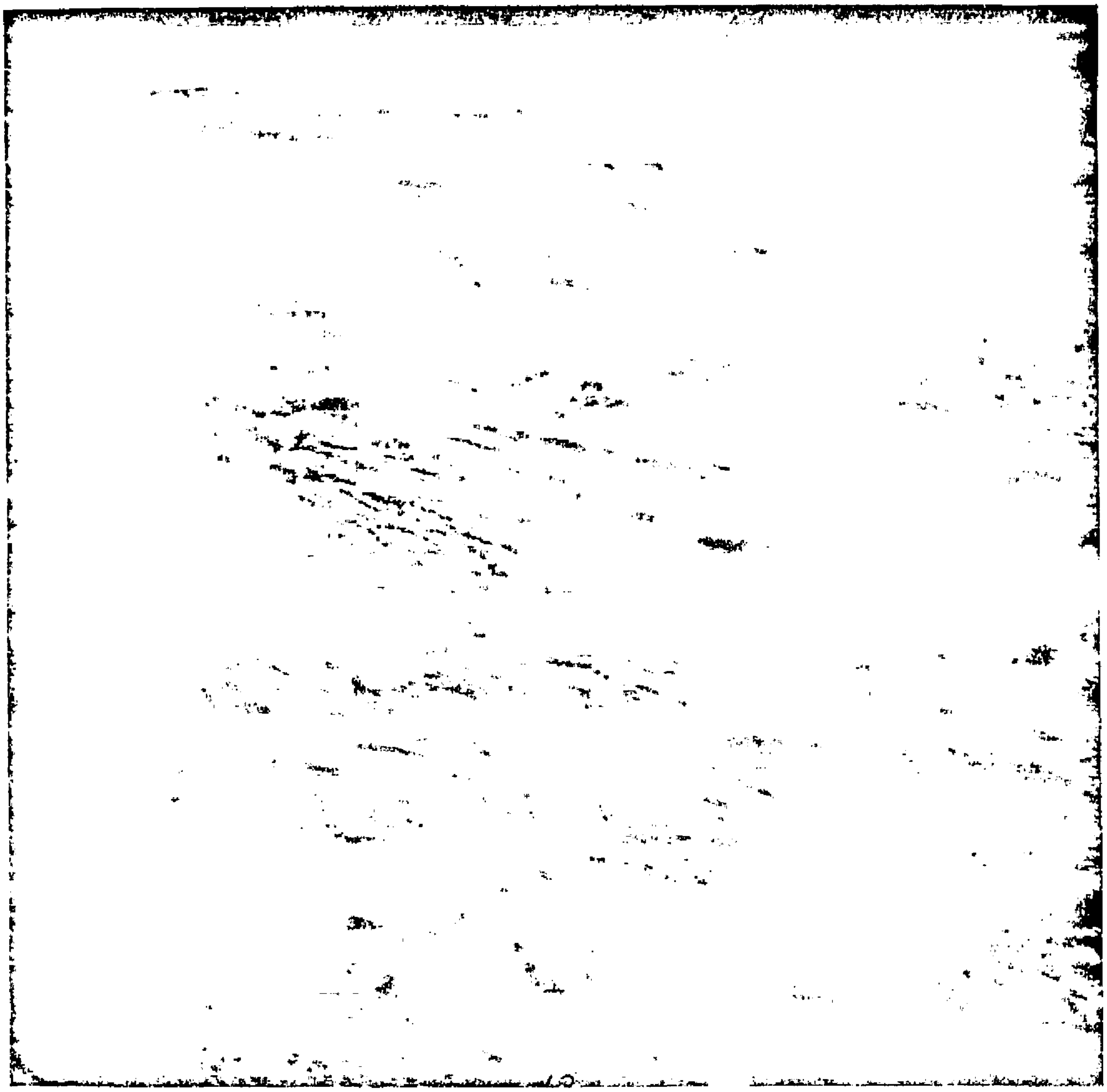


Figure 12-1.- Cloud pattern associated with extratropical cyclone near New Zealand (SL4-137-3565).

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

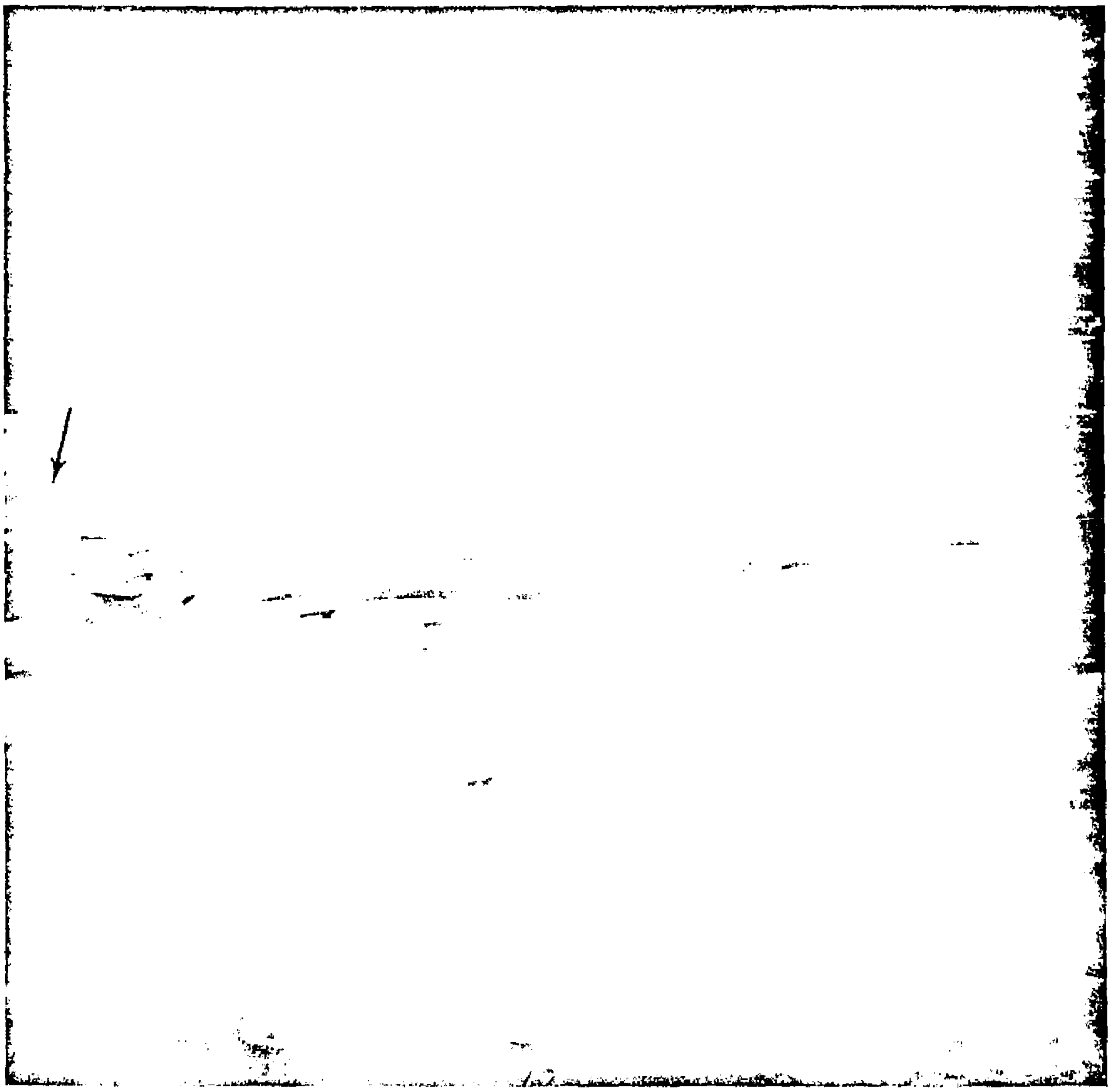


Figure 12-2.- Extratropical storm over the South Atlantic (SI4-136-3497).

and towering cumulus in a cloud band on the equator side of the storm center (under the cirrus shield of the cloud spiral near the horizon). The low-level winds must have a westerly component that is consistent with the circulation around the portion of the cyclone nearest the Equator. However, the cirrus blowoff from the top of the cumulonimbus clouds indicates an easterly component, or less of a westerly component, in the upper troposphere. It cannot be determined whether the winds are easterly because the eastward shearing of the cirrus blowoff could be produced by the faster eastward movement of the entire band rather than by the speed of west winds aloft. Apparently, there is not a strong vertical shear up to the tops of the towering cumulus clouds because there is no evidence in the photograph of blowoff from the tops.

In a later report, these interpretations of figures 12-1 and 12-2 will be combined with other data sources to provide a more definitive description of each event.

JET STREAM CIRRUS

A good example of cirrus clouds associated with a subtropical jet stream over the southwestern United States is shown in figure 12-3. This photograph is one-half of a stereopair. When the pair is viewed through a stereoscope, it is evident that the cirrus is located at many levels. This indicates that errors in estimating the cloud-top height would be made for individual cloud elements if the cirrus cloud tops were assumed to be at a uniform height. The height differences indicate the value of stereoscopic techniques for measuring cloud top heights and the difficulties that would be encountered in trying to use any radiometric technique that depends on temperature or cloud emissivity, if these variables could not be determined. It is also evident that a valuable amount of wind profile information could be gathered on the upper troposphere if the cloud motions for each element could be obtained from a series of geosynchronous satellite images and if the cloud top heights could be accurately determined.

COLD AIR OVER WARM WATER

A classic example of the effects of cold air flowing over a warmer water surface is shown in figure 12-4. In this photograph, cold, relatively dry air flows from the northwest across New England and New York. Only a short distance offshore, enough moisture, instability, and convergence are created in the lower troposphere for the formation of stratocumulus.

These clouds become more widespread farther offshore, and the most intense cloudiness appears to be downstream from the clouds that formed nearer the coast. The crewmen observed the same situation over the Great Lakes, where the most intense cloudiness appeared to be generated from clouds that formed a short distance offshore after the air had moved offshore. This information could be valuable for predicting areas of locally heavy snowfall along the

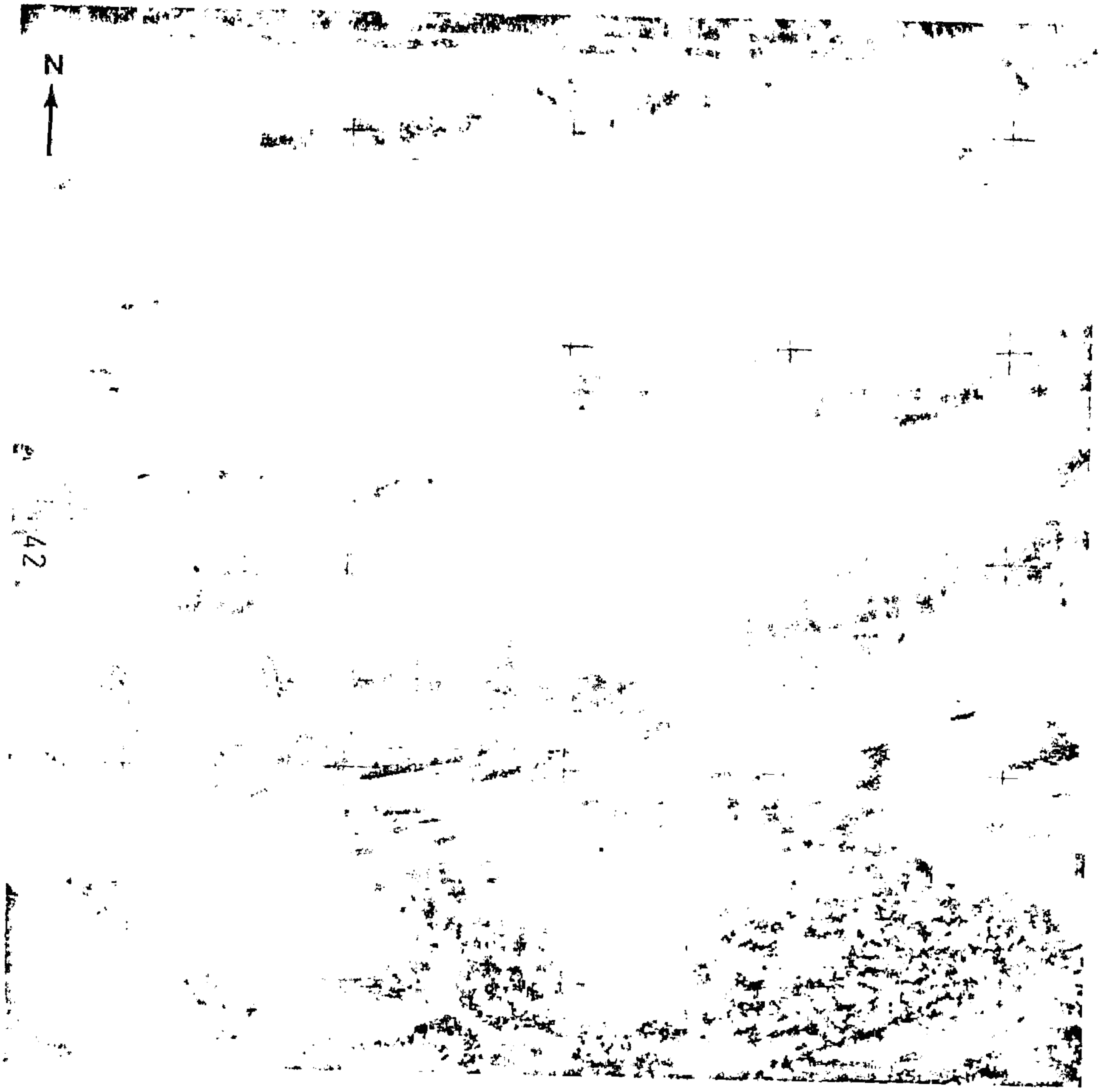


Figure 12-3.- Jet stream cirrus over the southwestern United States (SL4-141-4390).

Figure 12-4.- Cold air advection over warmer water off the New England coast (SL4-139-3990).

windward shores of the Great Lakes. Adjacent to the areas of greatest activity over the ocean, there was enough convective overturning within the unstable layer to produce subsidence that was sufficient to produce clear regions.

Several hundred kilometers southeast of the New England coast, there are two long, thin lines of higher clouds with their shadows plainly visible on the lower clouds. This type of cloudiness is often associated with the jet stream and has been a diagnostic tool for locating the position of the jet stream with meteorological satellite data.

CONCLUDING REMARKS

Photographs taken from an Earth-orbital satellite are useful in understanding meteorological phenomena and in predicting meteorological conditions. Stereographic photographs are particularly helpful in forming accurate estimates of the dimensions of cloud features and understanding the ways in which these features interact to produce meteorological phenomena.

13. CLOUD FEATURES

David E. Pitts,[a†] Y. Sasaki,[b] J. Fein,[b] and J. T. Lee[c]

Visual observations and photographic documentation of cloud streets and severe storm features by the Skylab crewmen have provided information pertinent to the study of storm system development. Further study of the Skylab data in conjunction with ground measurements will be required to fully document the utility of man's observations in the analysis of meteorological features.

CLOUD STREETS

Cloud streets are long lines of cumulus clouds separated by narrow, clear areas. These clouds usually form at low altitude along the low level wind, but occasionally these clouds form perpendicular to the wind vector.

The crewmen's task was to photograph cloud-street patterns, to estimate the physical dimensions of cloud streets, and to describe their relationship to other cloud features and to land features. The purpose of this investigation was to observe whether cloud streets manifested moisture convergence and whether cloud-street curvature had a source of angular momentum for rotating storms that might produce tornadoes.

The Skylab 4 crewmen observed and photographed many interesting examples of cloud streets. Because these observations were made during the winter, most of the cloud streets were observed over the Great Lakes in the United States and over South America. Cloud streets over the Great Lakes were caused by cold air occurring over warm water, whereas those over South America were due to thermal convection caused by solar heating (either over land or water).

The crewmen did not observe cloud streets at midlatitudes (e.g., those that originated in the Intertropical Convergence Zone (ITCZ)). Perhaps this phenomenon did not occur at this time of year, the Skylab altitude was not high enough for the synoptic perspective needed to observe the phenomenon, or the phenomenon does not occur in the ITCZ.

---

[a] NASA Lyndon B. Johnson Space Center.

[b] The University of Oklahoma.

[c] National Severe Storm Laboratory of the National Oceanographic and Atmospheric Administration.

[†] Principal Investigator.

The crewmen acquired interesting new data on cloud streets; however, for future manned missions, additional detailed observations would prove useful in determining the relationships between land features and cloud streets. For example, as shown in figure 13-1, the cloud streets over Honduras seem to terminate abruptly for no apparent reason. This condition could be caused by changes in the convection strength of windspeed or by moisture availability. Additional crewmen comments on apparent causes for this phenomenon would be helpful in explaining mesoscale circulation patterns in the global circulation. Figure 13-2 is a photograph of what appears to be a roll cloud immediately inland on the coast of South America. This cloud may have been caused by the interaction of seabreeze and some type of barrier (mountains or a front). Some of the cirrus clouds might have been caused by smoke from brush fires. If this hypothesis is true, the photographs will need to be reinterpreted.

In addition to acquiring data on cloud streets, the crewmen were able to determine wind direction, which was helpful in the photographic analyses. They also acquired more stereopairs, which are required for comprehensive cloud-feature analyses, than had been acquired on previous manned missions.

The crewmen observed many cloud colors in the down-Sun (antisolar) direction. This glory effect (zero-phase angle), which had not been observed from space before the Skylab 4 mission, seemed to emanate primarily from cirrus and stratus clouds. The size, shape, and associated phenomena, and color distribution may be used to distinguish the type of cloud, the droplet size, distribution, et cetera. Further discussion with the crewmen will be needed to clarify this possibility. The relationship of color to the edges of severe storms should be investigated in the Apollo-Soyuz Test Project (ASTP).

The crewmen were asked to observe cloud-street patterns on consecutive passes and to interpret surface-feature effects and cloud-street convergence, divergence, or oscillation for several hours. This task was not accomplished, primarily because work schedules often precluded constant observation.

The crewmen photographed many examples of cloud-street curvature, but, because of the limited time allotted for observations, only a few comments concerning curvature were recorded. Future observations of these features should be made over the United States where high-density supporting ground measurement is available for examining the cause of such curvature.

PERPENDICULAR CLOUD STREETS

A downwind cloud off the island Fernando de Noronha, which is located approximately 480 kilometers northeast of Recife, Brazil, and a background of cloud streets that are oriented perpendicular to the downwind cloud are shown in figure 13-3. The ITCZ north of the island and the transverse cloud streets oriented north-south, which indicate an eastward flow, are shown in figure 13-4, an Applications Technology Satellite (ATS-3) photograph. The island-wake cloud is therefore west of the island. These data were collected on [illegible], 1974, at 12:27 Greenwich mean time (G.m.t.). The character of this

Figure 13-1.- Handheld photograph of cloud streets over Honduras (SL4-138-3796).

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

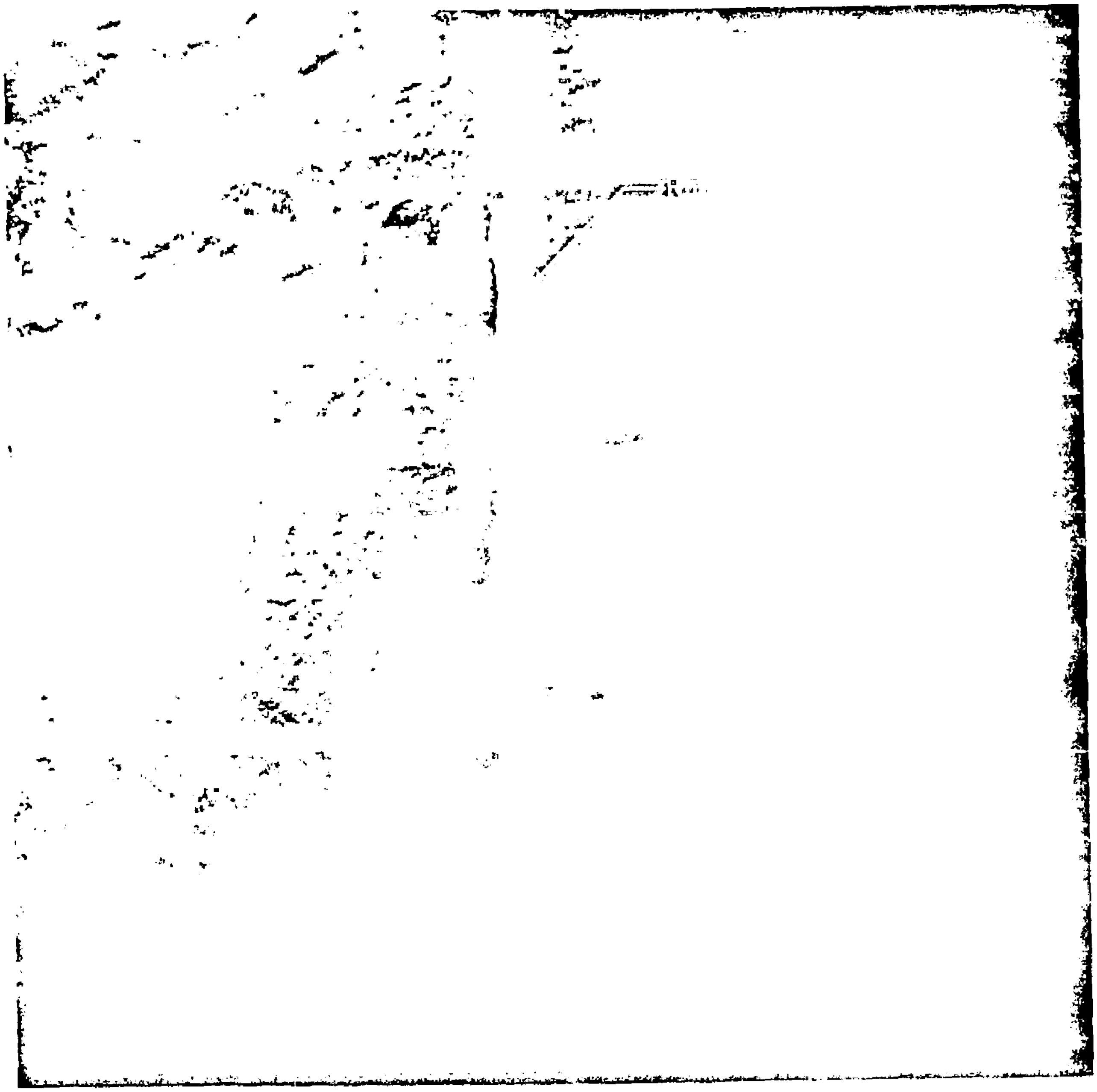


Figure 13-2.- Handheld photograph of roll-type cirrus cloud (SL4-139-3943).

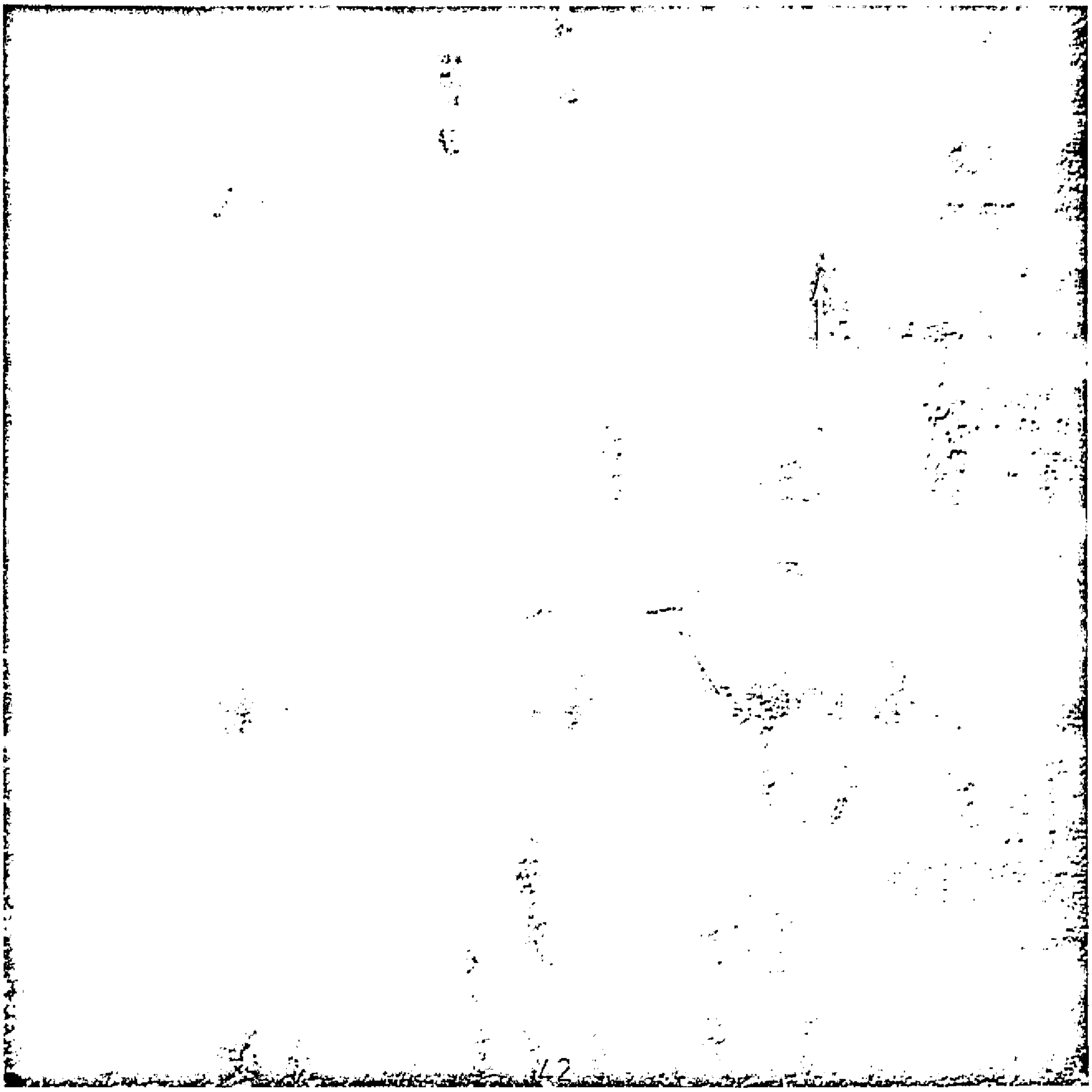


Figure 13-3.- Handheld photograph of downwind cloud off the island Fernando de Noronha. Wind direction is from right to left (SL4-138-3874).

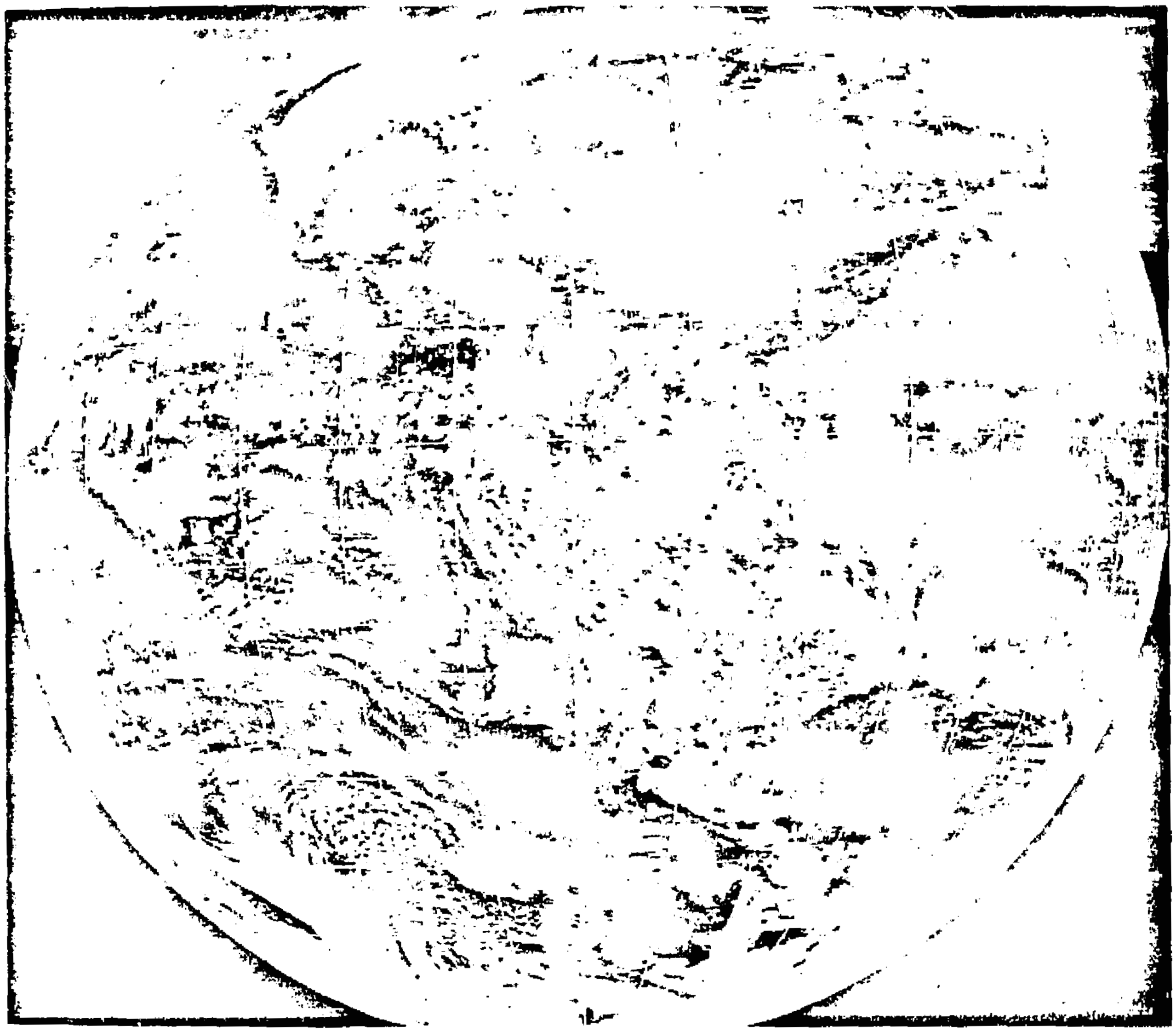


Figure 13-4.- An ATS-3 synoptic photograph taken at approximately the same time as figure 13-3.

downwind cloud indicates a flow with a low Reynolds number (6 to 60). The background clouds are probably cloud streets that are forming transverse waves perpendicular to the mean flow. These transverse waves do not occur as frequently as the more common roll-type cloud street, which forms along the mean flow. Figure 13-4 is significant because it shows the breakdown of the metastable transverse cloud streets by a perturbation from the island that caused the more favored roll-type cloud street to occur. Similar small perturbations over land may trigger severe storm genesis because preincipient storm conditions often may exist in metastable equilibrium.

CLOUD STREETS OVER LAKE SUPERIOR

Unusual cloud streets over eastern Lake Superior are shown in figure 13-5. These data were taken at 18:21 G.m.t. on January 10, 1974, when Lake Superior had little, if any, ice cover. This photograph is important because the cloud streets seemingly indicate a region of convergence in the middle of the lake as manifested by the dense cloud line, which is oriented east-west. The cloud streets also indicate a curvature that forms an apparent cyclonic rotation in the region of convergence. Light winds, cold temperatures, and high humidity were evident over the Great Lakes with a surface low in the Appalachian Mountains. The surface meteorological chart at 18:00 G.m.t. showed no apparent cause for the line of convergence, the cloud-street convergence, or the curvature. With this particular condition, the water in the lake is probably near the freezing point, and the air temperature over the lake is probably 266.5 to 272.05 K lower. This situation creates significant atmospheric convection.

Many of the cloud streets are parallel to the shoreline. This condition indicates that the heat source represented by the lake and the cold sink represented by the land can produce coupling effects that might interact with the mean flow to produce regions of high relative angular momentum. Figure 13-5 is significant because it supports the idea that locations with a high incidence of severe storms may produce this same heating differential if areas of land that vary in usage and temperature are closely related geographically. This phenomenon could account for the source of angular momentum for the tornado-producing clouds. Regions of the world that have large areas devoted to specific land use practices can produce large temperature differentials and may exhibit this same effect. Urban areas that are adjacent to cool water or green vegetation and mature wheatfields adjacent to cool water or vegetation are two examples.

MECHANICAL PROCESSES ASSOCIATED WITH ISLAND CLOUD PATTERNS

Although the Kármán vortices and lee gravitylike wave have been previously observed and studied rather extensively, the studies have been somewhat limited by a lack of adequate meteorological data. Selected Skylab 4 photographs of Kármán vortices have renewed the interest in studying this phenomenon. For

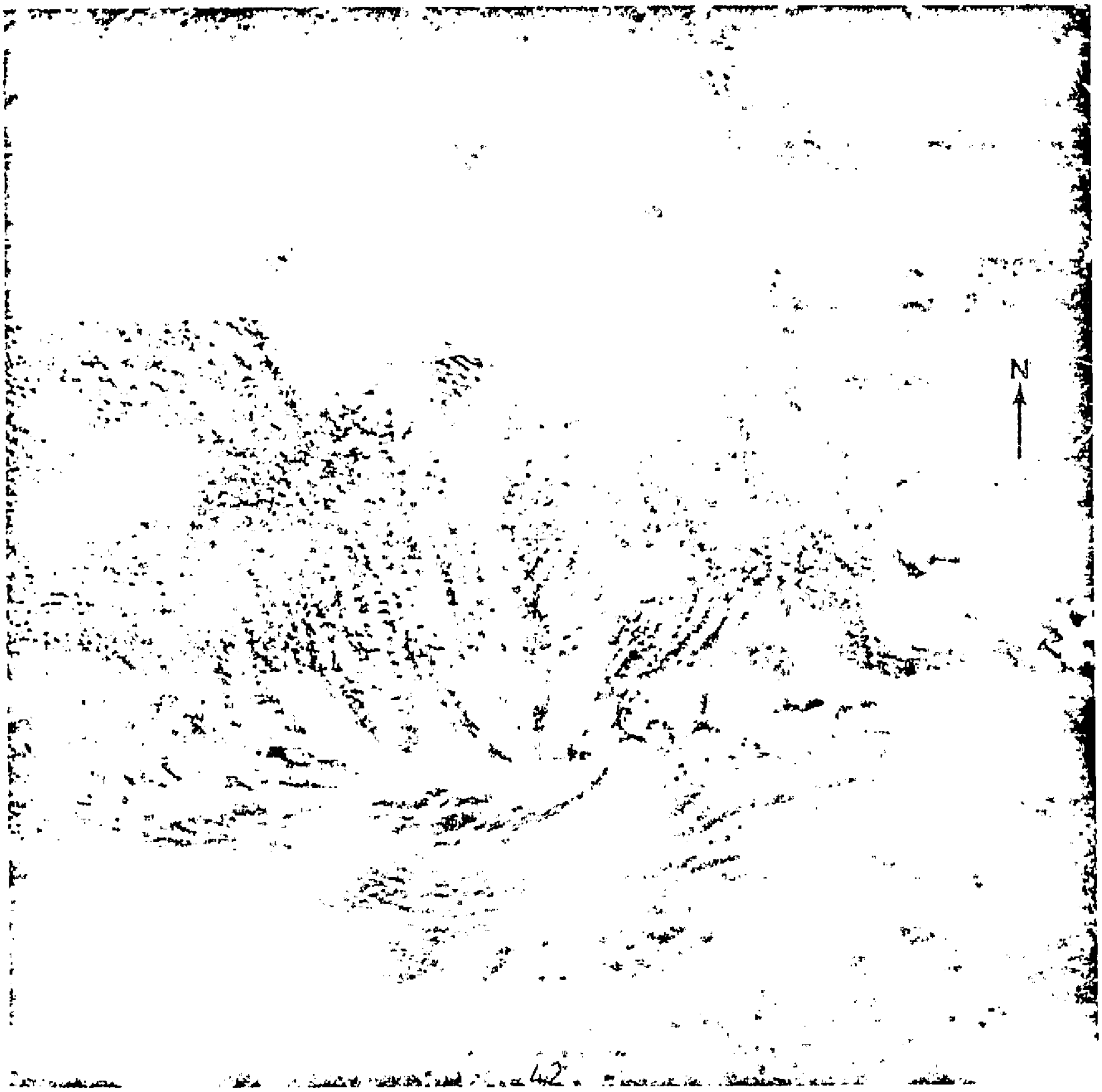


Figure 13-5.- Handheld photograph of cloud streets over Lake Superior (SL4-139-4041).

example, the Korean island of Cheju-Do, located in a region relatively rich in meteorological data just south of South Korea (33.5° N 126.5° E), is a mountain island favorably positioned for the mechanical generation of Kármán vortices. These patterns have been observed regularly during winter by Earth-orbiting satellites because such studies further the understanding of turbulent transport processes in the planetary boundary layer.

The bow-shock-type waves photographed by the Skylab 4 crewmen are unusual and exciting. One such photograph (fig. 13-6), taken over Campbell Island approximately 644 kilometers south of New Zealand, showed a well-defined bow-type wave downwind of the island, but a shock-type wave was not evident. The crewmen described it as "a bow wave as though from a ship."

Another photograph (fig. 13-7), which was accompanied by extensive description by the crewmen, was taken over Diego Alvarez Island at approximately 48° S 4° W; a bow-type wave accompanied by a well-defined shock-type wave is shown in the figure. The crewmembers described the wave as being similar to a supersonic flow in which an object causes a diamond shock effect. Preliminary investigations reveal the possibility that these waves may be gravity shock waves that are generated in a neutral or stable planetary boundary layer in which the mean windspeed exceeds the propagation speed of the internal gravity wave. The combination of available meteorological data and photographic observations such as these should increase the understanding of gravity-generated shock waves and, hence, planetary boundary layer dynamics.

SEVERE STORM ENVIRONMENTS

Although inspection of the cloud photographs has been limited to date, these photographs obtained by the Skylab crewmen have stimulated interest in further investigations. Some of them clearly indicate phenomena that were heretofore unknown. The photographs will be used effectively for a better understanding of severe storm development and severe storm environments. Other photographs not discussed in this report are listed in table 13-I.

RECOMMENDATIONS

In this experiment, the crewmen's observations were especially helpful in the search for new and unusual phenomena, especially rare small-scale phenomena involving color. To increase man's capability as an observer, more tools such as infrared scanners, polarimeters, spectrometers with real-time output, low-light-level intensifying systems, stereopair viewing systems, weather charts, satellite data pertaining to the weather, et cetera, should be supplied. For ASTP and early Shuttle flights, crew aids such as Polaroid cameras and single-lens reflex viewing capability should be provided.

The analysis of some photographs is difficult because time was not recorded automatically for each photographic frame, and a spacecraft ephemeris

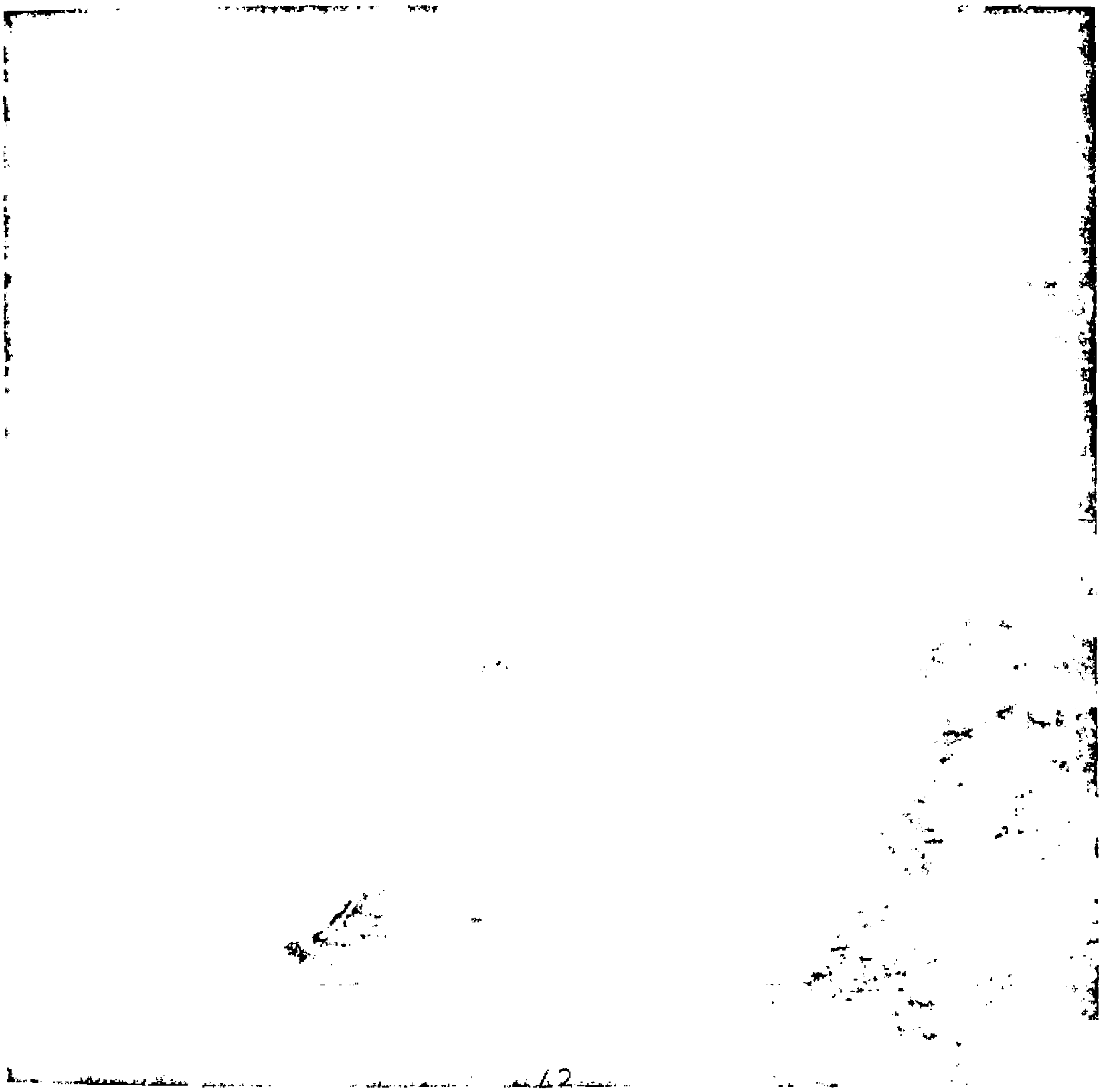


Figure 13-6.- Atmospheric bow wave in lee of Campbell Island (SL4-137-3668).

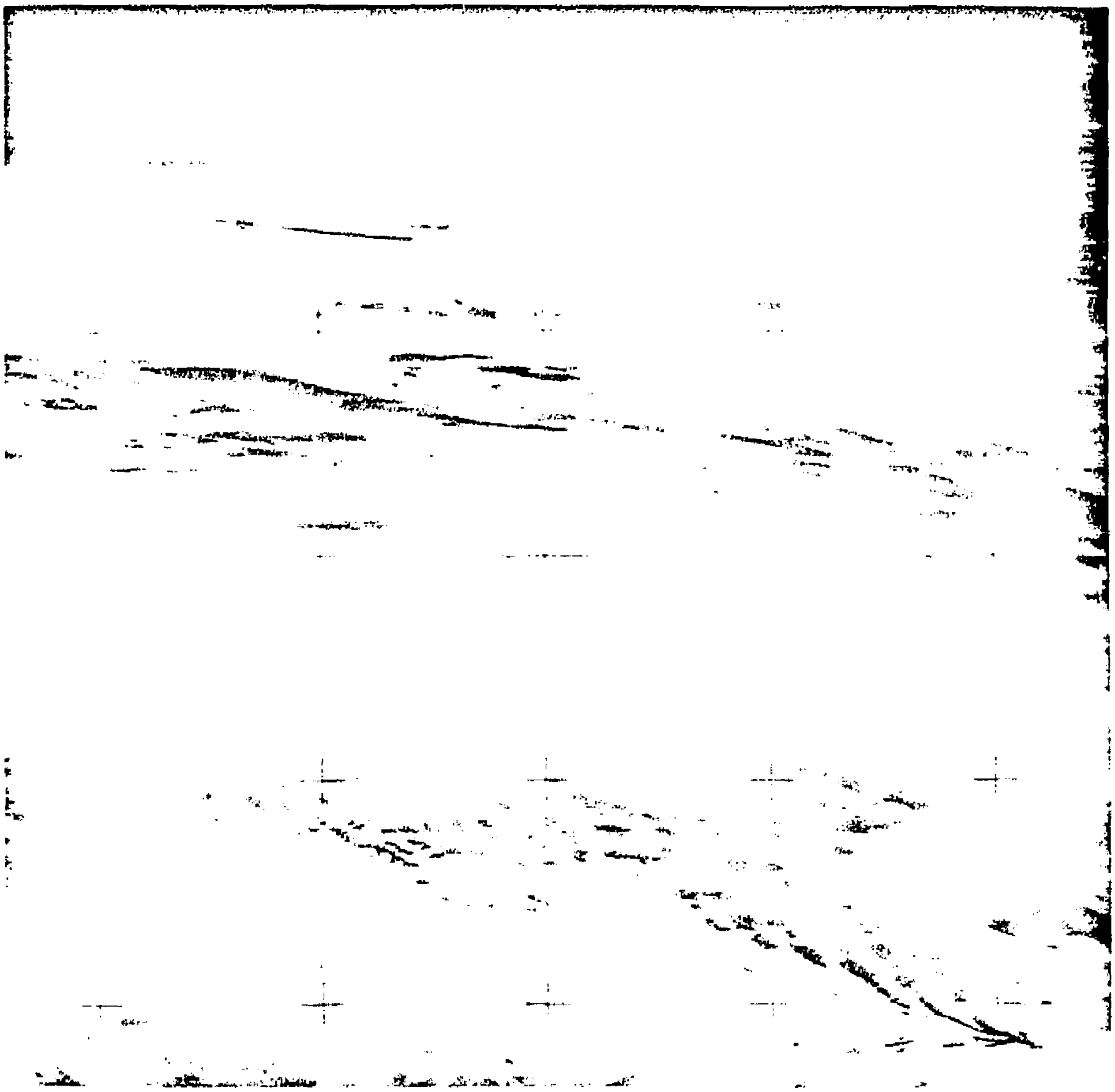


Figure 13-7.- Complex atmospheric wave in lee of Diego Alvarez Island (SL4-137-3632).

TABLE 13-I.- PHOTOGRAPHS PERTAINING TO SEVERE STORM ENVIRONMENTS

Frame no.	Area	Comments
Production of arc lines of cumulus and cumulonimbus		
SL4-138-3767	Bougainville Islands	Heating and orographic effects of island.
SL4-138-3798	Cozumel Island, Mexico	Thunderstorm development on an arc line with clear area on one side and cloudy area on the other.
SL4-137-3681	East of Argentina	A line of thunderstorms with new cell development produces arc lines of cumulus.
SL4-136-3436	East of Taiwan	A frontal system produces a line of cumulus and cumulonimbus, presumably the early stage of a squall line formation.
Supercell-type thunderstorms		
SL4-138-3798	Cozumel Island, Mexico	Skylab photographs yield a remarkable overall view of severe storm and severe storm environment.
SL4-138-3805	East of North and South Carolina	Cloud streets entering into storm center are remarkably clear in conjunction with the overall thunderstorm complex.

for visual observations was not available for the preliminary screening. These areas should be planned carefully for ASTP.

The capability of man to take high oblique photographs and stereophotographs in space is unique. This capability should be used to the fullest extent in future missions. The invaluable information gained from the Skylab crewmen's visual observations and photographic documentations indicates the value of future manned scientific missions.

14. PRELIMINARY ANALYSIS OF THE SKYLAB 4 IMAGERY OF ATMOSPHERIC POLLUTION

Darryl Randerson[a]

The usefulness of satellite photographs in detecting and evaluating atmospheric pollution events has been demonstrated (refs. 14-1 to 14-3). The Skylab 4 imagery offers improvements over previous satellite observations of pollution because the crewmen were specially prepared to observe air pollution phenomena and other features of geophysical and meteorological interest through lectures presented by the multidiscipline Visual Observations Project Team members and through individual study. Results of the preliminary analysis of some of the 70-millimeter imagery of atmospheric pollution taken by the crewmen are discussed in this report.

DATA

During their 84-day mission, the Skylab 4 crewmen took more than 1300 photographs of the Earth with a handheld, 70-millimeter Hasselblad camera. Preliminary review of these photographs revealed approximately 15 to 2 useful pictures of atmospheric pollution episodes. The imagery can be separated into two categories of fundamental sources of pollution: natural and manmade. Natural sources consist of dust clouds, naturally induced forest fires, and smoke generated by volcanic activity. Manmade sources include brush fires, industrial smoke plumes, palls, contrails, and ship trails. One photograph of special interest shows a snow plume that may have resulted from the input of a manmade energy source. The results of the debriefing of the Skylab 4 crewmen and of the identification and preliminary examination of some of the more interesting photographs are discussed in this section.

ANALYSIS

Sakura-zima Volcanic Activity

The volcanic island of Sakura-zima is located in the northern part of Kagoshima Bay. According to the Center for Short-lived Phenomena at the Smithsonian Institution, emissions of volcanic smoke began on November 27, 1973. Local reports from Kagoshima, located approximately 10 kilometers west

---

[a] Air Resources Laboratory, Las Vegas, Nevada.

of the volcano, indicated frequent explosions with detonations, air shocks, and strong emissions of smoke reaching altitudes of approximately 4000 meters. A 70-millimeter photograph of this volcano, taken on January 7, 1974, is shown in figure 14-1. In this photograph, the visible smoke plume extends toward the southeast; however, as the plume crosses over the extreme southern end of Kyushu, it appears to diffuse rapidly and fan out toward the northeast. During debriefing, the crewmen indicated that it appeared to them that the plume had risen to a higher elevation where the wind was more southwesterly. Further investigations are planned to attempt to determine the cause of these changes in trajectory and diffusion characteristics. Preliminary estimates indicate that the plume is approximately 125 kilometers long.

Argentine Forest Fires

During the period from December 16, 1973, to January 6, 1974, the worst woodland fires in Argentine history occurred in the sparsely populated area of the central La Pampa Territory. The fires were reported to have consumed 5000 square kilometers (1.2 million acres) of densely forested land. Some of the trees destroyed by the fires were 300 to 400 years old. Thousands of cattle were also destroyed on ranches in the area. Weather conditions during the burning were reported to have been very hot; a temperature of 316 K (110° F) was specified in one report. Wind directions were reported as variable with speeds estimated at 4 to 9 m/sec. Some thunderstorms were reported in the vicinity of the fires.

A photograph of La Pampa Territory taken on December 28, 1973, is shown in figure 14-2. A rather large smoke plume and accompanying pall are visible across the center of the photograph. Observations by the crewmen on December 20 and 28 indicated that the spatial coverage by the smoke pall was extensive. The crewmen also indicated that the smoke appeared to be billowing straight up, an observation implying that the surface wind conditions may not have been as strong as preliminary reports indicated.

African Brush Fires

The imagery presented in figure 14-3 is a 70-millimeter photograph of numerous brush fires in Africa. Debriefing exchanges with the crewmen revealed that these fires covered an area of approximately 40 000 square kilometers in Nigeria, Chad, and Cameroon. On January 26, 1974, the crewmen reported a spectacular night scene of fires. These fires had also been observed by the crewmen on January 24, when they noted that smoke-plume orientation indicated low-level flow from the northeast. Figure 14-3 certainly constitutes a dramatic portrayal of the spatial coverage of smoke generated from large-scale slash-burning in Africa.

Figure 14-1.- Sakura-zima volcanic plume on January 7, 1974 (SL4-139-3942).

Figure 14-2.- Photograph taken on December 28, 1973, of a smoke plume and pall originating from Argentine woodland fires (SL4-138-3753).

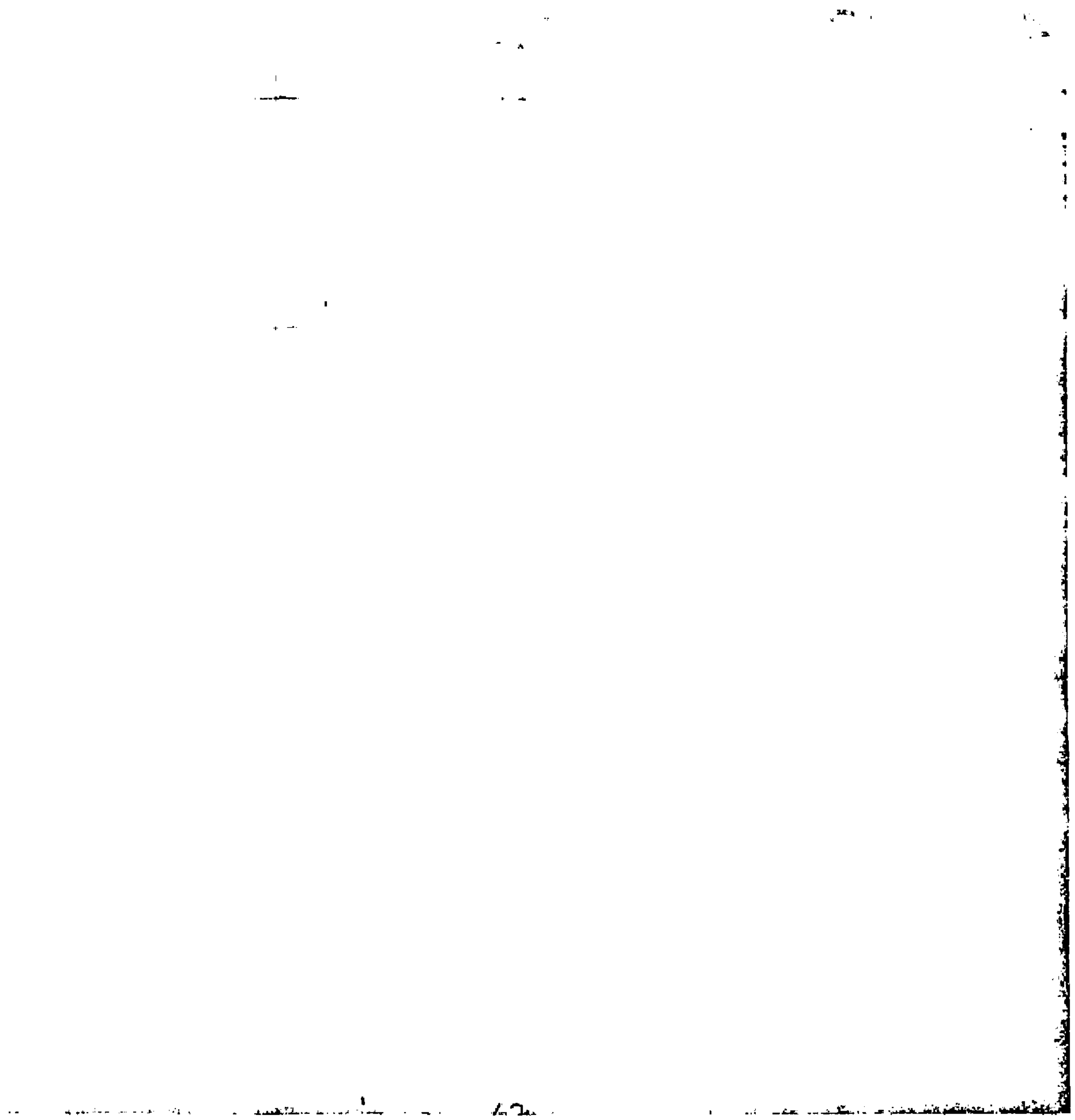


Figure 14-3.- African brush fires in progress on January 26, 1974
(SL4-138-3768).

Louisiana Smoke Plumes

At approximately 15:00 Greenwich mean time (G.m.t.), December 7, 1973, the Skylab 4 crewmen took a spectacular photograph (fig. 14-4) of two rather long smoke plumes emanating from unknown sources on the central Louisiana coast. Preliminary analysis of the imagery indicated that the visible part of the eastern plume was approximately 125 kilometers long and approximately 1 to 2 kilometers wide. The western plume was estimated to be 150 kilometers long and approximately 2 kilometers wide. Both plumes extended due southward into the Gulf of Mexico, a movement indicating a northerly airflow. The limited horizontal extent of the visible plumes implies the lack of directional wind shear in space and time and tends to imply a laminar-type flow.

A meteorological analysis of the surface synoptic situation at 15:00 G.m.t. on December 7, 1973, helped confirm the flow characteristics inferred from the imagery. The eastern half of the United States was dominated by a large polar airmass centered in Missouri. This situation resulted in a northerly to northeasterly flow in the surface layer. Analyses of the 12:00 G.m.t. rawinsonde data for Lake Charles, Louisiana (located approximately 125 kilometers west-northwest of the eastern plume) revealed the presence of an isothermal temperature layer extending from just above the surface to approximately 1200 meters (4000 feet) above mean sea level. Northerly winds through this 1200-meter layer averaged approximately 8 m/sec. Given the approximate plume dimensions and the mean speed of the wind transporting the plume, the simple formulas proposed in references 14-4 and 14-5 and used recently in reference 14-2 can be applied to obtain an estimate of the horizontal eddy diffusivity. Preliminary calculations showed that the horizontal diffusivity was approximately 1.8×10^4 cm^2/sec for the eastern plume and approximately 2.4×10^4 cm^2/sec for the western plume. These results indicate that a rather stable flow regime was advecting the visible plumes shown in figure 14-4.

Contrails

The imagery presented in figure 14-5, taken on December 2, 1973, at approximately 15:00 G.m.t, shows the Lake Erie, Michigan, area. Several jet contrails are clearly visible just north of Lake St. Clair (the small lake just north of Lake Erie). The longest contrail is in the vicinity of Flint, Michigan, and is estimated to be 80 to 100 kilometers long. The contrail north of Lake St. Clair is approximately 50 kilometers long. Both of these contrails cast visible shadows on the ground.

Ship Trail

Information to accurately locate and identify the imagery shown in figure 14-6 is limited; however, during debriefing of the crewmen, the plume was identified as a ship trail, a plume of condensed water vapor originating from the exhaust of an ocean-going vessel, in the North Pacific Ocean. These anomalous cloud lines were first reported in references 14-6 and 14-7 and more

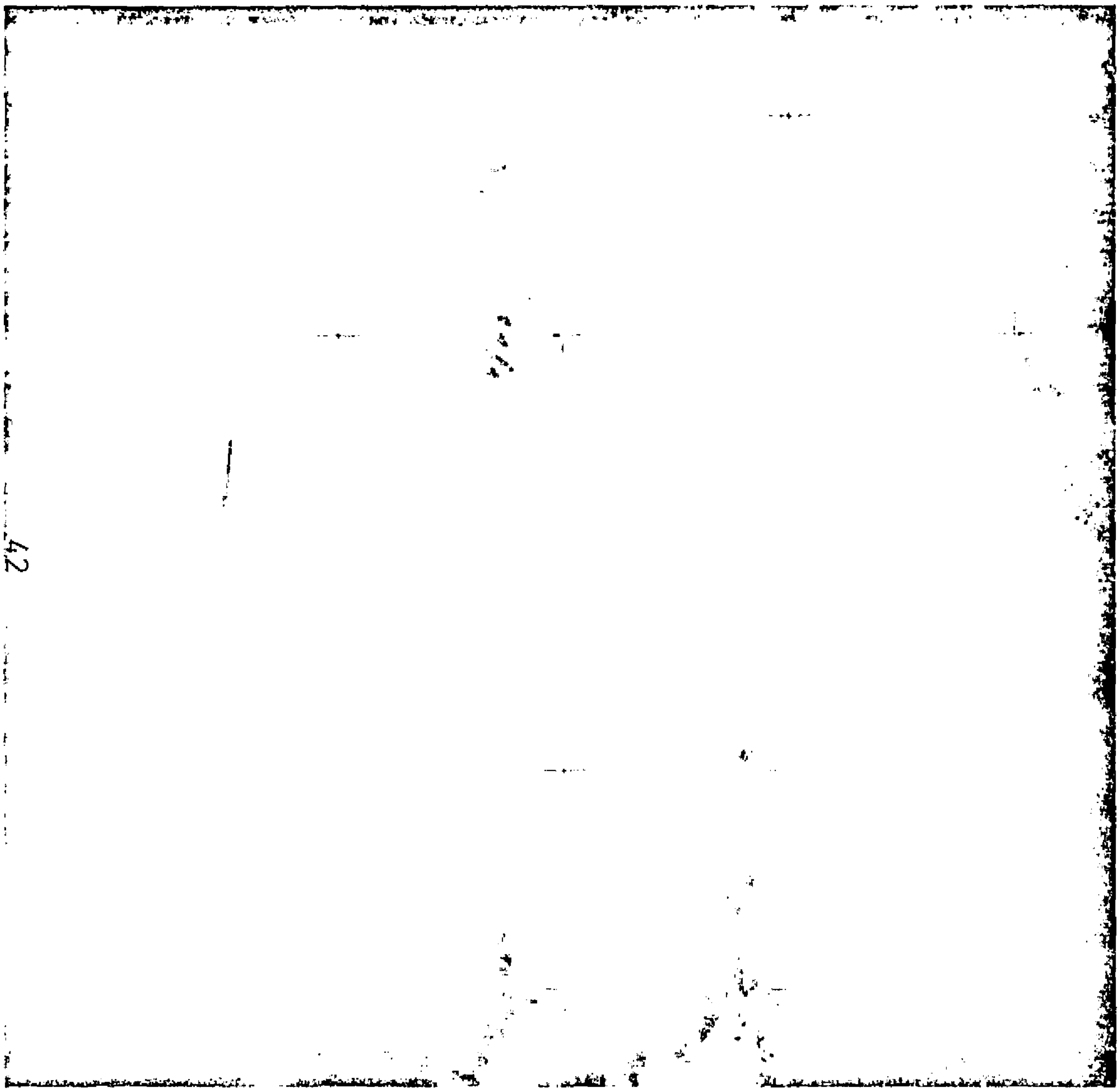


Figure 14-4.- Two long smoke plumes originating from sources on the central Louisiana coast on December 7, 1973 (SL4-136-3475).

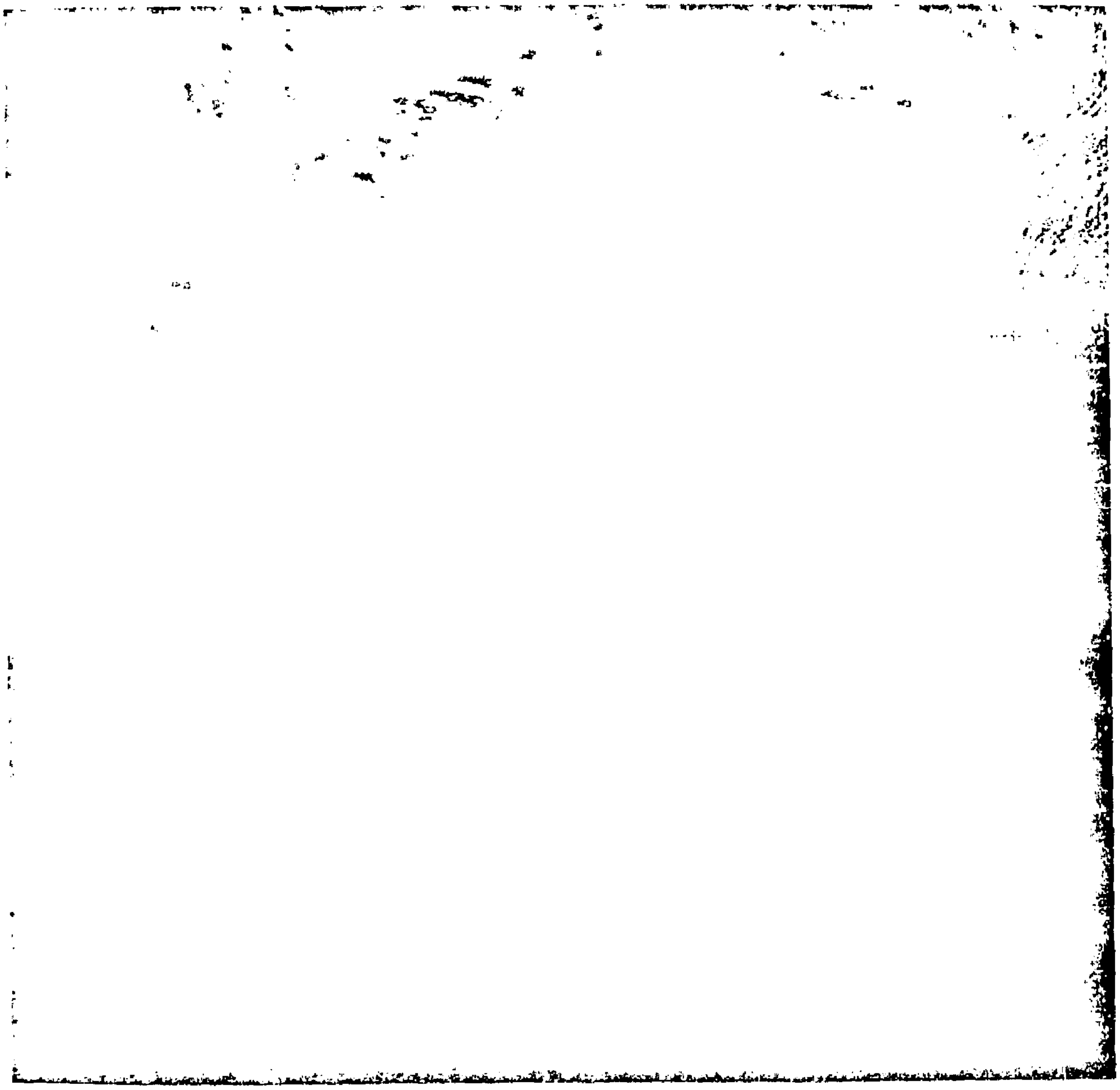


Figure 14-5.- Jet contrails in the vicinity of Lake Erie on December 2, 1973 (SL4-136-3405).

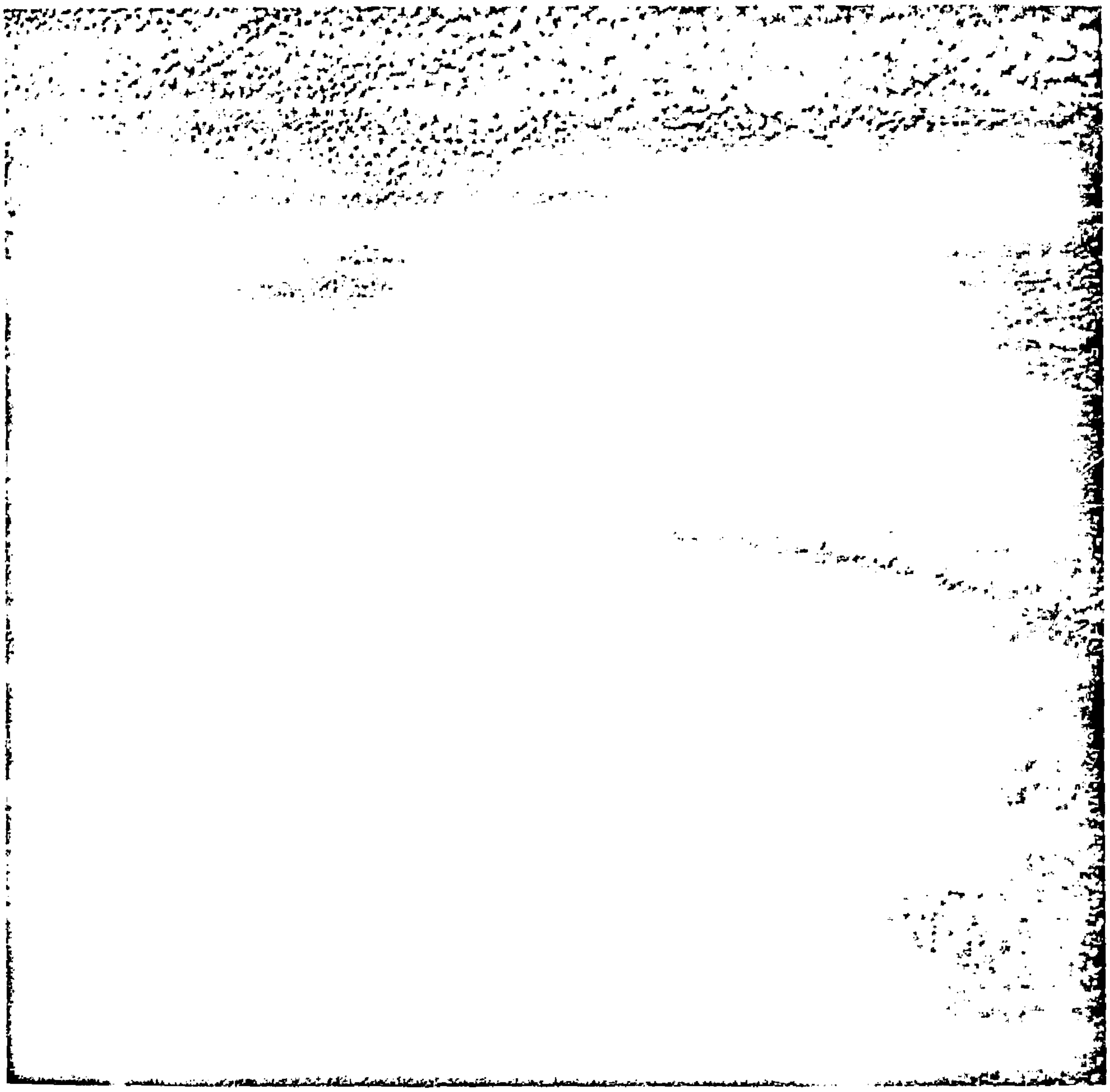


Figure 14-6.- Ship trail (SL4-140-4126).

recently in reference 14-8. According to reference 14-7, the critical atmospheric conditions permitting the formation of ship trails are (1) the existence of a convectively unstable layer from the surface to a low-level stable layer, (2) saturation or slight supersaturation near the top of the convective layer, and (3) a deficiency of cloud nuclei in the convective layer.

Duststorm

A photograph of a dust cloud over the Arabian Sea, taken on January 20, 1974, at approximately 12:00 G.m.t., is shown in figure 14-7. The most conspicuous feature in the photograph is the distinct frontal-type line of the dust cloud curving southward in the western part of the photograph. The dust cloud appears to lie approximately between Chāh Bahār to the west and eastward beyond Ormāra.

Preliminary estimates of the dust line shown in figure 14-7 indicate an approximate length of 500 kilometers that extends beyond the image boundaries. The area covered by the dust cloud, over the water only, is estimated to be approximately 1.3×10^5 square kilometers.

Snow Plume

The photograph presented in figure 14-8 contains a very interesting streak or plume of snow through the middle of the photograph. The approximate location of the photograph has permitted tentative identification of the large river on the western side as that part of the Missouri River extending between Omaha, Nebraska (upper left corner of photograph) and the area of Kansas City, Missouri (lower left corner of photograph). The snow plume extends east-northeasterly from north of the Tuttle Creek Reservoir, Kansas, to near Ottumwa, Iowa, a distance of approximately 300 kilometers; this location is based on approximate gridding. In reference 14-9, snow plumes have been recently reported in the vicinity of the Great Lakes and may have resulted from enhancement of precipitation by thermal pollution and frictional convergence in the vicinity of Lakes Erie and Ontario. These two explanations appear inadequate to account for the plume shown in figure 14-8.

CONCLUDING REMARKS

A discussion of the results of a preliminary analysis of photographs depicting atmospheric pollution episodes, taken by the Skylab 4 crewmen for the Earth observations program, has been presented. The success of atmospheric pollution imagery collected during the Earth observations program can be traced directly to the special training of the crewmen in the basic data needs of various scientific disciplines. Direct communication with the crewmen after the mission was particularly useful. The personal accounts given by the crewmen of the Visual Observations Project were especially instrumental in

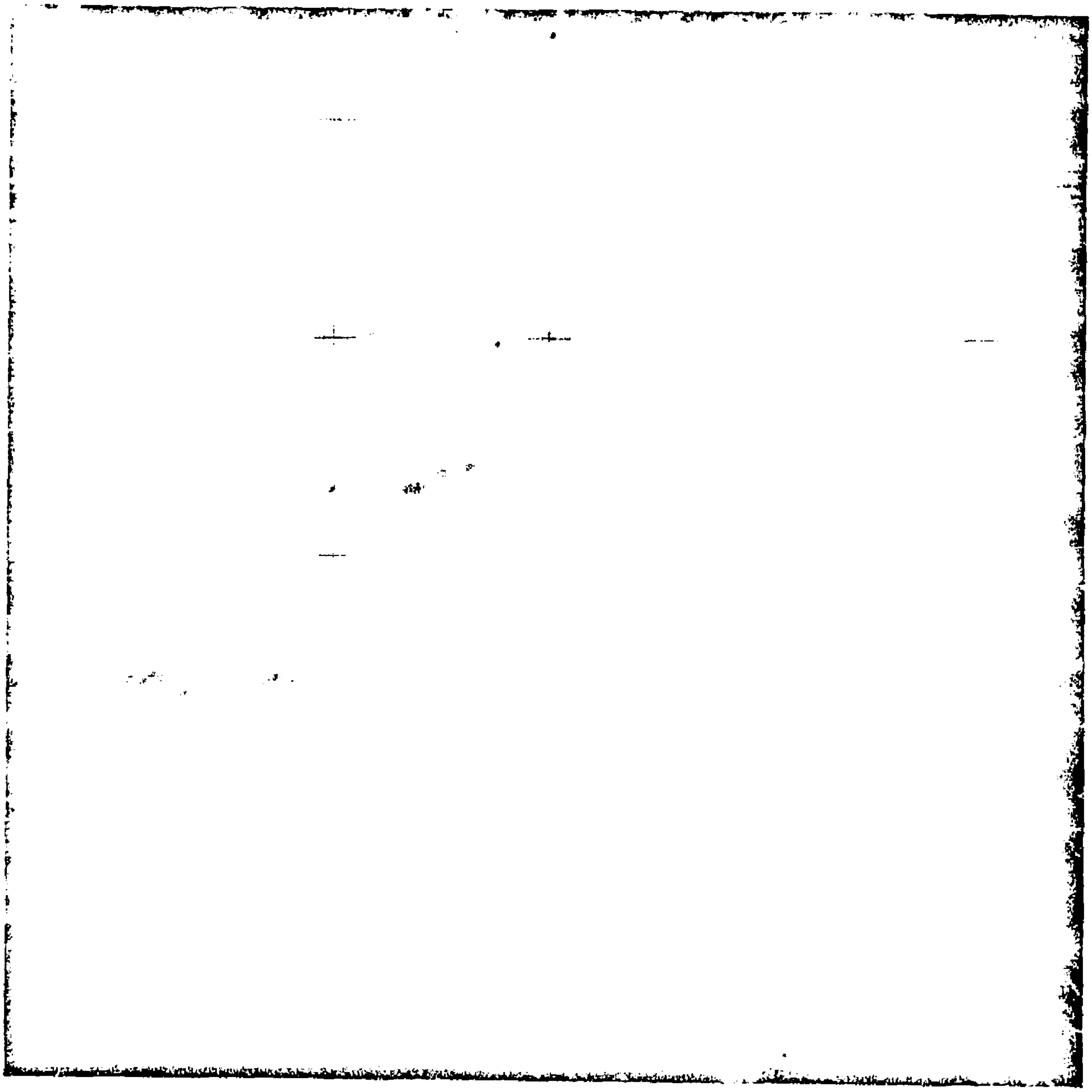


Figure 14-7.- Dust cloud over the Arabian Sea on January 20, 1974 (SL4-141-4280).

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

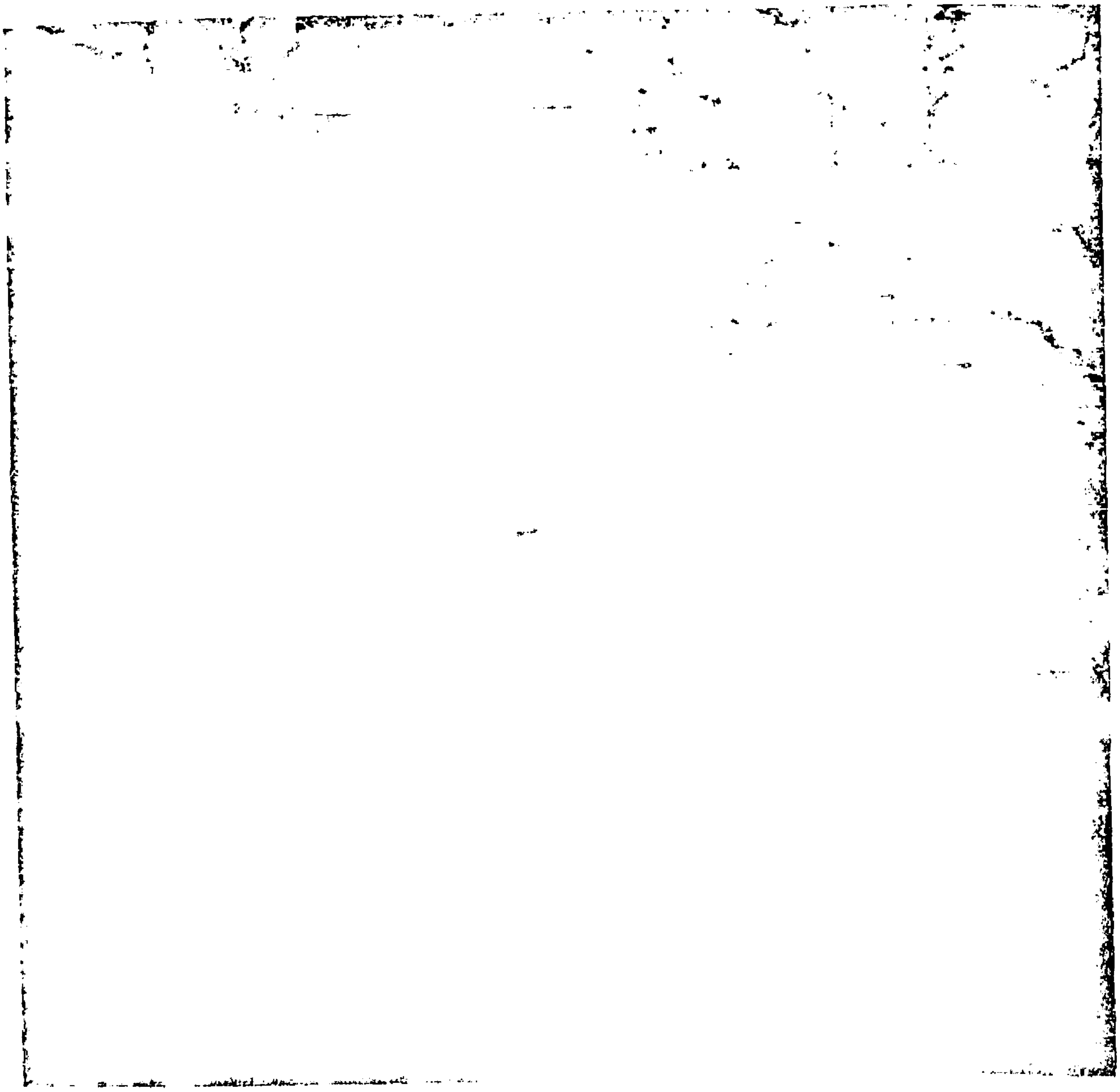


Figure 14-8.- Snow plume near St. Joseph, Missouri, on January 23, 1974
(SL4-142-4467).

determining the geographic location of the imagery, in obtaining a firsthand assessment of the possible dynamic and kinematic processes involved in smoke-plume formation, and in developing an observations program for future missions.

REFERENCES

14-1. Randerson, D.: A Study of Air Pollution Sources Viewed by Earth Satellites. J. Air Poll. Control Assoc., vol. 18, 1968, pp. 249-253.

14-2. Randerson, Darryl; Garcia, Joe G.; and Whitehead, Victor S.: Photogrammetric and Photometric Investigation of a Smoke Plume View From Space. J. Appl. Meteor., vol. 10, Dec. 1971, pp. 1122-1131.

14-3. Lyons, Walter A.; and Pease, Steven R.: Detection of Particulate Air Pollution Plumes From Major Point Sources Using ERTS-1 Imagery. Bull. Am. Meteorol. Soc., vol. 54, no. 11, Nov. 1973, pp. 1163-1170.

14-4. Gifford, F. A.: Smoke Plumes as Quantitative Air Pollution Indices. Inter. J. Air Poll., vol. 2, 1959, pp. 42-50.

14-5. Gifford, F. A.: An Outline of Theories of Diffusion in the Lower Layer of the Atmosphere. Meteorology and Atomic Energy, Government Printing Office, 1968, pp. 65-116.

14-6. Conover, John H.: Anomalous Cloud Lines. J. Atmospheric Sci., vol. 23, no. 6, Nov. 1966, pp. 778-785.

14-7. Conover, John H.: New Observations of Anomalous Cloud Lines. J. Atmospheric Sci., vol. 26, no. 5, Part II, Sept. 1969, pp. 1153-1154.

14-8. Parmenter, Frances C.: Picture of the Month - Ship Trails or Anomalous Cloud Lines. Monthly Weather Rev., vol. 100, no. 8, Aug. 1972, pp. 646-647.

14-9. Parmenter, Frances C.: Observing and Forecasting Local Effects From Satellite Data. Proceedings of the Fifth Conference on Weather Forecasting and Analysis, American Meteorological Society (Boston, Mass.), 1974, pp. 46-49.

15. SNOW-MAPPING EXPERIMENT

James C. Barnes[a†]

Snow has an enormous effect on the large-scale geophysical environment of the Earth. Seasonal changes in snow cover produce variations in the albedo of the land areas of the Earth that are unmatched by any other phenomena. The albedo variations have a significant influence on the radiation balance at the surface, which, in turn, influences both short-term and long-term weather conditions. Moreover, in regions such as the western United States, snow has a direct economic impact. In many parts of the West, much of the water used comes from accumulated mountain snowpacks. The snowmelt runoff is used for irrigation, industrial production, power generation, public consumption, and recreation. Too much runoff may have strong adverse effects, such as destructive flooding.

Despite the economic and scientific implications of snow cover, existing data collection methods often cannot provide either the desired areal coverage or the desired observational frequency. The capabilities of remote sensing from Earth-orbiting satellites offer promise for the development of a more cost-effective means for monitoring snow cover. The results of studies in which Earth Resources Technology Satellite (ERTS) and Skylab Earth resources experiment package (EREP) data were used have been encouraging. The extent of the mountain snowpacks can be mapped from ERTS data in more detail than is depicted in aerial survey snow charts; similarly, examination of the initial EREP data from the Skylab 2 mission indicates that it may be possible to obtain additional information on snow extent from the measurements made in the near-infrared, thermal-infrared, and microwave portions of the spectrum.

Although the results of the studies in which ERTS and EREP data were used have been encouraging, certain problems in mapping snow from space do exist. The particular problems include distinguishing between snow and cloud, which may have nearly identical reflectances; detecting snow in heavily forested areas; detecting snow in areas within mountain shadows; mapping irregular snowlines in areas where uneven melting has occurred; and measuring snow depths. These problems are particularly critical when data are mechanically processed and objective analysis techniques are required. The direct participation of the Skylab 4 crewmen in the snow-mapping experiment as part of the overall Visual Observations Project has provided information that will be valuable for developing improved methods for mapping snow cover.

---

[a] Environmental Research and Technology, Inc., Lexington, Massachusetts.

[†] Principal Investigator.

DATA SAMPLE

As part of the Skylab 4 Visual Observations Project, more than 200 handheld camera photographs of snow cover were taken by the crewmen. The data sample comprises approximately 150 70-millimeter Hasselblad photographs and at least 25 to 30 35-millimeter Nikon photographs over the United States and Canada. The size of the 35-millimeter data sample is only an estimate based on the mission photography log, because those photographs have not yet been made available to the investigators. The remaining photographs show snow in other parts of the world, primarily in Europe (the Alps) and in Asia (the Himalayas). Because of lighting conditions, almost all the data sample over the United States was taken during January.

The 70-millimeter photographs, all of which have been reviewed, cover most parts of the United States where snow existed during the mission. Some of the specific areas covered are the Sierra Nevada Mountains of California, the Salt-Verde watershed in central Arizona, the Rocky Mountains in Colorado, the Great Salt Lake and Yellowstone Park areas in Utah and Wyoming, the Black Hills area in South Dakota, and the Great Lakes area. Thus, the sample of handheld camera photographs includes snow cover in both mountainous and relatively flat terrain; in fact, during January, snow cover was observed by the crewmen in the central plains as far south as Oklahoma. The crewmembers were able to obtain repetitive observations of several key areas.

Both vertical-looking and oblique 70-millimeter photographs were taken by the crewmen. According to the log, several 35-millimeter vertical-looking photographs were taken with the 300-millimeter lens. It is anticipated that some photographs in both the 70- and 35-millimeter samples will be useful as stereopairs. The overall quality of the 70-millimeter photographs appears to be excellent. Even over broad snowfields, where the albedo is very high, nearly all the photographs are exposed correctly. Almost all the photographs are sufficiently cloud free to enable snow to be positively identified. The existence of the cloud-free photographs is firm evidence that the crewmen were indeed able to distinquish visually, in most circumstances, between snow and clouds.

RESULTS OF INITIAL EXAMINATION OF 70-MILLIMETER PHOTOGRAPHS

Identification of Snow Cover

The excellent quality of the 70-millimeter photographs is illustrated in figure 15-1, which is centered in the Yellowstone Park area of northwest Wyoming. With the exception of a small area in the upper part of the photograph, the field of view is essentially cloud free; the clouds can be readily distinguished from the snow-covered terrain primarily because of their fuzzier appearance and the shadow they cast on the underlying surface.

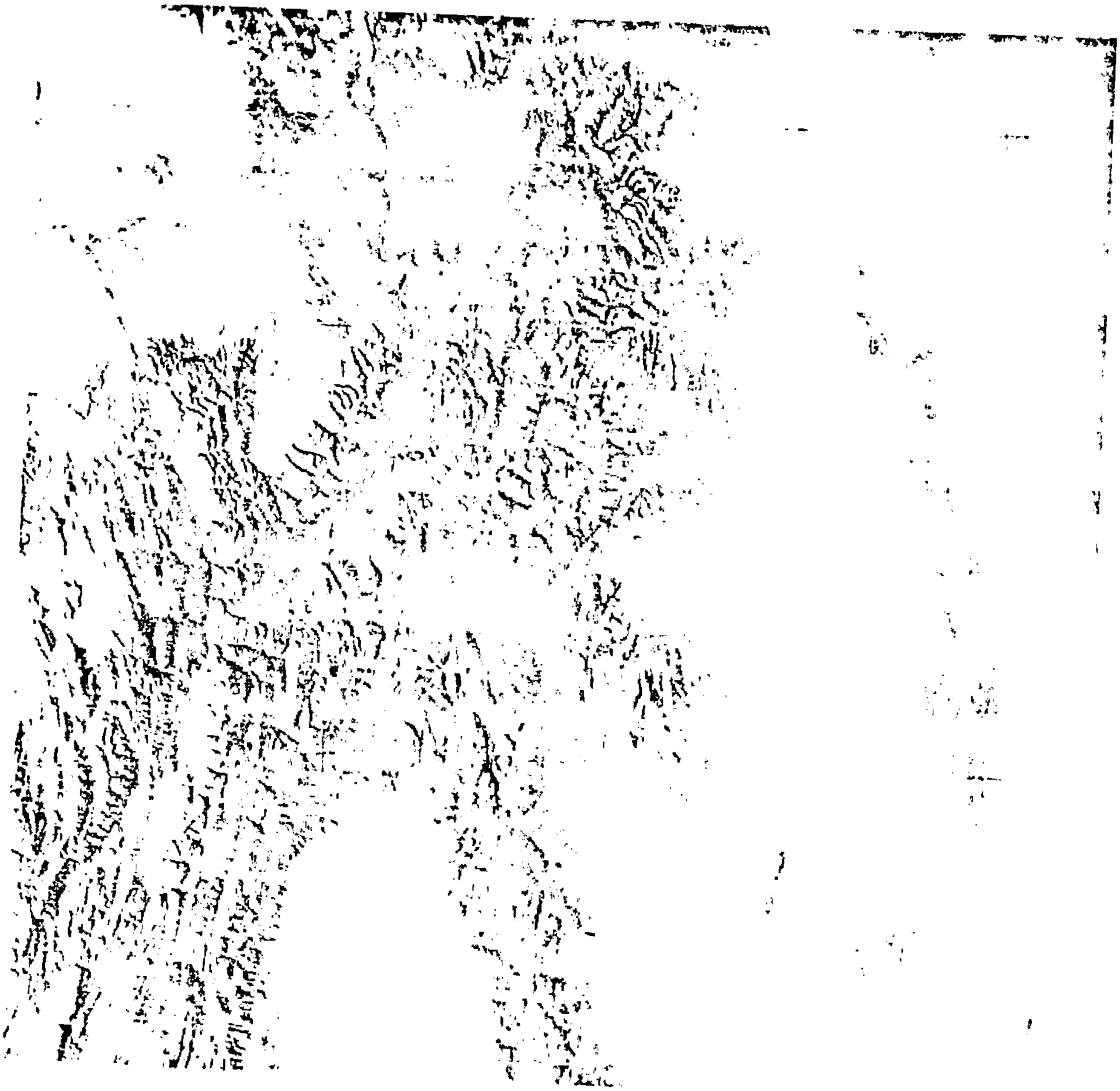


Figure 15-1.- The Yellowstone Park area in northwestern Wyoming (SL4-138-3846).

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

The various mountain ranges, including the Grand Tetons, Wind River Range, Absaroka Range, and Big Horn Mountains, are distinct although the lower elevation terrain is also snow covered. In photographs taken by the Skylab 2 and 3 crewmen in the late spring and summer, the mountain ranges such as these are snow covered, whereas the surrounding land is snow free. In the midwinter observation (fig. 15-1), the combination of snow and low Sun angle enhances the geological structure of the mountains and aids in identification of topographic features such as the individual mountain chains.

The darker area in the upper center portion of the photograph is forest cover. This pattern corresponds closely with the pattern of the heavily forested area indicated on land usage charts. Yellowstone National Park lies wholly within this area; Yellowstone Lake, frozen and snow covered, can easily be seen. Within Yellowstone Park, the geothermal activity may have caused some snow-free terrain; however, it is difficult to distinguish the geothermal areas from the areas that are snow covered but heavily forested.

Dynamic Change in Snow Cover

Photographs of the Great Salt Lake area are shown in figures 15-2 and 15-3. The photograph in figure 15-2 was taken on January 8, 1974, and the one in figure 15-3 was taken on January 16, 1974. A dynamic change in the snow cover is evident over the 8-day interval.

The clouds to the north of Great Salt Lake are readily distinguishable in figure 15-2. The possibility of snow in an area west of Great Salt Lake was eliminated because of the low reflectance and brown tone. Cultural patterns, such as intersecting dark roads against the snow, in Salt Lake City and the other cities are easily detected.

In figure 15-3, the snow-free area west of the lake has greatly extended. Salt Lake City and the other cities also appear much darker in tone, which indicates snowmelt. Snow-cover charts show a reported depth at Salt Lake City of 25 centimeters on January 8; on January 16, the reported depth is only 8 centimeters.

The snowmelt patterns were observed visually by the crewmembers. In the photography log for January 8, they reported, "Comparison for snowmelt from previous day's pictures; snow is starting to melt." Thus, the snowmelt, which had apparently begun even earlier than the January 8 observation, could be monitored as it progressed.

Observations of Unusual Snow-Cover Patterns

An east-looking oblique photograph of the Missouri River Basin is shown in figure 15-4. The distinct kidney-shaped pattern is the lower portion of the photograph is the heavily forested Black Hills area. Just beyond the Black Hills, in central South Dakota, is another area of low reflectance; the Missouri River, partly ice covered, crosses the darker area. A sharp cloud

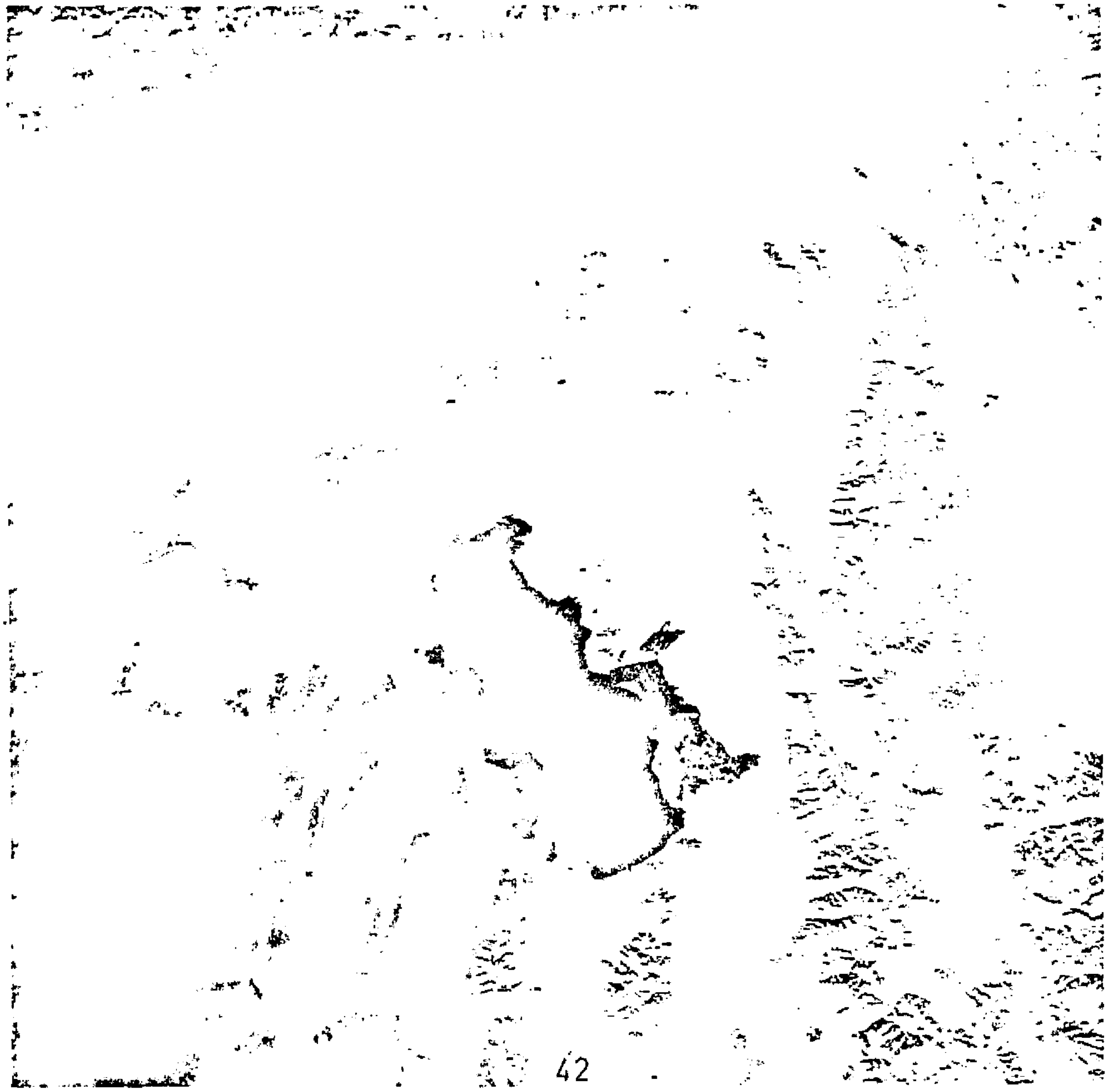


Figure 15-2.- Great Salt Lake, Utah, on January 8, 1974 (SL4-139-3992).

Figure 15-3.- Great Salt Lake, Utah, on January 16, 1974 (SL4-140-4167).

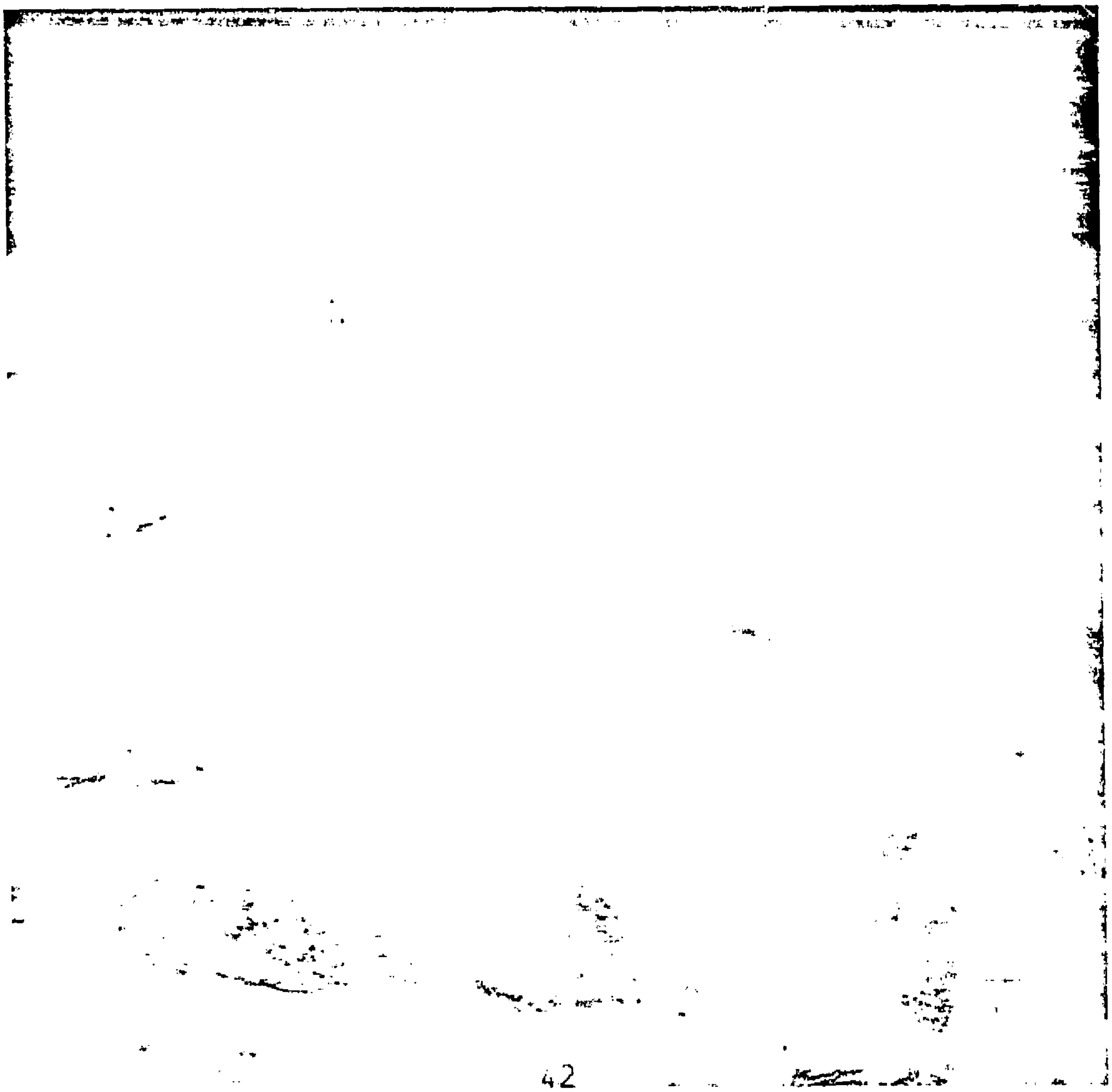


Figure 15-4.- Missouri River Basin and the Black Hills, South Dakota (SL4-139-3994).

edge with an accompanying shadow extends in a general east-west direction just south of the dark area; because of the well-defined edge, this cloud is probably associated with the jet stream.

The central part of South Dakota is not forested, so the dark pattern must be associated with an area of little or no snow cover. Snow charts on January 8, 1974, the date of the observation, show substantial snow amounts throughout the Northern Plains (as much as 20 centimeters in eastern South Dakota, 23 centimeters in North Dakota, and 40 centimeters in Nebraska). In contrast, only two stations in the central and western part of South Dakota reported any snow cover, and these stations reported depths of only a trace and 2.5 centimeters, respectively.

No snow was reported in that part of South Dakota for several days before the date of the Skylab observation. Therefore, that area originally may not have had as much snow as the surrounding areas. The crewmen reported that the snow-free area continued to expand as the snowmelt continued. Other rather unusual snow-cover patterns were also observed by the crewmen; some of these patterns appear to be associated with narrow snowfall bands, such as might occur in a snow squall situation, rather than with snowmelt.

PLANNED ANALYSES

Both the 70- and 35-millimeter photographs will be analyzed in detail, with particular attention being given to the geographic areas for which repeated coverage was obtained. The southern Sierra Nevada Mountains in California and the Salt-Verde watershed in central Arizona are two areas in which snow hydrology is of great importance. These areas were designated as prime test sites in the experiment. The handheld camera photographs from the earlier Skylab missions will also be analyzed in conjunction with the Skylab 4 photographs; although the data samples from the Skylab 2 and 3 missions are considerably smaller, it will be possible to compare the late spring and summer snow patterns with the winter patterns for some of the high mountain areas.

In the analysis procedure, the snow extent will be mapped from the photographs and will be correlated with snow-cover data. In addition, the handheld camera photographs will be compared with the EREP data and possibly with other satellite data, such as from ERTS. The dynamic changes in snow cover will be carefully mapped, and the difficulties related to identifying snow in heavily forested areas and in shadow areas will be investigated. These problems are illustrated in the photographs given as examples.

PRELIMINARY CONCLUSIONS AND RECOMMENDATIONS

The initial examination of the 70-millimeter photographs collected in the Skylab 4 Visual Observations Project has indicated a substantial amount of useful snow-mapping information. The sample of the 70-millimeter photographs alone is extensive and provides coverage of most of the snow-covered areas of the United States; it is anticipated that with the addition of the 35-millimeter data sample, numerous repetitive photographs of certain test sites will be available. The Skylab 4 crewmen collected data over the United States during a fortunate period for snow-mapping studies because of a general snowmelt trend in the central and western part of the country following the widespread snowfalls in late December and very early January. Thus, it was possible for the crewmen to observe dynamic changes in snow cover as the month of January progressed.

The visual observations of the crewmen as well as the handheld camera photographs will provide valuable information for developing improved techniques to map snow from orbital altitudes. A preliminary assessment of the accomplishments of the crewmen follows.

1. Changing snow-cover patterns were recognized, and repeated photographs of specific areas in which snowmelt was occurring were obtained.

2. Visual observations were made of the progression of the snowmelt and, in particular, of the relationships between snowmelt and cultural features. It appears, for example, that the influence of cities on the albedo of snow and on the rate of snowmelt may be even greater than had been expected.

3. A data sample was obtained that comprised various modes of photography including vertical viewing, oblique viewing, narrow angle (300 millimeter) lens, Sun angle variations, and stereopairs. This data sample will enable the problems inherent in mapping snow from orbital altitudes to be investigated more thoroughly than has heretofore been possible. For example, the crewmen reported that the influence of forest cover on identifying snow appeared to be considerably more severe when viewing an area obliquely; they also reported that low Sun angles facilitate the task of distinguishing snow from clouds but cause a more severe mountain shadow problem.

4. Visual observations that will be useful in the analysis of the photographic data were made. The observations provided by the crewmen include the relationships in color tone between snow and snow-free terrain, which at times were different from those depicted in the photographs, and an assessment of the types of clouds that are the most difficult to distinguish from the underlying snow.

Although the planned Apollo-Soyuz Test Project (ASTP) mission will occur in midsummer, it will be worthwhile to obtain photographs of the snow cover remaining in the high mountain areas of the United States. The photographs taken by the ASTP crewmen can then be compared with those taken on the Skylab missions during the summer and the winter.

A comparison between two different summer seasons will indicate whether year-to-year variations exist in the midsummer snowpack. For example, the Skylab 2 and 3 photographs of the mountains in the Pacific Northwest were taken following a winter of exceptionally low snowfall amounts; it will be interesting, therefore, to compare those photographs with photographs of the same area taken during the ASTP mission, presumably following a winter of more normal, or perhaps above normal, snowfall amounts. Because an objective of the experiment will be to compare in detail the extent of the summer snowpacks, it is recommended that 300-millimeter, vertical-looking photographs be taken.

16. PRELIMINARY ASSESSMENT OF HANDHELD PHOTOGRAPHIC OBSERVATIONS OF TROPICAL STORMS FROM SPACE

Peter G. Black[a]

Handheld photographs of tropical storms from the three manned Skylab missions have recently been reviewed. None of these photographs have been studied in detail to date. Nevertheless, several interesting features have emerged and will be briefly described in this preliminary report.

This report will, of necessity, be limited to suggestions and recommendations for improving the quantity and quality of handheld camera photographs on future manned space flights as well as for improving the logistics involved in defining the target area, which for tropical storms is intermittent and always moving.

METEOROLOGICAL SIGNIFICANCE OF HANDHELD CAMERA PHOTOGRAPHS OF TROPICAL STORMS

The handheld camera photographs from the Skylab missions appear to confirm several tentative observations made recently from satellites and aircraft. These observations are illustrated in figures 16-1 to 16-4. A photograph of the formative stages of tropical storm Ellen in the North Atlantic, taken on September 19, 1973, is shown in figure 16-1. This photograph illustrates the presence of vigorous updrafts by the overshooting cloud tops over a large area as well as a series of concentric wave clouds centered on the largest overshooting top. At this time, the location of the center of circulation is uncertain, but the presence of these overshooting tops appears to precede and then accompany storm development. Other photographs appear to confirm the widespread existence of overshooting cloud tops in young storms. However, as the storm matures, the overshooting tops appear to become less distinct. This condition seems to be substantiated by aircraft observations in which much more intense updrafts have been encountered in developing storms than in mature storms.

The Skylab photographs also show that the amount of overshoot appears to decrease as the storm intensifies. Perhaps the available energy goes more

---

[a] National Oceanic and Atmospheric Administration, National Hurricane Research Laboratory, Miami, Florida.

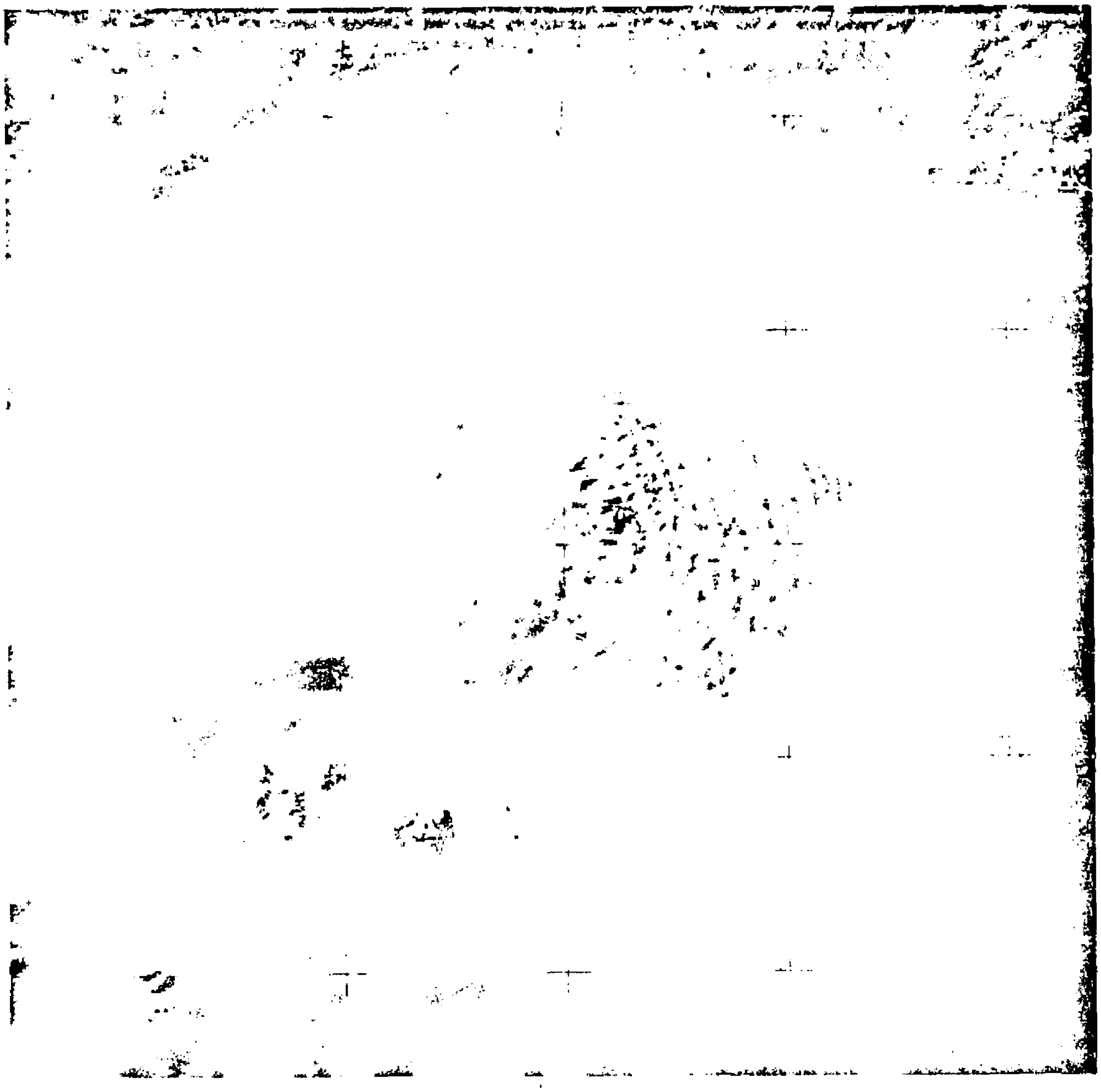


Figure 16-1.- Tropical storm Ellen forming in the North Atlantic on September 19, 1973, at 20:18 Greenwich mean time (G.m.t.). Maximum winds at this time were approximately 18 m/sec (SL3-122-2572).

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

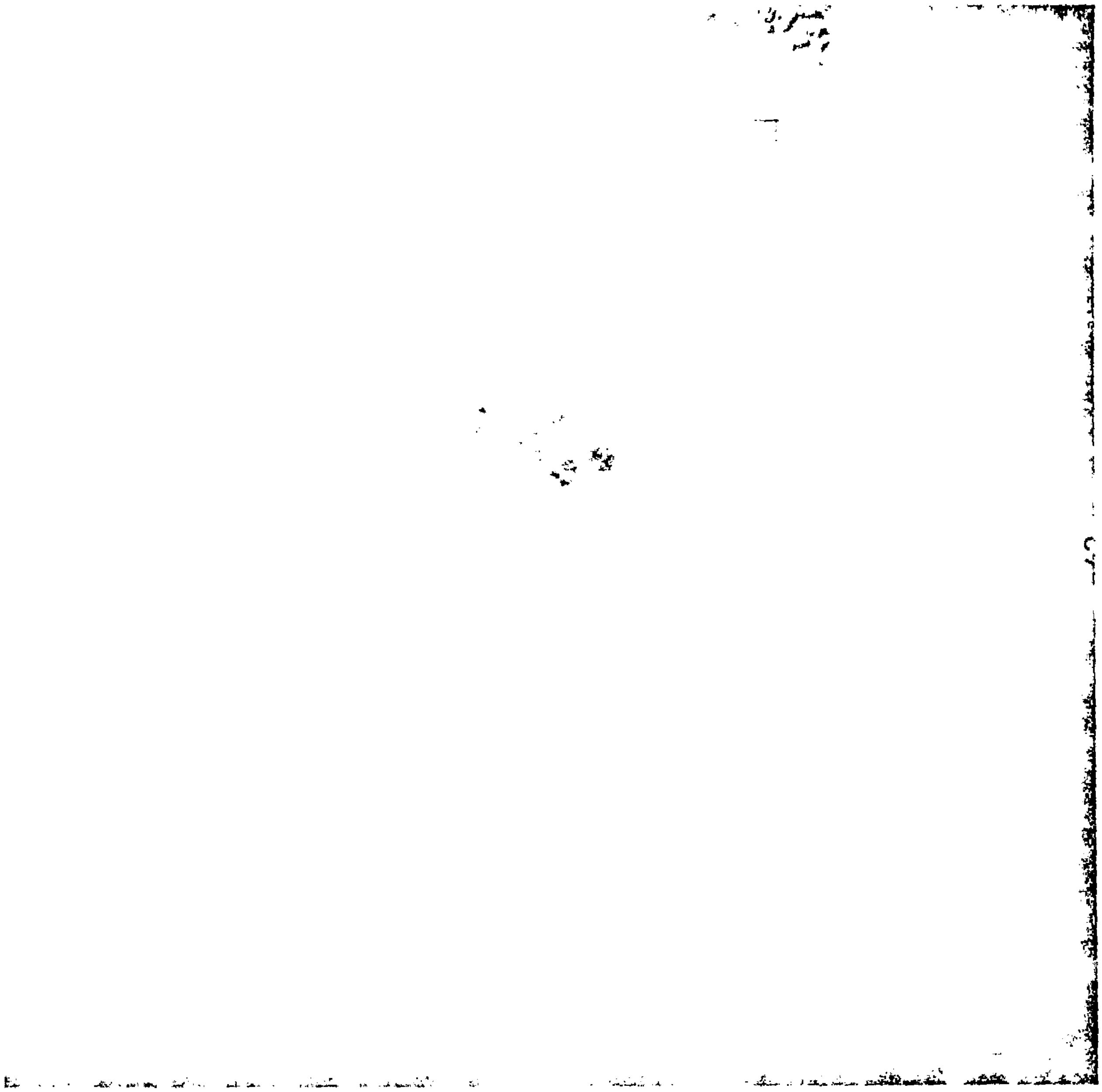


Figure 16-2.- Hurricane Ellen from directly above, approximately 1100 kilometers east of Bermuda on September 21, 1973, at 18:50 G.m.t. Maximum winds at this time were approximately 61 m/sec. Sun illumination emanates from the upper left (SL3-122-2602).

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

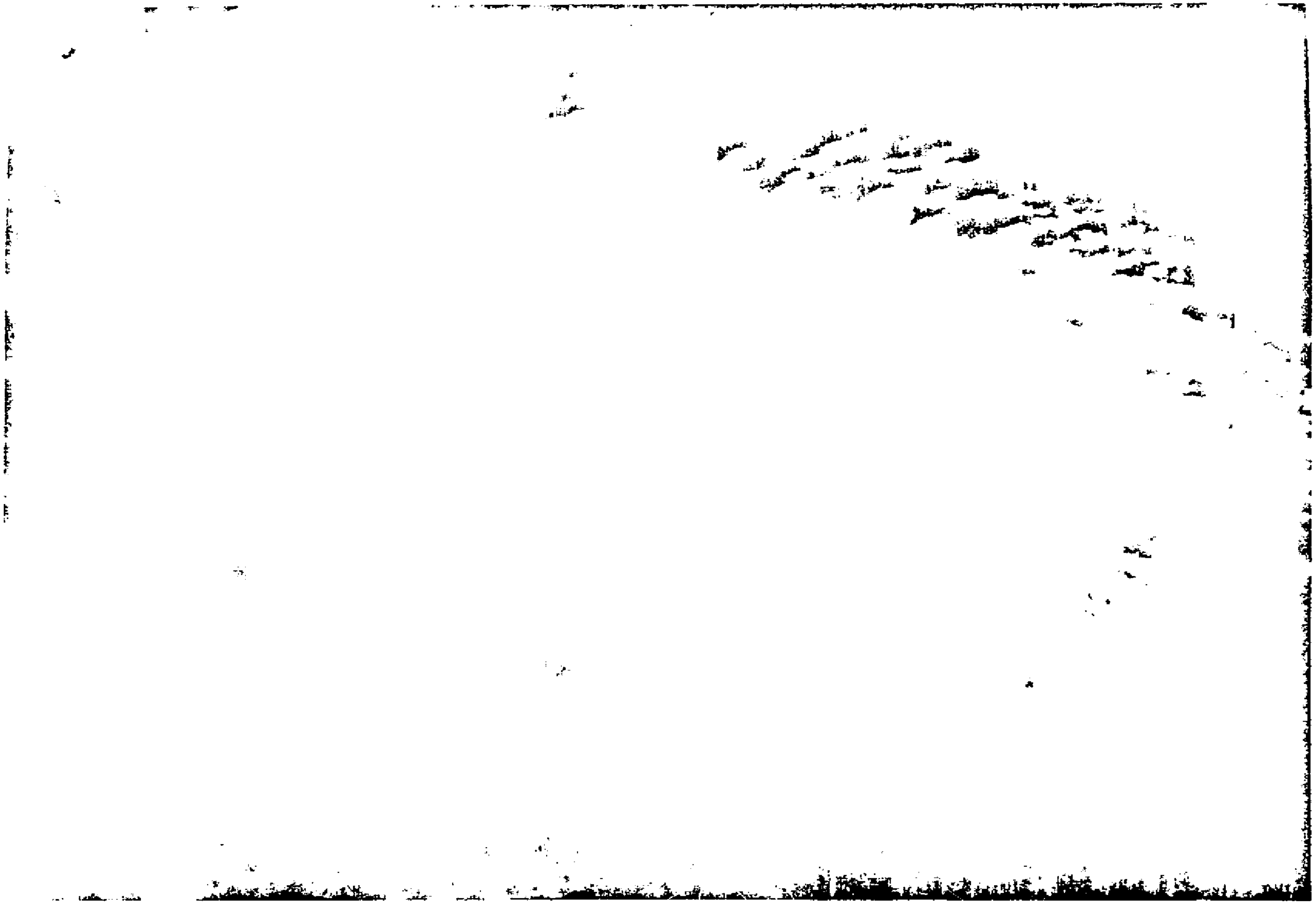


Figure 16-3.- Oblique view of hurricane Ellen on September 23, 1973
(SL3-118-2189).

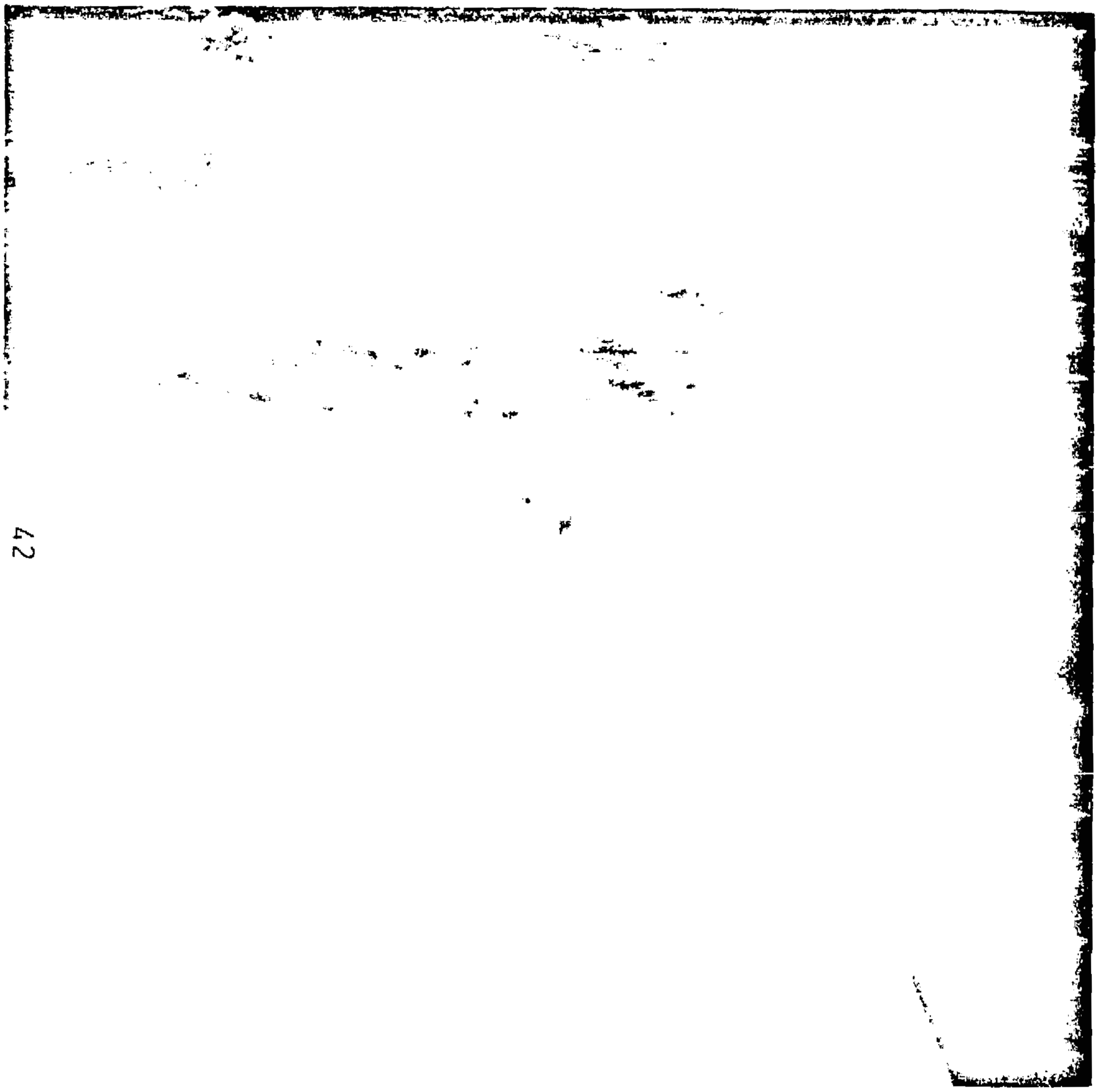


Figure 16-4.- Hurricane Lottie over Nandi, Fiji, on December 8, 1973, at 23:40 G.m.t. Maximum winds at this time were approximately 36 m/sec (SL4-136-3514).

into horizontal motions as the storm vortex develops than into vigorous vertical motions.

The significance of the wave clouds noted previously in figure 16-1 is unknown at this time. However, the fact that they exist means that they must play a significant role in the energy balance of a developing storm. Internal waves such as these are usually ignored and would probably act as an energy sink in the outflow layer.

The most significant feature of tropical storms revealed by Skylab photographs is the apparent existence of an outward tilt of the wall cloud with height. In figures 16-2 to 16-4, the diameter of the eye of a tropical storm appears to be much larger at the top of the storm than at the bottom. A photograph taken directly above hurricane Ellen on September 21, 1973, is shown in figure 16-2. An oblique view of the storm taken 2 days later is shown in figure 16-3; this view more graphically illustrates the sloping eyewall. A photograph of tropical storm Lottie in the South Pacific on December 8, 1973, is shown in figure 16-4.

Radar observations of the vertical cloud structure from an aircraft flying in hurricane Ellen at the time figure 16-2 was taken show that the eyewall was tilted outward at approximately 45° above an altitude of approximately 4600 meters. This type of observation has been noted before but has nearly always been attributed to radar peculiarities. Figures 16-2 to 16-4 may verify that the past radar observations were correct.

The existence of an eyewall that tilts outward with height is significant because this means that the updraft in the wall could tilt outward with height. This tilting, in turn, means that precipitation, which forms in the updraft in the middle level of the cloud, will fall next to the updraft, not through it. Hence, the associated downdraft will not kill the updraft but instead may establish a vertical circulation that would help sustain the life cycle of the updraft for a much longer period of time than if the updraft were vertical.

One fact that supports this concept is that the life cycle of active convective precipitation echoes observed by radar increased dramatically in hurricane eyewall regions as opposed to outer rainband regions. Echoes in the latter regions have lifetimes of approximately 10 minutes, whereas those in the former region are approximately 45 minutes.

An additional significant feature of the tilting eyewall and associated updraft is that the vertical mass flow would have a component in the radial direction that would affect the overall mass flow budget of the storm. Therefore, variations in vertical velocity would result in variations in the radial component of horizontal velocity. If the existence of the tilting eyewall can be substantiated, it would greatly improve the present knowledge of the role that convective elements play in the dynamics of the hurricane eyewall.

Many more observations of hurricane eyewall slopes from space would therefore be desirable to confirm whether or not this is a general feature of all hurricanes and typhoons, whether or not the slope varies with the quadrant of the storm, and whether or not the magnitude of slope is related to the life cycle of the storm.

SUGGESTIONS FOR IMPROVING TROPICAL STORM PHOTOGRAPHIC QUALITY AND DOCUMENTATION

One of the major problems in photographing clouds is the lack of contrast. There are several photographic techniques that can be used to enhance the little contrast that exists. The simplest and easiest method is to underexpose the photograph. In the case of bright tropical storm tops, this underexposure must be at least two f-stops less than the normal cloud exposure settings.

The exposure depends on Sun angle; however, judging from the f/8-at-1/250 and f/11-at-1/250 exposures used for most tropical storm photographs, better settings might be f/11 at 1/500 or f/16 at 1/500 with the color-exterior film. The 1/500 shutter speed is suggested because there appears to be some loss in cloud definition due to spacecraft motion.

A film with greater exposure latitude is highly recommended because this type film would not wash out if the observation site were overexposed by two f-stops. In the case of cloud photography, such a film might be a black-and-white negative or color negative film. If this type of film were used, a slight overexposure would be better than a slight underexposure because the clouds would be black instead of white.

Black-and-white negative film would be the best for clouds because a further increase in contrast can be obtained by use of a red filter on the camera. Haze and polarizing filters probably should also be used to increase contrast further.

The use of infrared film is not recommended because of its narrow exposure latitude. If clouds are overexposed by one-half of an f-stop when photographed with infrared film, they will be washed out.

One of the biggest problems in working with the handheld photographs was determining the date, time, and location of exposure. This difficulty would be eliminated if one of the newer cameras were used that is equipped with a clock and prism arrangement so that the correct day and time appears in a corner of the photograph in a format similar to the Earth terrain camera experiment (S190B) frames. The loss of a small corner of the frame would be more than offset by the advantage of knowing the precise time. (The photograph time logged by the Skylab crewmen was off by several minutes in some cases, which caused considerable uncertainty in photograph location. However, having an approximate time logged for each photograph was a quantum improvement over having no log.) The photograph times could then be tabulated and precise subpoint track locations could be computed for all the handheld photographs. The clock should be accurate to the nearest second; time checks should be made periodically.

A selection of cameras should be available so that one or two wide-angle photographs of the site could be taken. Perhaps one wide-angle exposure could be taken both approaching and receding from the site. A series of standard or telephotographic shots could then be taken. In this way, the narrow field of view could be placed in perspective with respect to the wider field of view. In the case of tropical storms, the wide-angle photographs could be placed in perspective with respect to the large-scale, limited-resolution view available from meteorological satellites.

The quality of 70-millimeter photographs seems superior to that of 35-millimeter photographs. Therefore, it would be advisable that three 70-millimeter single-lens reflex cameras, each equipped with clock data chambers, be carried on the next manned mission. One camera should have a wide-angle lens, another a standard lens (e.g., a 90-millimeter lens), and another a telephotographic lens (e.g., a 200-millimeter lens).

The usefulness of stereopair photographs exceeds that of a single photograph because quantitative calculations of cloud height can be made from them. Because overshooting tops are of such special significance in tropical storms, it is recommended that stereopair photographs be taken at every opportunity so that a relationship between storm intensity and the height of overshooting cloud tops might be established.

SUGGESTIONS FOR IMPROVING DATA ACQUISITION AND ANALYSIS

The two areas in which the need for improved data acquisition and analysis were identified as a result of the Skylab 4 Visual Observations Project are (1) scheduling of crew activities to ensure optimum photographic coverage of tropical storms, and (2) eliminating delays in obtaining the photographic data for analysis and integration with the crew transcripts.

Crew scheduling must have the flexibility to incorporate the tropical storm identification information obtained from the National Environmental Satellite Service (NESS) through the Space Flight Meteorology Group at the NASA Lyndon B. Johnson Space Center into the daily flight plan of the crewmen. The NESS locates and identifies tropical storms throughout the world twice a day within 3 hours of receiving satellite images. Continuation of the direct communication link with NESS during the next manned flight is required to increase the data-gathering opportunities.

Major problems in planning the study of tropical storms from space involved long site-planning time and inflexible crew schedules. Because the greatest potential payoff from handheld photographs is the large amount of scientific data return realized by only a very small amount of effort, it should be possible to schedule handheld photography with less than 12 hours notice to the planning personnel on the ground. Likewise, it should be possible to allow sufficient time in the flight plan to acquire the necessary stereopair photographs. For the next manned space flight, a flexible system should be set up for studying variable and moving observation sites such as tropical storms.

The delay in availability of photographic data on the ground slows data analysis and incorporation of the results in ongoing tropical storm research. In the case of tropical storms, scientists should be able to review the film, reproduce it for use locally, and request high-quality second-generation copies of specific frames to preserve maximum contrast. The capability for accomplishing these requirements should be available before public release dates, if necessary. Regulations regarding the data should not be self-defeating but, instead, should be flexible.

CREW TRAINING

The 1-hour lecture given to the Skylab 4 crewmembers preflight was a progressive step toward acquainting them with the features of tropical storms to be observed. However, one lecture proved inadequate for transforming them into trained observers. Therefore, it is recommended that a workshop on tropical storms be made part of the training schedule for the next manned flight. No two tropical storms look alike; however, a crewman can be trained to notice common features. The workshop would span approximately 2-1/2 working days. Old tropical storm photographs obtained from manned and unmanned satellites would be used to identify significant features; to determine storm intensity; and to estimate whether or not the storm is weakening, strengthening, or remaining in a steady state.

The NOAA technical memorandum NESS-45, "A Technique for the Analysis and Forecasting of Tropical Cyclone Intensities From Satellite Pictures," dated February 1973, is an excellent report to be used as a textbook or guide for the workshop. During the workshop, ideas from the referenced memorandum and proven interpretation techniques would be presented in a manner specifically oriented toward taking handheld photographs from manned spacecraft. A trained tropical storm observer would be the product of such a workshop. Of course, preflight practice would be necessary. With the advent of the Space Shuttle Program, a meteorologist could be used as an observer, thus eliminating the need for a training workshop.

USEFULNESS OF VOICE TRANSCRIPTS

The transcripts of voice communications with the crewmen served to relate the date and time of photographs to the frame numbers. The Principal Investigators used the transcripts to learn what features were being observed in real time. This was extremely useful because adjustments could be made in the emphasis of the types of photographs being taken while the crewmen were still in space. For example, when it became evident that [illegible] stereopair photographs of tropical storms had been taken, the crewmen were instructed to emphasize this type of data. The result was a succession of stereopair photographs of tropical storm Pam near the end of the mission.

The transcripts, however, must be supported by photographs. The meteorologist must always have documentation of the existence of a phenomenon in the form of a photograph, a measurement, or other tangible data. Stereopair photographs are requested so that measurements can be made. A trained meteorologist viewing a photograph will interpret it far differently than will a nonmeteorologist. The trained person also may interpret the photograph differently after he integrates the photographic information with other sources of information.

COMMENTS ON METEOROLOGICAL OBSERVATIONS FROM MANNED SPACECRAFT

The question will inevitably be asked, are manned observations of meteorological sites, such as tropical storms, likely to yield a greater scientific return than unmanned observations? Or, restated, what can a man in Earth orbit tell about tropical storms that would not be evident to an Earth-controlled robot in orbit? To answer this question, the advantages must be weighed against the disadvantages; a preliminary evaluation follows.

After July 1974, meteorologists will have available a geostationary satellite viewing the Earth with an approximate 800-meter resolution in the visible and a 6-kilometer resolution in the infrared. A new system of high-density packing will allow these data to be recorded on magnetic tape for the entire Earth disk as seen from an altitude of 35 400 kilometers. A second such satellite will be available in September 1974, and a third, a Japanese satellite, in October 1976. Therefore, the North and South Pacific and Atlantic areas will be covered by 1976.

Sometime after 1980, a geostationary satellite will be available with a 200-meter resolution in the visible and a 3-kilometer resolution in the infrared over certain selected areas, which will be restricted to the United States, Central America, and South America.

From the viewpoint of the meteorologist, these satellites are an arsenal against which man will be compared in the next 5 to 10 years. The question then is, can man improve or complement data on tropical storms that these sensors will provide?

The advantage of a human observer over the unmanned satellite is that the observer can scan any area of the world for storms and photograph offtrack or ontrack sites. The satellite sensors will be limited only to certain areas of the world, especially for the next 2 years.

Man in Earth orbit can acquire stereopair photographs, whereas this is impossible in the geosynchronous altitudes. However, time histories of less than 1 day can be obtained from geosynchronous altitudes, whereas they cannot be obtained from orbiting manned spacecraft.

Observations of small-resolution features, less than 800 meters, can be accomplished by man and can complement unmanned satellite data. Such observations are difficult to rectify and locate; this problem can be solved with improved documentation.

CONCLUSIONS AND RECOMMENDATIONS

Potentially significant scientific results from the Skylab handheld photographs of tropical storms include the documentation of an outward tilting wall cloud, of internal waves surrounding overshooting clouds in developing storms, and of overshoot by hurricane clouds that is small but extensive in area for young storms.

Recommendations concerning future handheld photography of tropical storms from space are as follows.

1. Black-and-white negative film would be best for tropical storm photography.

2. Contrast could be further improved by use of red, haze, and polarizing filters.

3. Cameras with clock data chambers should be used.

4. Locations for specifically timed photographs should be computed.

5. A wide-angle-lens, standard-lens, and telephotographic-lens camera combination should be available.

6. The use of 70-millimeter film is more desirable than use of 35-millimeter film.

7. Stereopair photographs should be taken whenever possible.

8. Direct liaison between the NASA and the NESS should be arranged for locating the tropical storms.

9. Crew schedules should be flexible enough to allow for last-minute scheduling of handheld photography.

10. A training workshop on tropical storm identification should be conducted before manned space flight.

17. PRELIMINARY REPORT ON VISUAL OBSERVATIONS OF THE OCEANS FROM SKYLAB 4

R. E. Stevenson,[a] L. D. Carter,[b] and S. P. Vonder Haar[b]

The descriptive visual observations and photographic documentation of the Skylab 4 crewmen have contributed more to the study of ocean dynamics than all other Earth-orbital manned space flights. In four cases, Earth-orbital manned space flight is the only technique available for confirmation of the oceanographic features; and in three cases, it is the only conceivable method of obtaining data at the present time. Furthermore, only one of the major features observed by the Skylab 4 crewmen can be examined from present unmanned satellites, and the image provided lacks the precise definition supplied by the crewmen.

The exact eventual impact of the Skylab 4 information on oceanography, forecasting, and marine-resource development obviously cannot be determined now; however, to say it will be substantial is clearly an understatement because the new information is [illegible] impressive. These new developments are discussed in the following paragraphs.

Research in hydrodynamics at the California Institute of Technology, funded by the Office of Naval Research, to establish the origin and growth of eddies from velocity shears in a jet is being reconsidered with a view toward modeling full-scale eddies as they form in western boundary currents. This reconsideration is in response to photographs from the Skylab 2, 3, and 4 missions and the confirmation by the Skylab 4 crewmen that cold-water eddies occur in boundary currents in the western North and South Atlantic and in the western South Pacific.

An international experiment will be conducted in the Coral Sea, east of Australia, in March 1975. The eddies reported by the Skylab 4 crewmen will be tracked, measured, and studied for their persistence and continuity as mesoscale ocean turbulence by scientists from the United States and from the Australian and New Zealand Navies.

The confirmation by the Skylab 4 crewmen of large-scale ocean turbulence, which in itself seems to confirm the theory of eddies formed in velocity shears, provides the rational base for positioning buoys in a planned deployment network that has been studied for 6 years. The plan, sponsored by the

---

[a] Office of Naval Research, Scripps Institute of Oceanography.

[b] University of Southern California.

Department of Defense and the National Science Foundation and coordinated by the National Oceanic and Atmospheric Administration (NOAA), was finalized in mid-March, after the debriefing of the Skylab 4 crewmembers, and the suggested initial deployment network will meet research requirements for measuring the turbulence described by the crewmen.

There has been no greater impact on oceanography since 1938, when oceanographic technicians of Woods Hole Oceanographic Institution perfected the mechanical bathythermograph for the Navy. Data from that instrument confirmed the existence of internal waves in the ocean and thereby revolutionized the concepts of energy and momentum transfer in the sea.

SKYLAB 4 CREW DEBRIEFING

A casual comment by the commander (CDR) evidenced the value of debriefings and of time to record impressions quickly during flight. In describing his "corduroy sea" (parallel ocean waves) and "double-knit sea" (two or three intersecting series of ocean waves), he mentioned how they seemed to spread across the ocean surface only to become "absorbed" at the boundaries of ocean currents. The concept of refraction, reflection, or confining of ocean waves by strong currents received no serious thought until the late 1960's, when oceanographers at the University of Rhode Island initiated a 5-year research effort. The study was inconclusive because of the lack of data. The aforementioned description by the CDR was brought to the attention of the oceanographer (now located at Scripps) who led the research, and the study will be reconsidered.

The ramifications of the CDR's observation, with respect to the forecasting of storm waves and surges, are not easily assessed, but the problem of "losing" or "gaining" unforecasted waves may just be the result of wave/current interaction.

Another comment regarding the position of the sediment front in the Rio de la Plata brought attention to a concept concerning circulation in estuaries - a concept that had been lost in the literature of the 1930's. The magnitude of saltwater intrusion into an estuary and the subsequent fate of the suspended sediments as the wedge moves back and forth has been described by inference but never measured. The relationship of riverflow to tidal forces is known for only a few, well-measured estuaries in the Northern Hemisphere. A more complete understanding of river/ocean interaction will be required to predict the volume of storm runoff through estuaries and to determine the dispersal of manmade constituents in estuaries and lagoons.

The statement by the pilot (PLT) that he never saw suspended sediments far from the coast was also a revelation. Although marine scientists have never measured large quantities of suspended sediment far from an open-ocean shore (i.e., at a distance of more than 50 kilometers), the actual number of samples collected and areas studied has been few; consequently, the observation by the PLT was a significant confirmation of what was assumed to be true.

In this respect, the observation by the CDR of the tremendous volume of suspended sediment in the Yellow and East China Seas was useful. That is the one marine area of the world where tremendously fast rates of deposition have occurred far from the source, the Yellow River.

From the standpoint of observing the ocean from space, the most valuable information from the debriefing pertained to the visual acuity of the crewman with respect to discerning color and discrete features. In both areas, the crewmen had far better perception than had been anticipated, and each crewman saw sea-surface features that the others did not notice or did not recognize as being different. The CDR saw "textile seas"; the science pilot (SPT) saw "long, discontinuous waves," which were actually windrows (Langmuir cells); and the PLT discriminated subtle color distinctions more than the others. Each crewman recognized the features that intrigued the others when the sea-surface texture or color was indicated during the debriefing. The desirability of onboard conferences among the crewmen and a real-time recording system was thereby accented.

Similarly, the acute recognition of ocean waves (the textile sea) contrasted with the rare viewing of internal waves, much larger than surface waves, seems to be a paradox. Internal waves are certainly not as universally visible at the surface as are wind waves and swells; yet from the few photographs of them (from all camera systems), the internal waves appear to be spectacular when they do occur. The most likely answer to this seeming paradox is that during the limited viewing minutes per day, surface manifestations of internal waves were not present in the observable sites. The comments by all the crewmen that they could see such waveforms along "long, straight boundaries" in the reflection of the Sun well out in the open ocean, however, confirm a long held but unproven concept that internal waves surface along the "beveled" surface of water-mass boundaries.

HIGHLIGHTS OF SELECTED OCEANOGRAPHIC VISUAL OBSERVATION EXPERIMENTS

In-flight references to oceanic features are listed in table 17-I. The highlights of several of the visual observations experiments are included in the following discussion.

Current Boundaries, HH30

The Skylab 4 crewmen were able to clearly distinguish current boundaries when plankton blooms were present, but in the absence of plankton, they could determine the presence of a current only by sunglint patterns or by sediment-dispersal patterns. The Falkland Current off the coast of Argentina was easily seen throughout the flight because of the vivid colors of plankton blooms; at one time, the current was described as resembling a surrealist painting. On one pass, a colored eddy that had spun off from the current and had occupied

TABLE 17-I.- IN-FLIGHT REFERENCES TO OCEANIC FEATURES

FROM THE VERBAL TRANSCRIPTS OF THE SKYLAB 4 CREWMEN

Feature mentioned	Total no. of times mentioned
River and coastal sediment entering ocean	29
Volcanic sediment entering ocean	6
Duststorm sediment entering ocean	5
Seamounts	4
Atolls and shoals	4
Island wakes	14
Eddies	37
Distinct wave patterns	15
Currents	93
Upwelling	15
Unexplained major turbulence	2
Subtotal	224
Additional coastal and ocean areas (mentioned by name but no details given) . . .	161
Total	385

Gulfo San Jorge was observed. The effects of such an occurrence on the biota of the gulf are unknown. The crewmen were able to see the confluence of the Falkland and Brazil Currents and observed that the zone of confluence migrates north and south several hundred kilometers. Because of color differences, the crewmen were able to determine that the water masses of the two currents do not mix at the confluence but travel side by side until they dissipate approximately 3000 kilometers to the southeast.

In contrast to the Falkland Current, the Humboldt Current (fig. 17-1) could be seen only in sunglint, where its presence is indicated by patterns of turbulence along the coast of Chile. Near Arica, where the South American coast juts to the northwest, a large eddy formed by deflection of the Humboldt Current was observed.

Cold-Water Eddies, HH33-A

The ability of the Skylab 4 crewmen to respond to verbal descriptions of ground features previously unknown to them was demonstrated perfectly in the case of cold-water eddies. These rotating systems in ocean currents were unknown before interpretation of the Skylab 2 photographs, which occurred after the Skylab 4 crewmen were in orbit. After the Visual Observations Project Team teleprinted up a description of the eddies, which was based on the Skylab 2 photographs, the three crewmen were quick to recognize the atmospheric effects of the eddies/clouds. This recognition enabled them to observe and photograph the turbulent areas in ocean regions where the ground team thought they would exist, as well as in ocean regions where the ground team considered their existence unlikely (fig. 17-2).

This sequence of events clearly indicates the tremendous value of the trained man in space and the desirability of close communication between the individual crewman and the ground team. It also points out the need for mutual trust between the crewman and the ground team.

Island Wakes and Vortices, HH34

The crewmen could see island wakes when atmospheric and lighting conditions were favorable. For example, in figure 17-3, current-generated turbulence at the lee of each island (Cape Verde Islands) is clearly visible. The dark area at the lee of Santo Antao Island is a region of upwelling, developed as surface water was moved away from the coast by the Canary Current and replaced by cold water from below. Such cold water brings nutrients to the surface, which then attract fish; thus, these areas are usually good fishing grounds. These features were visible to the crewmen, and their descriptions indicated that they were able to visually distinguish more details than could be discerned on the photograph. Other observations of island wakes were made at the Aleutian, Galapagos, and Canary Islands, at Antipodes Island, and at several other locations.

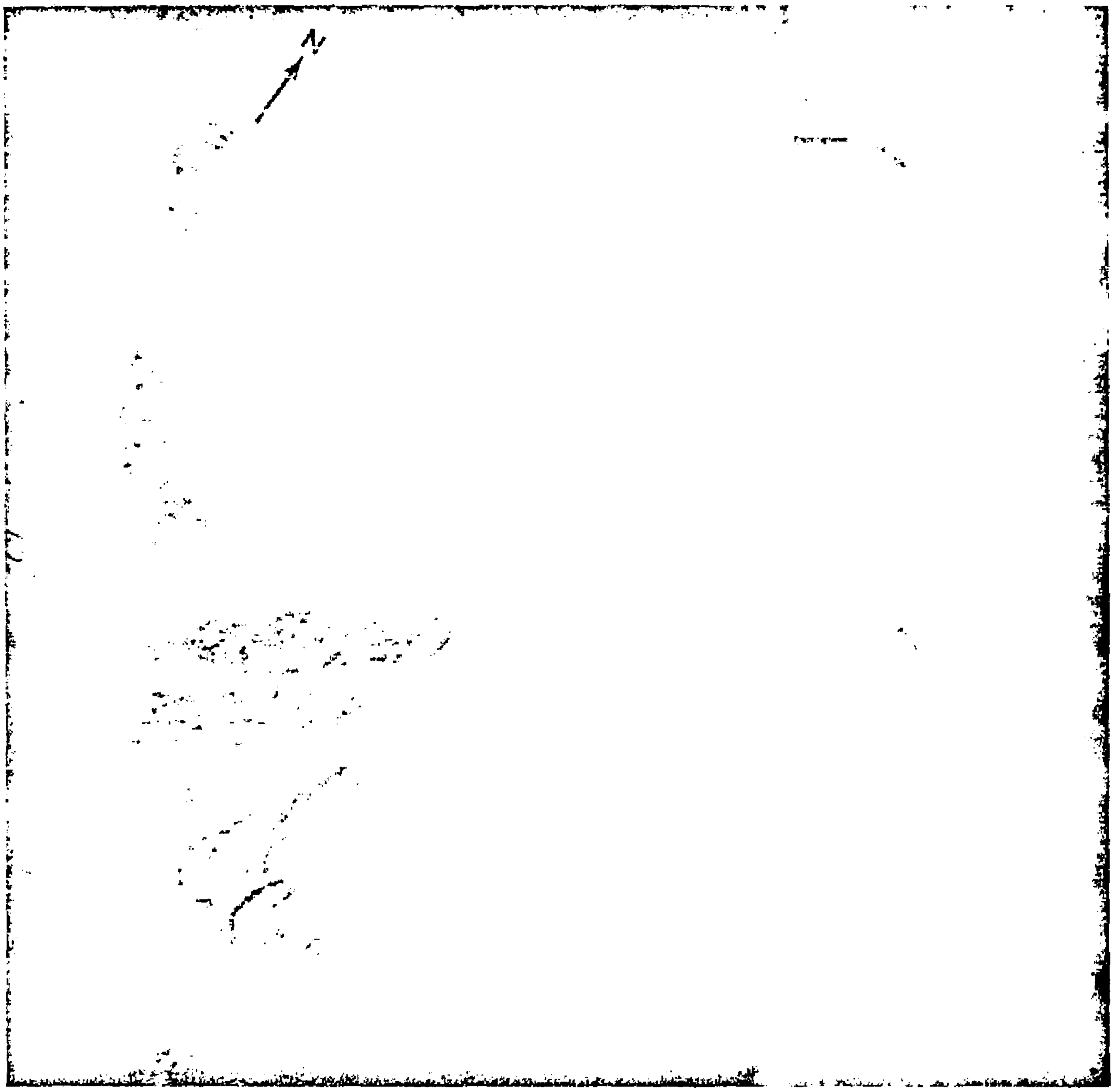


Figure 17-1.- Patterns of turbulence within the Humboldt Current can be seen in the reflection of the Sun off the coast of Chile (SL4-138-3858).

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

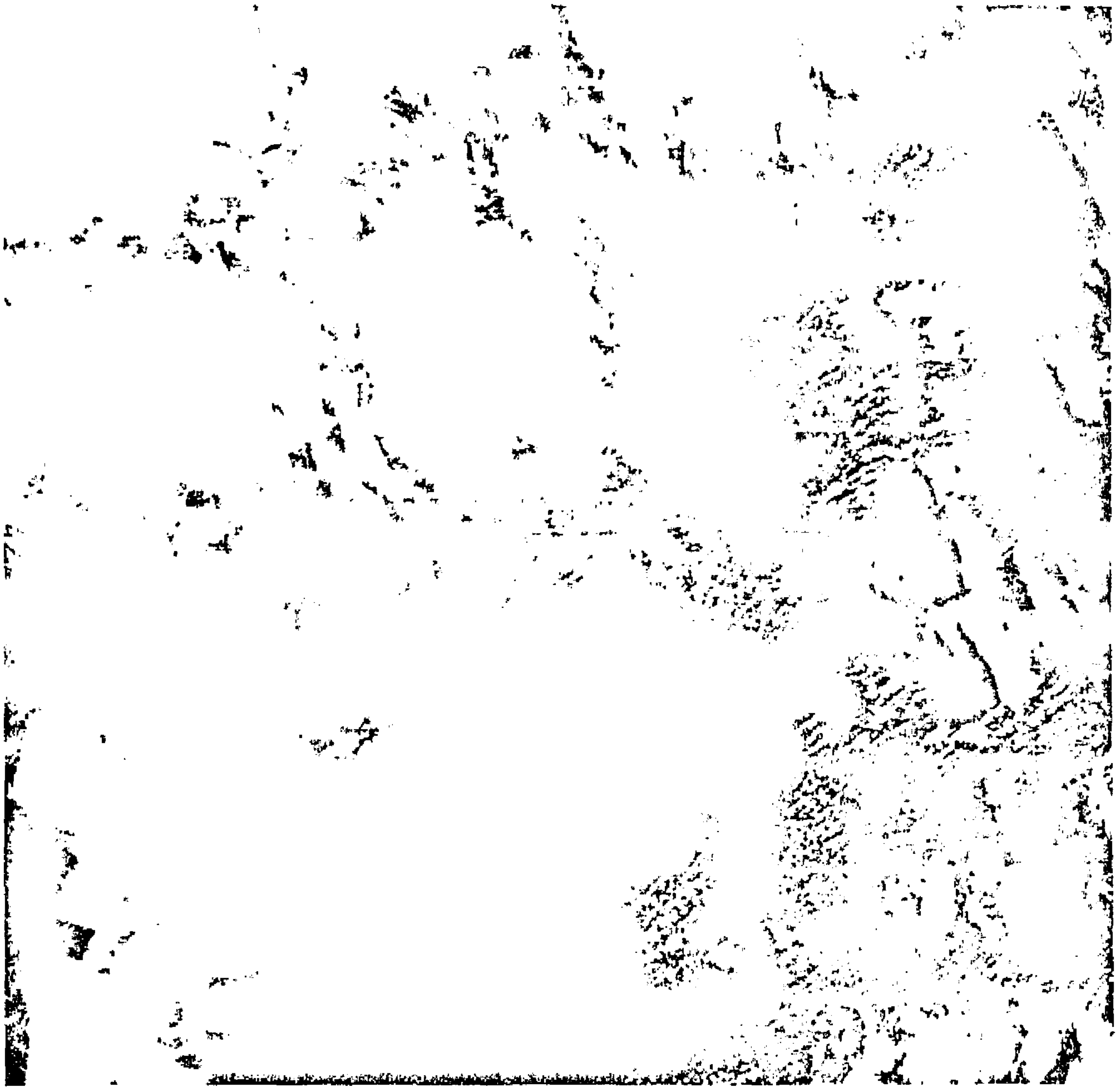


Figure 17-2.- Atmospheric effects of cold-water eddies (the connective clouds over the Brazil Current east of Puerto Deseado, Argentina). The cold Falkland Current, over which no connective (cumulus) clouds are forming, flows near shore (SL4-137-3608).

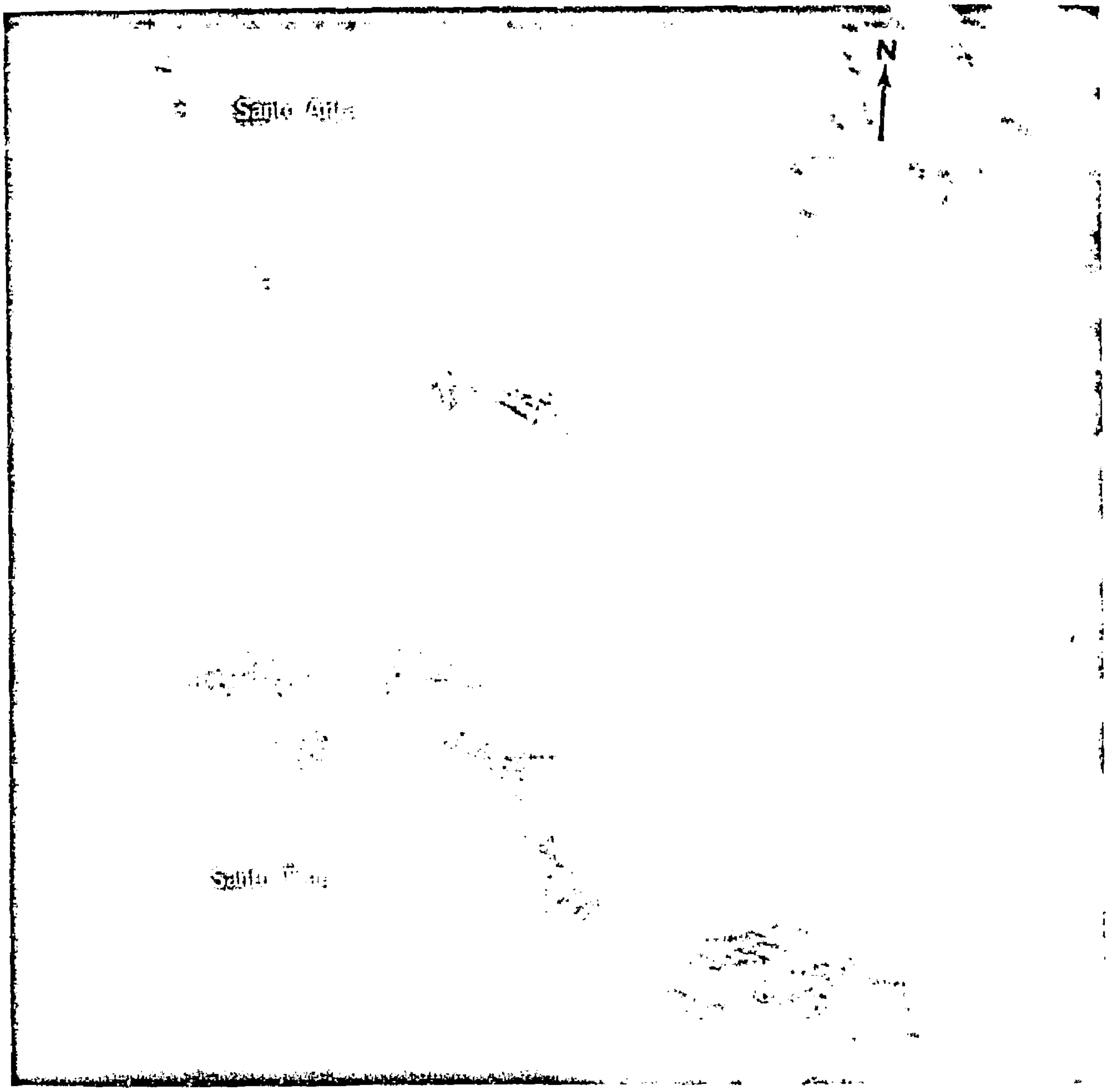


Figure 17-3.- Wakes are visible as they extend down current from the Cape Verde Islands, and a patch of dark upwelling water can be seen at the lee of Santo Antao (SL4-139-3907).

Seamounts and Shoals, HH35

Seamounts in the open ocean and shoals adjacent to islands were generally described by the crewmen as being greener than the surrounding ocean water. The crewmen made eight references to seamounts in the transcripts; and although one attempt to see Orne Seamount (30 meters below the surface) proved fruitless, they demonstrated that under the proper conditions seamounts with tops near the surface can be detected by men in space. Seamounts or reefs and shoals were recognized just south of Ulithi Atoll, in the French Frigate Shoals, and in the vicinity of Fiji and Tonga. Descriptions by the crewmen of this latter group indicate that they could distinguish considerably more detail visually than that discerned from photographs taken with handheld cameras. It was possible for the crewmen to distinguish between atolls and seamounts with tops very near the surface, whereas this distinction could not always be made when viewing the photographs.

Although shoal areas of islands are specifically mentioned only a few times in the transcript, shoals are readily discerned in the photographs. For example, shoal areas around islands in the Bahamas can be distinguished by their color (light blue) relative to that of adjacent deep water. In the Gulf of Venezuela, shoals and the deeper passages through them are distinct.

Internal Waves, HH36

Although the origin and propagation of internal waves are generally understood theoretically, the details of their natural occurrence are largely unknown. The characteristics and occurrence of internal waves were observed and photographed several times during the Skylab 4 mission. For example, it was observed that internal waves are generated as water flows southeasterly through Cook Strait, New Zealand, and these were photographed early in the mission (fig. 17-4). Later in the mission, internal waves at this location were again observed and described. A similar situation existed at the Cape Verde Islands, where the Canary Current generated internal waves as it passed between the islands (fig. 17-3).

Internal waves of unknown origin were also observed. Off the coast of Colombia, seven or eight waves of long wavelength, trending roughly perpendicular to the coast, were described. The presence of only four to eight crests was a characteristic of internal waves that was commonly observed.

Coastal Sediment Plumes, HH37

Sediment issuing from river mouths is readily recognized from space and can provide valuable information about coastal current strengths and directions and sediment dispersal paths. The crewmen were able to distinguish areas in which rivers constantly carry large loads of sediment to the sea; other areas in which the sediment influx to the sea was episodic during the mission were observed. Among those areas in which turbid water was repeatedly observed are the northern coast of Korea, the mouths of the Mississippi River

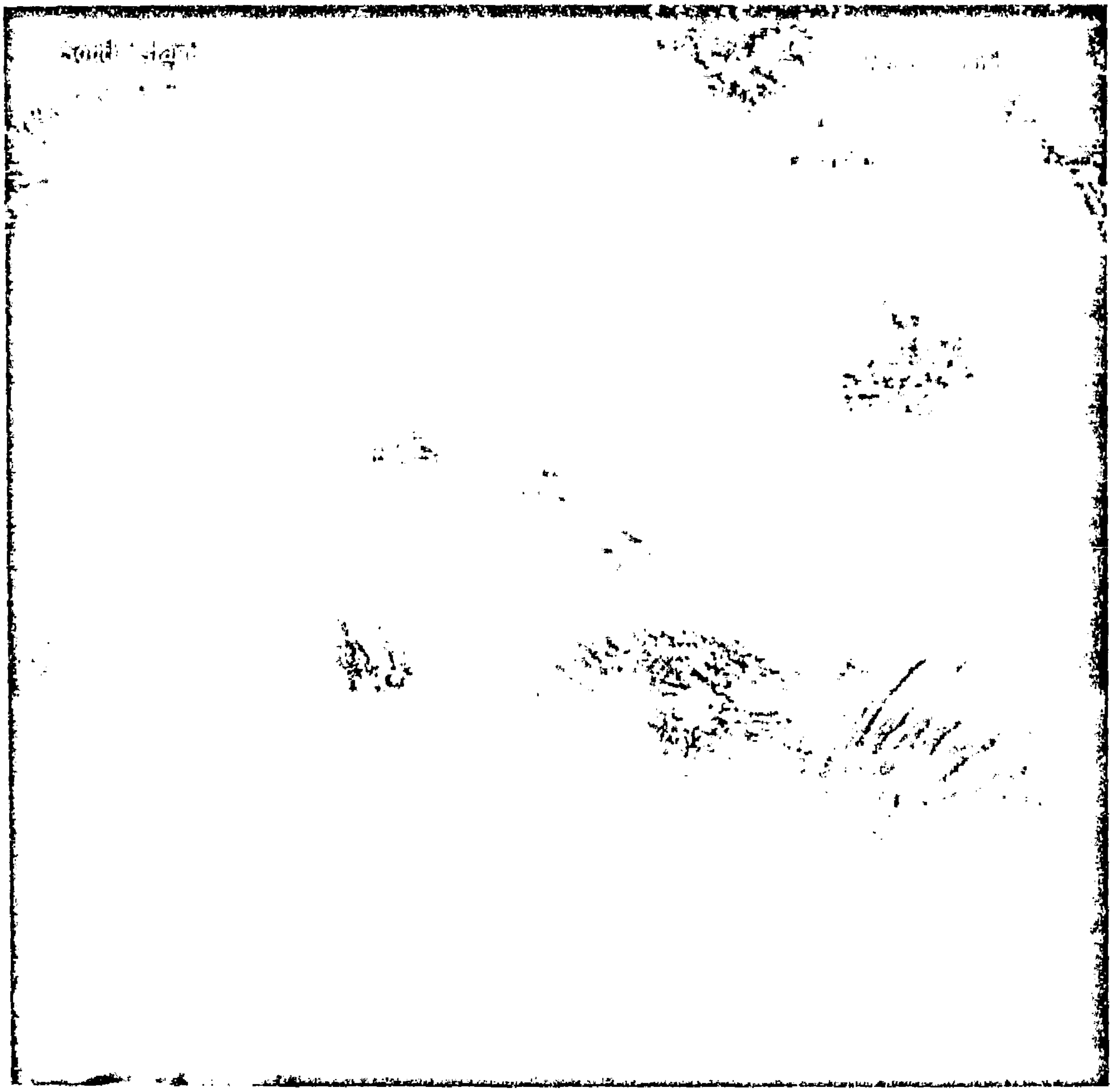


Figure 17-4.- Internal waves generated by flow between North Island and South Island, New Zealand, are visible just above the center of the photograph (SL4-137-3725).

and the Atchafalaya Basin in Louisiana, the Rio Magdalena in Colombia, and the Rio Sao Francisco in Brazil. Early in the mission, sediment entering the sea from Rio Magdalena was seen to move northwest along the coast under the influence of strong current flow. Later observations by the crewmen disclosed the same pattern of movement. In Brazil, observations of sediment entering the sea from Rio Sao Francisco indicated that sediment was moving southward along the coast. These observations were documented by handheld photographs and confirmed expectations that sediment dispersal along these parts of the South American coast is dominated by equatorial currents rather than by storm-generated swells.

The value of the Skylab 4 sediment-plume observations in determining the variability in patterns of sediment transport can be seen by comparing observations and photographs of the Atchafalaya coastal region that were taken in early December with those that were taken in late January. In December, sediment entering the Gulf from the Atchafalaya Basin was transported seaward and dispersed by strong offshore winds, and a turbid eddy was visible offshore. On January 30, winds were onshore, and sediment remained close to the coast and was carried westward by alongshore drift.

At the mouth of the Rio de la Plata (fig. 17-5), between Argentina and Uruguay, the crewmen were able to see fluctuations of the position of the interface between sediment-laden river water and clear ocean water. The interface was seen to migrate upstream a considerable distance but was not observed to occur seaward of the river mouth.

CONCLUSIONS AND RECOMMENDATIONS

The Skylab 4 mission allowed large-scale, dynamic, ocean features - such as ocean currents and associated eddies, island wakes, and internal waves - to be observed, described, and photographed in their entirety. Such synoptic study is vital to the understanding of these features and was accomplished by visual observations and handheld photography. The flexibility and advantages unique to this method were demonstrated by the Skylab crewmen and can be summarized as follows:

1. Crewmen are able to choose direction and angle of observation so that the number of possible observations of a single site can be maximized and sites of opportunity can be selected. This ability also increases the use that can be made of the reflection of the Sun because current boundaries, zones of turbulence, and slicks are best observed in sunglint.

2. Crewmen are able to take selected oblique photographs. This ability is important because this is the only way systems that are 300 kilometers or more in diameter can be photographed.

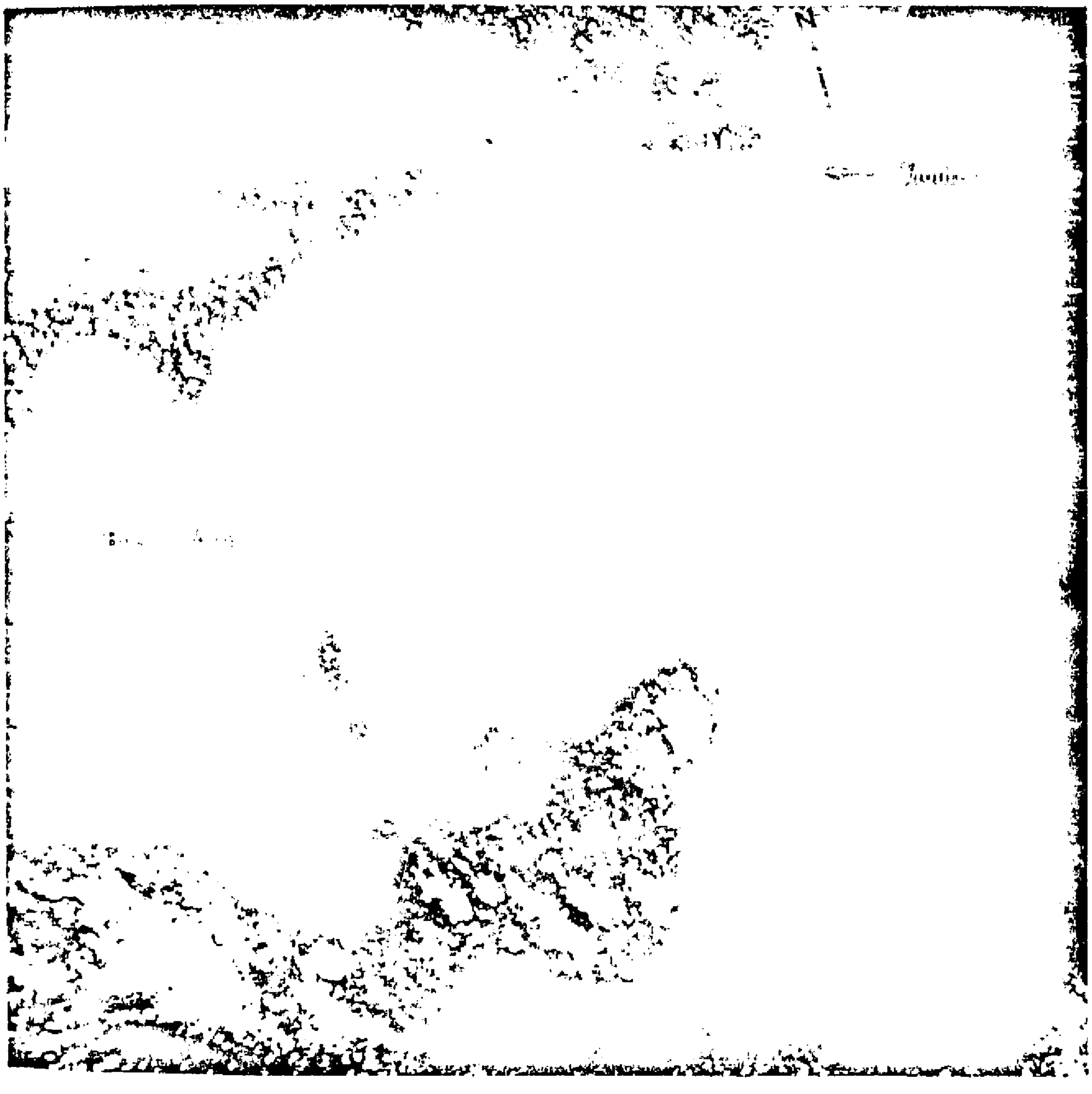


Figure 17-5.- Interface between the sediment-laden river water of the Rio de la Plata and clear ocean water (SL4-143-4608).

3. Valuable visual observations can be made when cloud cover or haze precludes photography. The crewmen were able to look through small clear areas and thin cirrus overcasts and describe features that they were unable to photograph.

4. Certain wind conditions create cloud patterns useful in the detection of dynamic ocean features. Such conditions can be recognized and photographed by crewmen but would be photographed only by chance with an automatic system.

5. The crewmen provide a real-time capability; data can be discussed and transmitted as they are gathered so that existing conditions can be studied.

To realize more fully the potential capabilities of the Visual Observations Project, two changes in the systems used on Skylab 4 are recommended. First, a communication system that will allow real-time communication between the crewmen and potential data users, such as oceanographers and fisheries experts, should be developed for future orbiting laboratories. This system should include both voice and visual-display panels, the latter with "slave" stations aboard a variety of sea-going vessels. Second, a more sophisticated, manually operated camera system should be used. Such a system should have at least the resolution of the Skylab multispectral photographic experiment (S190A) cameras. The Skylab 4 crewmen were able to visually distinguish and resolve more colors than can be seen on the handheld photographs; better photographic documentation of the visual observations is needed.

In addition, the following items should be emphasized during training of the Apollo-Soyuz Test Project (ASTP) and the Space Shuttle crewmen:

1. Increase in preflight instruction to crewmen by scientists

    a. Emphasis on quantitative and repetitive observation

    b. Use of surface texture, sunglint areas, cloud patterns, and color to view ocean features and processes

    c. Increase in vertical stereophotography of small features by oblique shots for features with a diameter greater than 320 kilometers

    d. Scientific and social reasons for the specific processes

2. Need for a greater amount of in-flight communication between crewmen and scientists in contact with the Visual Observations Team leader than was possible during Skylab

    a. Shorter turnaround time for information requested from space or on the ground

    b. Eventual use of electronic visual display panels for real-time, two-way discussions

3. Formal briefing of ASTP crewmen by Skylab crewmen on the techniques and limitations of visual observations from space

4. Sketches of oceanographic features (e.g., island wakes, eddies, and internal waves) while in space

a. Use of a television-type system in which the sketches can be viewed in real time (or near real time) on ships at sea or at land facilities (the best method)

b. Acquisition by the crewmen of Polaroid-type photographs on which they can enhance the features they have photographed while in flight with respect to either color or detail

5. Great need for documenting Sun angle and exact location and time that photograph or visual observation was made

6. Increased observation of the open-ocean surface patterns (e.g., an entire sequence of overlapping shots across a major ocean area with simultaneous visual observations (highly recommended for ASTP))

7. Use of zooming technique for observation and photography

a. Description of general current boundary, followed by description of increasingly smaller features, such as eddies and loops

b. Use of wide-angle lens for overviews, followed by two or three telephotographic closeup shots

c. Use of television imagery for large areas, followed by a zoom-in on important details

8. For ASTP, photography of coastal sediment associated with river mouths; important for pollution, runoff, siltation of harbor, and estuarine scientific studies

9. Observation of whether the contact between features, such as island wakes and the open ocean, is abrupt or gradational

10. A schedule for the training of the ASTP crewmen in visual observations of the ocean, corresponding perhaps to a minimum of 4 hours (two 1.5-hour increments and one 1-hour session) to be organized as follows:

a. One and one-half hours in July or August 1974 for a presentation on oceanography and ocean features visible from space

b. One and one-half hours in December 1974 or January 1975 for a discussion of the specific ocean sites to be viewed during ASTP, the kinds of features that are of interest, the reasons for the interest, and the kinds of surface measurements that will be available at each site during the mission

c. One hour in late May or early June 1975 for a review of the sites and their oceanographic features, for a short consideration of sites of opportunity, and for a review of the visual observations flight manual (VOFM)

The ASTP VOFM for oceanography should be composed of three pages: one listing the test sites and pertinent data, one with four 3- by 4-inch photographs of significant features to be viewed at the test sites, and the third with four 3- by 4-inch photographs of ocean features desired from sites of opportunity.

The scientist who will be "online" for consultation during the ASTP flight should attend each briefing so that the crewmen will know him as well as possible.

18. PRELIMINARY ASSESSMENT OF OCEANIC OBSERVATIONS FROM SKYLAB 4

George A. Maul[a†]

An evaluation of recorded visual observations, handheld photographs, and Earth resources experiment package (EREP) passes made during the Skylab 4 mission provided new and important information on the aquatic environment of the Earth. The value of these data will not become fully apparent until research scientists have completed extensive analyses. However, a critique of certain aspects of the flights may be performed, and a preliminary evaluation may be made, both of which concern the potential impact of space photography on the space program, in general, and on oceanography, in particular. It is with conservative optimism, then, that a few representative photographs of oceanic significance, transcriptions of tape-recorded visual observations, crew training, and near-real-time communication from the spacecraft to qualified earthbound scientists will be mentioned; the report will also offer recommendations for future experiments and equipment design.

PHOTOGRAPHIC OBSERVATIONS

An example of high-oblique photography showing the confluence of the Falkland Current and the Brazil Current is given in figure 18-1, which is an east-looking view with South America in the foreground. It was totally unexpected that the Falkland Current would appear bright green as it flowed northeast from Cape Horn, past the Falkland Islands, and eventually east into the South Atlantic off the Rio de la Plata. The Skylab 4 crewmen reported that the boundary of the warm Brazil Current and the cool Falkland Current could be visually followed for over 3500 kilometers and that the two currents formed intertwining paths but never showed mixing across the boundary. Before this mission, the growth and separation of meanders and current rings were never seen in this South Atlantic analog to the Gulf Stream-Labrador Current system. The combination of orbital groundtrack convergences at 51° S permitted repeated observations of the currents during January 1974. A time series of the current paths may be constructed as soon as the photographs are accurately oriented. In addition, new observations by the crewmen of what appear to be red tides may provide biological oceanographers with further insight into the spatial and temporal extent of these destructive plankton blooms. Ordinarily, sunglint is

---

[a] National Oceanic and Atmospheric Administration, Environmental Research Laboratories.

[†] Principal Investigator.

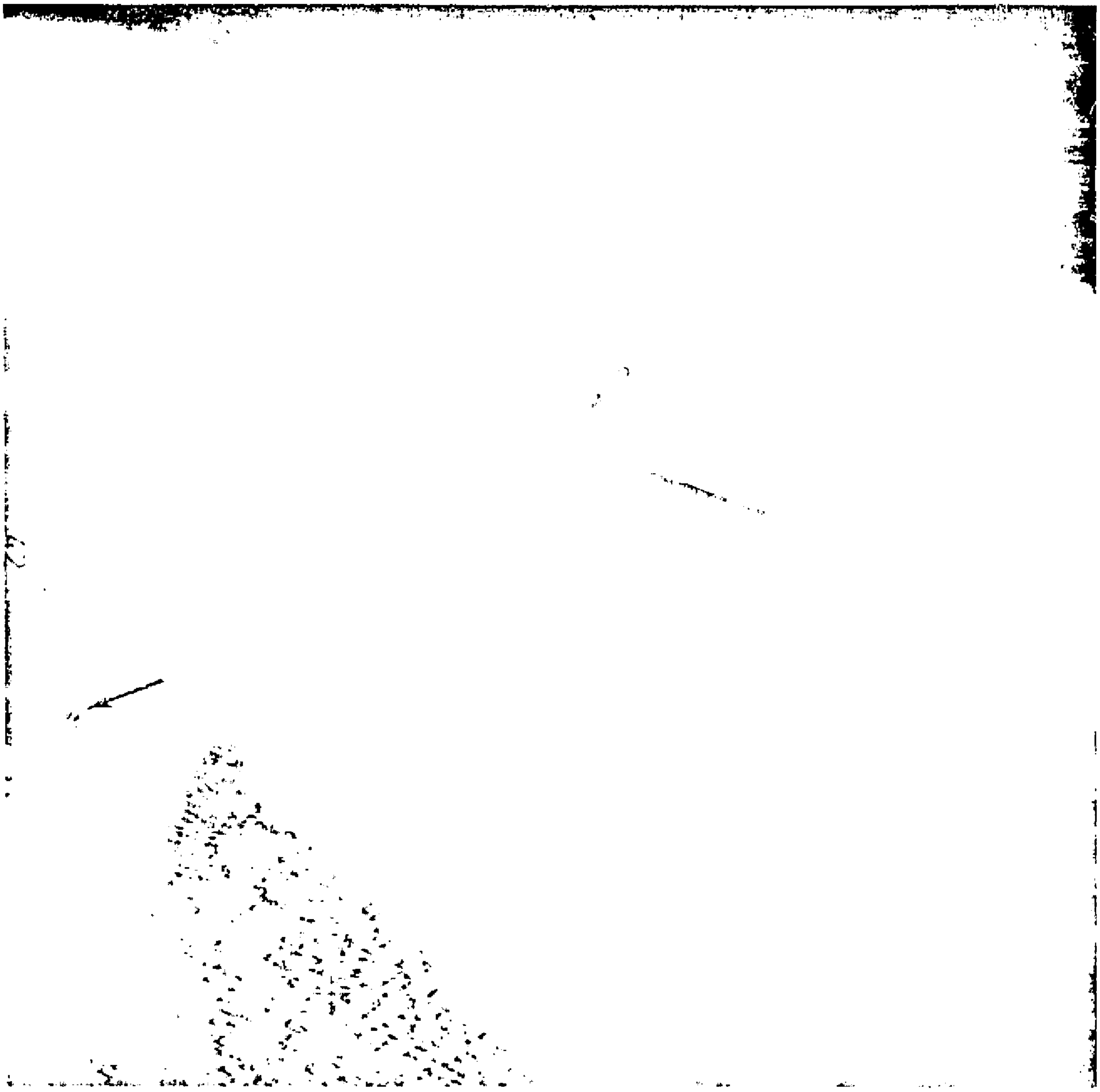


Figure 18-1.- Handheld photograph of the confluence of the Falkland Current and the Brazil Current (SL4-137-3690).

avoided in over-water photography (fig. 18-1) because color information is lost in the specular reflection. The Skylab 4 crewmen, however, reported that a large amount of information could be found in the glitter patterns. An example of mesoscale ocean eddies observed, because of the sunglint in a vertical photograph, is given in figure 18-2. These eddies are associated with the Loop Current in the eastern Gulf of Mexico, and their location has been correlated with the known position of this Gulf Stream-type flow. This represents not only the important discovery that such features can be seen in an otherwise rejected photographic technique but also the promise of searching for other examples for a frequency-of-occurrence evaluation. Studying the patterns in sunglint and relating them to the formation of the wind-stress vector also enhances air-sea interaction studies.

Whereas ocean eddies may represent a major energy dissipation mechanism, internal waves may play a similar role in tidal dissipation and vertical mixing. Figure 18-3 is a near-vertical or low-oblique photograph of a possible internal wave field near the mouth of the Magdalena River in Colombia. The less dense river water overlying the ocean water provides the discontinuity in stratification that encourages such internal (interfacial) waves. Furthermore, the sediment plume from the river indicates littoral transport, which is important in studies performed by marine geologists on erosion and deposition in near-shore areas. The studies of the frequency of internal waves and the persistence of longshore drift are important contributions to oceanography. These data may well exist in the photographs from the Skylab 4 mission.

A final example of the usefulness of Earth observations is shown in figure 18-4, which is a photograph of the New York Bight that documents the waste acid dumping event observed so often in the Earth Resources Technology Satellite multispectral scanner imagery. The crewmen remembered that water contamination, in general, rarely had been observed from space and that natural suspended loads were a much more common feature. Man's hidden contribution (from chemical disposal) to natural plumes could not be estimated. The crewmen further remarked that because most harbors resembled New York Harbor in that few, if any, bottom features could be recognized, photographic methods of bathymetry would probably work only in a few select regions of the Earth, such as the tropics.

VISUAL DESCRIPTIONS

Transcripts of recorded visual observations commentary, not all of which were related to photography, provided the most important link for feedback between the crewmen and oceanographers. There are many examples of the value of manned space vehicles to science, particularly in the area of flexibility of observation programs and routines. Crew training in the disciplines of marine science emphasized the principles of anticipating an observation, and when the Falkland Current (fig. 18-1) was unexpectedly sighted, the response of the crewmen was immediate and positive. Many vivid descriptions of the flow accompanied the photographs, and it was through these transcripts that the Science Team was able to realize the need for serial information and to relay that need to the crewmen. That is, a

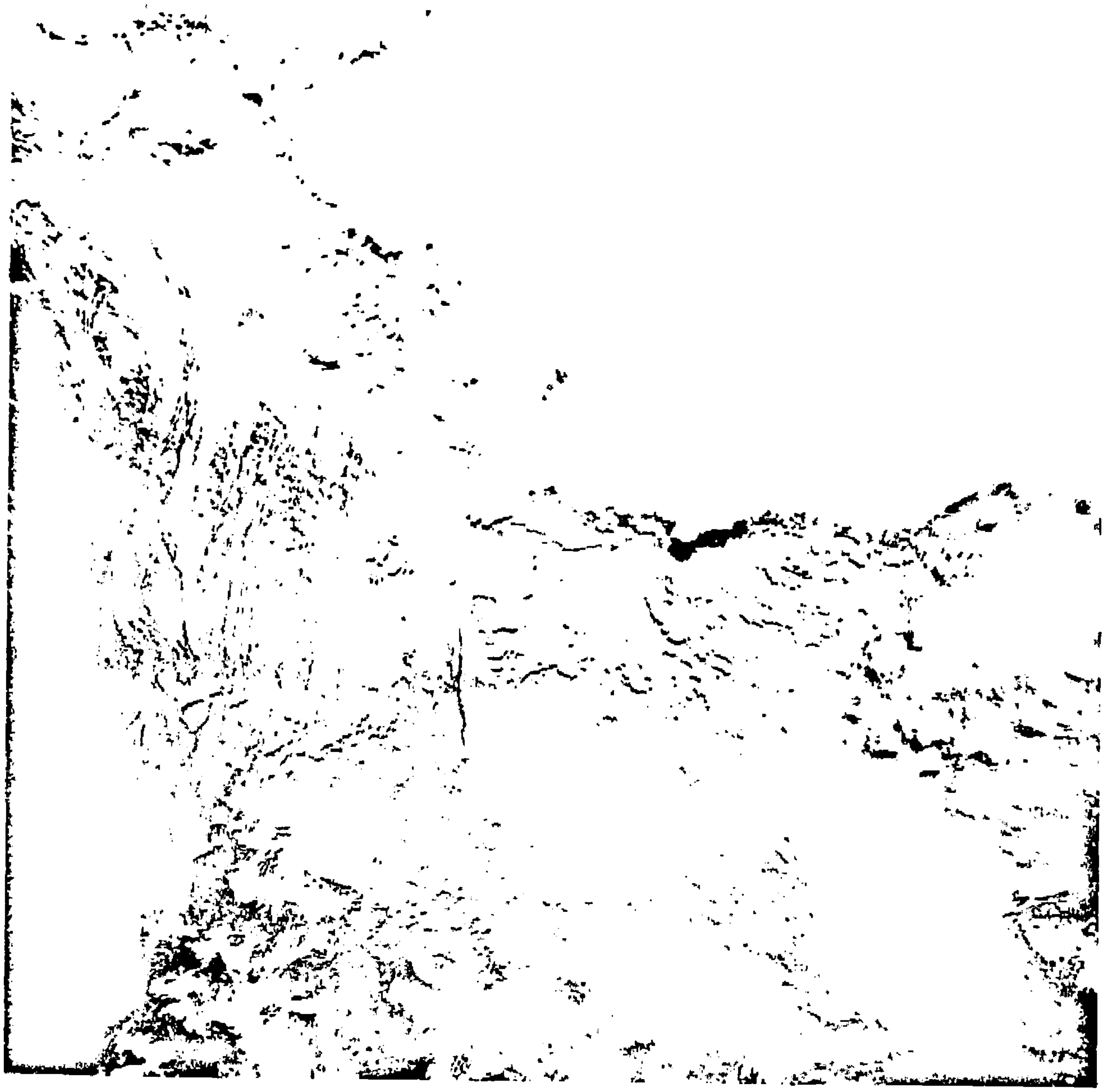


Figure 18-2.- An S190A photograph of mesoscale eddies seen in sunglint (SL3-22-124).

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

Figure 18-3.- Handheld photograph of possible internal wave field near the mouth of the Magdalena River in Colombia (SL4-143-4602).

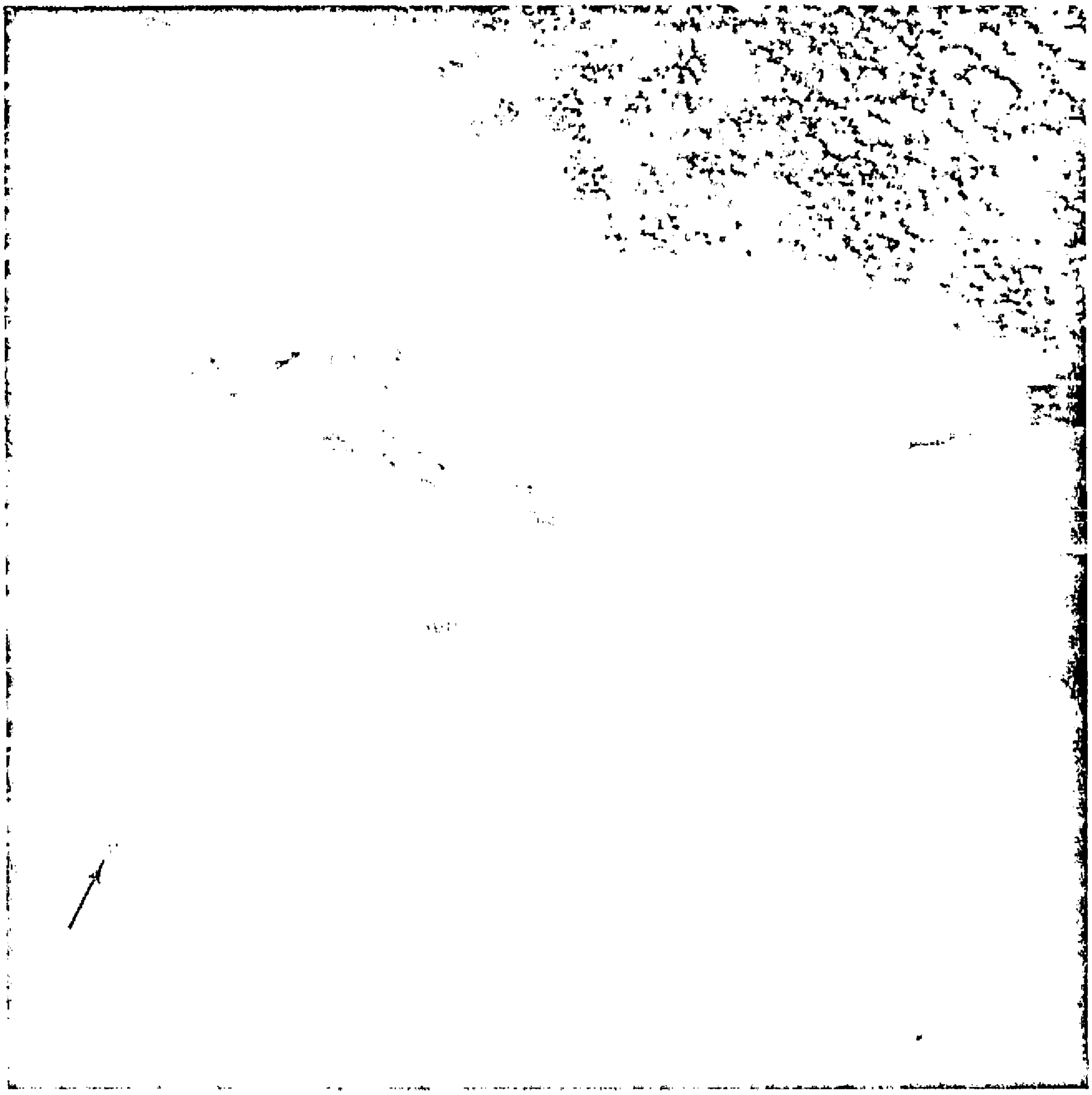


Figure 18-4.- Handheld photograph of the New York Bight acid-dump area (SL3-121-2463).

time history of the flow was photographically recorded and the crewmen were always encouraged to comment on their photographs and observations. Near-real-time interaction maintained though the use of transcripts also provided the capability to respond to the visual findings of the crewmen and to direct them to perform special EREP passes, such as the one over the Falkland Current.

Although the scientific usefulness of handheld photography has a distinct role in reconnaissance, it cannot surpass the quantitative possibilities of a multispectral observation in a known attitude. The Skylab 4 crewmen remarked that the handheld photographs were often disappointing because the 70-millimeter photographs did not reveal the detail or the vividness of their sightings. They felt that the multispectral photographic camera experiments (S190A) and especially the Earth terrain camera experiments (S190B) were more representative of visual clarity. For example, the commander remarked that the ocean appeared to have a fine texture that resembled corduroy material. This pattern, which is probably a manifestation of surface waves, could only be detected with a magnifier when the S190B photographs were examined.

The crewmen remarked that they used the binoculars at least half the time; this fact may explain their disappointment with the handheld 70-millimeter photographs and the reason why the S190B product was much closer to the detail actually seen. Similarly, with a narrow field of view, less contrast is sacrificed because of atmospheric scattering. Thus, many of the descriptions given were made while using binoculars; the relatively wide field of view of the 70-millimeter camera, which was used without a viewfinder, did not reproduce the observation.

RECOMMENDATIONS

The most significant shortcoming of handheld photographs of the ocean depths is the inability to determine the exact location. For a scientific study, such as a time sequence of the Falkland Current, the problem becomes critical. In addition, if the observer is interrupted while taking photographs, it may be hours before he can return to comment on the shot.

These inadequacies, and the need for magnification to properly observe surface features, suggest the need to develop a new handheld camera system before the Apollo-Soyuz Test Project flight. A compact, single-lens reflex camera with a zoom lens would be suitable. The field of view should contain digital Greenwich mean time and Julian day readouts, such as those available on electronic watches, that would be photographed together with the scene. The lens settings and selected focal length must be automatically recorded to further quantify the data. In addition, rapid (or automatic) film advance is needed so that a sequence of photographs can be taken to reproduce the sense of motion that the Skylab 4 crewmen believed to be an integral part of scene identification. (One of the most valuable aspects of debriefing was watching the television tapes to learn how the Earth is seen from orbit.) Finally, an integral voice recording system must be incorporated to ensure a record of the observation while it is in progress. The formidable ergonomics of such a system may indicate that a very-high-resolution television system would be superior.

Crew training for future flights should include simulated identification of oceanic features at the same scale as those seen during orbit. This can be accomplished by flying aircraft missions that simulate the speed, resolution, and color observed from space and by reviewing photographs from previous space flights.

The experience of the Skylab 4 crewmen may be the most important link in such a training procedure, and they should be directly involved in the research connected with their photographs. The training of future crewmen to observe and photograph Earth features is the most important long-term contribution that the Skylab 4 crewmen can provide.

19. CULTURAL FEATURES IN SKYLAB 4 HANDHELD PHOTOGRAPHS

Robert K. Holz[a]

The world can be studied by Earth scientists from at least two viewpoints: from the purely physical or natural landscape view and from the cultural or human aspect. In reality, physical and cultural studies cannot be divorced from each other because man is an important agent of the natural landscape. Man clears forests, plants cropland, drains swamps, builds dams to create lakes, constructs transportation and communication links, erects cities, and makes pollution, together with many other macrotraces and microtraces on the physical landscape. Man is the most important element of nature because he can think abstractly and deliberately modify the environment over large segments of the Earth. Because of his culture, he has the tools to study, understand, manipulate, and classify nature. Man is an agent of change - a builder and a destroyer.

The physical and cultural environments of the Earth cannot be separated, but one or the other can be emphasized in studies of the Earth. In the past, remote sensing of the environment and studies of the Earth from space have been focused on the physical phenomena at the expense of cultural features. The cultural features observable in the Skylab 4 handheld photographs are now being studied.

Modification of the Earth surface by man is the predominant component of the landscape in many areas of the world. For example, over the eastern United States, western Europe, the settled areas of the Middle East and Northeast Asia, the dominant landscape features at the surface are all man made or considerably modified by man. Many elements of this cultural pattern are observable in the Skylab 4 handheld photographs. The crewman could observe these patterns from space and report on spatial and temporal changes. Examples of these patterns, the problems of cultural object recognition, and a review of cultural phenomena in selected Skylab 4 photographs will be discussed in this section.

CULTURAL OBJECT RECOGNITION

Imagery generated from space is generally produced at a small scale and presents the interpreter a regional view. Often, such imagery is valuable in studies of physical features because it provides an overview or regional look at very large features that are difficult or impossible to perceive from

---

[a] The University of Texas at Austin.

ground observations. Large geomorphic features such as major faults, fracture patterns, lineaments, surface structure, and gross drainage patterns have been studied as a unit. These features often are observable in a single photograph (ref. 19-1). Overviews of hundreds or thousands of square kilometers were not possible before the advent of space photography.

Because photographs taken from space have lacked sufficient cultural detail and resolution to provide significant information, scientists have ignored cultural features observable in the photographs or have noted the features as curiosities. Recent studies (refs. 19-2 and 19-3) indicate that valuable cultural detail can be extracted from small-scale photographs of the Earth.

To date, only a few of the Skylab 4 handheld photographs have been available for preliminary study. Examination of these photographs has revealed interesting potential for research of cultural features of the Earth surface.

Consciously or unconsciously, photointerpreters evaluate a series of key factors as they identify objects in aerial photographs. The key factors are tone, pattern, size, shape, shadow, topographic location, texture, association, and color (if color film is used). As the sensor platform is moved farther from the Earth into space, some of these factors lose significance or importance while the value of others increases. Carter and Stone (ref. 19-4) have recently studied recognition elements in space photographs. The results of their work indicate that size and scale are of little value in interpreting space-generated photographs of the Earth. To this, the recognition of shadow element should be added because, at this small scale, shadows characteristic of individual ground objects are obscured or are too faint to see. Color, tone, texture, and pattern are more useful elements in recognizing cultural features. For example, a very large building in an urban environment is extremely difficult or impossible to delineate in Skylab 4 handheld photographs. Even with the aid of binoculars, the Skylab 4 crewmen were unable to see pyramids in Egypt or the Pentagon in Washington.

Some cities, such as Dallas and Fort Worth (fig. 19-1), are quite obvious to orbiting observers. However, the Skylab 4 crewmen reported several times that some cities are nearly impossible to locate from space because of the low site-to-background ratio and the speed at which the spacecraft traveled. Where cities can be observed, their outline, size (actual buildup area), and shape can be determined easily from photographs. Successive views taken over a period of time or compared to previously drafted maps are excellent for documenting the rate and direction of urban growth. Once established, urban shape is remarkably persistent. Even as a central area grows, it maintains the shape that was established initially (ref. 19-5).

Perhaps the most significant research tool that will result from remote-sensing imagery generated from space will be the ability to monitor temporary phenomenon. Short-lived phenomena that affect man, such as intense tropical storms, volcanic eruptions, floods, extent of snow cover, and the maturing of agricultural crops, are easily monitored from space. Trained observers who

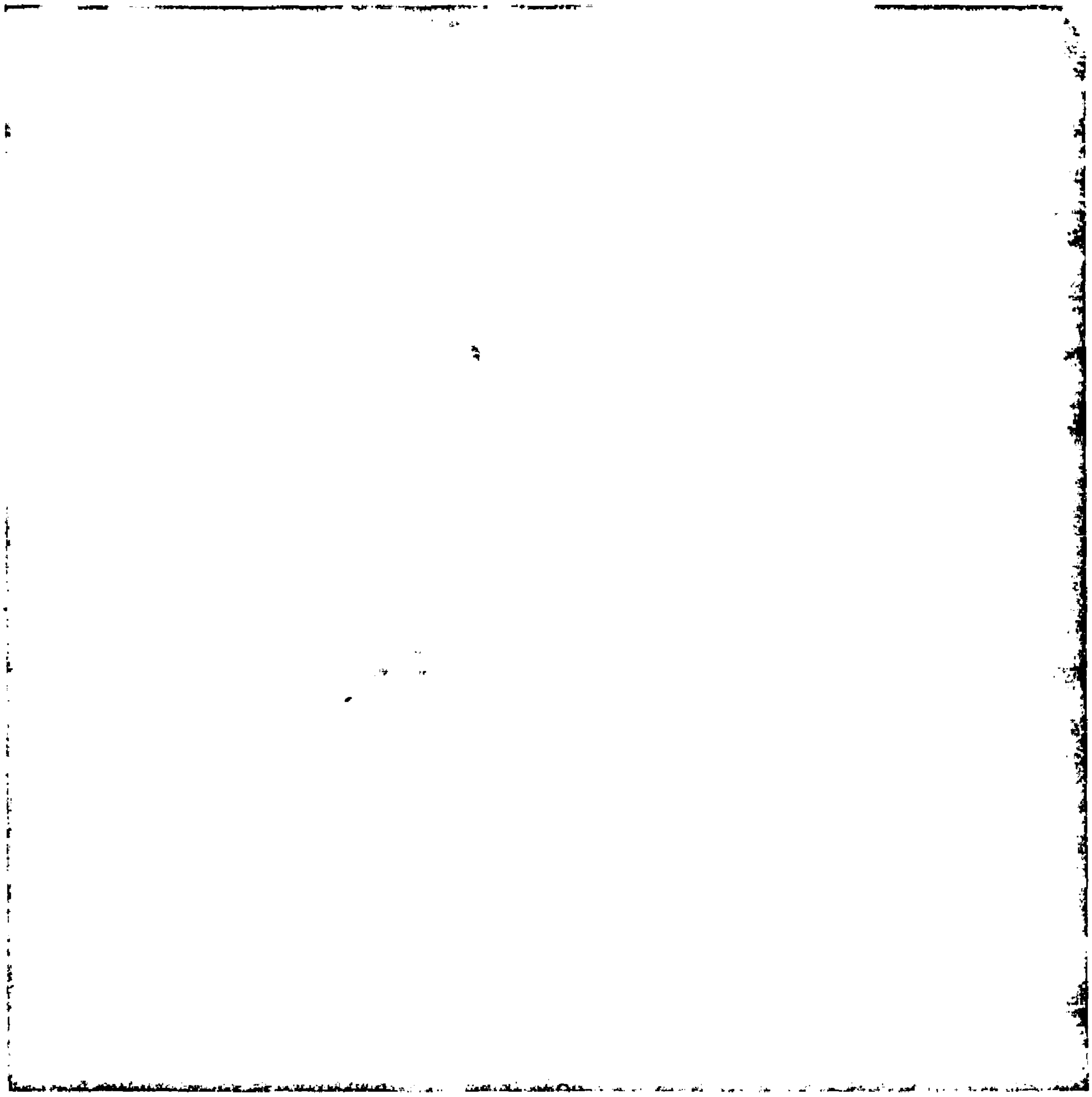


Figure 19-1.- Skylab 4 handheld 70-millimeter, low-oblique photograph of the Dallas/Fort Worth area (SL4-139-3950).

have the flexibility in judgment and the ability to maneuver an orbiting spacecraft so that its sensors are pointing toward a relatively short-lived phenomenon can accomplish this type of monitoring best. Skylab 4 crewmen related that no image of the Earth generated from space has the subtlety of shade and color that is perceptible to the human eye from the same vantage point. The trained observer in space greatly increases the interpretation of imagery generated from Earth orbit by providing the added dimension of personal experience in the interpretative process.

The value of space imagery as historical documentation has been given little consideration. Repeated looks at the same cultural feature over long periods of time will provide useful information about changes. This imagery will provide a bench mark for the monitoring and measurement of changes, especially changes that occur so slowly that they would be overlooked by observations made on the ground.

OBSERVABLE CULTURAL FEATURES

Man is continually modifying the Earth surface to meet his specific needs. As population increases, these changes become more extensive and more observable from space. Selected Skylab 4 handheld photographs are discussed in the following paragraphs; interpretation of these photographs focuses on manmade changes of the landscape.

The Chicago/Milwaukee Area

The Skylab 4 crewmen took the photograph in figure 19-2 from a position over east-central Illinois looking somewhat east of north. The southern shore and part of the western shore of Lake Michigan are clearly visible. In the original color photograph, lighter tones along the shore, in contrast to the darker blue tones of the water, may indicate ice forming on the lake. These color-intensity changes were visible to the Skylab 4 crewmen. The Earth surface in the northeastern quadrant of the photograph is obscured by a dense, although somewhat broken, layer of stratocumulus clouds.

The region shown in figure 19-2 has a light snow cover, which provides a strong background contrast that enhances certain types of land use and cultural detail. The area covered in the photograph is approximately 320 by 320 kilometers or approximately 102 400 square kilometers. The surface area included is from north of Milwaukee, near Sheboygan, Wisconsin, to south of Kankakee, Illinois, and from near Streator, Illinois, in the west to the headwaters of the Tippecanoe River in northeastern Indiana.

The dominant cultural feature in figure 19-2 is the built-up area of Chicago and its suburbs extending along the southern and southwestern parts of Lake Michigan. This built-up area extends from the edge of the cloud cover in southwestern Michigan through Michigan City, Gary and East Chicago in Indiana,

Figure 19-2.- Skylab 4 handheld 70-millimeter, low-oblique photograph taken from a position over east-central Illinois (SL4-139-3954).

and through Chicago, Oak Park, Evanston, and Waukegan to Zion, Illinois, on the border of Wisconsin. North of Zion, the smaller, more distinct central place nodes of Kenosha, Racine, and Milwaukee, Wisconsin, can be clearly identified along the Lake Michigan shore.

Careful examination of the Chicago megalopolis on a high-quality color image reveals the densely built-up, older central core of the city. The central core appears much darker than the suburbs in the photograph. In this area, the "heat island" of the inner city, larger buildings, less green or unoccupied space, more pollution of the snow cover, and snow removal probably have combined to reduce the effect of the white background. In this darker area, parks, golf courses, airports, and other land uses with low building density can be identified clearly by lighter tones. Even in the most densely built-up part of the city, major lineaments or arterials are shown. These lineaments represent major transportation routes (streets, highways, railroads, and pipelines) and drainageways (rivers and canals). Near the center of the inner city, the Chicago River Canal can be seen as a sharp lineament cutting northeastward across the built-up area. Paralleling the Lake Michigan shore and beginning near the Wisconsin border north of Chicago is a dark line that marks the course of the Des Plaines River. The darker tones probably result from a denser biomass cover (trees and brush) and other changes in land use that mask the snow cover. This same effect is observable on the rural landscape where the major drainage lines of the region can be clearly traced. In Chicago, these darker tones can be used to identify the Chicago Forest Preserves.

Urban researchers have identified three types of city growth: zonal, nodal, and sectorial. Careful examination of the built-up area in and around Chicago reveals elements of all three growth patterns. The more densely built-up inner city can be delineated and, even within this area, other zones or subzones are apparent. The inner city is surrounded by several zones in which there is a decreasing intensity of land use. However, within these zones, nodes of concentrated human activity are evident. Perhaps the tendrils that follow transportation routes into the suburban fringe are the most startling features of Chicago urban growth. Clear, fringelike sectors of a major urban development can be seen, for example, to the northwest (Palatine, Arlington Heights, Mount Prospect, and Des Plaines) in two lines to the west (West Chicago, Glen Ellyn, and Elmhurst and Naperville, Downers Grove, and La Grange) and to the south (Park Forest, Homewood, and Harvey). Within these sectors, nodes of more intense development are identifiable. From this pattern, sectors appear to grow by outward directional expansion of previously existing nodes. Nearer the core of the city, the zones between the sectors have been occupied. If the normal pattern of urban growth results in the filling in of the unoccupied land between built-up sectors, the size and shape of the city can be predicted. Obviously, there is considerable potential for growth in these unoccupied spaces.

Near the bottom center of figure 19-2 is a dark line crossing the landscape. This line represents the Kankakee River and can be traced northeastward into Indiana and southern Michigan. The conurbation of Kankakee and Bradley, Illinois, bisected by the Kankakee River, is evident in the bottom center of the photograph. Even in this smaller central place, the three types of growth observed in larger development around Chicago occur. The major lineament running through Kankakee and trending toward the top of the photograph is Interstate Highway 57 paralleled by the Illinois Central Railroad. Careful observation reveals numerous central place nodes along these transportation links. From south to north, these are Ashkum, Clifton, Chebanse, Kankakee, Manteno, Peotone, and Monee. The effect here is similar to the pater noster lakes observed in areas of alpine glaciation where small circular tarn lakes are connected by a common stream. The spatial distribution of these nodes is interesting because they seem to be somewhat uniformly spaced and of approximately the same size in the built-up area, except in the Kankakee area. Many other central places of varying size are distributed over the rural landscape. In this humid area of intensive agricultural development, a light snow cover distinctly enhances the outlines of the built-up area of central places. Photographs of this type would be excellent for monitoring the growth and development of smaller central places for which current data are difficult to obtain.

On a good reproduction of figure 19-2, or under magnification, a faint but clearly discernible rectilinear pattern can be seen in the snow cover on the rural countryside. No groundtruth checks were made in this area at the time the photograph was taken, but there does seem to be an explanation for this pattern. Property in Illinois and Indiana is divided by the U.S. Land Survey system. This system, which uses the square mile (section or 640 acres) as its basic unit, is alined north-south and east-west. Normally, around each square mile there is a section-line road. These roads are cleared of snow by plowing, salting, or heating generated from vehicular traffic. The rectilinear pattern of these cleared roads is clearly shown against the background of lighter snow cover.

Northern Illinois historically was a vegetative transition zone between the mixed hardwood forest of the northeastern United States and prairie grasslands farther to the west. This particular area was originally long-grass prairie, dotted with a few trees. However, along the stream courses, the eastern forest continued to the grassland in galeria-type forests. This change in vegetation and land use exists today and is helpful in defining the outline of the major drainage networks in the area. The Kankakee River can be traced from its headwaters in southern Michigan southwesterly through northwestern Indiana into Illinois where it joins the Des Plaines River. One of the major tributaries of the Kankaee River, the Iroquois River, empties into the larger stream southeast of the city of Kankakee. The Des Plaines River can be traced from its headwaters near the border of Wisconsin, through the built-up area of Chicago, and then southwesterly toward its confluence with the Illinois River. Farther to the west and near the Wisconsin border, the headwaters of the Fox River give rise to southwesterly flowing streams that join the Des Plaines River. East of the city of Kankakee, the Kankakee River makes a sharp, almost right-angle turn to the northeast. North of this bend and bisected by the river is the city of Momence, Illinois, only a few kilometers from the Indiana border. Land use along the river here changes; the signature of the river valley is thicker and darker. Just northeast of Momence, a ledge of resistant limestone has created a natural dam or barrage in the river. Historically, beyond this dam the great Kankakee Swamp formed, reaching northeastward to the present-day border of Michigan. The Corps of

Engineers removed this natural barrier and drained the swamps. The drained bottom land should have been agriculturally productive, but the light, sandy soils soon lost their fertility because of intensive annual cropping. Except for small areas of specialized agriculture (such as the area of gladiola bulb production around Momence), most of these fields were abandoned. The area has grown up in thick brush and second growth timber, which produces a signature much like that along the Des Plaines River north of Chicago.

Northwest of Kankakee where the Kankakee River joins the Des Plaines River (near Braidwood, Coal City, and Wilmington), large, dark rectilinear patterns are evident on the landscape. In this region, the upper edge of the Illinois Basin comes very near the surface. By removing a loose regolith or overburden, coal seams may be reached. The dark patterns in the photograph could be active strip-mining operations. Sequential photographs taken from space of this area would present the best measurable evidence of the rate, direction, and size of strip-mining operations.

The historic significance of the photograph in figure 19-2 will be realized by further study. Careful enlargement, edge enhancement, and machine processing undoubtedly should reveal considerably more information. For example, measurements of the size and spacing of the central places on this relatively flat, uniform, productive agricultural plain could be made. By measuring the actual size of built-up urban places and comparing this size with the known population, a model of central place population could be developed. The model would be based on actual built-up area and other observable phenomena such as transportation links and distance to and size of nearest larger neighbor. The potential of this photographic image taken from space is limited only by man's imagination. One significant point that should be emphasized is that a light snow cover enhances the outline of central places when observed from space.

THE DALLAS/FORT WORTH AREA

The Skylab 4 crewmen took the photograph shown in figure 19-1 from a viewing angle southwest of the Dallas/Fort Worth area in Texas. A broken cloud cover extends from the southwest to the northeast across the upper third of the photograph. It is difficult to determine the exact area photographed because of the cloud cover, the oblique photograph angle, and the haze. The conurbation of the Dallas/Fort Worth area is located in the lower right part of the photograph. The built-up pattern of these two urban centers and changes in rural land use patterns in the area surrounding the cities will be discussed.

The cities of Dallas and Fort Worth are growing toward each other. Twin arms of urban growth (northward and southward) have almost coalesced to connect the two cities. The growth arms have been called field lines by Nunley (ref. 19-6). These field lines now enclose a zone of unoccupied space along the Dallas/Fort Worth toll road. This space is rapidly being filled, and a comparison with the 1968 Apollo 6 photograph (fig. 19-3) that was previously examined (ref. 19-5) indicates the rapid rate at which this buildup

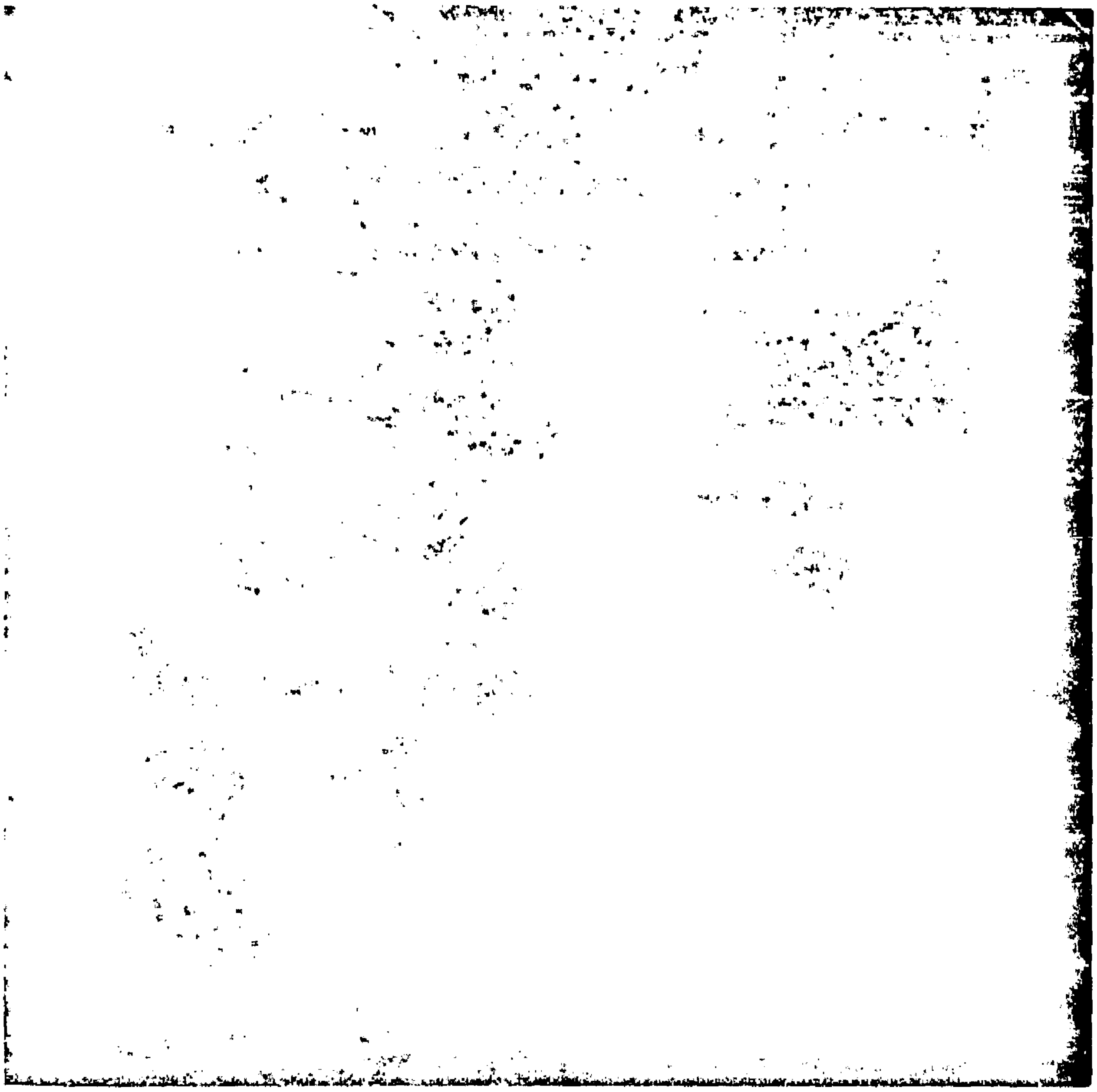


Figure 19-3.- Apollo 6 photograph of the Dallas/Fort Worth area. (AS6-2-1462).

is occurring. The major gaps in the buildup of the southern arm are caused primarily by physical features. Southeast of Fort Worth, Lake Arlington interrupts the urban pattern; southwest of Dallas, the break results from Mountain Creek Lake. Urban growth is now beginning to bypass these reservoirs to the north, east, and west. A gap exists in the northern arm of urban growth, just south of the Greater Southwest International Airport, which appears as a bright, arrowlike pattern just northwest of Dallas. With the stimulus to growth that this transportation facility will provide, this unoccupied space will undoubtedly be used rapidly.

The urban pattern of Dallas/Fort Worth is interrupted by the Trinity River flood plain cutting across the city from the northwest to the southeast. White Rock Reservoir on White Rock Creek, a tributary of the Trinity, is clearly visible in the city of Dallas. The urban growth from Dallas has reached the eastern edge of Ray Hubbard Lake as a result of the growth of the cities of Garland and Mesquite.

The clear fork of the Trinity River angles across Fort Worth from southwest to northeast and interrupts the mottled gray signature of built-up urban space. To the southwest, this stream has been dammed to form Benbrook Lake, which is clearly visible on the photograph, as are Lake Worth and Eagle Mountain Lake to the north. In this climatic transition zone between the humid-continental climate to the east and the semiarid-steppe climate to the west, reservoir sites are invaluable. However, it is obvious that the development of these reservoirs restricts, confines, or redirects urban growth patterns.

Both of these urban places exhibit aspects of Burgess' classical hypothesis of city growth by concentric zones, although the pattern is stronger for Dallas, especially on the northeastern and eastern sides of the city. Urban development between Dallas and Richardson to the northeast has almost coalesced and certainly has expanded considerably since the 1968 Apollo 6 photograph was taken. To the east, growth around Garland and Mesquite has almost filled the unoccupied gap between them. Careful examination of the Skylab 4 photograph will reveal a developing, noncontiguous series of smaller central places. These urban places already show evidence of growth toward each other and could form the next concentric zone still farther from the central city.

More recent theories developed in social-area analysis and empirical studies in ecology indicate that cities may grow in specific patterns. These patterns have been identified or associated with types of social organization. Development can occur in sectors or perhaps around nodes. The transportation system, which can be traced well into the built-up space of the cities, and the unoccupied flood-plain zones of the drainage patterns divide both major cities into clearly recognizable sectors. Delineation of these sectors from this photograph is possible. Process-oriented morphological research should be designed to test the validity of these urban sectors as seen in space imagery. Such studies would provide bench-mark information for the theory of urban sectoral development. Even within these sectors, nodes of development can be observed and measured. Some of these nodes are previously existing communities that have been encompassed by the expansion or growth of a concentric zone or sector. Other nodes appear to be shopping centers, residential development, or industrial concentrations that form an independent center of human activity in a specific sector or zone. Careful study of the built-up urban space in this Skylab photograph reveals elements of all three types of growth. This suggests still another theory of urban development that would encompass elements of all three theories (concentric zone, sectoral, and nodal) into a single unified statement.

In the mottled gray of the city signatures in figure 19-3 are variations in tone, texture, pattern, and color. These variations undoubtedly represent differences in urban land use. These changes could reveal high-, middle-, and low-income housing; the central business district; industrial or manufacturing zones; and old (as opposed to newer) development. The internal signatures of urban land use need to be examined in more detail.

The agricultural land use patterns around Dallas/Fort Worth are clearly recorded in the Apollo 6 photograph (fig. 19-3). A considerable amount of field variation is observable although this photograph was taken at the end of the growing and harvesting season. No groundtruth is available to reveal the nature of individual crop signatures shown in the photograph, but cultivated fields are discernible from noncultivated fields or pasturelands.

Perhaps the regional trend of the rural land use patterns, where a north-south orientation predominates, is more important. Changes in the land use patterns are evident, especially east of Dallas, between Dallas and Fort Worth, and west of Dallas. These changes in land use are further accentuated by the drainage patterns, which generally run from north to south. A study of the regional boundaries of the major geologic units within the area (fig. 19-4) reveals the north-south trend of rural land use patterns and drainage. The Paluxy, Woodbine, and Glen Rose boundaries are quite distinct. One minor exception occurs to the southeast where the boundary is crossed and masked by the Brazos River. Other identifiable units with sharp zones of contact are the Goodland, Austin, and Eagle Ford areas. The greatest difficulties in mapping these contacts occur where they are masked by the combined effect of the built-up areas of Dallas/Fort Worth and the flood plain of the Trinity River. Because each of these geologic units has a different lithologic composition, the soils that develop from these parent materials have different agricultural potentials. It is not unusual that the zones of contact between the geologic units mark sharp changes in land use patterns; in fact, it is probably this land use change that, in large measure, makes these boundaries discernible.

Continued examination of this Skylab photograph will reveal even more cultural detail. One question arises: Why do these two cities show up in such marked contrast to their background when large cities in other parts of the world are almost invisible? In part, the answer may be the way Western man adapts the landscape to meet his own needs. By contrast, cities in the developing world have fewer high-rise buildings and are more likely to be built of materials from the local environment. Therefore, these cities have a photographic signature much like the background around them. The problem of locating cities from space is one that requires continued study.

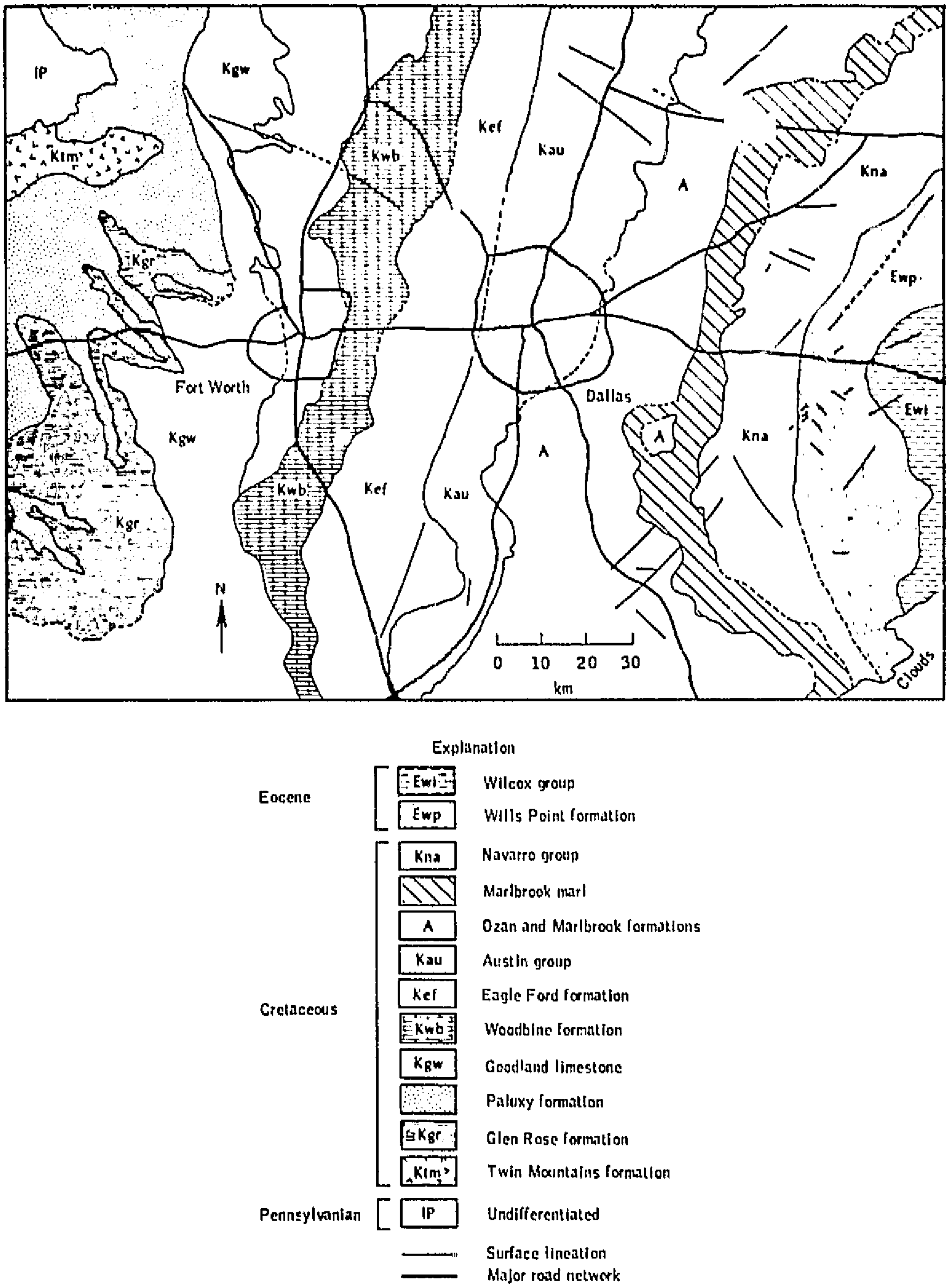


Figure 19-4.- Geological map of the Dallas/Fort Worth area prepared from geological literature and from an interpretation of Apollo 6 photographs.

MIAMI AND THE SOUTHERN TIP OF THE FLORIDA PENINSULA

The southern tip of Florida is shown in figure 19-5. Scattered fair-weather cumulus clouds cover the southeast coast and extend out over the ocean. The geographical area covered in the photograph reaches from north of Lake Kissimmee (in the upper left corner) to Florida Bay in the south, a distance of approximately 300 kilometers, and from the Atlantic Ocean on the east to the Gulf of Mexico on the west. An Earth surface area of approximately 67 000 square kilometers is shown in figure 19-5.

Along the west coast, the large bay near the left margin of figure 19-5 is Charlotte Harbor. The drainage lines of the Myakka and Peace Rivers are shown discharging into this bay. The discharge of sediment from two major passes, Boca Grande Pass and, slightly to the south, Captiva Pass, into the Gulf of Mexico is shown. Still farther to the south, the drainage network of the Caloosahatchee River can be traced inland to Lake Okeechobee, which is the large inland water body near the upper center of the photograph. The stream that connects Lake Okeechobee northward to Lake Kissimmee is very evident in the photograph; the high albedo of its signature indicates a low water stage with considerable exposed alluvial fill in the stream channel.

On the west coast around Charlotte Harbor and south to the city of Naples, discontinuous patches of cultivation and other rural land use activities can be seen. Some of these, such as the light-colored square northwest of Lake Okeechobee, are quite large. A faint, light-colored line extends straight eastward from Naples to Fort Lauderdale on the east coast. This is the photographic signature of the Everglades Turnpike, also known as Alligator Alley. Just north of the turnpike, a sharp land use boundary change occurs, which indicates that this land is used for growing winter vegetables and grazing cattle. South of this boundary, the relatively uniform response of the dense vegetative cover of the Everglades is prevalent. From near Naples on the west coast, another sharp boundary change extends southeastward at an angle inland. This line represents another vegetation change (mangrove swamp growth) and marks the approximate boundary of the Everglades National Park.

The cloud cover over the east coast masks some of the finer urban detail, but there is sharp contrast in the original color photograph between the mottled gray of the coastal urban built-up areas and the darker blue green of the Everglades inland. Perhaps the most startling area of contrast is the continuous nature and density of urban buildup that extends approximately 120 kilometers from Perrine, on Biscayne Bay south of Miami, northward to West Palm Beach. The almost uniform distance that this urban buildup extends inland, or westward, is remarkable. Clear evidence of westward expansion is evident only near Miami. This uniform east-west width of the built-up area probably results from the combination of many factors. The most important factors are the limiting environmental, economic, and physical constraints to suburban development imposed by the Everglades to the west and by the beachfront-oriented tourist trade that has had such a strong influence on the development of this region.

Figure 19-5.- Skylab 4 handheld 70-millimeter, low-oblique photograph of the southern tip of Florida (SL4-139-3982).

The urban development occurring north of Miami contrasts sharply with that development observed around Chicago (fig. 19-2). Chicago is also a coastal city, but to the west, a fertile, relatively flat, agricultural plain invites easy expansion, especially along transportation routes. The Chicago suburbs are dominated by radial, spokelike development. The urban development along the east coast of Miami is confined to a rather narrow coastal corridor, with the ocean to the east and the Everglades to the west. For environmental, aesthetic, and economic reasons, urban growth is not penetrating into the poorly drained Florida interior. From older maps, the urban expansion northward from Miami seems to have resulted from the growth and merging of a series of smaller central place nodes. Even today, careful examination of the built-up urban area reveals nodes of denser concentration. In this sense, the urban development of Miami appears to contrast sharply with that of Chicago, and this variation should offer an interesting field for comparative study of how cities in varying spatial locations developed. As a final point, Miami is unusual in that it does not have a well-developed productive hinterland immediately surrounding it.

SOUTHERN MOROCCO, THE ATLAS MOUNTAINS, AND SOUTHWESTERN ALGERIA

Near the northwest coast of Africa looking approximately eastward, the Skylab 4 crewmen took the photograph shown in figure 19-6. Cloud cover, haze, and the high oblique angle of the photograph make it difficult to determine the exact area covered. For study of cultural patterns, the area shown in the bottom (western) two-thirds of the photograph is the most valuable.

The Oued (River) Tensift (lower left corner of fig. 19-6) flows through the Haouz Plain, a densely occupied plain that stretches from the coast to Marrakech. The Oued Tensift appears on the photograph as a dark line, probably because of dense vegetation, and can be traced well back into the interior of the region, past the city of Marrakech, to the foothills of the High Atlas Mountains.

Few works of man are visible on the landscape of the Haouz Plain. Vegetation, or the lack of it, causes much color differentiation in the original color photograph. The northern and western slopes of the High Atlas Mountains are well watered and thus appear to be green. This green shade also is evident along some of the river channels well away from the mountains. In all other areas, vegetation is sparse or lacking, and various rock or surface material colors (i.e., white, yellow, brown, red, gray, etc.) can be distinguished. Some of the major tributaries of the Oued Tensift can be delineated, and the photographic signature in this area is probably again due to denser, better-watered vegetation. Much of this vegetation is irrigated cultivation. Overall, there is no striking pattern of rural land use that can be easily observed, as in rural areas of the Western world.

Figure 19-6.- Skylab 4 handheld 70-millimeter, high-oblique photograph of southern Morocco, the Atlas Mountains, and southwestern Algeria (SL4-139-3910).

The dominant landform in figure 19-6 is the main thrust of the High and Middle Atlas Mountains. In this photograph, which is essentially free of clouds along the bottom (western) two-thirds, the white area is snow cover on the upper slopes of the mountains. By using this snow cover as an indicator, the drainage network of the mountain system can be accurately mapped. By computing the area of snow cover and correlating it with time of year and snow depth, the amount of water available for irrigation could be predicted. Such a prediction would be extremely important in southern Morocco where most cultivation is the direct result of irrigation.

Careful study of figure 19-6 will reveal the presence of the city of Marrakech, slightly to the lower left of the center. The city is near the V-shaped confluence of the Oued Tensift and one of its major tributaries from the High Atlas Mountains, the Oued Issil.

Eastward from Marrakech, the valley of the Oued Zate can be traced back into the interior of High Atlas. The main ridge of the mountains can be crossed through the Tizi n' Tichka Pass into the valley of Drâa on the eastern or Saharan side of the mountains. The complexity of the geologic structure to the east of the mountain stands out sharply in figure 19-6 because, in this desert, environmental structure is not masked by overlying vegetation. Just to the lower right of the center of the photograph, the linear signature of the irrigated cultivation in the Drâa Valley appears dark green. This signature can be traced across or through the geologic structure to the edge of the desert where it turns sharply southeastward. The Oued Drâa flows toward the Atlantic Ocean along the southern edge of the Anti-Atlas where its course is largely controlled by the up-tilted rock formations of the Saharan Plateau that form the southern flanks of the Anti-Atlas.

Another valley can be seen between the High Atlas to the north and the Anti-Atlas to the south (beginning at the lower center and ending at the bottom margin of fig. 19-6). This is the valley of the Oued Sous. Land use is intense over much of the valley, and a condition of rural overpopulation sends migrants to all parts of Morocco. Yet, except along the water courses, few traces of man's activity can be observed on the landscape.

To the northeast of the Sous Valley, a spur of snow-covered highlands separates the Sous and Drâa Valleys. This area is shown as a knot of high ground that connects the Anti-Atlas with the High Atlas. Known as Jebel Siroua, these highlands are somewhat different in character from the Anti-Atlas and High Atlas; they appear more rounded and the drainage basins are less numerous and appear less deeply entrenched. Geologically younger and sharply contrasted with the folded sediments of the other two mountain ranges, Jebel Siroua is a large volcanic extrusion.

The steep mountain valleys of these ranges are peopled largely by Berbers living in isolated, fortified villages. The villages are so small that they are unobservable at the scale shown in figure 19-6. It is impossible to distinguish the intensive land use in these valleys.

Southern Morocco is not densely populated by world standards, yet there are many people living on the land, especially in small, nucleated villages. The land is cultivated intensively where irrigation water is available, and it is used extensively for grazing on the nonirrigated uplands. In photographs of this sparsely vegetated region, however, a photointerpreter with some knowledge of the landscape must search carefully before he can detect traces of man. The urban signatures in this photograph are extremely different from those shown in the photographs of Chicago, Dallas/Fort Worth, and Miami. In this generally semiarid landscape, the cities of the developing country blend into the background of the landscape. There are probably many reasons for this, but city size, building size, and building materials are undoubtedly the most important factors.

REFERENCES

19-1. Raina, B. N.: The Use of Satellite Photography in Interpretation of Regional Geology. Proceedings of the Eighth International Symposium on Remote Sensing of Environment, vol. II, Environment Research Institute of Mich., Willow Run Lab. (Ann Arbor, Mich.), 1972, pp. 1213-1236.

19-2. Holz, Robert K.; Huff, David L.; and Mayfield, Robert C.: Urban Spatial Structure Based on Remote Sensing Imagery. Proceedings of the Sixth International Symposium on Remote Sensing of Environment, vol. II, Infrared Optics Lab., Willow Run Lab. (Ann Arbor, Mich.), 1969, pp. 819-830.

19-3. Simonett, D. S.; and Henderson, Floyd M.: On the Use of Space Photography for Identifying Transportation Routes: A Summary of Problems. Proceedings of the Sixth International Symposium on Remote Sensing of Environment, vol. II, Infrared Optics Lab., Willow Run Lab. (Ann Arbor, Mich.), 1969, pp. 855-878.

19-4. Carter, Louis D.; and Stone, Richard O.: Interpretation of Orbital Photographs. Phot. Eng., vol. XL, no. 2, Feb. 1974, pp. 193-198.

19-5. Holz, Robert K.; and Boyer, Robert E.: Patterns From Apollo VI Photos. Phot. Eng., vol. XXXVIII, no. 10, Oct. 1972, pp. 974-984.

19-6. Nunley, R. E.: Living Maps of the Field Plotter. Commission on College Geography, Tech. Paper 4, The Association of American Geographers, Washington, D.C., 1971.

20. AFRICAN DROUGHT AND ARID LANDS

N. H. MacLeod[a†] and J. S. Schubert[b]

The conclusions discussed in this report are based on Skylab 4 premission briefings, a study of some of the handheld photographs, and postmission debriefings. From these findings, superiority in some aspects of the observational capacity of man in space over that of ground-based scientists has been established. Scientists on the ground used mechanical data sources such as the Earth Resources Technology Satellite (ERTS), whereas the Skylab crewmen used premission onboard references and in-flight orientation materials and other data sources as a basis for their observations. The crewmen's visual acuity and color separation ability, correlative and integrative functional ability, physical ability to aim sensors at selected sites, and the Gestalt function of his mind (a human ability to fill information gaps caused by clouds, atmospheric opacity, etc.) are the basis for this conclusion.

Crewmen can learn to classify features that are new to them; they are already trained to recognize landmarks useful in pilotage. During the Skylab 4 mission, the crewmen learned to classify land use units, to estimate the proportions of the components of land units, and to classify land use features previously unknown to them (i.e., cultural patterns in East Africa).

The African drought sector was observed and photographed by the Skylab 4 crewmen. Seasonal burning patterns, dust- and smoke-cloud movement, vegetational patterns of freshwater marshes, and land surface color and characteristics were of direct interest.

In terms of arid areas, the crewmen were able to differentiate clearly between western or European arid land development and that found in Africa. This differentiation involved an independent learning process through which the crewmen recognized anomalies in African land use and correctly assessed their significance.

In a negative sense, the crewmen experienced difficulties in locating small features and in orienting themselves before site acquisition. While vegetative differences were observed, differences in contiguous plant communities were obscured because of low contrast. The difficulty in observing seasonal changes and dormant or dead vegetation in Africa may be attributed to the very high

---

[a] The American University.

[b] NASA Goddard Space Flight Center.

[†] Principal Investigator.

reflectance of the land surface in the drought areas. The observer on the ground can use false color techniques and digital enhancement to improve contrast, and to make use of reflectance characteristics. The crewmen did not have this capability. Special sensors such as high-resolution radiometers that produce multiband data might be provided so that observers could check their assumptions, enhance contrast, use digital analysis in real time, and generally expand their analytical resources. In this manner, intepretations and recommendations from future observers can be accomplished in real time.

Because arid regions are frequently uniform in brightness and because any atmospheric aerosols reduce scene contrast, these regions are difficult for the human sensors and mind to classify. The Skylab 4 crewmen reported that semiarid regions (those of particular current interest to land-management specialists) have even less visual contrast and appear even more "bland." Semiarid regions are inherently difficult to observe because of this characteristic. Where western land use practices were used, the patterns were rectilinear and the observational capacities of the crewmen resulted in a facility for classifications. In underdeveloped areas where curvilinear geometries of land use patterns prevailed, the crewmen were less confident of their classifications.

NEW FEATURES AND PHENOMENA

Burning

In Australia, Argentina, and East and West Africa, both visual observations and handheld photography were used to observe large-scale burning. While burning is considered to be both good and bad, the extent of burning in arid and semiarid regions (both developed and developing) is surprising. Scientists realized this fact after studying the Skylab 4 visual sightings and photographs. In Nigeria, Cameroon, and the Central African Republic, for example, firelines (actual lines of burning) extending more than 640 kilometers (east-west orientation) were observed during nighttime flyover. Smoke plumes and burn scars from recent burns were photographed in these areas.

A particularly interesting visual observation made over the Gourma region of Mali (southeast Mali) was that the burn was occurring on a landscape that appeared to be void of vegetation. After the rainy season for this area, the vegetation was straw colored, the color of the soil. In this zone, the burning was destroying reserve fodder (bushes and trees) in an area in which cattle were dying of drought-induced starvation. Observations such as these could be used to warn herders to avoid the area.

The enormous extent of burning in the Sahelian Zone of Africa is slowly being recognized from the Skylab 4 visual and photographic documentation, ERTS imagery, and other sources. In a current study, ERTS imagery is being used to classify the region in which long firelines were observed by the crewmen according to intensity of the burning. The particular area was not previously classified as high-intensity burning although it was observed as such from the Skylab 4 spacecraft. This visual observation is, therefore, a valuable addendum to the study.

Although burning does increase mineral availability to plants, reduce insect population, selectively maintain resistant plant species, and simplify clearing activities, there are negative aspects. The most harmful result of the burning is the removal of vegetative cover during the hottest and windiest season, which increases the susceptibility of the land to wind erosion. Burning also reduces the organic matter of the soil, which was already badly depleted in the Sahel. Organic matter is an important factor in the maintenance of good soil physical properties, available minerals, and litter that moderates the surface microclimate of the soil.

In addition, rangeland burning reduces the number of useful plant species. Although the burning of rangeland traditionally results in new grass growth, burning destroys bushes and trees that are important forage producers in the Sahel where cattle are well adapted to this food source. The current view maintained by U.S. agencies and scientists who are preparing development strategies in the Sahel is that burning occurs just before the rainy season starts; burning at this time results in minimum harm and maximum benefit. The Skylab 4 observations, however, clearly indicate that the burns occur at the worst time, or just after the rainy season ends. The near-real-time information transfer from space by the crewmen over this part of Africa and the supporting photographs are being used to correct the erroneous impression of the U.S. planners.

Dust and Smoke Clouds

Very significant observations of cloudiness in Africa were made by the Skylab 4 crewmen as they described and differentiated these "smoky" or "dusty" clouds from white clouds. They observed the movement of these former cloud systems into the Atlantic and Indian Oceans from West, Central, and East Africa.

The significance of the observations is twofold. First, the crewmen were able to separate the cloud types into normal and dusty clouds; second, the crewmen were able to observe the distribution and fate of the clouds as the systems moved on a continental scale far into adjacent oceans.

National Oceanic and Atmospheric Administration studies have shown that the cloud systems moving from West Africa into the Atlantic Ocean reduce solar irradiation of the ocean surface by 25 percent, that the systems retain their identity as a stable inversion layer as far as the Caribbean Sea, and that this layer suppresses cumulus cloud formation (i.e., the normal exchange of water and energy between atmosphere and ocean does not occur).

The ability of the crewmen to classify the cloud systems and to note their extent should lead to further analysis of the effect of African dust and smoke on global weather events. If the denuded Sahel is a significant source of dust and smoke and if these aerosols are significantly affecting both energy balance and regional hydrologic cycles, the observations of the Skylab 4 crewmen should be used to provide more and faster aid in the effort to revegetate and restabilize this region. Skylab visual observations data, in this instance, should stimulate action in the interest of the United States as well as the afflicted African states.

Land Use Patterns

A particularly interesting learning cycle occurred during the Skylab observations regarding the crewmen's recognition of the rectilinear land use patterns of western agriculture in arid regions as contrasted to the traditional patterns found in Africa. The crewmen were briefed on a land use problem in the Sahel (overcropping and use of marginal lands) but were not able to assess these problems from space in the context in which they were presented in premission briefings.

However, the crewmen independently analyzed the circular "cellular" patterns common in the Sahel and the interfluvial cropping patterns of Tanzania. They hypothesized, correctly, that they were observing the local pattern of cultivated land, the feature that had been ineptly described to them for West African observations. Although the crewmen did not feel that they could observe the features requested, they did observe subtle anomalies on the land surface and integrated their observations into a hypothetical scheme. The result was the development of a new observational skill. This skill required months for the authors and their colleagues to acquire even with consultation with anthropologists familiar with the area.

The land use patterns derived from observations of Tanzania are new. These patterns will be compared to similar land use patterns in Zaire and Angola and to dissimilar patterns in West Africa. In Zaire, at least, the land use patterns observed during the Skylab mission indicate advanced deterioration of the land surface.

Vegetation in the Inland Delta of the Niger River

Because the crewmen could easily identify the inland delta of the Niger River in Mali and because the photographs are valuable data for the Niger River hydrologic studies, two of these photographs (figs. 20-1 and 20-2) are currently being studied. The problem being studied is the disappearance of vegetation in the permanent lakes of the inland delta. This problem may be an important factor in explaining the observed changes in the amplitude and period of the Niger River flood crest. The use of floodwaters for irrigating rice downstream vitally affects food production of the region. The removal of vegetation in the delta is thought to have resulted in a more rapid and higher flood that lasted 1 month instead of 3 months. In 1973 and 1974, for instance, the flood arrived at Niamey, Niger, 2 months early, which drastically affected vegetable, rice, and other irrigated crop production in that area.

Areas east of the delta in which a large, dry streambed has been noted are included in figure 20-2. This streambed previously had not been visible in either ERTS or Apollo Earth-looking imagery. These streambeds are very important in the future development of the Sahel. Although they are difficult for crewmen to observe, this photograph indicates that observations from space can provide new information on this important resource. The streambeds, which have not yet been exploited, are important because of their juxtaposition to irrigable soils and near-surface water in these dry channels.

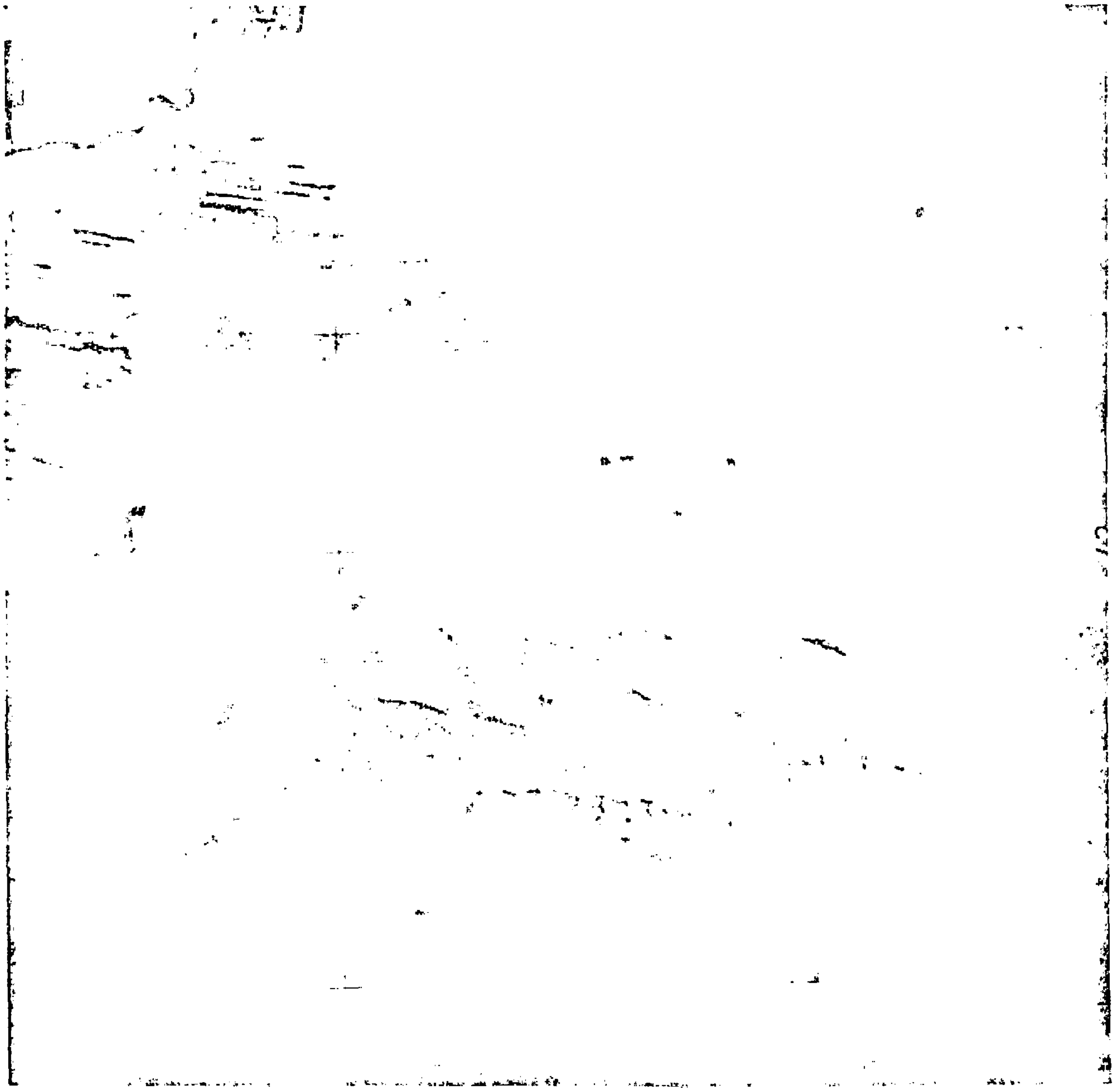


Figure 20-1.- Inland delta of the Niger River in Mali (SL4-136-3380).

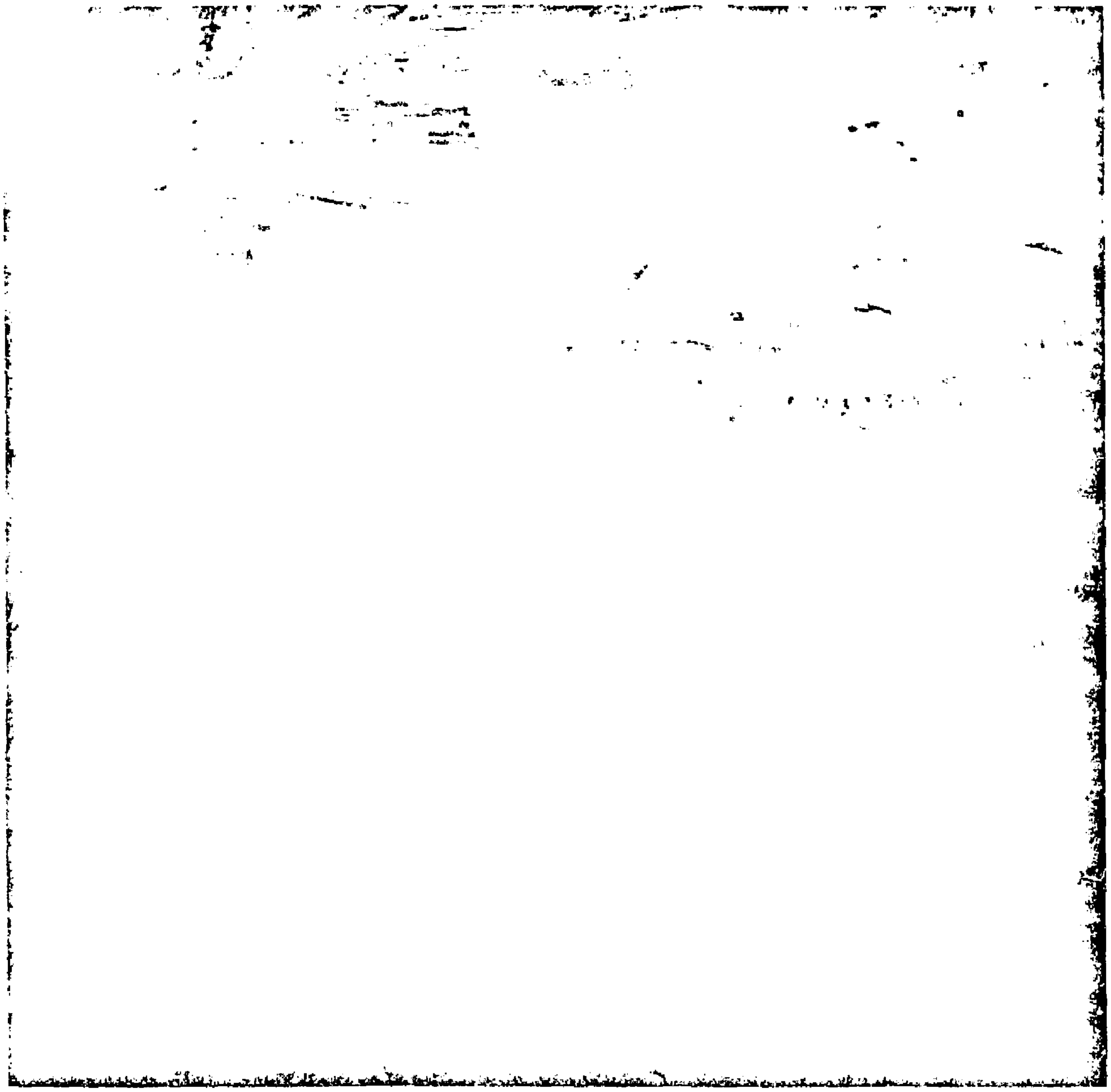


Figure 20-2.- Area east of the inland delta of the Niger River showing a large, dry streambed (SL4-136-3382).

CHARACTERISTICS OF THE OBSERVATIONAL CAPACITY

OF THE CREWMEN

In the debriefing session with the crewmen, it became evident that man's mode of observation from space and that used by Earth-observing sensors mounted on a satellite platform are quite different. In this and other visual observations subjects that were debriefed, it became evident that not only the mode of observing the Earth is different but that the intent of man observing the Earth is different when man controls how and what he sees. It became obvious that because of these differences, the two systems (man and sensor packages) are each uniquely adapted for specific functions and that these functions are, in many cases, complementary. During the debriefings, it became evident that man sees correlatively, observes and analyzes relative to his own knowledge, selectively observes, integrates what he sees into a "permanent" record and updates that record, compares what he observes with the record, and makes conclusions based on this comparison. Man's permanent record makes it possible for him to retain both synoptic and historical information and to compare or analyze each new observation relative to that store of knowledge in a real-time mode. Earth-observing sensors, in contrast, observe unselectively but objectively and are more easily adapted to form a permanent but nondiscriminating record. In addition, they may be designed to make finer discriminations (e.g., in color or tone) and to filter out all other unwanted information - a difficult task for man. The crewmen stated that small differences in tone for features of pastel colors were easier to discriminate than dark features of any color.

A specific example of man's correlative observational ability and his ability to integrate information was demonstrated by the observer's description of the source of smoky clouds in the Indian Ocean. The crewmen were able, by observing on successive passes at different times of day and by using their recording and relating ability, to identify the source of some of the clouds as the burning practices in Tanzania and Kenya. As previously mentioned, this observation is very significant in furthering the understanding of environmental relationships in Africa.

The discovery of the source of the clouds actually was based on two separate types of observation. The first of these was the observation of unusual clouds. The crewmen observed that the density and shape of these clouds were similar to cirrus formations, but they appeared to be darker. No altitudinal information was available to the crewmen; such information also would not have been available through conventional sensors for observing surface features. The presence of multilayer atmospheric samplers activated by the crewmen could have confirmed the presence and type of these clouds as well as provided a permanent record for further analysis. This type of sampling might provide confirmation data and a better descriptive base for future observations by man.

In addition to the cloud observations, at night the crewmen observed a bright strip of land (approximatley 640 kilometers long) on the African Continent. By day, this strip was obscured by dark plume patterns that moved. The commander concluded that the dark plumes represented smoke produced by fires, which were the bright spots at night. In addition, because of the extent of the fires and their proximity to what he identified as vegetation, he was able to conclude that he was seeing a slash-and-burn agriculture on a scale never before recognized. This conclusion confirms man's ability to observe, remember what was previously observed, compare the observations by using background knowledge, infer causal relationships, and arrive at a feature identification. Although sensors or cameras could be used to obtain such data, the process of interpreting the data, whether recorded by sensors or by man, and drawing conclusions from them is still only possible through the reasoning power of man.

Discerning the relationship between the fires and the smoky clouds is the type of correlative integration of information that may always be unique to man. The crewmen decided to follow the smoky clouds to their source or sources; thus, ignoring gaps in the data, they selectively observed the clouds as they progressed over the African Continent. Human synoptic selective memory made it possible to screen out other, unrelated information and thus to be able to track clouds. Because of their ability to compare and correlate, the crewmen were able to observe similar clouds emanating from fires and to conclude that the fires were a source of the clouds. Although the crewmen were not able to observe discrete sources for other smoky clouds, including the Atlantic Ocean clouds, they were able to search for such a source. Dust arising from the desert is also a possible source of cloud formation. In future missions, with the descriptive material that can be provided by the crewmen, clouds may be traced to their source.

TRAINING FOR FUTURE MISSIONS

Although the training time for crewmen on future missions is very limited, particularly for the Apollo-Soyuz Test Project, observations on Shuttle missions may be assisted by intensive training in ecological subjects. Such training will provide crewmen with the sense of interrelationships of soil, water, vegetation, and human-occupation patterns that is essential for making correlative and interpretive observations. These interrelationships are expressed as subtle but recognizable differences in the land surface. In addition to such training, sensors for direct use by crewmen should be developed to permit observations of phenomena outside the visible spectrum. Further, a major effort should be made to integrate data flow from unmanned satellites and to provide observers in orbit with the output from resource information systems that are now under development. The Skylab 4 crewmen demonstrated clearly that the synthesis of information by orbiting observers does lead to new and important insights regarding the condition of the surface of the Earth. Further training, special sensors, and a continuous information uplink will provide the capability for man in space to exploit his special abilities.

21. PRELIMINARY REPORT ON SKYLAB DIM-LIGHT ACTIVITIES

L. Dunkelman[a†]

This preliminary report on specific activities involving dim-light and twilight observations includes general comments on day and night handheld photographs. The report is divided into three sections: scientific return, in-flight techniques, and ground administrative techniques. The section on scientific return is limited in scope for two reasons. First, the relatively small time allotment for low-light-level observations precluded an abundant data return. Second, much of the film used for these observations has not yet been made available for examination.

SCIENTIFIC RETURN

Photographs taken by the Skylab 3 and 4 crewmen of the limb of the Earth in the direction of the Sun, with the Sun just below the horizon, will be valuable in establishing the nature of the twilight bands reported (refs. 21-1 and 21-2) as a result of visual observations and as a result of analyses of 16-millimeter color photographs taken during the Gemini IV mission (refs. 21-3 and 21-4). Analyses of these photographs may provide additional information in support of the theory described in reference 21-3 that states that the Chappuis visible absorption bands of ozone are responsible for the central blue band that is seen between the two whitest bands.

The Skylab crewmen were unable to distinguish, either visually or photographically, the city of Addis Ababa, Ethiopia, during daytime observations. Perhaps when a city has such extreme lack of contrast in visible light, night photography can be useful in gaining information on the cultural patterns. Photographs of other cities were taken at night during the Skylab 4 mission.

---

[a] NASA Goddard Space Flight Center.

[†] Principal Investigator.

IN-FLIGHT TECHNIQUES

The handheld cameras and the film on board Skylab were adequate to satisfy the objectives of the Visual Observations Project. However, there is a need for either quick-exchange film magazines or dedicated film and camera body systems, for greater recording sensitivities, and for an intensifier camera, if special low-light-level experiments are included.

RECOMMENDATIONS

For the Apollo-Soyuz Test Project and Shuttle missions, the visual observations ground support team should include a photoscientist and a camera engineer to assist the crewmen with lens setting and filter selection and with camera anomalies. Future visual observations teams should study the results of the Skylab visual observations and participate in the visual observations experiment training together with the crewmen.

REFERENCES

20-1. Schirra, Walter M., Jr.: Air-Ground Communications of the MA-8 Flight. Results of the Third United States Manned Orbital Space Flight. NASA SP-12, 1962, p. 104.

20-2. O'Keefe, John A.; Dunkelman, Lawrence; Soules, Stanley D.; Huch, William F.; and Lowman, P. D., Jr.: Observations of Space Phenomena. Mercury Project Summary Including Results of the Fourth Manned Orbital Flight. NASA SP-45, 1963.

20-3. Dunkelman, L.; Gill, J. R.; McDivitt, J. A.; Roach, F. E.; and White, E. H., II: Geo-Astronomical Observations, Manned Space Flight Experiments Symposium, Gemini Missions III and IV. Oct. 1965, pp. 1-18.

20-4. Dunkelman, Lawrence; and Mercer, Robert D.: Dim Light Photography. Gemini Mid-Program Conference. NASA SP-121, 1966.

PART C

RECOMMENDATIONS

22. RECOMMENDATIONS

The Visual Observations Project Team[a]

The recommendations by the Visual Observations Project Science Team members and the crewmen for improved techniques, methods, equipment, training, and overall conduct of Earth observations for future missions are important results of the Visual Observations Project. The need for improved training was stressed throughout the debriefing sessions by both the members of the Science Team and the crewmen. The crewmen recommended that training begin 2 years before a mission and include overflying sites to develop observation techniques and to practice using the handheld camera equipment in a limited time line. A concentrated study of previous space imagery should be integrated into crew training. The crewmen also stressed the early preparation of the onboard data packages to increase the time available for studying and reviewing the visual observations material with the Science Team members. The extent of the training should be determined partly by the mission profile. However, the crewmen recommended that the training provide a broad knowledge of the disciplines, such as an understanding of the relationships among soil, water, and vegetation in an ecological system, and the specific types of information to be collected for individual sites. Extensive use of photographs that illustrate a variety of Sun angles and viewing angles is also recommended to acquaint the observer with the appearance of the sites and features.

For the Apollo-Soyuz Test Project mission, the crewmen recommended concentrating the training on a limited number of sites because of the short duration of the mission and the limited time allotted to the experiment.

To increase the scientific returns on future Earth observation manned missions, the Science Team members recommended that one of the crewmen be a scientist with academic training and experience in Earth science.

Major criticisms from the crewmen and the Science Team members concerned the onboard equipment. The crewmen indicated that the camera systems were not designed to obtain photographs of the wide variety of specific features and phenomena required to support visual observations. The following additions to the visual observations equipment were recommended.

1. A compact single-lens reflex camera with zoom lens

2. Camera imagery that contains digital Greenwich mean time and Julian day readouts

---

[a] The members of the Visual Observations Project Team are listed in table 4-III of this report.

3. An automatic recording system for lens settings, focal lengths, and frame and magazine numbers

4. Infrared scanners

5. Color charts

6. Polarimeters

7. Spectrometers with real-time readouts

8. Polaroid cameras

9. Black-and-white film for tropical storm photographs

10. Remote-control cameras

11. Collapsible optics that could be articulated without altering spacecraft attitude

12. Real-time recording system for crew observations

13. Instruments for measuring and estimating distances

The need for more effective visual aids to assist in determining the location of geographic sites and features from the spacecraft was also emphasized. Such aids would include a moving map display with filmed projections of groundtracks, an image-projection device (to supplement the Visual Observations Book), and microfilm or video cassettes designed for study of specific features or phenomena.

Specialized viewing aids would also be necessary for certain disciplines. Color charts available on board Skylab 4 often required looking from the binoculars to the chart and back, which wasted valuable viewing time. Incorporating a color chart or color wheel in the binoculars would save time and would ensure a greater degree of accuracy in determining the natural color of features. For identification of geologic features and phenomena, color charts such as the rock color charts used by the U.S. Geological Survey would be useful. Similarly, the Forel scale modified for easy use would provide a basis for documenting ocean colors.

Other suggestions for facilitating Earth observations for future missions included high-resolution television cameras, weather charts, a system for integrating information from unmanned satellites with mission information, and headsets adapted for real-time recording of observational data.

The crewmen agreed that the ideal visual observations system for future missions would include an Earth observatory in the spacecraft. This observatory could resemble a bombardier's turret and would provide a permanent Earth-viewing station for performing visual observations tasks and for collecting visible, infrared, and microwave data with a series of sophisticated sensors. The sensors could be operated in an automatic mode or by the crewmen for obtaining information over specific sites or to record unique phenomena. In addition to unmanned synoptic Earth resources studies, other missions using man in real time to determine the type of remote-sensor information to be obtained and the conditions for sensing will greatly increase the capability to acquire new knowledge of Earth resources.