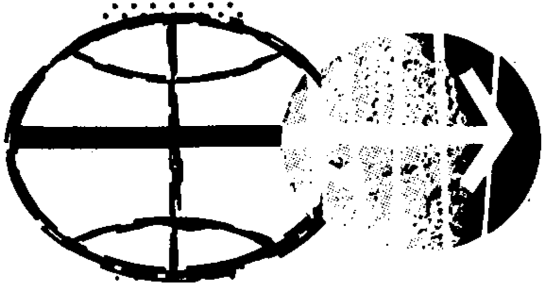
Copy No.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

ACCESSION LIST
FOR THE
EARTH RESOURCES AIRCRAFT PROGRAM
DATA BANK

MARCH 15, 1967

(THIS ISSUE SUPERSEDES ALL PREVIOUS ISSUES)



MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

ACCESSION NUMBER

FILE IDENTIFICATION	DOCUMENT TYPE	ZONE	SITE NUMBER	BIN OR FILE NUMBER
NR-	01-	DK-	002-	0003

1. NR - Distinguishes this file (Natural Resources) from other NASA files

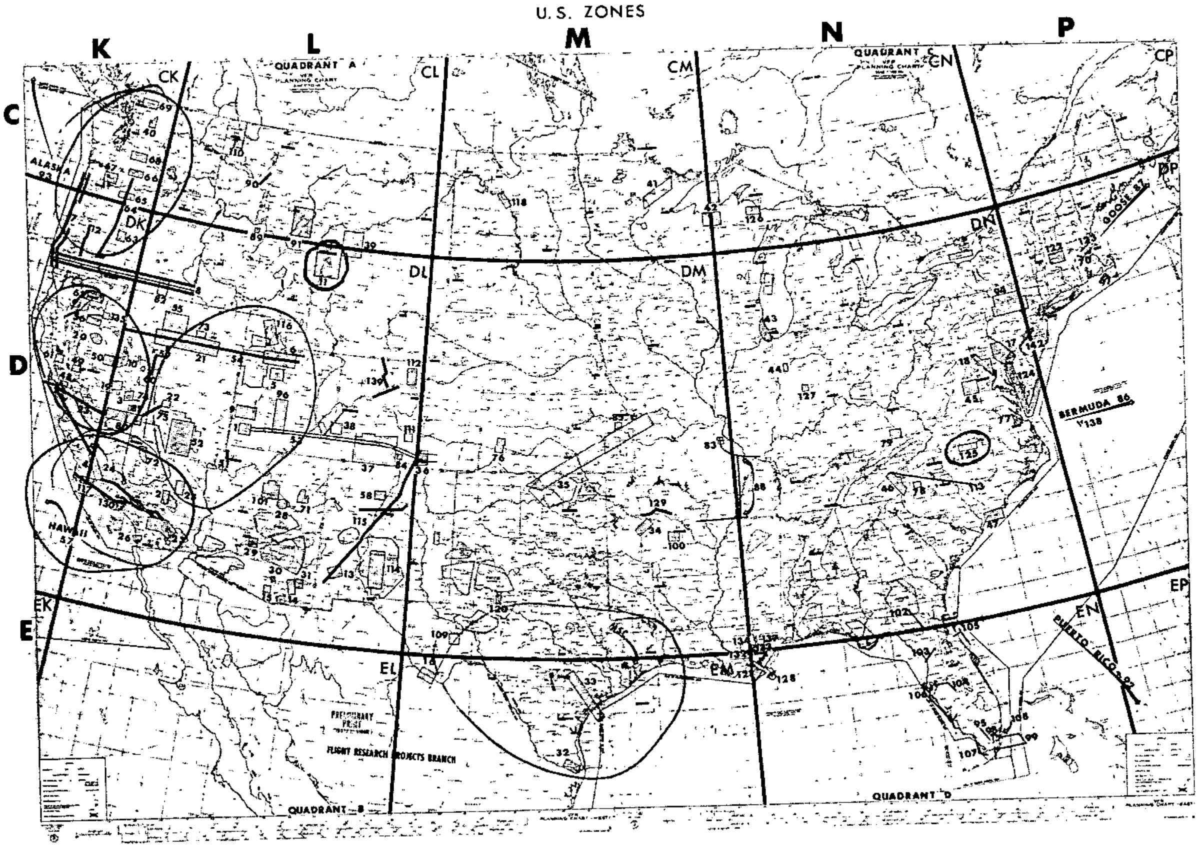
2. Document Type

   01 - Site Maps
   02 - Site Description
   03 - Mission Request
   04 - Mission Reports
   05 - Technical Reports
   06 - Progress Reports
   07 - Summary Reports
   08 - Miscellaneous Documents

3. Zone - Locates general geographic area where data was collected. This field groups documents by general geographic area when more than one site is overflown. If more than one zone is overflown, document is classified in the zone of greatest coverage. The numerals "00" are used when zoning is not appropriate. See pages iv and v for zone numbers.

4. Site Number - Site numbers are indicated in the U.S. zone shown on page iv. Site numbers are assigned by RESECS, U.S. Geological Survey.

5. Bin or File Number - The number used by the Data Bank to locate the shelf position.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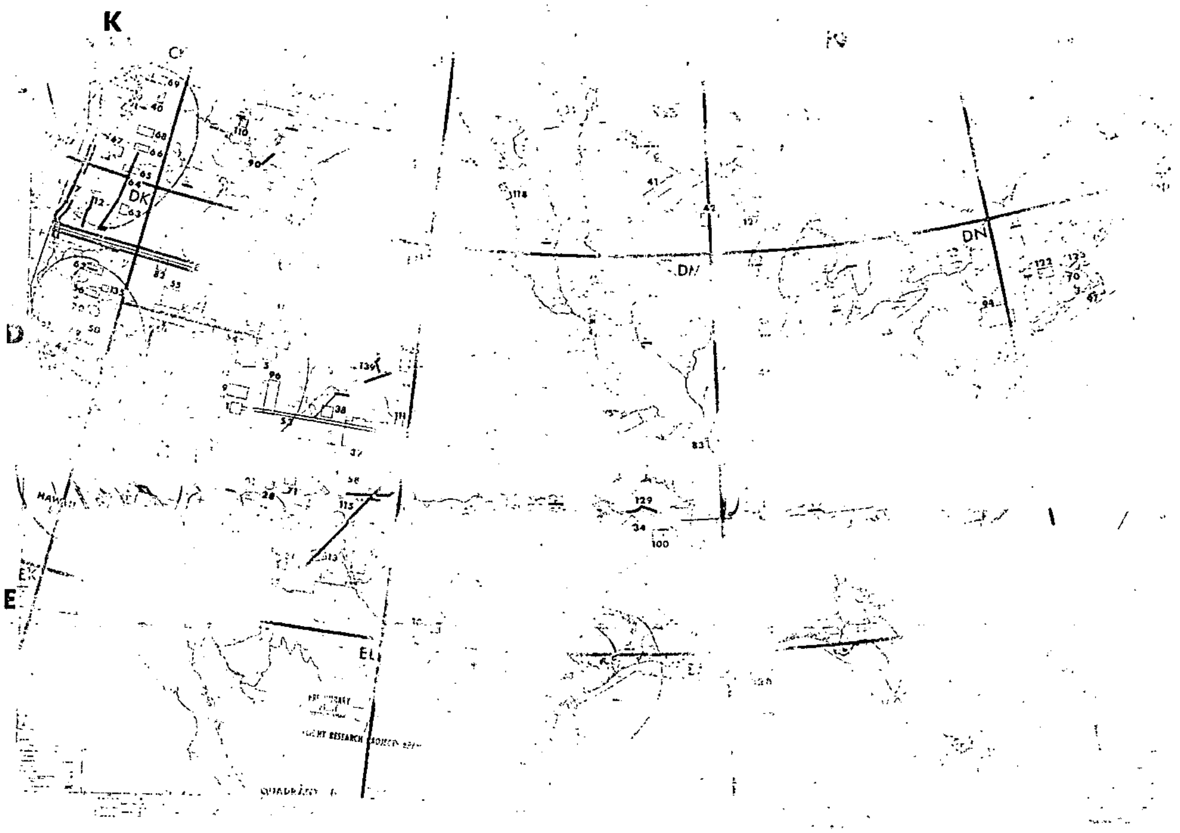
U.S. ZONE MAP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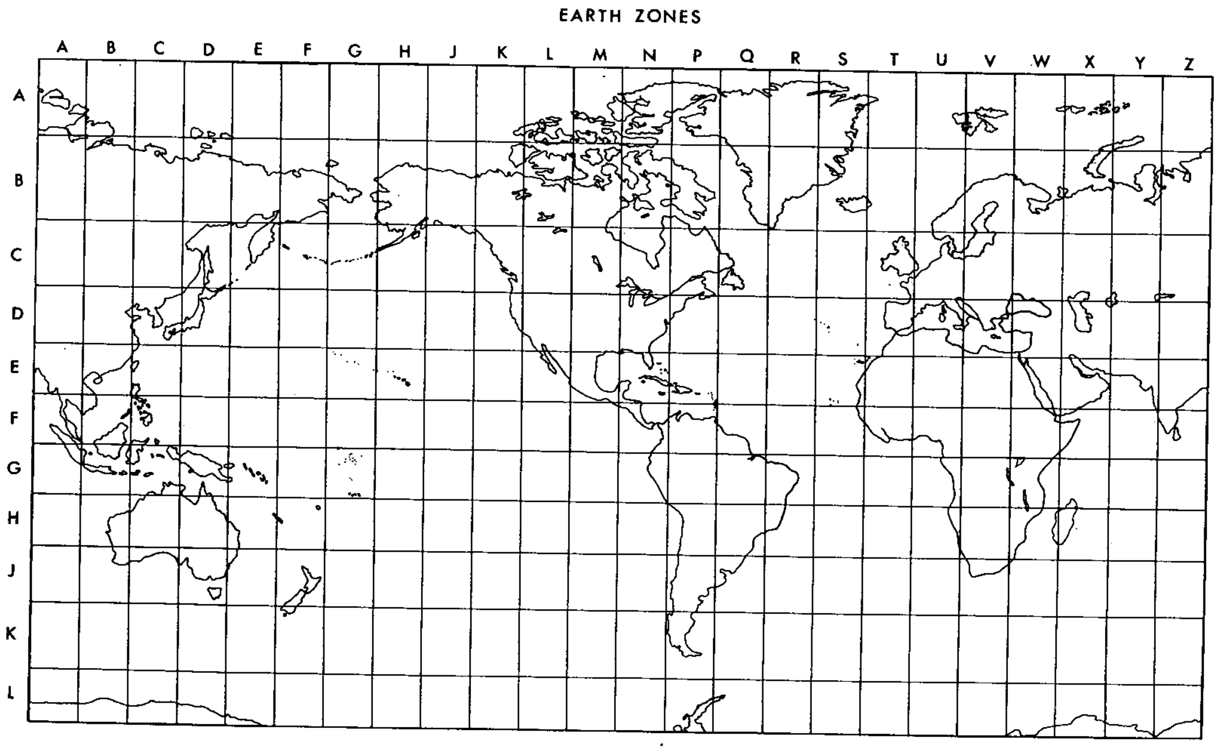

EARTH ZONE MAP

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SITE MAPS

Accession no.	Location	Type	Size
NR-01-00-999-0001		Map, U.S.A., Site Index	17" X 20"
NR-01-00-999-0002		Map, U.S.A., Site Index	8" X 10½"
NR-01-DK-002-0003	Site 002-Pisgah Crater, Calif.	Regional	17" X 20"
NR-01-DK-002-0004	Site 002-Pisgah Crater, Calif.	Detail	17" X 20"
NR-01-DK-003-0005	Site 003-Mono Craters, Calif.	Regional	17" X 20"
NR-01-DL-006-0006	Site 006-Salt Lake (Salt Lake Dist.) Utah	Detail	17" X 20"
NR-01-DK-007-0007	Site 007-Coast Range, Ore./Wash.	Detail	17" X 20"
NR-01-DL-029-0008	Site 029-Phoenix, Ariz.	Detail	17" X 20"
NR-01-DL-031-0009	Site 031-Willcox Dry Lake, Ariz.	Detail	17" X 20"
NR-01-DK-040-0010	Site 040-Cascade Mtns. (Cascade Glacier Site)	Detail	17" X 20"
NR-01-DN-046-0011	Site 046-Asheville, N. C.	Regional	17" X 20"
NR-01-DN-046-0012	Site 046-Asheville, N. C.	Detail	24" X 176"
NR-01-DL-051-0013	Site 051-Mesquite Sedimentary Site, Ariz.	Regional	24" X 176"
NR-01-DL-051-0014	Site 051-Mesquite Sedimentary Site, Ariz.	Detail	24" X 176"
NR-01-DK-072-0015	Site 072-Coso Hot Springs, Calif.	Detail	24" X 176"
NR-01-DP-086-0016	Site 086-Argus Isle, Bermuda	Regional	24" X 176"
NR-01-DP-086-0017	Site 086-Argus Isle, Bermuda	Detail	24" X 176"
NR-01-EM-032-0018	Site 032-Weslaco, Tex.	Regional	17" X 22"

SITE MAPS (cont)

Accession no.	Location	Type	Size
NR-01-DN-043-0019	Site 043-Evanston, Ill.	Detail	17" X 22"
NR-01-DN-043-0020	Site 043-Englewood, Ill.	Detail	17" X 22"
NR-01-DN-043-0021	Site 043-Aurora, Ill.	Regional	17" X 22"
NR-01-EN-105-0022	Site 105-Crescent Beach Submarine Spring, Fla.	Regional	17" X 22"
NR-01-EN-106-0023	Site 106-Clearwater/Naples Submarine Spring, Fla.	Regional	17" X 22"
NR-01-EN-108-0024	Site 108-Cutler Area Submarine Spring, Fla.	Regional	17" X 22"
NR-01-DL-003-0025	Site 003-Mariposa, Calif./Nev.	Regional	17" X 22"
NR-01-CP-087-0026	Site 087-Goose Bay	Regional	17" X 22"
NR-01-EN-128-0027	Site 128-Bretion Sound	Detail	17" X 22"
NR-01-CK-040-0028	Site 040-Cascade Mtns.	Detail	17" X 22"
NR-01-DL-130-0029	Site 130-Southern Calif.	Detail	17" X 22"
NR-01-DL-130-0030	Site 130-Southern Calif.	Regional	17" X 22"
NR-01-DL-011-0031	Site 011-Yellowstone Nat'l. Park	Detail	17" X 22"
NR-01-DL-011-0032	Site 011-Yellowstone Nat'l. Park	Regional	17" X 22"
NR-01-DM-076-0033	Site 076-Garden City, Kansas	Regional	17" X 22"
NR-01-DL-114-0034	Site 114-White Sands, N. M.	Regional	17" X 22"
NR-01-DK-024-0035	Site 024-San Andreas Fault	Regional	17" X 22"
NR-01-DK-003-0036	Site 003-Mono Crater, Calif.	Detail	17" X 22"
NR-01-DK-020-0037	Site 020-Bucks Lake, Calif.	Detail	17" X 22"
NR-01-DL-052-0038	Site 052-Nevada AEC	Regional	17" X 22"

SITE MAPS (cont)

Accession no.	Location	Type	Size
NR-01-DK-019-0039	Site 019-Sonoro Pass	Detail	17" X 22"
NR-01-DK-135-0040	Site 135-Harvey Valley, Calif.	Detail	17" X 22"
NR-01-DN-043-0041	Site 043-Chicago, Ill.	Detail	17" X 22"
NR-01-DN-043-0042	Site 043-Chicago, Ill.	Detail	17" X 22"
NR-01-DL-114-0043	Site 114-White Sands, N. M.	Regional	17" X 22"
NR-01-EN-099-0044	Site 099-Florida Straits	Regional	17" X 22"
NR-01-EN-128-0045	Site 128-Mississippi Delta	Regional	17" X 22"
NR-01-DP-138-0046	Site 138-Gulf Stream North	Regional	17" X 22"
NR-01-00-999-0047	*U.S. Site index to Special Missions 1-26, IR Imagery August 1966, U.S. Geological Survey (Reference only)		
NR-01-00-998-0048	Quadrant A	Map, U.S.A., Site Index	17" X 22"
NR-01-00-998-0049	Quadrant B	Map, U.S.A., Site Index	17" X 22"
NR-01-00-998-0050	Quadrant C	Map, U.S.A., Site Index	17" X 22"
NR-01-00-998-0051	Quadrant D	Map, U.S.A., Site Index	17" X 22"
NR-01-EM-032-0052	Site 032-Weslaco, Tex.	Detail	17" X 22"
NR-01-EN-095-0053	Site 095-Everglades, Fla. (Hydrology)	Detail	17" X 22"
NR-01-EN-128-0054	Site 128-Mississippi Delta, New Orleans	Regional	17" X 22"

*All request for IR Imagery Index should be directed to Mr. R. W. Fary, Jr., Code RESECS, see distribution list for address.

SITE MAPS

Accession no.	Location	Type	Size
NR-01-EN-998-0055	Site 098-Homestead, Fla.	Regional	17" X 22"
	Site 102-Statenville/Lake City, Fla., Phosphate		
	Site 103-Crystal River, Fla., Phosphate		
	Site 104-Wauchula/Tampa, Fla., Phosphate		

SITE DESCRIPTION

Accession no.	Description
NR-02-DL-001-0001	Site 001-Cedar City (Iron Springs, Utah)
NR-02-DK-002-0002	Site 002-Pisgah Crater, Calif.
NR-02-DK-004-0003	Site 004-Carrizo Plains, Calif.
NR-02-DL-005-0004	Site 005-Eureka (Tintic Dist., Utah)
NR-02-DL-006-0005	Site 006-Salt Lake (Salt Lake Dist.)
NR-02-EK-007-0006	Site 007-Coast Range Lines, Ore.
NR-02-DL-009-0007	Site 009-San Francisco Dist., Utah
NR-02-DL-010-0008	Site 010-Carson City (Comstock Dist., Nev.)
NR-02-DL-011-0009	Site 011-Yellowstone (Yellowstone Nat'l. Park)
NR-02-DL-015-0010	Site 015-Twin Buttes (Pima Dist., Ariz.)
NR-02-DN-017-0011	Site 017-Baltimore (Harford-York Md./Pa.)
NR-02-DN-018-0012	Site 018-Hagerstown (Central Appalachian Piedmont, Md./Pa./Va.)
NR-02-DK-019-0013	Site 019-Sonora Pass
NR-02-DL-021-0014	Site 021-Battle Mtn. (Rye Patch Res.-Ruby Mtns., Nev.)
NR-02-DL-022-0015	Site 022-Tonopah, Nev.
NR-02-DK-023-0016	Site 023-Inyo Nat'l. Forest (Ward Mtn.-Crater Mtn. Site)
NR-02-DL-024-0017	Site 024-San Andreas Fault
NR-02-DL-026-0018	Site 026-Scripps Beach, Calif.
NR-02-DL-027-0019	Site 027-Salton Sea
NR-02-DL-028-0020	Site 028-Winslow (Meteor Crater)

SITE DESCRIPTIONS (cont)

Accession no.	Description
NR-02-DM-034-0021	Site 034-Ouachita Mtns.
NR-02-DM-036-0022	Site 036-Spanish Peaks
NR-02-DL-038-0023	Site 038-Great Sage Plain (Lisbon Valley Dist., Utah/Colo.)
NR-02-CK-040-0024	Site 040-Cascade Mtns. (Cascade Glacier Site)
NR-02-DN-044-0025	Site 044-Purdue (Purdue Ag. Site)
NR-02-DK-050-0026	Site 050-Donner Pass
NR-02-DL-051-0027	Site 051-Mesquite Sedimentary Site
NR-02-DL-052-0028	Site 052-Nevada AEC
NR-02-DL-054-0029	Site 054-Smoke Creek Desert-Heber, Utah Line
NR-02-DK-064-0030	Site 064-Central Cascade Range Lines
NR-02-DP-070-0031	Site 070-Hopkinton-Milford, Templeton, Orange Lines
NR-02-DL-071-0032	Site 071-Hopi Buttes, N. M.
NR-02-DL-073-0033	Site 073-Lynn District, Nev.
NR-02-DL-075-0034	Site 075-Goldfield, Nev.
NR-02-DN-079-0035	Site 079-Matewan, Ky.
NR-02-DL-082-0036	Site 082-Alvord Valley, Ore.
NR-02-DM-083-0037	Site 083-Ironton (S) Mo.
NR-02-DP-086-0038	Site 086-Argus Isle, Bermuda
NR-02-DP-087-0039	Site 087-Goose Bay Labrador
NR-02-DN-088-0040	Site 088-Mississippi Valley
NR-02-CL-089-0041	Site 089-Blackbird Dist., Idaho

SITE DESCRIPTIONS (cont)

Accession no.	Description
NR-02-CL-090-0042	Site 090-Alberton, Mont.
NR-02-EP-092-0043	Site 092-Puerto Rico
NR-02-DN-094-0044	Site 094-NE Pennsylvania (Peat Bogs)
NR-02-EN-096-0045	Site 096-Dixie (Fish Lake Nat'l. Forest, Utah)
NR-02-EN-098-0046	Site 098-Homestead, Fla.
NR-02-EN-099-0047	Site 099-Florida Straits (Oceanographic)
NR-02-DL-101-0048	Site 101-San Francisco Volcanic Fields, Ariz.
NR-02-DL-114-0049	Site 114-White Sands Missile Range, N. M.
NR-02-DL-115-0050	Site 115-New Mexico Mineral and Structural Belts
NR-02-DN-127-0051	Site 127-Johnson County Gravel Test No. 1 (Geological)
NR-02-DM-129-0052	Site 129-Arkansas Basin (Geological)
NR-02-DL-130-0053	Site 130-Southern Calif.
NR-02-DK-131-0054	Site 131-Sonora Pass (II) Supplement to NR-02-DK-019-0013
NR-02-DK-008-0055	Site 008-South Oregon Strip
NR-02-DL-139-0056	Site 139-Steamboat Springs, Colo.
NR-02-EN-095-0057	Site 095-Everglades, Fla.
NR-02-DM-120-0058	Site 120-Lake Colorado City, Tex.
NR-02-DN-125-0059	Site 125-Roxboro Reservoir, N. C.
NR-02-DN-141-0060	Site 141-Charleston/Columbia, S. C.
NR-02-DP-142-0061	Site 142-Delaware River Estuary
NR-02-DP-148-0062	Site 148-Lehigh River, Pa.

Aircraft Mission Requests

AIRCRAFT MISSION REQUESTS

Accession no.	Description
NR-03-DK-004-0001	Site 004-Carrizo Plains, Calif.
NR-03-DL-006-0002	Site 006-Salt Lake (Salt Lake Dist.) Utah
NR-03-DK-007-0003	Site 007-Coast Range, Ore/Wash.
NR-03-DK-008-0004	Site 008-South Oregon Strip, Ore.
NR-03-DL-010-0005	Site 010-Carson City (Comstock Dist.) Nev.
NR-03-DL-011-0006	Site 011-Yellowstone Nat'l. Park, Wyo./Mont./Idaho
NR-03-DN-015-0007	Site 015-Twin Buttes (Pima Dist.) Ariz.
NR-03-DN-017-0008	Site 017-Baltimore (Harford-York, Md./Pa.)
NR-03-DN-018-0009	Site 018-Hagerstown (Central Appalachian Piedmont, Md./Pa./Va.)
NR-03-DL-021-0010	Site 021-Battle Mtn. (Rye Patch Res.-Ruby Mtns., Nev.)
NR-03-DL-022-0011	Site 022-Tonopah, Nev.
NR-03-DK-023-0012	Site 023-Inyo Nat'l. Forest (Ward Mtn.-Crater Mtn. Site)
NR-03-DL-024-0013	Site 024-San Andreas Fault, Calif.
NR-03-DL-027-0014	Site 027-Salton Sea, Calif.
NR-03-DL-028-0015	Site 028-Winslow (Meteor Crater) Ariz.
NR-03-DL-038-0016	Site 038-Great Sage Plain (Lisbon Valley Dist.) Utah/Colo.
NR-03-CK-040-0017	Site 040-Cascade Mtns. (Cascade Glacier Site) Ore.
NR-03-DL-052-0018	Site 052-Nevada AEC
NR-03-DL-054-0019	Site 054-Smoke Creek Desert (Heber, Utah)
NR-03-DK-064-0020	Site 064-Central Cascade Range

AIRCRAFT MISSION REQUESTS (cont)

Accession no.	Description
NR-03-DP-070-0021	Site 070-Hopkinton-Milford/Templeton/Crane Lines
NR-03-DL-072-0022	Site 072-Coso Hot Springs, Calif.
NR-03-DL-073-0023	Site 073-Lynn Dist., Nev.
NR-03-DL-075-0024	Site 075-Goldfield, Nev.
NR-03-DN-079-0025	Site 079-Matewan, Ky.
NR-03-DL-082-0026	Site 082-Alvord Valley, Ore.
NR-03-DM-083-0027	Site 083-Ironton, Mo.
NR-03-CL-089-0028	Site 089-Blackbird Dist., Idaho
NR-03-CL-090-0029	Site 090-Aberton, Mont.
NR-03-EP-092-0030	Site 092-Puerto Rico
NR-01-DN-094-0031	Site 094-NE Pennsylvania (Peat Bogs)
NR-03-EN-095-0032	Site 095-Everglades, Fla. (Hydrology)
NR-03-DL-096-0033	Site 096-Dixie (Fish Lake Nat'l. Forest, Utah)
NR-03-EN-098-0034	Site 098-Homestead, Fla.
NR-03-EN-099-0035	Site 099-Florida Straits
NR-03-DM-100-0036	Site 100-Hot Springs, Ark.
NR-03-DL-109-0037	Site 109-Sierra Madera
NR-03-DL-112-0038	Site 112-Northeast Range, Colo.
NR-03-DL-114-0039	Site 114-White Sands, N. M.
NR-03-DN-126-0040	Site 126-Marquette/Republic Trough, Mich.
NR-03-DM-129-0041	Site 129-Arkansas Basin
NR-03-DK-131-0042	Site 131-Sonora Pass (II)

AIRCRAFT MISSION REQUESTS (cont)

Accession no.	Description
NR-03-EN-132-0043	Site 132-New Orleans, La.
NR-03-EN-133-0044	Site 133-Michoud, La.
NR-03-DN-134-0045	Site 134-Slidell, La.
NR-03-DN-135-0046	Site 137-Mississippi Test Facility
NR-03-DN-127-0047	Site 127-Johnson County Gravel Test
NR-03-DL-115-0048	Site 115-New Mexico Mineral and Structural Belts
NR-03-EM-102-0049	Site 102-Statenville/Lake City, Fla. Phosphate Site 103-Crystal River, Fla. Phosphate Site 104-Wauchula/Tampa, Fla. Phosphate
NR-03-DL-130-0050	Site 130-Southern Calif.
NR-03-DL-139-0051	Site 139-Steamboat Springs, Colo.
NR-03-EN-095-0052	Site 095-Everglades, Fla.
NR-03-DL-005-0053	Site 005-Eureka (Tintic District) Utah
NR-03-DL-027-0054	Site 027-Salton Sea, Calif.
NR-03-DL-071-0055	Site 071-Hopi Buttes, Ariz.
NR-03-DM-120-0056	Site 120-Lake Colorado City, Tex.
NR-03-DN-125-0057	Site 125-Roxboro Reservoir, N. C.
NR-03-DN-141-0058	Site 141-Charleston/Columbia, S. C.
NR-03-DP-142-0059	Site 142-Delaware River Estuary
NR-03-DP-148-0060	Site 148-Lehigh River, Pa.

MISSION REPORTS

Accession no.	Description
NR-04-00-999-0001	Reference Document: Introduction to NASA 926 and NASA 927 Remote Sensor Aircraft as applied to the Natural Resources Program, March 1966
NR-04-00-000-0002	Mission no. 13 Sites 003, 007, 019, 020, 050, 051, 040, 048, 049
NR-04-00-998-0003	Mission no. 14 Sites 043, 046
NR-04-DL-031-0004	Mission no. 15 Site 031
NR-04-EM-032-0005	Mission no. 16 Site 032
NR-04-EM-032-0006	Mission no. 17 Site 032
NR-04-00-998-0007	Mission no. 18 Sites 015, 027, 028, 031, 051
NR-04-DL-029-0008	Mission no. 19 Site 029
NR-04-DP-086-0009	Mission no. 20 Site 086
NR-04-00-998-0010	Mission no. 21 Sites 002, 003, 040
NR-04-CP-087-0011	Mission no. 22 Site 087
NR-04-EM-032-0012	Mission no. 24 Site 032
NR-04-00-998-0013	Mission no. 25 Sites 043, 088
NR-04-00-998-0014	Mission no. 23 Sites 046, 095, 099, 105 - 108
NR-04-EN-128-0015	Mission no. 26 Site 128
NR-04-EM-032-0016	Mission no. 27 Site 032
NR-04-00-998-0017	Mission no. 29 Sites 040, 130
NR-04-00-998-0018	Mission no. 28 Sites 024, 114, 130
NR-04-00-998-0019	Mission no. 32 Sites 011, 076
NR-04-00-998-0020	Mission no. 30 Sites 003, 020, 052, 019, 135

MISSION REPORTS (cont)

Accession no.		Description
NR-04-DN-043-0021	Mission no. 31	Site 043
NR-04-DL-114-0022	Mission no. 33	Site 114
NR-04-00-998-0023	Mission no. 34	Sites 099, 128, 138
NR-04-EM-032-0024	Mission no. 35	Site 032
NR-04-EN-095-0025	Mission no. 36	Site 095
NR-04-DM-128-0026	Mission no. 37	Site 128

TECHNICAL REPORTS

Accession no.	Description
NR-05-00-000-0006	Technical Letter NASA-6, Ultraviolet Absorption and Luminescence Investigations Progress Report U.S. Geological Survey
NR-05-DL-002-0007	Technical Letter NASA-7, Typographic Studies of Pisgah Crater, California. U.S. Geological Survey
NR-05-00-000-0008	Technical Letter NASA-8, Reflectance Measurements in the 0.6 to 2.5 Micron Part of the Spectrum. U.S. Geological Survey
NR-05-DL-003-0009	Technical Letter NASA-9, Preliminary Geologic Map of the Mono Craters Quadrangle, California. U.S. Geological Survey
NR-05-DL-002-0011	Technical Letter NASA-11, Geologic Map of the Pisgah and Sunshine Cone Lava Fields. U.S. Geological Survey
NR-05-DK-000-0013	Technical Letter NASA-13, Infrared Spectral Emittance of Rocks from the Pisgah Crater and Monocraters Area, California. U.S. Geological Survey
NR-05-00-000-0014	Technical Letter NASA-14, Summary of Significant Results of Remote Sensing Studies in 1965. U.S. Geological Survey
NR-05-00-000-0015	Technical Letter NASA-15, A Millimeter Wavelength Interferometer Spectrometer. U.S. Geological Survey
NR-05-DK-007-0016	Technical Letter NASA-16, Geological Evaluation of AN/APQ-97 Radar Imagery, Oregon Coast. U.S. Geological Survey
NR-05-DL-130-0017	Technical Letter NASA-17, Evaluation of Ektachrome and Multiband Photography in Calieute Range, California. U.S. Geological Survey

TECHNICAL REPORTS (cont)

Accession no.	Description
NR-05-CK-040-0019	Technical Letter NASA-19, Geological Evaluation of Radar Imagery of the Central Part of the Oregon High Cascade Range. U.S. Geological Survey
NR-05-DL-002-0020	Technical Letter NASA-20, Composition of Basalt Flows at Pisgah Crater, California: Preliminary Data. U.S. Geological Survey
NR-05-00-000-0021	Technical Letter NASA-21, Lake Surveying Techniques in the Geological Survey - Progress Report. U.S. Geological Survey
NR-05-00-000-0022	Technical Letter NASA-22, Time, Shadows, Terrain and Photointerpretation. U.S. Geological Survey
NR-05-DK-008-0023	Technical Letter NASA-23, Geological Appraisal of Southwestern Oregon. U.S. Geological Survey
NR-05-00-000-0024	Technical Letter NASA-24, Photogeologic Interpretation of Gemini IV Color Photograph: Baja, California. U.S. Geological Survey
NR-05-DK-008-0025	Technical Letter NASA-25, Evaluation of Radar Imagery of Highly Faulted Volcanic Terrain in Southeast Oregon. U.S. Geological Survey
NR-05-CK-040-0026	Technical Letter NASA-26, Application of Radar Imagery to a Geologic Problem at Glacier Park Volcanic, Washington. U.S. Geological Survey
NR-05-DL-109-0027	Technical Letter NASA-27, Geologic Evaluation of Radar Imagery of Flights 100-B and 100-C Across the Central Sierra Nevada, California. U.S. Geological Survey
NR-05-DL-015-0028	Technical Letter NASA-28, Radar Imagery of Twin Buttes Area, Arizona. U.S. Geological Survey
NR-05-DL-027-0029	Technical Letter NASA-29, Radar Imagery: Salton Sea Area, California. U.S. Geological Survey

TECHNICAL REPORTS (cont)

Accession no.	Description
NR-05-DL-011-0030	Technical Letter NASA-30, Preliminary Evaluation of Radar Imagery of Yellowstone Park. U.S. Geological Survey
NR-05-00-000-0031	Technical Letter NASA-31, Comparative Study of Ultraviolet Instrumentation Suitable for Orbital Remote Sensing Experiments. U.S. Geological Survey
NR-05-00-000-0032	Technical Letter NASA-32, Laboratory Measurement of Ultraviolet Reflection (2200-7000A) and Simulated Emission of Rocks and Rock-Forming Minerals. U.S. Geological Survey
NR-05-00-000-0033	Technical Letter NASA-33, A Proposal for Geological Studies of the Earth and Planetary Surfaces by Ultraviolet Absorption and Simulated Luminescence. U.S. Geological Survey
NR-05-00-000-0033	Technical Letter NASA-33A, Geological Studies of the Earth and Planetary Surface of Ultraviolet Absorption and Simulated Luminescence. U.S. Geological Survey
NR-05-DL-027-0034	Technical Letter NASA-34, Gemini IV Color Photography of Salton Sea Area, California. U.S. Geological Survey
NR-05-00-000-0036	Technical Letter NASA-36, The Effect of Ultraviolet Radiation on the Intensity of Luminescence. U.S. Geological Survey
NR-05-00-000-0037	Technical Letter NASA-37, Preliminary Ultraviolet Reflectance of Some Rocks and Minerals from 2000 Å to 3000 Å. U.S. Geological Survey
NR-05-DL-001-0038	Technical Letter NASA-38, Geological Evaluation of Radar Imagery, Southwestern and Central Utah. U.S. Geological Survey

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Accession no.	Description
NR-05-DL-998-0039	Technical Letter NASA-39, Interpretation of Ultraviolet Imagery of the Meteor Crater, Salton Sea, and Arizona and Sedimentary Test Sites. U.S. Geological Survey
NR-05-00-000-0040	Technical Letter NASA-40, Geologic Interpretation of the Gemini V Photograph of the Salt Range Potwan Plateau Region, West Pakistan. U.S. Geological Survey
NR-05-00-000-0041	Technical Letter NASA-41, Possible Application of Remote Sensing Techniques and Satellite Communications for Earthquake Studies. U.S. Geological Survey
NR-05-DK-024-0042	Technical Letter NASA-42, Use of Infrared Imagery in Study of the San Andreas Fault System, California. U.S. Geological Survey
NR-05-00-000-0043	Technical Letter NASA-43, Geological Utilization of Gemini Color Photograph of Duba Area, Saudi Arabia. U.S. Geological Survey
NR-05-DL-001-0044	Technical Letter NASA-44, Preliminary Report on Radar Imagery of Cedar City - Iron Spring Area Utah. U.S. Geological Survey
NR-05-DL-024-0045	Technical Letter NASA-45, Geologic Evaluation of Radar Imagery: San Andreas Fault Zone From Stevens Creek, Santa Clara County to Missel Rock, San Mateo County, California. U.S. Geological Survey
NR-05-00-000-0046	Technical Letter NASA-46, An Evaluation of the Gemini IV Color Photos of the Gulf of California-Central Texas Area. U.S. Geological Survey
NR-05-DM-036-0047	Technical Letter NASA-47, Geologic Evaluation of Radar Imagery of the Spanish Peaks Region Colorado. U.S. Geological Survey

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Accession no.	Description
NR-05-DN-008-0048	Technical Letter NASA-48, Geological Evaluation of Radar Imagery Appalachian Piedmont, Harford and York Counties, Maryland and Pennsylvania. U.S. Geological Survey
NR-05-DL-073-0049	Technical Letter NASA-49, Geological Evaluation of K-Band Radar Imagery, North-Central, Nevada. U.S. Geological Survey
NR-05-00-000-0050	Technical Letter NASA-50, A Preliminary Evaluation of Airborne and Spaceborne Remote Sensing Data for Hydrologic Uses. U.S. Geological Survey
NR-05-00-000-0051	Technical Letter NASA-51, Application of Remote Sensor Data to Cartographic Programs. U.S. Geological Survey
NR-05-00-000-0052	Technical Letter NASA-52, Geologic Investigations of Remote Sensing Techniques: Final Report to NASA FY 1966. U.S. Geological Survey
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NR-05-00-000-0054	Technical Letter NASA-54, Potential Time-Cost Benefits from Use of Orbital-Height Photographic Data in Cartographic Programs. U.S. Geological Survey
NR-05-AP-000-0056	Technical Letter NASA-56., Geological Evaluation of Numbus Vidicon Imagery Northwest Greenland. U.S. Geological Survey
NR-05-00-000-0057	Technical Letter NASA-57, Liquid Nitrogen Black-body for Spectral Emittance Studies. U.S. Geological Survey
NR-05-DL-053-0058	Technical Letter NASA-58, Geologic Evaluation of Radar Imagery in Southern Utah. U.S. Geological Survey

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Accession no.	Description
NR-05-00-000-0059	Technical Letter NASA-59, Analysis of Earth Orbiter Test Site Program in Relation to U.S. Mineral Needs. U.S. Geological Survey
NR-05-DL-000-0060	Technical Letter NASA-60, Extent of Relict Soils Revealed by Gemini IV Photographs. U.S. Geological Survey
NR-05-DL-006-0061	Technical Letter NASA-61, Hydrologic Interpretation of Numbus Vidicon Image - Great Salt Lake, Utah. U.S. Geological Survey
NR-05-DL-028-0062	Technical Letter NASA-62, Radar Images - Meteor Crater, Arizona. U.S. Geological Survey
NR-05-DL-080-0063	Technical Letter NASA-63, Preliminary Studies of Soil Patterns Observed in Radar Images, Bishop Area, California. U.S. Geological Survey
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NR-05-00-000-0065	Technical Letter NASA-65, Dispersive Multispectral Scanning Feasibility Study. U.S. Geological Survey
NR-05-DK-998-0066	Technical Letter NASA-66, Status Report of Infrared Investigations (July 1, 1966 to September 30, 1966.) U.S. Geological Survey
NR-05-00-000-0070	Technical Letter NASA-70, Measurements of Luminescence by the Fraunhofer Line Depth Method. U.S. Geological Survey
NR-05-00-000-0100	Preliminary Report on a Multispectral Experiment; prepared by Abraham Anson, Systems Branch, Intelligence Division, USAEGIMARADA. Issue Date: February 18, 1965 (Reference copy only)
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Accession no.	Description
NR-05-00-000-0102	The Investigations of Flame Spreading over the Surface of Igniting Solid Propellants; NASA Grant NGR-31-003-014, January 1966
NR-05-00-000-0103	Infrared and Ultraviolet Studies of Terrestrial Materials; U.S. Geological Survey
NR-05-00-000-0104	Some Empirical and Theoretical Interpretations of Multiple Polarization Radar Data; CRES, University of Michigan, Report No. 61-10, NASA Contracts NSR 17-004-003 and NSG-298
NR-05-00-000-0105	Vegetation Analysis with Radar Imagery; CRES Report No. 61-9, University of Kansas, NASA Contract 17-004-0003
NR-05-00-000-0106	Fresnel Zone Processing of Synthetic Aperture Radar Data; Technical Report 61-1, CRES, University of Kansas
NR-05-00-000-0107	Five Papers on Remote Sensing and Urban Information Systems; Technical Report No. 1, Contract Nonr-1228 (37), April 1966
NR-05-00-000-0108	Northwestern University Report No. 1, NASA Research Grant NGR-14-007-027
NR-05-00-000-0109	Plane Wave Scattering from a Rough Surface with Correlated Large and Small Scale Orders of Roughness; CRES, University of Kansas, Technical Report 61-2
NR-05-00-000-0110	Aspects of Geological Sampling at Test Sites; Northwestern University Report No. 4, NASA Research Grant NGR-14-007-027, July 11, 1966
NR-05-00-000-0111	A Model for the Areal Pattern of Retail and Service Establishments Within an Urban Area; Technical Report No. 2, Contract Nonr-1228 (37), April 1966

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Accession no.	Description
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NR-05-00-000-0113	Cenozoic Volcanism of the Central Sierra Nevada, California; Technical Report No. 4, NCR 29-001-015, April 1966
NR-05-DK-020-0114	Geology of the Bucks Lake, California; NASA Remote Sensing Test Site, Technical Report No. 5, NCR 29-001-015, May 1966
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NR-05-DK-019-0116	Geology of the Sonora Pass-Emigrant Basin, California, NASA Remote Sensing Test Site, Technical Report 1, NGR-20-001-015, December 1965
NR-05-00-000-0117	The Directional Spectrum of a Wind Generated Sea as Determined from Data Obtained by the Stereo Wave Observation Project; Meteorological Papers, Vol. 2, No. 6, June 1960
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NR-05-00-000-0122	Theoretical and Observed Results for the Zero and Ordinate Crossing Problems of Stationary Gaussian Noise with Application to Pressure Records of Ocean Waves; New York University, Research Division, Technical Report No. 1 under Contract Nos. 72018(1734F), December 1958
NR-05-00-000-0123	The Apparent Loss of Coherency in Vector Gaussian Processes Due to Computational Procedures with Application to Ship Motions and Random Seas; New York University, Research Division, Technical Report under Contracts Nonr-285(17) and Nonr-263(09) (Reference only)
NR-05-00-000-0124	Models of Random Seas Based on the Lagrangian Equations of Motion; New York University, Research Division, Technical Report under Contract Nonr-285(03)
NR-05-00-000-0125	On the Phases of the Motions of Ships in Confused Seas; New York University, Research Division, Technical Report No. 9 under Contract Nonr-285(17), November 1957
NR-05-00-000-0126	The Accuracy of Present Wave Forecasting Methods with Reference to Problems in Beach Erosion on the New Jersey and Long Island Coasts; New York University, November 1950
NR-05-00-00-0127	The Average Horizontal Wind Driven Mass Transport of the Atlantic for February as Obtained by Numerical Methods; New York University, Research Division, Technical Report under Contract Nonr-285(03), December 1962 (Reference only)

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Accession no.	Description
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NR-05-00-000-0130	Automatic Processing of Multispectral Images; CRES Report No. 71-16, George W. Dalke, The Remote Sensing Laboratory Information Sciences Group. The University of Kansas. Lawrence, Kansas, NASA Contract NSR17-004-003.
NR-05-00-000-0131	Polarization Dependent Radar Return from Rough Surfaces; Technical Report EE-TR-2, Kumar Krishen, W. W. Koepsel, S. H. Durrani; Department of Electrical Engineering, Kansas State University, Manhattan, Kansas. January 1966. NASA Contract NSR17-004-003
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NR-05-00-000-0133	Backscatter of Ultrasonic Waves from a Rough Layer; Technical Report EE-TR-4. Wu-Shi Shung, W. W. Koepsel, S. H. Durrani. Department of Electrical Engineering, Kansas State University, Manhattan, Kansas. May 1966. NASA Contract NSR17-004-003.
NR-05-DK-002-0134	Statistical Problems Involved in Remote-Sensing of the Lithosphere-Atmosphere Interface; Northwestern University, Department of Geology. Contract No. NGR-14-007-027. February 1967.

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<u>Accession no.</u>	<u>Description</u>
NR-05-00-000-0135	<u>The General Linear Equation in Prediction</u>; Northwestern University, Department of Geology. Contract No. NGR-14-007-027, February 1967.

PROGRESS REPORTS*

Accession no.	Description
NR-06-00-000-0001	Radar Sensing for Geoscience Purposes; Monthly Progress Report CRM 61-15, NASA Contract NSR 17-004-003, October 1, 1965 through November 1, 1965
NR-06-00-000-0003	Quarterly Progress Report No. 81, April 15, 1966
NR-06-00-000-0004	Quarterly Progress Report for December 1, 1965 through February 28, 1966 and March 1, 1966 through May 30, 1966. Contract No. NSR-36-008-027, Ohio State University Research Foundation Antenna Laboratory, Project 1903
NR-06-00-000-0005	Quarterly Status Report, October 1, 1965 through April 1, 1966, NASA Contract R-09-038-002
NR-06-00-000-0006	Investigations of In Site Physical Properties of Surface and Subsurface Site Materials by Engineering Geophysical Techniques; Project Quarterly Report, January 1, 1966 through March 31, 1966
NR-06-00-000-0007	Status Report, October 1, 1965 through December 31, 1965, NASA Contract R-146
NR-06-00-000-0008	Quarterly Status Report, September 15, 1965 through December 15, 1965, NASA Contract R-09-020-019
NR-06-00-000-0009	Quarterly Progress Report, June 1, 1965 through August 31, 1965, NASA Contract NSR-36-008-027
NR-06-00-000-0010	Geoscience Data Management; NASA-Defense, PRR-47-009-006, Fifth and Final Quarterly Progress Report, June 30, 1966
NR-06-00-000-0011	Recording and Processing of Multifrequency Radar Data; Quarterly Progress Report, September 1, 1965 through November 30, 1965, University of Michigan

*NOTE: Circulation of Progress Reports is limited to NASA Personnel Only. Requests for circulation outside NASA must be reviewed by the Chief, Earth Resources Office, NASA Manned Spacecraft Center, Houston, Texas.

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Accession no.	Description
NR-06-00-000-0012	First Quarterly Progress Report of the Laboratory for Agricultural Remote Sensing, NGR-15-005-028, March 31, 1966
NR-06-00-000-0013	Semi-Annual Progress Report CRSA 61-2, NASA Contract No. NSA 17-004-003 for period January 1, 1966 to June 30, 1966. Center for Research, University of Kansas, Lawrence, Kansas
NR-06-00-000-0014	Semi-Annual Progress Report, MacKay School of Mines, University of Nevada, January 1, 1966 through June 10, 1966
NR-06-00-000-0015	Semi-Annual Progress Report, June 18, 1965 through December 31, 1965, NASA Contract NGR-29-001-015
NR-06-00-000-0016	Semi-Annual Report, NASA Contract NSR-22-009-120, Massachusetts Institute of Technology, September 1, 1965 through February 28, 1966, Submitted May 4, 1966
NR-06-00-000-0017	Semi-Annual Progress Report on Research Grant, NSG-722, January 1, 1966
NR-06-00-000-0018	Urban and Transportation Information Systems; Annual Report, Contract Nonr-1228(37), April 1966
NR-06-00-000-0019	Remote Multispectral Sensing in Agriculture; R. A. Holmes and R. M. Hoffer, Purdue University, Lafayette, Indiana, Semi-Annual Progress Report NGR-15-005-028
NR-06-00-000-0020	Statistical Evaluation of the Composition, Physical Properties, and Surface Configuration of Terrestrial Test Sites and their Correlation with Remotely Sensed Data; NASA Research Grant NGR-14-007-027, Semi-Annual Status Report, March 31, 1966

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Accession no.	Description
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NR-06-00-000-0022	TERRAIN QUALIFICATION Phase I: Surface Geometry Measurements; FINAL REPORT, Contract No. AF 19(628)-481, Project No. 6728, December 31, 1962, by Texas Instruments Incorporated
NR-06-00-000-0023	Manned Mars Surface Operations; FINAL REPORT, Detailed Technical Report, Parts 4 through 7, RAD-TR-65-26, Contract Number NAS 8-11353, September 30, 1965 (Reference only)
NR-06-00-000-0024	Oceanographic Satellite System Concept and Feasibility Study (U); FINAL REPORT, August 1963, N-600(19)58467
NR-06-00-000-0025	Feasibility of Objective Color Systems; FINAL REPORT, September 13, 1965, by A. Anson
NR-06-00-000-0026	Field Infrared Analysis of Terrain; First Annual Report, 1 November 1965 - 30 October 1966. Remote Sensing Laboratory Geophysics Department, Stanford University, California. NASA Contract NGR-05-020-115
NR-06-00-000-0027	Space Oceanography Project; Status Report, February 1966 - October 1966, Department of Oceanography. Texas A&M University, Office of Naval Research. Contract Nonr 2119(04) (Reference only)
NR-06-00-000-0028	Detail Plan and Status Report of United States Geological Survey Research in Remote Sensing Under the Natural Resources Space Applications Program; Second Edition, U.S. Geological Survey (Reference only)

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Accession no.	Description
NR-06-00-000-0029	Detail Plan and Status Report of United States Geological Survey Research in Remote Sensing Under the Natural Resources Space Application Program. Supplement 1 Proposed Programs Objectives. Tasks and Budget for FY 1966 (Reference only)
NR-06-00-000-0030	Statistical Evaluation of the Composition, Physical Properties, and Surface Configuration of Terrestrial Test Sites and Their Correlation with Remotely Sensed Data. Semi-Annual Status Report dated September 30, 1966. Northwestern University, Department of Geology. Contract No. NGR-14-007-027
NR-06-00-000-0031	Semi-Annual Progress Report, June 10, 1966 through November 11, 1966. Mackay School of Mines, University of Nevada, Contract No. NGR-29-001-015
NR-06-00-998-0032	Aircraft Test Site Requirements Study for Spacecraft Oceanography; (Final Report), September 23, 1966. U.S. Naval Oceanographic Office, Washington, D.C., Contract No. N62306-2075. (Copy available on one-month loan bases only)
NR-06-00-000-0033	Semi-Annual Report, NASA Contract NSR-22-009-120, Massachusetts Institute of Technology, March 1, 1966 through August 30, 1966.

SUMMARY REPORTS

Accession no.	Description
NR-07-00-000-0001	Peaceful Uses of Earth-Observation Spacecraft; Volume I, Introduction and Summary, NASA CR-586, Contract No. NASw-1084 by University of Michigan, Ann Arbor, Michigan
NR-07-00-000-0002	Peaceful Uses of Earth-Observation Spacecraft; Volume II, Survey of Applications and Benefits, NASA CR-587, Contract No. NASw-1084 by University of Michigan, Ann Arbor, Michigan
NR-07-00-000-0003	Peaceful Uses of Earth-Observation Spacecraft; Volume III, Sensor Requirements and Experiments, NASA CR-588, Contract No. NASw-1084 by the University of Michigan, Ann Arbor, Michigan
NR-07-00-000-0004	Oceanography from Space; NASA Contract NsR-22-014-003, Woods Hole Oceanographic Institution, Issued April 1965

MISCELLANEOUS DOCUMENTS

Accession no.	Description
NR-08-00-000-0001	Manned Lunar Orbital Missions; Volume I (2nd Edition), April 1965, Preliminary Mission Definition for Post Apollo Manned Exploration of Space
NR-08-00-000-0002	Manned Lunar Orbital Missions; Volume IA, April 1965, Revised Submissions from Potential Experimenters
NR-08-00-000-0003	Analysis of Remote Sensing Data Requirements by Experiment; NASA MSC, Issue date: November 1965
NR-08-00-000-0004	Manned Earth Orbital Mission; November 1965, Preliminary Mission Definition for Post Apollo Manned Exploration of Space
NR-08-00-000-0005	Consolidation of Aeronautical Chart and Information Center and Army Map Service Lunar Control Systems; NASA Defense Purchase Request T-42805 (G)
NR-08-00-000-0006	Manned Lunar Exploration Investigations and Appendix; U.S. Geological Survey
NR-08-00-000-0007	Proceedings of the Fourth Symposium on Remote Sensing of Environment, April 12-14, 1966; Infrared Physics Laboratory, Willow Run Laboratories, University of Michigan, Ann Arbor, Michigan (Reference only)
NR-08-00-000-0008	Manned Earth Orbital Missions; Part II (2nd Edition), Preliminary Mission Definition for Post-Apollo Manned Exploration of Space
NR-08-00-000-0009	Report of Work Under NASA Transfer of Funds to the Economic Research Service, USDA; Department of Agriculture, R-09-038-001
NR-08-DK-019-0010	Preliminary Details of Sampling Locations at NASA Sonora Pass Test Site, California; Northwestern University Report No. 5, NASA Research Grant NGR-14-007-027, July 22, 1966

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Accession no.	Description
NR-08-00-000-0011	Remote Sensor Aircraft Data Gathering System Data Processing and Distribution Unit; Natural Resources Program, March 1966
NR-08-00-000-0012	Preliminary Newsletter, "Purdue Field Experiments Using the Perkin-Elmer SG-4 Spectrometer;" July 11, 1966, Purdue University, Lafayette, Indiana
NR-08-00-000-0013	Spacecraft Oceanography Project Briefing; NASA Headquarters, April 4, 1966
NR-08-00-000-0014	Detailed Plan for the U.S. Naval Oceanographic Office Participation in the NASA Natural Resources Program, March 1966
NR-08-00-000-0015	Official Report of the U.S. Delegation to the United Nations Regional Cartographic Conference for Africa; July 1-13, 1963
NR-08-00-000-0016	Report of Work Under NASA Transfer of Funds to the Economic Research Service, USDA; Department of Agriculture, R-09-038-001
NR-08-00-000-0017	Proposed Instrument Calibration Sites, Applications Areas and Responsible Areas and Responsible Scientists, May 2, 1966
NR-08-00-000-0018	DATA (Oceanography Issue); Vol. 9, No. 5, May 1964

Film Data

9½" BLACK AND WHITE AERIAL FILM

Location	Film	Footage	Camera	Date
Phoenix	Plus-X	185	T-11	7/1/65
Zuni-San Francisco				
Mono Craters-Pisgah Crater	Plus-X	180	RC-8	5/4/66
Sonora Pass				
Death Valley-Mono Craters	Plus-X	150	RC-8	10/1/65
Oregon Coast	Plus-X	40	RC-8	9/24/65
Tonopah, Salt Lake	Plus-X	180	T-11	2/16/65
San Andreas Fault	Plus-X	180	T-11	6/3/65
San Andreas Fault	Dup. Pos.	180	T-11	6/3/65
Asheville, N. C.	Dup. Pos.	60	RC-8	11/15/65
Salton Sea (Hi-Alt)	Dup. Pos.	150	T-11	1/12/66
Pisgah Crater	Dupont Cronar	50	RK-1	1/28/65
Pisgah Crater	Dup. Pos.	75	T-11	1/11/65
Mesquite Sed.-Twin Buttes	Dup. Pos.	180	T-11	1/9/65
Twin Buttes	Infrared	95	T-11	1/10/66
San Diego-San Clemente	Plus-X	180	RC-8	4/21/65
Oregon Coast	Plus-X	180	RC-8	9/24/65
Mono Craters	Plus-X	180	RC-8	9/30/65
Chicago	Tri-X	75	RC-8	11/19/65
Wilcox Dry Lake	Tri-X	80	RC-8	12/20/65
Wilcox-Meteor Crater	Plus-X	180	T-11	1/7-1/8/65
Pisgah Crater	Plus-X	180	T-11	6/23/65
Goose Bay (7 rolls)	Plus-X	1160	RC-8	4/16-4/20/66
Wilcox & Little Dragon	Plus-X	180	T-11	6/2/65
Salton Sea	Tri-X	125	RC-8	1/11/66
Pisgah Crater	DuPont Cronar	180	RK-1	12/30/64
Apollo/Little Joe Mosaic	Ansco-A	200	K-17C	8/22/63
Apollo/Little Joe Mosaic	Ansco-A	200	K-17C	8/22/63
Phoenix-Shapran Test	Kodak Experimental	180	KC-1	Not Known
Phoenix-Shapran Test	Kodak Experimental	180	KC-1	Not Known
Bucks Lake	Infrared	12	T-11	6/5/65
Asheville, N. C.	Tri-X	50	RC-8	5/7/66

(This film is not good - completely underexposed)

9½" BLACK AND WHITE AERIAL FILM - Concluded

Location	Film	Footage	Camera	Date
Chicago - Miss. Valley (3 rolls)	Plus-X	450	RC-8	7/1/66
Miss. Delta (5 rolls)	Plus-X	830	RC-8	7/6/66
Weslaco (2 rolls)	Plus-X	290	T-11	7/8/66
San Andreas Fault	Plus-X	75	RC-8	7/28/66
Sonora Pass	Plus-X	230	RC-8	8/30/66
Nevada AEC	Plus-X	75	T-11	9/3/66
Cascade Mtns.	Plus-X	75	RC-8	8/11/66

EKTACHROME

Location	Film	Footage	Camera	Date
Chicago	Ektachrome	150	RC-8	11/19/65
Mono Lake	Ektachrome	30	RC-8	9/29/65
Cane Spring, Ariz. Sedimentary	Ektachrome	38	RC-8	1/9/66
Cane Spring, Ariz. Sedimentary	Ektachrome	75	RC-8	1/8/66
Asheville, N. C.	Ektachrome	75	RC-8	11/15/65
Asheville, N. C.	Ektachrome	75	RC-8	11/17/65
Phoenix	Ektachrome	75	RC-8	2/15/66
Twin Buttes	Ektachrome	7	RC-8	1/10/66
Cascade Glacier	Ektachrome	40	RC-8	9/23/65
Phoenix	Ektachrome	75	RC-8	2/15/66
Asheville, N. C.	Ektachrome	60	RC-8	11/17/65
Chicago	Ektachrome	150	RC-8	11/19/65
Cascade Glacier	Ektachrome	35	RC-8	4/4/66
Crater Lake	Ektachrome	75	RC-8	4/3/66
Asheville, N. C.	Ektachrome	75	RC-8	5/7/66
Site 106	Ektachrome	75	RC-8	5/10/66
Sites 107, 108, 095, 098	Ektachrome	75	RC-8	5/9-10/66
Sites 095 and 105	Ektachrome	65	RC-8	5/11/66
Tampa, Fla.	Ektachrome	75	RC-8	5/8/66
Miami Reef	Ektachrome	30	RC-8	5/9/66
Sites 095, 106, and 107	Ektachrome	75	RC-8	5/10/66
Asheville, N. C.	Ektachrome	75	RC-8	5/7/66
Chicago - Miss. Valley (4 rolls)	Ektachrome	300	RC-8	6/30/66
White Sands, N. M.	Ektachrome	45	RC-8	7/26/66
Bucks Lake, Calif.	Ektachrome	75	RC-8	9/1/66

Film Data

EKTACHROME I.R.

Location	Film	Footage	Camera	Data
Bucks Lake	B&W IR	13 frames	T-11	6/5/65
Thermo Grid Bermuda	Ektachrome IR	75	RC-8	3/10/66
Asheville, N. C.	Ektachrome IR	60	RC-8	11/17/65
Asheville, N. C.	Ektachrome IR	75	RC-8	11/17/65
Weslaco	Ektachrome IR	75	RC-8	1/5/66
Mono Lake	Ektachrome IR	60	RC-8	9/30/65
Weslaco	Ektachrome IR	35	RC-8	5/14/66
Thermo Grid Bermuda	Ektachrome IR	75	RC-8	3/10/66
Bermuda	Ektachrome IR	75	RC-8	3/9/66
Thermo Grid Bermuda	Ektachrome IR	75	RC-8	3/10/66
Cascade Glacier Oregon Terrain Crator Lake	Ektachrome IR	75	RC-8	4/4/66
Salton Sea	Ektachrome IR	75	RC-8	1/12/66
Slaton Sea	Ektachrome IR	75	RC-8	1/12/66
Cascade Glacier	Ektachrome IR	40	RC-8	9/23/65
Mono Lake	Ektachrome IR	75	RC-8	9/30/65
Asheville, N. C.	Ektachrome IR	75	RC-8	11/17/65
Phoenix	Ektachrome IR	75	RC-8	2/15/66
Phoenix	Ektachrome IR	75	RC-8	2/15/66
Thermo Grid Bermuda	Ektachrome IR	75	RC-8	3/10/66
Weslaco	Ektachrome IR	75	RC-8	12/22/65
Chicago	Ektachrome IR	150	RC-8	11/19/65
Twin Buttes	Ektachrome IR	75	RC-8	1/9/66
Weslaco	Ektachrome IR	75	RC-8	12/22/65
Weslaco	Ektachrome IR	35	RC-8	1/5/66
Asheville, N. C.	Ektachrome IR	75	RC-8	5/7/66
Asheville, N. C.	Ektachrome IR	75	RC-8	5/7/66
Meteor Crater	Ektachrome IR	75	RC-8	1/8/66
Pisgah Crater	Ektachrome IR	75	RC-8	4/5/66
Chicago - Miss. Valley (4 rolls)	Ektachrome IR	300	RC-8	6/30/66
Weslaco	Ektachrome IR	225	RC-8	7/8/66
Mono Crater, Calif. Bucks lake, Calif. Miss. Test Facility	Ektachrome IR	375	RC-8	9/1/66
Nevada AEC	Ektachrome IR	75	RC-8	9/3/66
Southern Calif.	Ektachrome IR	135	RC-8	8/8/66

DATA PANEL - 35 MM

Location	Footage	Date
Wilcox Dry Lake		
Meteor Crater	50	1/7-8/66
Phoenix	50	2/15/66
Twin Buttes, Salton Sea	50	1/10/66
Weslaco	50	1/5/66
Ariz. Sedimentary Twin Buttes	50	1/8-9/66
Salton Sea	50	1/12/66
Wilcox and Phoenix Weslaco, Little Dragon	100	7/1/65
Sondra Ariz.	25	10/2/65
Weslaco and Brownsville	20	6/21/65
Brownsville and Carizzo	25	6/18/64
Wilcox, Ariz.	25	12/18/65
San Pablo, Davis and Donner Pass	25	9/28/65
Weslaco	25	12/22/65
Bucks Lake	50	9/26/65
Cascade	50	9/23-24/65
Mono Lake	50	9/30/65-10/1-2/66
Asheville and Chicago	100	11/19/65
Asheville, N. C.	100	11/15/65
Mono Lake	100	9/30/65
Argus Isle, Bermuda	35	3/6/66
Argus Isle, Bermuda	35	3/7-8/66
Argus Isle, Bermuda	35	3/10-11/65
Argus Isle, Bermuda	35	3/9-10/65
Cascade Glacier and Mono Lake	25	4/4-5/66
Zuni Salt Lake and San Francisco Vol. Fields	25	4/2/66
Pisgah Crater	50	4/5/66
Ranger VII	318	8/21/64
Ranger VIII	144' + 4 frames	2/20/65
Ranger IX	120	4/15/65
Weslaco	25	5/14/66
Chicago - Miss. Valley	75	6/30/66
Miss. Delta	60	7/6/66
Weslaco	50	7/8/66
Mono Crater, Calif. Sonora Pass, Calif. Bucks Lake, Calif.		8/30/66-9/3/66

DATA PANEL - 35 MM - Concluded

Location	Footage	Date
Miss. Test Facility	93	8/30/66-9/3/66
San Andreas, Calif. White Sands, N. M. Southern Calif.	40	7/29/66
Cascade Mtns.		8/8/66
Southern Calif.	50	8/11/66

MULTI-BAND

Location	Film	Footage	Camera	Date
---	ZX & IR	250	Multi-Band	3/10/66
Phoenix	ZX & IR	400	Multi-Band	7/2/65
---	ZX & IR	250	Multi-Band	3/10/66
Sites 106, 095, 105, 102	ZX & IR	200	Multi-Band	5/11/66
Sites 107, 095, 108, 098	ZX & IR		Multi-Band	5/9/66
Chicago (Line 3 + Part of 4)	ZX & IR	250	Multi-Band	11/19/65
Sites 106, 107	ZX & IR	250	Multi-Band	5/10/66
Asheville, N. C.	ZX & IR	250	Multi-Band	11/15/65
Thermo Grid Bermuda	ZX & IR	250	Multi-Band	3/10/66
Goose Bay	ZX & IR	250	Multi-Band	4/19/66
Weslaco	ZX & IR	60	Multi-Band	5/14/66
Weslaco	ZX & IR	250	Multi-Band	12/22/65
Davis San Pablo Donner Pass	ZX & IR	170	Multi-Band	9/28/65
Weslaco	ZX & IR	200	Multi-Band	1/5/66
Miami (Davis Reef)	ZX & IR		Multi-Band	5/9/66
Chicago	ZX & IR	250	Multi-Band	11/19/65
Chicago	ZX & IR	250	Multi-Band	11/19/65
Goose Bay	2 Plus X	250	Multi-Band	4/21/66
Asheville, N. C.	1 Plus X 1 - IR	250	Multi-Band	11/17/65
Mono Lake	2 Plus X	250	Multi-Band	10/2/65
Cascade Site	2 X + IR	200	Multi-Band	9/28/65
Asheville, N. C.	4 Plus 2 IR	1500	Multi-Band	5/7-10/66
Pisgah Crater	2 Plus X 1 IR	750	Multi-Band	4/8/66
Phoenix	2 Plus X 1 IR	750	Multi-Band	2/15/66
Chicago	2 Plus X 1 IR	750	Multi-Band	6/30/66

Film Data

RECONOFAX IV - 70 mm

(The 70 mm Reconofax IV film itself is classified CONFIDENTIAL)

Location	Footage	Film (mm)	Date
Goose Bay	40	70	4/28/66
Goose Bay	40	70	4/25/66
Goose Bay	50	70	2/65
Miss. Delta, Site 128	50	35	7/6/66
Chicago	15-20	70	6/29/66
Asheville, N. C.	10	35 - UV	5/19/66
Weslaco	30	70	5/16/66
Miss. Delta, Site 128	80	70	7/6/66
San Andreas	75	70	6/3-4/65
Mono Lake	75	70	
Bucks Lake	75	70	
Davis	75	70	
San Pablo	75	70	
Wilcox	50	70	7/1-2/65
Weslaco			
Phoenix			
Miss. Delta, Site 128	60	70	7/6/66
Ashville, Sites 098, 099, 107, 108	100	70	
Weslaco			
Wilcox	15	70	7/1-2/65
Chicago	15	35	6/30/65
OSSA Hogs	40	70	4/6/66
Zuni Salt Lake			
S.F. Vol. Crater			
Cascade Glacier			
Pisgah Crater			
Bermuda	65	70	3/15/66
Argus Isle, Bermuda	60	70	3/15/55
Gulf Stream	100	70	3/15/66
Mission 13, Nat. Resources	100	35 (IR)	
Pisgah Crater	150	35	
Tonopah			
Salt Lake			
Pisgah Crater	100	35	
Tonopah			
Salt Lake			
San Andreas			
White Sands			
Southern Calif.	50	70	8/1/66

RECONOFAX IV - 70 mm - Concluded

(The 70 mm Reconofax IV film itself is classified CONFIDENTIAL)

Location	Footage	Film (mm)	Date
Cascade Mtns.			
Southern Calif.	50	70	8/12/66
Mono Crater, Calif.			
Sonora Pass, Calif.			
Bucks Lake, Calif.			
Miss. Test Facility			
Nevada AEC	60	70	9/3/66
Cascade Glacier	40	70	10/7/65
Oregon Coast			
Mission 18, Sites 031, 015, 027, 028, 051	50	35	
Cascade Glacier	50	70	
Oregon Coast			
So. Oregon Strip			
Oregon Coast			
So. Oregon Strip	25	70	
Pisgah	100	70	2/65
Tonopah			
Salt Lake Area			
Wilcox			
Weslaco	20	35	12/20-12/22/65
Weslaco	15	35 - UV	1/5/66
Test Flight out of Houston	50	70	6/30/65
Wilcox	10	70	
Test Flight out of Houston	50	70	6/30/65
Chicago - Miss. Delta	20	70	6/29/66
Miss. Delta	140	70	7/6/66
Weslaco	20	70	7/8/66

Film Data

AAS-5

Location	Film Type	Footage	Film Size	Date
Chicago - Miss. Delta	TRI-X	15	35 mm	6/30/66
Miss. Delta	TRI-X	40	35 mm	7/6/66
Weslaco	TRI-X	10	35 mm	7/8/66
Mono Crater, Calif. Bucks Lake, Calif Sonora Pass, Calif.	UV	40		9/2/66
Nevada AEC				
Miss. Test Facility				
San Andreas Fault White Sands, N. M.	UV	30		8/1/66
Southern Calif.				
Cascade Mtns. Southern Calif.				

CARTOGRAPHIC FILM DATA FILE

Date of Photography	Site No.	Site Name	Mission Number	Camera	Film Type	Film Size	Footage
8-30-1966	19-20	Sonora Pass-Bucks Lake	30	Multi-Band	Plux X	70 mm	500
8-30-1966	19-20	Sonora Pass-Bucks Lake	30	Multi-Band	Infrared	70 mm	250
9-1-1966	135	Harvey Valley	30	Multi-Band	Plus X	70 mm	1000
9-1-1966	135	Harvey Valley	30	Multi-Band	Infrared	70 mm	500
9-15-1966	43	Chicago	31	Multi-Band	Plux X	70 mm	500
9-15-1966	43	Chicago	31	Multi-Band	Infrared	70 mm	250
9-15-1966	43	Chicago	31	RC-8	Ektachrome IR	9½ in.	150
9-15-1966	43	Chicago	31	Reconofax IV	TX-475	70 mm	25
9-15-1966	43	Chicago	31	AAS-5	TX-417	35 mm	25
9-15-1966	43	Chicago	31	Nikon Data-Pan.	Plus X	35 mm	25
9-(19-22)-1966	11	Yellowstone Nat'l. Park	32	RC-8	Ektachrome	9½ in.	150
9-(19-22)-1966	11	Yellowstone Nat'l. Park	32	RC-8	Ektachrome IR	9½ in.	675
9-(19-22)-1966	11	Yellowstone Nat'l. Park	32	Multi-Band	Plus X	70 mm	2500
9-(19-22)-1966	11	Yellowstone Nat'l. Park	32	Multi-Band	Infrared	70 mm	1250
9-(19-22)-1966	11	Yellowstone Nat'l. Park	32	Nikon Data-Pan.	Plus X	35 mm	90
9-23-1966	11	Yellowstone Nat'l. Park	32	Reconofax IV	TX-475	70 mm	50
9-23-1966	11	Yellowstone Nat'l. Park	32	AAS-5	TX-417	35 mm	50
10-3-1966	114	White Sands	33	RC-8	Plus X	9½ in.	100
10-3-1966	114	White Sands	33	Nikon Data-Pan.	Plus X	35 mm	8
10-(11-14)-1966	46-99-138	Asheville-Miami-Norfolk	34	RC-8	Ektachrome	9½ in.	525
10-11-1966	46	Asheville	34	RC-8	Ektachrome IR	9½ in.	150
10-17-1966	128	Mississippi Delta	34	RC-8	Plus X	9½ in.	120
10-(10-14)-1966	46-99-138	Asheville-Miami-Norfolk	34	Multi-Band	Plus X	70 mm	1600
10-(10-14)-1966	46-99-138	Asheville-Miami-Norfolk	34	Multi-Band	Infrared	70 mm	800
10-(10-14)-1966	46-99-138	Asheville-Miami-Norfolk	34	Nikon Data-Pan.	Plus X	35 mm	160
10-(10-14)-1966	46-99-138	Asheville-Miami-Norfolk	34	Reconofax IV	TX-475	70 mm	100
10-(10-14)-1966	46-99-138	Asheville-Miami-Norfolk	34	AAS-5	TX-417	35 mm	40
12-5-1966	32	Weslaco, Texas	35	Nikon-Data Panel	Plus X	35 mm	25
12-5-1966	32	Weslaco, Texas	35	AAS-5	TX-417	35 mm	18
12-5-1966	32	Weslaco, Texas	35	Reconofax IV	TX-475	70 mm	20
12-5-1966	32	Weslaco, Texas	35	Multi-Band	Plus X	70 mm	900
12-5-1966	32	Weslaco, Texas	35	Multi-Band	Infrared	70 mm	450
12-5-1966	32	Weslaco, Texas	35	RC-8	Ektachrome IR	9½ in.	225

CARTOGRAPHIC FILM DATA FILE - Continued

Date of Photography	Site No.	Site Name	Mission Number	Camera	Film Type	Film Size	Footage
12-9-1966	95-98-102 103-104	Everglades-Homestead-Statenville-Crystal River-Wachula, Fla. Phosphate	36	Nikon Data-Pan.	Plus X	35 mm	44
12-9-1966	95-98-102 103-104	Everglades-Homestead-Statenville-Crystal River-Wachula, Fla. Phosphate	36	AAS-5	TX-417	35 mm	50
12-9-1966	95-98-102 103-104	Everglades-Homestead-Statenville-Crystal River-Wachula, Fla. Phosphate	36	Multi-Band	Plus X	70 mm	500
12-9-1966	95-98-102 103-104	Everglades-Homestead-Statenville-Crystal River-Wachula, Fla. Phosphate	36	Multi-Band	Infrared	70 mm	250
12-9-1966	95-98-102 103-104	Everglades-Homestead-Statenville-Crystal River-Wachula, Fla. Phosphate	36	Reconofax IV	TX-475	70 mm	35
12-9-1966	95	Everglades, Fla.	36	Multi-Band	Plus X	70 mm	350
12-9-1966	95	Everglades, Fla.	36	Multi-Band	Infrared	70 mm	175
12-(7-8)-1966	95	Everglades, Fla.	36	RC-8	Ektachrome IR	9½ in.	190
12-(6-7)-1966	98-102	Homestead-Statenville-Crystal River-Wachula, Fla. Phosphate	36	RC-8	Ektachrome IR	9½ in.	260
12-14-1966	128	Mississippi Delta	37	Nikon Data-Pan.	Plus X	35 mm	20
12-14-1966	128	Mississippi Delta	37	AAS-5	TX-417	35 mm	15
12-14-1966	128	Mississippi Delta	37	RC-8	Ektachrome IR	9½ in.	180

CARTOGRAPHIC FILM DATA FILE

Date of Photography	Site No.	Site Name	Mission Number	Camera	Film Type	Film Size	Footage
1-(22-25)-1967	86	Argus Isle, Bermuda	38	Nikon Data-Pan.	Plus X	35 mm	120
1-(22-25)-1967	86	Argus Isle, Bermuda	38	Multi-Band	Plus X	70 mm	1010
1-(22-25)-1967	86	Argus Isle, Bermuda	38	Multi-Band	Infrared	70 mm	505
1-(22-25)-1967	86	Argus Isle, Bermuda	38	RC-8	Ektachrome	9½ in.	245
2-4-1967	114	White Sands, N. M.	39	Nikon Data-Pan.	Plus X	35 mm	160
2-4-1967	114	White Sands, N. M.	39	RC-8	Ektachrome	9½ in.	210
2-(21-24)-1967	99-102-103-104	Florida Straits-Crystal River-Wauchula Phosphate	40	Nikon Data-Pan.	Plus X	35 mm	70
2-21-1967	99	Florida Straits	40	AAS-5	TX-417	35 mm	15
2-21-1967	99	Florida Straits	40	Reconofax IV	TX-475	70 mm	60
2-21-1967	99	Florida Straits	40	T-11	Plus X	9½ in.	130
2-21-1967	99	Florida Straits	40	RC-8	Ektachrome IR	9½ in.	125
2-24-1967	132	New Orleans	40	RC-8	Ektachrome	9½ in.	25
2-24-1967	128	Mississippi Delta	41	Nikon Data-Pan.	Plus X	35 mm	110
2-24-1967	128	Mississippi Delta	41	AAS-5	TX-417	35 mm	60
2-24-1967	128	Mississippi Delta	41	Reconofax IV	TX-475	70 mm	200
2-24-1967	128	Mississippi Delta	41	RC-8	Ektachrome IR	9½ in.	35
2-24-1967	128	Mississippi Delta	41	RC-8	Ektachrome	9½ in.	690

CENTRAL METRIC DATA FILE

Mission	Site	Flight	Line	Run	Recorded Date	Reel	Media	Type	Remarks	Security Classification	Accession Number
					06-12-66	1-1	AMT	RAD	DRC 6619	U	75-0186
					10-10-66	1-2	AMT	RAD	TEST FM ANA REC. MR-62+64	U	75-0184
					10-10-66	2-2	AMT	RAD	TEST FM ANA REC. MR-62+64	U	75-0185
					02-06-67	1-1	AMT	RAD	TEST SIMULATED DATA 2	U	75-0200
14	43	4			11-19-65	7-11	AMT	RAD		U	75-0164
14	43	5			11-19-65	8-11	AMT	RAD		U	75-0165
14	43	6			11-19-65	9-11	AMT	RAD		U	75-0166
14	43	6			11-19-65	10-11	AMT	RAD		U	75-0167
14	43	6			11-19-65	11-11	AMT	RAD		U	75-0168
14	46				11-15-65	3-11	AMT	RAD		U	75-0160
14	46				11-15-65	4-11	AMT	RAD		U	75-0161
14	46				11-16-66	5-11	AMT	RAD		U	75-0162
14	46				11-17-65	6-11	AMT	RAD		U	75-0163
14	46	1			11-15-65	1-11	AMT	RAD		U	75-0158
14	46	1			11-15-65	2-11	AMT	RAD		U	75-0159
14	46	3			11-17-65	7-11	AMT	RAD		U	75-0164
15	31	1			12-17-65	1-1	AMT	RAD		U	75-0169
16	32	1			12-22-65	1-1	AMT	RAD		U	75-0170
17	32	1			01-05-66	1-1	AMT	RAD		U	75-0171
18	15	5			01-09-66	1-1	AMT	RAD		U	75-0150
18	15	6			01-10-66	1-1	AMT	RAD		U	75-0151

CENTRAL METRIC DATA FILE - Continued

Mission	Site	Flight	Line	Run	Recorded Date	Reel	Media	Type	Remarks	Security Classification	Accession Number
18	27	2			01-12-66	2-4	AMT	RAD		U	75-0155
18	27	3			01-12-66	3-4	AMT	RAD		U	75-0156
18	27	4			01-12-66	4-4	AMT	RAD		U	75-0157
18	27	7			01-11-66	1-2	AMT	RAD		U	75-0152
18	27	7			01-11-66	2-2	AMT	RAD		U	75-0153
18	27	8			01-12-66	1-4	AMT	RAD		U	75-0154
18	28	2			01-08-66	1-2	AMT	RAD		U	75-0146
18	28	2			01-08-66	2-2	AMT	RAD		U	75-0147
18	31	1			01-07-66	1-1	AMT	RAD		U	75-0145
18	51	3			01-08-66	1-1	AMT	RAD		U	75-0148
18	51	4			01-09-66	1-1	AMT	RAD		U	75-0149
20	86	1			03-06-66	1-8	AMT	RAD		U	75-0118
20	86	1			03-06-66	2-8	AMT	RAD		U	75-0119
20	86	1			03-06-66	3-8	AMT	RAD		U	75-0120
20	86	1			03-06-66	4-8	AMT	RAD		U	75-0121
20	86	1			03-06-66	5-8	AMT	RAD		U	75-0122
20	86	1			03-06-66	6-8	AMT	RAD		U	75-0123
20	86	1			03-06-66	7-8	AMT	RAD		U	75-0124
20	86	1			03-06-66	8-8	AMT	RAD		U	75-0125
20	86	2			03-07-66	1-4	AMT	RAD		U	75-0126
20	86	2			03-07-66	2-4	AMT	RAD		U	75-0127

CENTRAL METRIC DATA FILE - Continued

Mission	Site	Flight	Line	Run	Recorded Date	Reel	Media	Type	Remarks	Security Classification	Accession Number
20	86	2			03-07-66	3-4	AMT	RAD		U	75-0128
20	86	2			03-07-66	4-4	AMT	RAD		U	75-0129
20	86	2	1	1	03-07-66	-	MIC	35MM	FORE RAD/PLOTS	U	75-0238
20	86	2	1	1	03-07-66	-	MIC	35MM	AFT RAD/PLOTS	U	75-0237
20	86	2	1	2	03-07-66	-	MIC	35MM	AFT RAD/PLOTS	U	75-0234
20	86	2	1	2	03-07-66	-	MIC	35MM	FORE RAD/PLOTS	U	75-0233
20	86	2	1	3	03-07-66	-	MIC	35MM	FORE RAD/PLOTS	U	75-0235
20	86	2	2	2	03-07-66	-	MIC	35MM	AFT RAD/PLOTS	U	75-0236
20	86	2	2	3	03-07-66	-	MIC	35MM	AFT RAD/PLOTS	U	75-0232
20	86	2	2	3	03-07-66	-	MIC	35MM	FORE RAD/PLOTS	U	75-0231
20	86	2	4	1	03-07-66	-	MIC	35MM	AFT RAD/PLOTS	U	75-0230
20	86	2	4	1	03-07-66	-	MIC	35MM	FORE RAD/PLOTS	U	75-0229
20	86	2	4	2	03-07-66	-	MIC	35MM	AFT RAD/PLOTS	U	75-0228
20	86	2	4	2	03-07-66	-	MIC	35MM	FORE RAD/PLOTS	U	75-0227
20	86	2	4	4	03-07-66	-	MIC	35MM	AFT RAD/PLOTS	U	75-0226
20	86	2	4	4	03-07-66	-	MIC	35MM	FORE RAD/PLOTS	U	75-0225
20	86	3			03-08-66	1-5	AMT	RAD		U	75-0130
20	86	3			03-08-66	2-5	AMT	RAD		U	75-0131
20	86	3			03-08-66	3-5	AMT	RAD		U	75-0132
20	86	3			03-08-66	4-5	AMT	RAD		U	75-0133
20	86	3			03-08-66	5-5	AMT	RAD		U	75-0134

CENTRAL METRIC DATA FILE - Continued

Mission	Site	Flight	Line	Run	Recorded Date	Reel	Media	Type	Remarks	Security Classification	Accession Number
20	86	4			03-09-66	1-1	AMT	RAD		U	75-0135
20	86	6			03-10-66	1-5	AMT	RAD		U	75-0136
20	86	6			03-10-66	2-5	AMT	RAD		U	75-0137
20	86	6			03-10-66	3-5	AMT	RAD		U	75-0138
20	86	6			03-10-66	4-5	AMT	RAD		U	75-0139
20	86	6			03-10-66	5-5	AMT	RAD		U	75-0140
20	86	7			03-11-66	1-1	AMT	RAD		U	75-0141
20	86	8			03-12-66	1-3	AMT	RAD		U	75-0142
20	86	8			03-12-66	2-3	AMT	RAD		U	75-0143
20	86	8			03-12-66	3-3	AMT	RAD		U	75-0144
21	2	1			04-02-66	1-1	AMT	RAD		U	75-0001
21	2	5			04-05-66	1-2	AMT	RAD		U	75-0005
21	2	5			04-05-66	2-2	AMT	RAD		U	75-0006
21	2	5	3	1	04-05-66	-	MIC	35MM	AFT RAD/PLOTS	U	75-0238
21	00	2			04-02-66	1-1	AMT	RAD		U	75-0002
21	10	12	1	1	04-05-66	-	MIC	35MM	AFT RAD/PLOTS	U	75-0240
21	10	12	1	1	04-05-66	-	MIC	35MM	FORE RAD/PLOTS	U	75-0240
21	10	12	1	3	04-05-66	-	MIC	35MM	FORE RAD/PLOTS	U	75-0239
21	32	5			04-05-66	1-2	AMT	RAD		U	75-0005
21	32	5			04-05-66	2-2	AMT	RAD		U	75-0006
21	40	3			04-02-66	1-1	AMT	RAD		U	75-0003

Tape Data

CENTRAL METRIC DATA FILE - Continued

Mission	Site	Flight	Line	Run	Recorded Date	Reel	Media	Type	Remarks	Security Classification	Accession Number
21	40	4			04-02-66	1-1	AMT	RAD		U	75-0004
22	87	1			04-19-66	1-2	AMT	RAD		U	75-0007
22	87	1			04-19-66	2-2	AMT	RAD		U	75-0008
22	87	2			04-19-66	1-2	AMT	RAD		U	75-0009
22	87	2			04-19-66	2-2	AMT	RAD		U	75-0010
22	87	3			04-20-66	1-3	AMT	RAD		U	75-0011
22	87	3			04-20-66	2-3	AMT	RAD		U	75-0012
22	87	3			04-20-66	3-3	AMT	RAD		U	75-0013
22	87	4			04-21-66	1-3	AMT	RAD		U	75-0014
22	87	4			04-21-66	2-3	AMT	RAD		U	75-0015
22	87	4			04-21-66	3-3	AMT	RAD		U	75-0016
23	46	1			05-07-66	1-4	AMT	RAD		U	75-0017
23	46	1			05-07-66	2-4	AMT	RAD		U	75-0018
23	46	1			05-07-66	3-4	AMT	RAD		U	75-0019
23	46	1			05-07-66	4-4	AMT	RAD		U	75-0020
23	46	2			05-07-66	1-1	AMT	RAD		U	75-0021
23	95	5			05-10-66	1-3	AMT	RAD		U	75-0028
23	95	5			05-10-66	2-3	AMT	RAD		U	75-0029
23	95	5			05-10-66	3-3	AMT	RAD		U	75-0030
23	95	6			05-11-66	1-1	AMT	RAD		U	75-0031
23	98	4			05-09-66	1-4	AMT	RAD		U	75-0024

CENTRAL METRIC DATA FILE - Continued

Mission	Site	Flight	Line	Run	Recorded Date	Reel	Media	Type	Remarks	Security Classification	Accession Number
23	98	4			05-09-66	2-4	AMT	RAD		U	75-0025
23	98	4			05-09-66	3-4	AMT	RAD		U	75-0026
23	98	4			05-09-66	4-4	AMT	RAD		U	75-0027
23	99	4			05-09-66	1-4	AMT	RAD		U	75-0024
23	99	4			05-09-66	2-4	AMT	RAD		U	75-0025
23	99	4			05-09-66	3-4	AMT	RAD		U	75-0026
23	99	4			05-09-66	4-4	AMT	RAD		U	75-0027
23	102	6			05-11-66	1-1	AMT	RAD		U	75-0031
23	102	7			05-11-66	1-1	AMT	RAD		U	75-0032
23	103	6			05-11-66	1-1	AMT	RAD		U	75-0031
23	103	7			05-11-66	1-1	AMT	RAD		U	75-0032
23	104	6			05-11-66	1-1	AMT	RAD		U	75-0031
23	105	7			05-11-66	1-1	AMT	RAD		U	75-0032
23	106	3			05-08-66	1-2	AMT	RAD		U	75-0022
23	106	3			05-08-66	2-2	AMT	RAD		U	75-0023
23	106	5			05-10-66	1-3	AMT	RAD		U	75-0028
23	106	5			05-10-66	2-3	AMT	RAD		U	75-0029
23	106	5			05-10-66	3-3	AMT	RAD		U	75-0030
23	107	4			05-09-66	1-4	AMT	RAD		U	75-0024
23	107	4			05-09-66	2-4	AMT	RAD		U	75-0025
23	107	4			05-09-66	3-4	AMT	RAD		U	75-0026

CENTRAL METRIC DATA FILE - Continued

Mission	Site	Flight	Line	Run	Recorded Date	Reel	Media	Type	Remarks	Security Classification	Accession Number
23	107	4			05-09-66	4-4	AMT	RAD		U	75-0027
23	107	5			05-10-66	1-3	AMT	RAD		U	75-0028
23	107	5			05-10-66	2-3	AMT	RAD		U	75-0029
23	107	5			05-10-66	3-3	AMT	RAD		U	75-0030
23	108	4			05-09-66	1-4	AMT	RAD		U	75-0024
23	108	4			05-09-66	2-4	AMT	RAD		U	75-0025
23	108	4			05-09-66	3-4	AMT	RAD		U	75-0026
23	108	4			05-09-66	4-4	AMT	RAD		U	75-0027
24	32	1			05-14-66	1-2	AMT	RAD		U	75-0033
24	32	1			05-14-66	2-2	AMT	RAD		U	75-0034
25	43	1			06-30-66	1-2	AMT	RAD		U	75-0035
25	43	1			06-30-66	2-2	AMT	RAD		U	75-0036
25	43	2			06-30-66	1-2	AMT	RAD		U	75-0036
25	43	2			06-30-66	2-2	AMT	RAD		U	75-0037
25	88	4			07-01-66	1-2	AMT	RAD		U	75-0038
25	88	4			07-01-66	2-2	AMT	RAD		U	75-0039
26	128	1			07-06-66	1-4	AMT	RAD		U	75-0040
26	128	1			07-06-66	2-4	AMT	RAD		U	75-0041
26	128	1			07-06-66	3-4	AMT	RAD		U	75-0042
26	128	1			07-06-66	4-4	AMT	RAD		U	75-0043
26	128	2			07-06-66	1-3	AMT	RAD		U	75-0044

CENTRAL METRIC DATA FILE - Continued

Mission	Site	Flight	Line	Run	Recorded Date	Reel	Media	Type	Remarks	Security Classification	Accession Number
26	128	2			07-06-66	2-3	AMT	RAD		U	75-0045
26	128	2			07-06-66	3-3	AMT	RAD		U	75-0046
26	128	3			07-06-66	1-1	AMT	RAD		U	75-0047
27	32	1			07-08-66	1-3	AMT	RAD		U	75-0048
27	32	1			07-08-66	2-3	AMT	RAD		U	75-0049
27	32	1			07-08-66	3-3	AMT	RAD		U	75-0050
28	24	1			07-25-66	1-1	AMT	RAD		S	75-0051
28	24	4			07-29-66	1-1	AMT	RAD		U	75-0052
28	24	6			07-29-66	1-1	AMT	RAD		U	75-0053
28	114	1			07-25-66	1-1	AMT	RAD		S	75-0051
28	114	4			07-29-66	1-1	AMT	RAD		U	75-0052
28	114	6			07-29-66	1-1	AMT	RAD		U	75-0053
28	130	1			07-25-66	1-1	AMT	RAD		S	75-0051
28	130	4			07-29-66	1-1	AMT	RAD		U	75-0052
28	130	6			07-29-66	1-1	AMT	RAD		U	75-0053
29	40	3			08-11-66	1-1	AMT	RAD		U	75-0058
29	40	4			08-11-66	1-1	AMT	RAD		U	75-0059
29	40	5			08-11-66	1-1	AMT	RAD		U	75-0060
29	40	6			08-11-66	1-1	AMT	RAD		U	75-0061
29	130	1			08-08-66	1-4	AMT	RAD		U	75-0054
29	130	1			08-08-66	2-4	AMT	RAD		U	75-0055

CENTRAL METRIC DATA FILE - Continued

Mission	Site	Flight	Line	Run	Recorded Date	Reel	Media	Type	Remarks	Security Classification	Accession Number
29	130	1			08-08-66	3-4	AMT	RAD		U	75-0056
29	130	1			08-08-66	4-4	AMT	RAD		U	75-0057
30	3	3			09-01-66	1-1	AMT	RAD		U	75-0067
30	3	5			09-01-66	1-2	AMT	RAD		U	75-0072
30	3	5			09-01-66	2-2	AMT	RAD		U	75-0073
30	19	1			08-30-66	1-2	AMT	RAD		U	75-0062
30	19	1			08-30-66	2-2	AMT	RAD		U	75-0063
30	19	2			08-31-66	1-3	AMT	RAD		U	75-0064
30	19	2			08-31-66	2-3	AMT	RAD		U	75-0065
30	19	2			08-31-66	3-3	AMT	RAD		U	75-0066
30	20	4			09-01-66	1-4	AMT	RAD		U	75-0068
30	20	4			09-01-66	2-4	AMT	RAD		U	75-0069
30	20	4			09-01-66	3-4	AMT	RAD		U	75-0070
30	52	6			09-03-66	1-2	AMT	RAD		U	75-0074
30	52	6			09-03-66	2-2	AMT	RAD		U	75-0075
30	52	7			09-03-66	1-2	AMT	RAD		U	75-0076
30	52	7			09-03-66	2-2	AMT	RAD		U	75-0077
30	135	4			09-01-66	3-4	AMT	RAD		U	75-0070
30	135	4			09-01-66	4-4	AMT	RAD		U	75-0071
31	43	1			09-15-66	1-1	AMT	RAD		U	75-0078
32	11	2			09-20-66	1-3	AMT	RAD		U	75-0081

CENTRAL METRIC DATA FILE - Continued

Mission	Site	Flight	Line	Run	Recorded Date	Reel	Media	Type	Remarks	Security Classification	Accession Number
32	11	2			09-20-66	2-3	AMT	RAD		U	75-0082
32	11	2			09-20-66	3-3	AMT	RAD		U	75-0083
32	11	3			09-20-66	1-3	AMT	RAD		U	75-0084
32	11	3			09-20-66	2-3	AMT	RAD		U	75-0085
32	11	3			09-20-66	3-3	AMT	RAD		U	75-0086
32	11	4			09-21-66	1-4	AMT	RAD		U	75-0087
32	11	4			09-21-66	2-4	AMT	RAD		U	75-0088
32	11	4			09-21-66	3-4	AMT	RAD		U	75-0089
32	11	4			09-21-66	4-4	AMT	RAD		U	75-0090
32	11	5			09-22-66	1-4	AMT	RAD		U	75-0091
32	11	5			09-22-66	2-4	AMT	RAD		U	75-0092
32	11	5			09-22-66	3-4	AMT	RAD		U	75-0093
32	11	5			09-22-66	4-4	AMT	RAD		U	75-0094
32	76	1			09-19-66	1-2	AMT	RAD		U	75-0079
32	76	1			09-19-66	2-2	AMT	RAD		U	75-0080
33	11	41	2	1	03-10-66	-	MIC	35MM	AFT RAD/PLOTS	U	75-0240
33	11	41	2	1	03-10-66	-	MIC	35MM	FORE RAD/PLOTS	U	75-0240
33	114	1			10-03-66	1-1	AMT	RAD		U	75-0095
34	46	1			10-11-66	1-4	AMT	RAD		U	75-0096
34	46	1			10-11-66	2-4	AMT	RAD		U	75-0097
34	46	1			10-11-66	3-4	AMT	RAD		U	75-0098
34	46	1			10-11-66	4-4	AMT	RAD		U	75-0099

CENTRAL METRIC DATA FILE - Continued

Mission	Site	Flight	Line	Run	Recorded Date	Reel	Media	Type	Remarks	Security Classification	Accession Number
34	99	3			10-12-66	1-5	AMT	RAD		U	75-0102
34	99	3			10-12-66	2-5	AMT	RAD		U	75-0103
34	99	3			10-12-66	3-5	AMT	RAD		U	75-0104
34	99	3			10-12-66	4-5	AMT	RAD		U	75-0105
34	99	3			10-13-66	5-5	AMT	RAD		U	75-0106
34	99	4			10-13-66	1-4	AMT	RAD		U	75-0106
34	99	4			10-13-66	2-4	AMT	RAD		U	75-0107
34	99	4			10-13-66	3-4	AMT	RAD		U	75-0108
34	99	4			10-13-66	4-4	AMT	RAD		U	75-0109
34	99	5			10-14-66	1-4	AMT	RAD		U	75-0110
34	99	5			10-14-66	2-4	AMT	RAD		U	75-0111
34	99	5			10-14-66	3-4	AMT	RAD		U	75-0112
34	99	5			10-14-66	4-4	AMT	RAD		U	75-0113
34	128	7			10-17-66	1-4	AMT	RAD		U	75-0114
34	128	7			10-17-66	2-4	AMT	RAD		U	75-0115
34	128	7			10-17-66	3-4	AMT	RAD		U	75-0116
34	128	7			10-17-66	4-4	AMT	RAD		U	75-0117
34	138	2			10-12-66	1-2	AMT	RAD		U	75-0100
34	138	2			10-12-66	2-2	AMT	RAD		U	75-0101
35	32	1			12-05-66	1-2	AMT	RAD		U	75-0172
35	32	1			12-05-66	2-2	AMT	RAD		U	75-0173

CENTRAL METRIC DATA FILE - Continued

Mission	Site	Flight	Line	Run	Recorded Date	Reel	Media	Type	Remarks	Security Classification	Accession Number
36	95	2			12-07-66	1-2	AMT	RAD		U	75-0178
36	95	3			12-08-66	1-2	AMT	RAD		U	75-0180
36	95	3			12-08-66	2-2	AMT	RAD		U	75-0181
36	95	4			12-08-66	1-2	AMT	RAD		U	75-0182
36	95	4			12-08-66	2-2	AMT	RAD		U	75-0183
36	98	2			12-07-66	2-2	AMT	RAD		U	75-0179
36	102	1			12-06-66	1-3	AMT	RAD		U	75-0175
36	103	1			12-06-66	1-3	AMT	RAD		U	75-0175
36	103	1			12-06-66	2-3	AMT	RAD		U	75-0176
36	104	1			12-06-66	2-3	AMT	RAD		U	75-0176
36	104	1			12-06-66	3-3	AMT	RAD		U	75-0177
38	86	1			01-22-67	1-4	AMT	RAD	DRC 6619	U	75-0187
38	86	1			01-22-67	2-4	AMT	RAD		U	75-0188
38	86	1			01-22-67	3-4	AMT	RAD		U	75-0189
38	86	1			01-22-67	4-4	AMT	RAD		U	75-0190
38	86	2			01-23-67	1-5	AMT	RAD		U	75-0191
38	86	2			01-23-67	2-5	AMT	RAD		U	75-0192
38	86	2			01-23-67	3-5	AMT	RAD		U	75-0193
38	86	2			01-23-67	4-5	AMT	RAD		U	75-0194
38	86	2			01-23-67	5-5	AMT	RAD		U	75-0195
38	86	4			01-24-67	1-2	AMT	RAD		U	75-0196

CENTRAL METRIC DATA FILE - Continued

Mission	Site	Flight	Line	Run	Recorded Date	Reel	Media	Type	Remarks	Security Classification	Accession Number
38	86	4			01-24-67	2-2	AMT	RAD		U	75-0197
39	114	1			02-04-67	1-1	AMT	RAD		U	75-0198
39	114	2			02-04-67	1-1	AMT	RAD		U	75-0199

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INFRARED SURVEYS OF HAWAIIAN VOLCANOES

by

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Infrared Surveys of Hawaiian Volcanoes

Aerial surveys with infrared imaging radiometer depict volcanic thermal patterns and structural features.

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Kilauea, on the island of Hawaii, has been one of the most active volcanoes in historic time. Though it has been studied intensively since establishment of the Hawaiian Volcano Observatory in 1912, little is known of the thermal regime, despite its obvious importance in volcanic processes. Published data include those of Jaggar (*1*), Ault and his co-workers (*2*), and Macdonald (*3*).

Obvious surficial thermal anomalies are associated with Kilauea, as visible steaming in many places attests to convective transfer of heat from subterranean sources. Ground adjacent to these steaming cracks commonly is abnormally warm. But the relative intensity and spatial configuration of the thermal patterns of this extensive volcanic system cannot easily be recorded by conventional means.

Modern infrared imaging radiometers have enabled us to map the distribution of anomalies associated with Kilauea and Mauna Loa, including some that have later been sites of volcanic eruption. These instruments have also made it possible to locate fresh water springs discharging into the ocean and to demonstrate relationships between surface configuration and consolidation and infrared emission that warrant further study, because of their possible application to lunar and planetary investigations.

Infrared radiometers have been used for many years to make surface-temperature (or, more strictly, energy-emission) measurements, but their application has generally been limited to spot measurements or traverses. In the last decade, airborne electromechanical imaging infrared radiometers have been developed for military purposes (*4*). We feel that these instruments could be adapted to thermal mapping for geophysical purposes. Instruments of this type, as they evolve, will doubtless provide quantitative data, but the present instrument configuration has provided only qualitative results. In this preliminary account we describe the data obtained for surface temperatures of Hawaii through the use of such a scanning device, supplemented by conventional aerial infrared and black-and-white photography. These sensors covered the 0.4- to 14-μ region of the electromagnetic spectrum, providing, in pictorial form, a measure of the electromagnetic energy being emitted or reflected from the earth's surface in that spectral region. The earth radiates energy whose spectrum approximates that of a black body at 300°K (Fig. 1), with a maximum near 9.5 μ. In addition, during daylight hours the earth reflects solar energy whose spectrum approximates that of a black body at 6000°K, with a maximum near 0.5 μ. The energy emitted or reflected from the earth's surface is selectively absorbed by the atmosphere, so only that part which passes through atmospheric windows (Fig. 2) reaches an airborne detector.

The sensors were carried in an A-26B aircraft operated by Aero Service Corporation. That organization was also responsible for the photography. Infrared imaging was carried out by the University of Michigan's Institute of Science and Technology. The aerial surveys were made from 26 January to 20 February 1963, under the direction of the U.S. Geological Survey.

Geologic Setting

Kilauea is a shield volcano built against the east side of its larger neighbor, Mauna Loa (Fig. 3). The volcano has grown to an altitude of about 1200 meters from repeated outpourings of basaltic lava along two major rift zones. At the summit is a caldera about 4 kilometers in diameter, whose floor is formed of lava erupted in historic time, most recently in 1954. Steam issues from arcuate patterns of cracks on the caldera floor and from several other localities adjacent to the caldera. Some cracks yield pure water vapor; some yield steam, at near-normal steam temperature, carrying salts in solution (for example, Sulfur Banks). A few, as at the crest of the Kilauea Iki cinder cone, are superheated. Halemaumau, a crater in the southwest part of the caldera, has been the scene of repeated volcanic activity. For many years it was filled with liquid lava, but the crust is now solidified. Adjacent to the caldera on the east is Kilauea Iki, a crater filled by a lava lake during a spectacular eruption in 1959 (*5*).

Two major rift zones transect the volcano. The east rift zone of Kilauea is a curvilinear system of faults, extending southeast from the summit area, thence east and northeast, where it intersects the coastline at Cape Kumukahi. Near the summit the rift is marked by a chain of pit craters; toward the east, open fissures and cinder cones are more common. The other major rift zone curves southwest from the summit to the sea. It is thought that, in the eruptive cycle of Kilauea, lava enters the summit area through a system of conduits beneath Halemaumau and commonly is discharged through tubes that follow the two rift zones. In the past two decades most of the lava eruptions have been in Halemaumau or along the east rift zone. The latest eruption prior to the survey discussed here was on 7 December 1962, when about 335,000 cubic meters of lava were discharged into and near Aloi Crater. (For additional details on the geology of Kilauea, see *6* and *7*.)

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The following aerial sensors were used.

1) An infrared scanner (Fig. 4) that records an image whose gray scale is controlled by the instantaneous energy focused upon the detector. Detecting elements sensitive to radiation in the 2- to 6-μ and 8- to 14-μ parts of the spectrum were used. The energy radiated from the earth's surface, and hence the image gray scale, is a function of surface temperature and emissivity. As emissivity of earth materials and vegetation ranges from perhaps 0.7 to 0.98, the image tone depicts what we term "apparent surface temperatures." Lighter shades on the accompanying images indicate higher apparent surface temperatures.

2) Infrared aerial photography (long-wavelength cutoff, $\sim 0.9\ \mu$) which records reflected solar infrared energy. These photographs helped identify features that were seen on other images and provided a means of estimating relative absorption of solar energy. Darker tones indicate greater absorption.

3) Conventional aerial photography, to assist in identification and to provide information on surface configuration and absorption of solar energy.

In the following discussion the records provided by the infrared scanning technique are termed *images*; the term *photographs* is used only for records obtained by conventional aerial cameras.

Temperature Measurements on the Ground

Figure 5 shows air temperatures and surface temperatures of several objects measured with a contact pyrometer. The apparent temperature of the soil, rock outcrops, and vegetation in a small area warmed by volcanic steam varied relatively little during the hours 0200 to 1000 (all times given here are local standard time), while other nearby materials show a normal diurnal temperature curve. Thus, between 0200 and daybreak at about 0630 (and probably for several hours before 0200), thermal anomalies have maximum contrast with their natural surroundings; this finding is confirmed by the infrared images shown in Figs. 6 and 7. The basalt outcrop and the blacktop road are very faint or absent they are nearly as bright as the thermal anomalies.

Field measurements made during this study suggest that the temperatures of some thermal sources vary with time; for instance, temperature of the ground surface adjoining a small steaming vent near Aloi Crater ranged from about 29° to 41°C during the survey period. The vent is in an active collapse area resulting from the December 1962 eruption.

Minor, short-term variations in temperature are related to changes in sky temperature, relative humidity, volcanic action, and rainfall. Rainfall is thought to be particularly significant; it percolates downward through the highly permeable volcanic rocks, is heated, and subsequently vented as steam or warm vapor. Many thermal anomalies on the infrared images correlate with this visible evidence of convective heat transfer.

Classification of Thermal Sources

A thermal source of given area and emissivity, as its temperature increases, emits increasing amounts of energy at decreasingly shorter wavelengths. Three anomaly groups were established through contrast of their relative emission in different parts of the infrared spectrum. The thermal sources were further classified into seven orders of magnitude, designated by roman numerals which indicate the relative amounts of energy emitted; the higher the energy, the smaller the numeral. Magnitude assignment within groups was accomplished by densitometer measurement of relative image brightness.

Group 1 (magnitudes I, II, and III). Sources visible on all infrared images, including those recording wavelengths $< 2.6\ \mu$.

Group 2 (magnitudes IV, V, and VI). Sources which appear only on images recording wavelengths $> 2.6\ \mu$.

Group 3 (magnitude VII). Sources which appear only on images recording wavelengths $> 5.5\ \mu$.

Measurements on the ground suggest that magnitude III sources have temperatures 5° to 10°C (varying with time) above ambient temperature (apparent temperature of the surrounding area). Locally this group may include small sources having appreciably higher temperatures.

lauea Summit Area

The dominant volcanic and structural features of the Kilauea summit area, as depicted by various sensors, are shown in Figs. 8–11. The spectral response of the infrared detectors was controlled by interference filters; Fig.

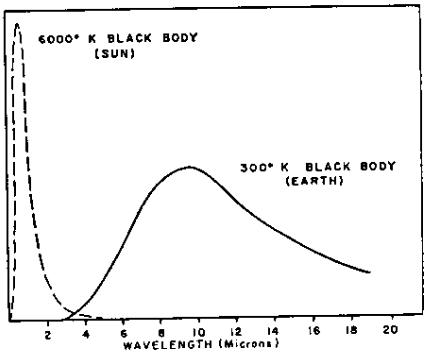


Fig. 1. Radiation curves for black bodies at temperatures of 6000° and 300°K. Earth materials, being "gray bodies," depart from this curve according to their spectral emissivity.

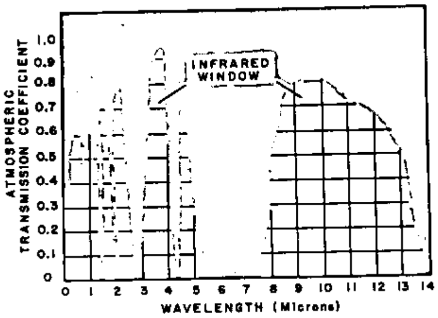


Fig. 2. Atmospheric transmission in the visible and the infrared regions of the spectrum.

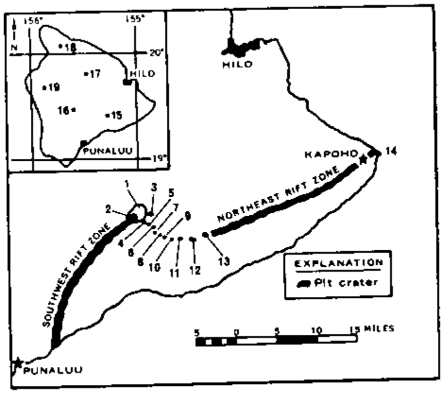


Fig. 3. Volcanic and other features of Hawaii. 1, Kilauea caldera; 2, Halemaumau; 3, Kilauea Iki; 4, Keanakakoi; 5, Lua Manu; 6, Puhimau; 7, Kokoolau; 8, Heake; 9, Pauahi; 10, Aloi; 11, Alae; 12, Makaopuhi; 13, Napau; 14, Cape Kumukahi. Inset: 15, Kilauea; 16, Mauna Loa; 17, Mauna Kea; 18, Kohala; 19, Hualalai.

10 (right) shows only the hotter areas [illegible] tions in apparent surface temperatures but does not resolve the hotter areas, and Fig. 11 is a compromise between these two extremes.

Most of the peripheral faults of the caldera show, on the infrared images, some thermal abnormality, ranging from very indistinct diffuse linear patterns to highly localized anomalies that are believed to be correlated with steaming vents. The caldera floor is reticulated, with curvilinear elements of greatly varying intensity that also correspond in part to steaming fissures. One prominent subcircular feature [*D* in Fig. 11, *a* and *b*] apparently corresponds to the buried margin of a sunken central basin that existed in the caldera during the 19th century, as described and mapped by Macdonald (*3*). Point *A* in Fig. 10 (right) has the highest apparent temperature of the thermal anomalies associated with Kilauea. It is the vent and spatter cone of the July 1961 eruption into the floor of Halemaumau, and it is located where the southwest rift zone intersects the crater wall. Rock temperatures of 100°C are measured here about a meter below the surface (see *8*).

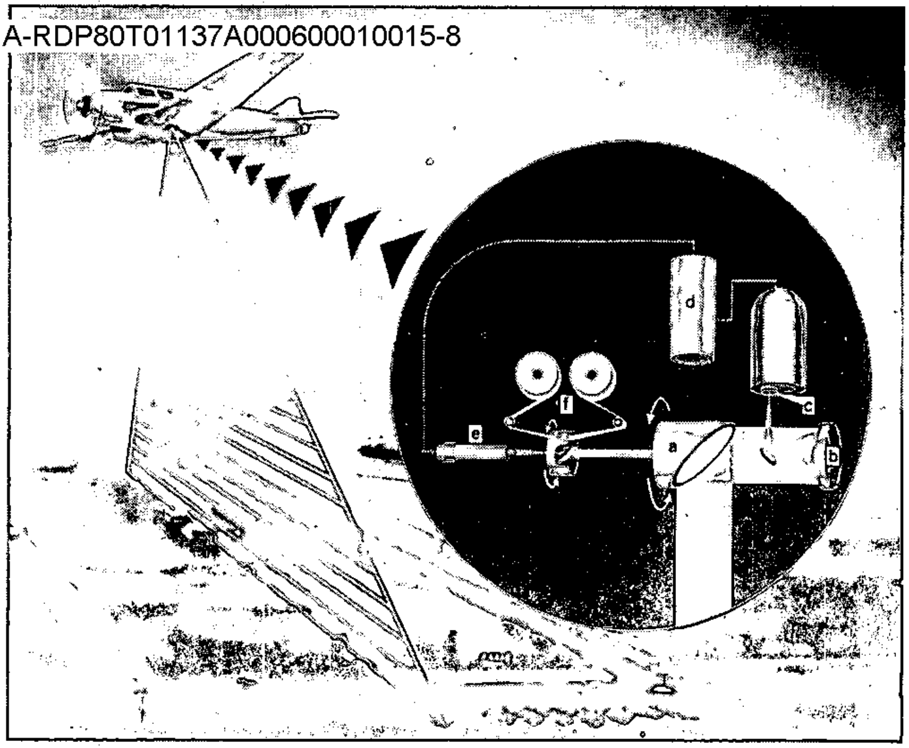


Fig. 4. Infrared scanning system. Radiation from the earth is collected on the surface of a rotating mirror *a*, reflected to the surface of a parabolic mirror *b*, and thence to the surface of a solid state detector *c*. The output of the detector is amplified *d* and modulates the output of a light source *e*. The modulated light is recorded on film *f*. Lateral coverage is obtained by rotation of the collecting mirror *a*; forward coverage is provided by forward movement of the aircraft and is coordinated with the recording film-transport mechanism. [Modified from diagram supplied by the H. R. B. Singer Corporation]

At Kilauea Iki, an intense thermal anomaly was recorded at the apex of the cinder cone (*B* in Fig. 11) on the southwest flank of the crater, immediately adjacent to the vent. Cinders on the crest of the cone are a bright yellow, in contrast to dull gray on the flanks and base. This color contrast, evident in the tones on the conventional photograph (Fig. 8), is attributed to pneumatolytic alteration and deposition. The lava lake, formed during the 1959–60 eruption, is about 110 meters deep; the solidified crust is now about 15 meters thick (*9*). The molten lava at the base of the crust has a temperature of about 1065°C (*2*). A double row of vents (Fig. 11) bordering the lava lake and along the walls of Kilauea Iki runs near or along the peripheral fracture zone developed during back-drainage of the lava. It is evident that there are differences in the apparent surface temperature of the lava lake (Fig. 11, areas 1 and 2), though there are no known corresponding compositional differences. Moreover, there is nothing obvious in the lake-bottom configuration to account for the apparent variation in surface temperature. There are differences in the surface texture of the lava (Fig. 12), however, which relate to differences in cooling history. One anomaly adjacent to the caldera (*B* in Fig. 10, left) is surrounded by a broad area of diffuse brightness (marked with arrows). This broad area does not appear on other images. Its margins do not correspond to topographic or vegetation boundaries.

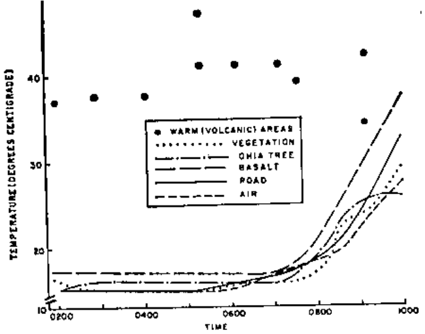
Southwest Rift Zone

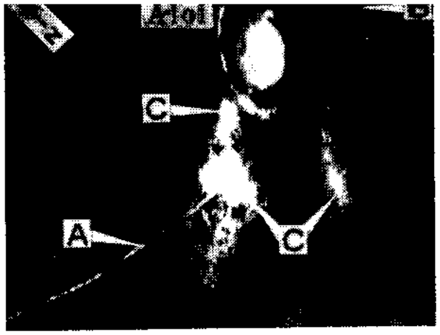
The most recent eruption along the southwest rift zone took place in 1920 in an area about halfway between the summit and the sea. A few local thermal anomalies, not manifested on conventional aerial photographs (Figs. 8 and 13), were recorded along the rift zone approximately 3 kilometers southwest of Halemaumau (Fig. 14). Field investigations at one of these disclosed a series of small vents (Fig. 15) from which water vapor, at a temperature of 91°C, issues at velocities of 16 to 32 kilometers per hour. No color changes in the rock or other manifestations of thermal alteration were found, except for slight coloration immediately adjacent to the vents. No other thermal anomalies were found between those shown in Fig. 14 and the coast. At the intersection of the southwest rift zone with the coastline, however, a warm spring of significant size issues into the relatively cool ocean waters.

Chain of Craters and East Rift Zone

The thermal expression of some volcanic features along the Chain of Craters (Fig. 16, top and bottom) in the summit area of the east rift zone appears differently on the two images, owing to differences in electronic gain, photographic processing, and time of recording. Some differences may also relate to changes in apparent temperature.

The linear thermal source *B* of Fig. 16 is faintly visible on images for the 2.0- to 2.6-μ region of the spectrum, and thus its temperature was significantly higher than ambient temperature on 17 February. It is likely that the linearity of this source relates to





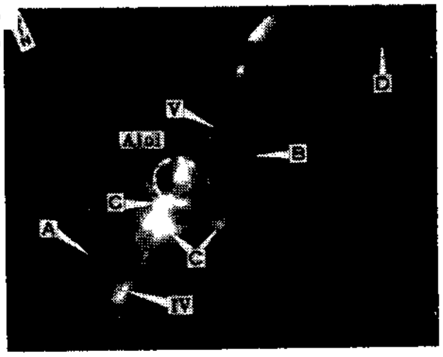
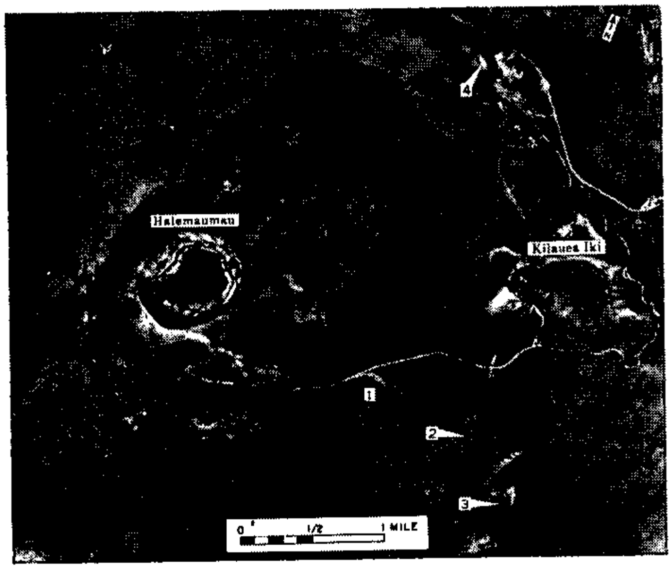
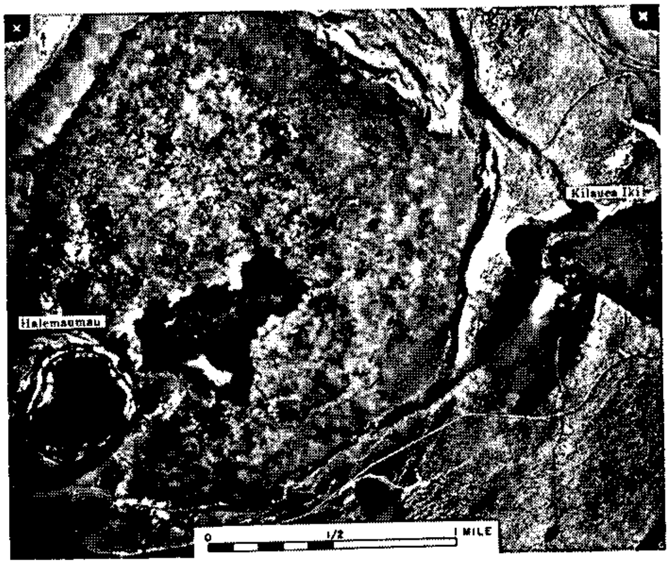


Fig. 5 (left). Temperature observations on the ground in the vicinity of Aloi crater, 6 February. Fig. 6 (middle). Infrared image of Aloi crater. Time, 1008, 3 February; spectral region, 4.2 to 5.5 μ; altitude, 450 meters. *A*, Blacktop road; *B*, basalt outcrop; *C*, areas warmed by volcanic processes. The image is somewhat distorted geometrically. Fig. 7 (right). Infrared image of Aloi crater. Time, 0640, 28 January; spectral region, 4.5 to 5.5 μ; altitude, 1800 meters. *A*, *B*, and *C*, same as in Fig. 6; *D*, Alea crater. Roman numerals indicate orders of magnitude of apparent temperature.





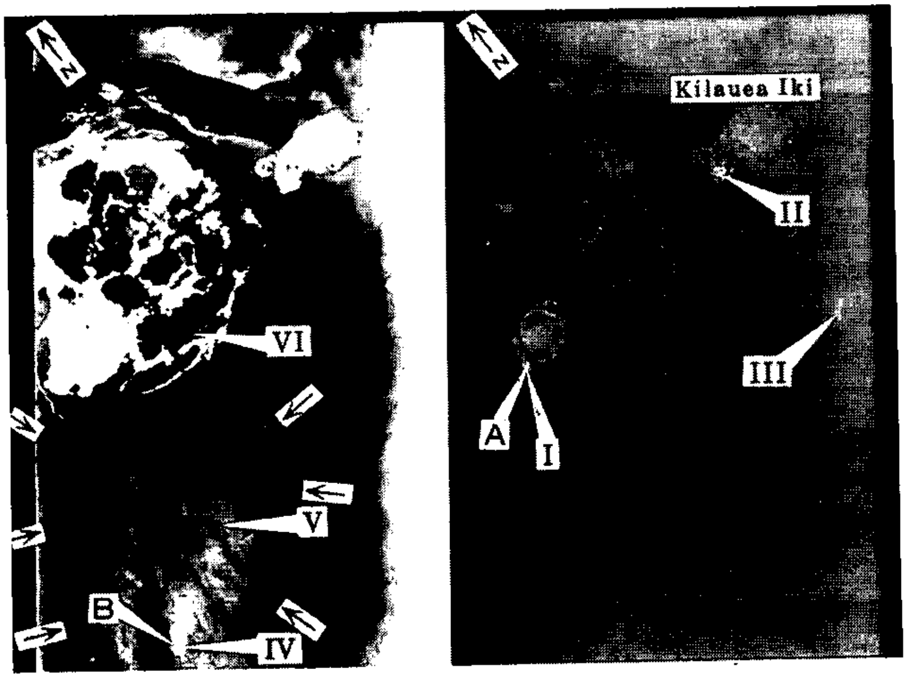
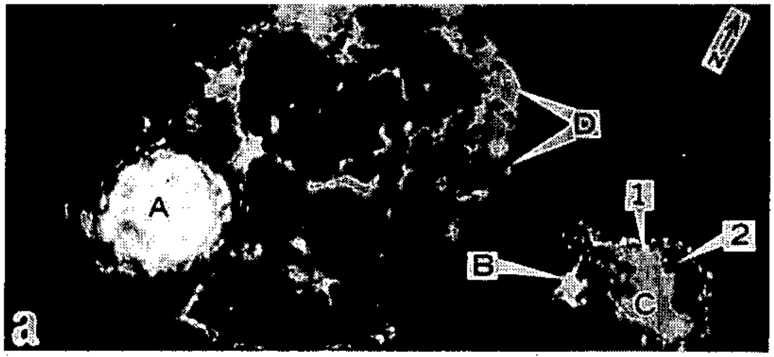


Fig. 8 (above, left). Conventional aerial photograph of Kilauea summit area: 1, Keanakakoi; 2, Lua Manu; 3, Puhimau; 4, Sulfur Banks.

Fig. 9 (above, right). Infrared photograph of Kilauea summit area. Reflected solar infrared energy is recorded, in spectral region 0.7 to 0.9 μ.

Fig. 10 (left). Simultaneous infrared images of Kilauea summit area. Time, 0517, 17 February; altitude, 5100 meters. Left image, spectral region, 1.9 to 5.5 μ; right image filtered (2.0- to 2.6-μ band pass) to show only areas of highest apparent temperature. Roman numerals indicate orders of magnitude of apparent temperature.



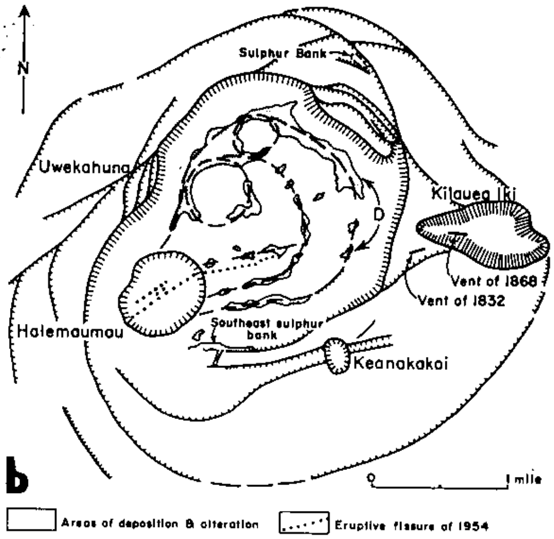
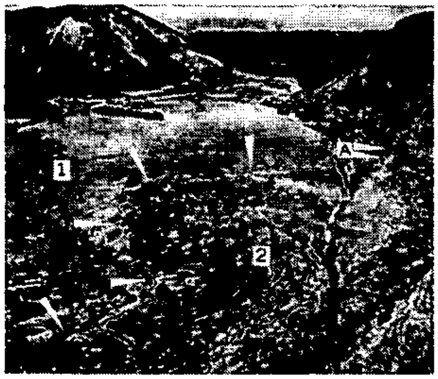
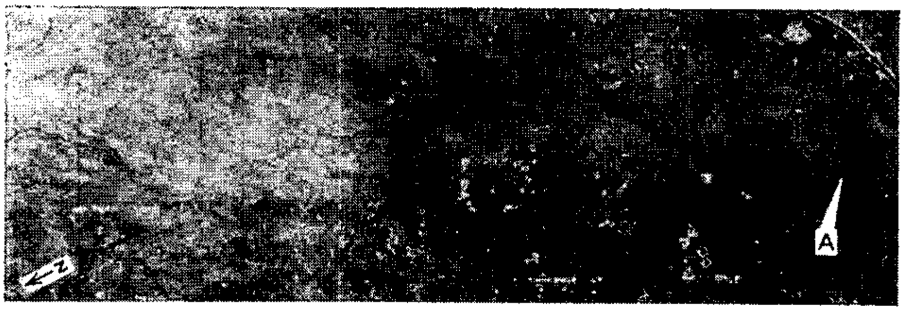


Fig. 11. (*a*) Infrared image of Kilauea summit area. Time, 0702. 28 January; spectral region, 4.5 to 5.5 μ; altitude, 1800 meters. *A*, Halemaumau; *B*, cinder cone formed during eruption of 1959; *C*, Kilauea Iki areas 1 and 2 shown in Fig. 12. (*b*) Map of Kilauea caldera, showing areas of pneumatolytic deposition and alteration. *D*, Suspected margin of inner basin in 1840. [From Macdonald (*3*)]





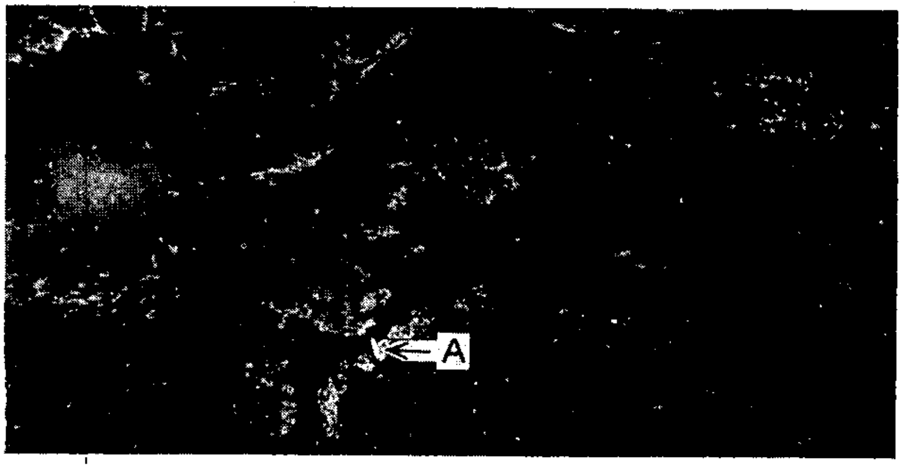


Fig. 12 (above). The floor of Kilauea Iki, as one looks westward. 1 and 2, Parts of the floor having different surface configurations. The line of contact between areas 1 and 2 is indicated by arrows. *A*, Peripheral fractures at the edge of congealed lava.

Fig. 13 (top, right). Conventional aerial photograph of area shown in Fig. 14. *A*, Area shown in Figs. 14 and 15.

Fig. 14 (middle, right). Infrared image of part of the southwest rift zone. Time, 0610, 17 February; altitude, 900 meters; spectral regions: top image, 2 to 2.6 μ; bottom image, 1.9 to 5.5 μ. *A*, Area shown in Figs. 13 and 15. On bottom image, note the progressive decrease in temperature with increase in ground elevation along the flight path, requiring a change in electronic gain. Roman numerals indicate orders of magnitude of apparent temperature.

Fig. 15 (bottom, right). Ground photograph of a steaming vent associated with thermal source *A* in Figs. 13 and 14. *A* in this figure indicates a cigarette, included for scale.

forms the northwest margin of the anomaly and which may form a path for hot gases escaping from below.

The low apparent temperatures of the floor of Keanakakoi and some other craters along the rift zone are believed to be caused by deposits of cinders on the crater floors. Repetitive observations of cinders discharged during the 1959–60 eruption suggest that, in early morning hours, cinders emit less energy than other surficial materials do.

The most thermally active area along the Chain of Craters is at Aloi, the A lava lake 13½ meters thick was formed at that time, but subsequent drainback reduced its depth to 4½ meters (*10*). Copious amounts of steam issue from fractures in and surrounding the crater. Surface cracks associated with these fractures were observed to both lengthen and increase in breadth during the course of the investigations. Field temperature measurements of a small thermal source near one of the steaming surface cracks (*A* in Fig. 16, bottom) varied from day to day but, on the whole, increased from 37°C (28 January) to [illegible] (17 February). On the infrared images Aloi Crater shows a slightly off-center vent and a peripheral ring. The large hot area, southwest of the crater, is a steaming area that lies along a northeast-trending fault system.

Linear thermal sources extending eastward from Aloi and Alae craters (Fig. 17) are fractures associated with movement along the east rift and with lava from the December 1962 eruption. These linear thermal sources consistently display right offset, *en échelon* displacement, and a fishtailing or splaying of their eastern termini. Common-

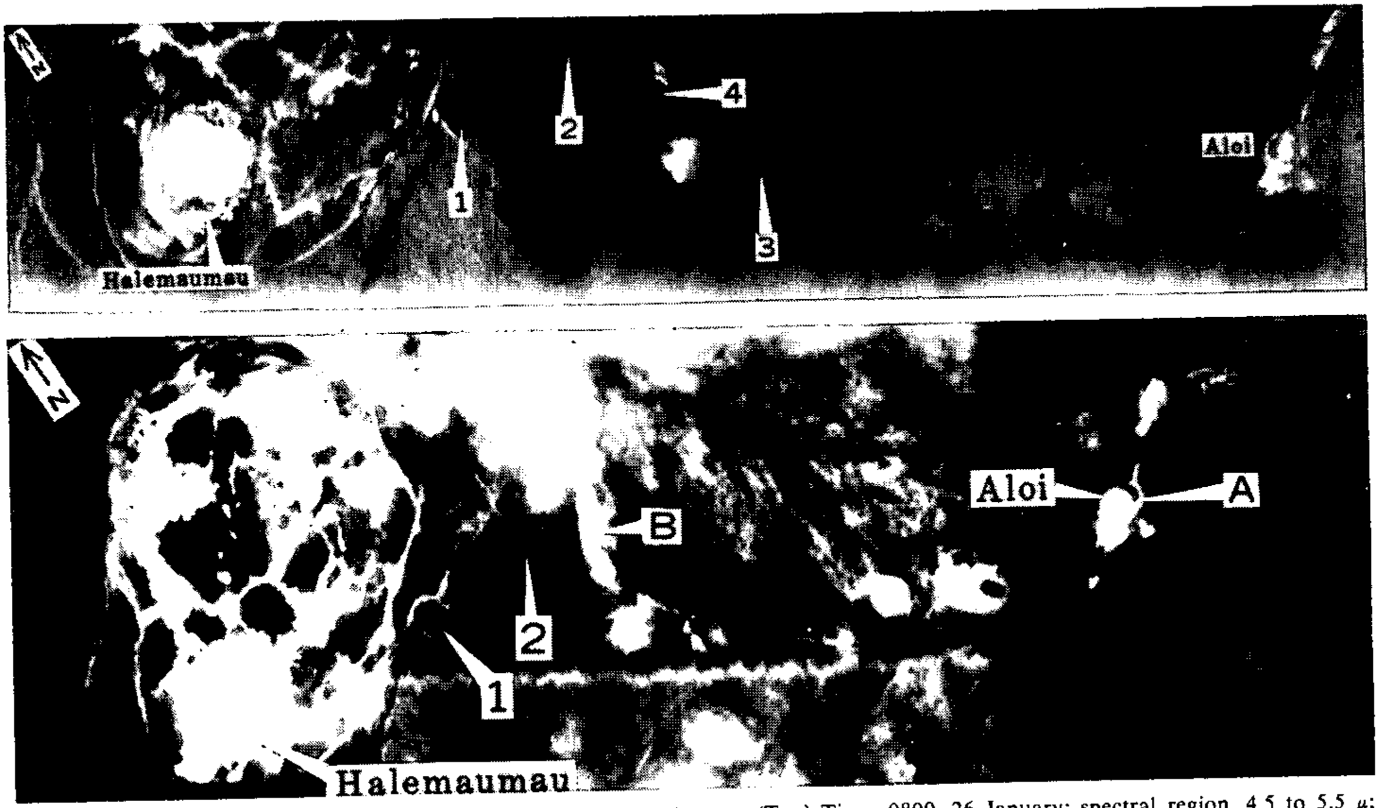


Fig. 16. Infrared images of Kilauea summit area and Chain of Craters. (Top) Time, 0800, 26 January; spectral region, 4.5 to 5.5 μ; altitude, 1800 meters. 1, Keanakakoi; 2, Lua Manu; 3, Kokoolau; 4, Puhimau. (Bottom) Time, 0455, 17 February; spectral region, 1.9 to 5.5 μ; altitude, 5100 meters. 1, Keanakakoi; 2, Lua Manu; *A*, thermal source near Aloi crater; *B*, linear thermal source. The bright linear streak passing through numeral 1 results from electronic malfunction.

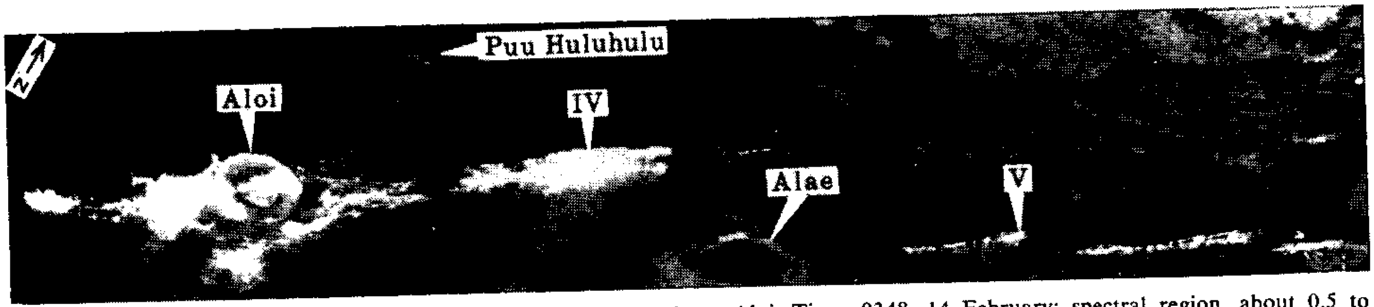


Fig. 17. Infrared image of part of the rift zone extending east from Aloi. Time, 0348, 14 February; spectral region, about 0.5 to 5.5 μ; altitude, 900 meters. Roman numerals indicate orders of magnitude of apparent temperature.

sources are sharply defined; the southern margins are diffuse and irregular. In Fig. 17, wind streaming contributes to the diffuse south limits of the fracture patterns.

The thermal patterns of parts of the rift zone east of Aloi may have changed during the course of the investigations. Figures 18*a* and 18*b* are images of Alae Crater; there is an obvious difference in electronic gain on the two images, but, in addition, thermal sources appear in Fig. 18*b* that do not appear in 18*a*. Images produced at times between those of Fig. 18 suggest a progressive development of these features. An eruption occurred in, and adjacent to, Alae Crater on 22 August 1963, along a northeast-trending fracture (*10*) which passes through the thermal sources shown in Fig. 18*b*. Figure 19 shows images of Napau Crater, approximately 5 kilometers east of Alae. An eruption occurred along this lineament on 6 October 1963 (*10*). Images of Napau Crater were recorded 12 times from 26 January to 20 February. The thermal anomaly, indicated by the unlabeled arrow in Fig. 19*b*, was first seen on 8 February on an image for the 8- to 14-μ region of the spectrum. As the survey progressed, the anomaly was detected at increasingly shorter wavelengths. Electronic gain settings varied from image to image, as shown in Figs. 19*a* and 19*b*; likewise, visible steaming associated with thermal anomalies is known to vary from time to time, and it is possible that this apparent change in thermal pattern relates entirely to one or both of these variables. The progressive development of this feature, however, and its appearance at successively shorter wavelengths, tempts us to speculate that its growth represents a change in the convective heat-transfer system associated with the ingress of magma prior to eruption.

Eastward from Napau Crater to the site of the former village of Kapoho (Fig. 3), the rift zone is expressed on infrared imagery by a series of warm *en échelon* fractures interspersed with thermal sources having roughly circular configurations. Additional apparent changes in thermal pattern were observed in this segment of the rift zone. One such change in an 8-day period occurs in an area approximately 16 kilometers east of Napau Crater (Fig. 20) along the north side of the rift area (*11*).

Figure 21 is a conventional aerial photograph showing the lava flow that destroyed the village of Kapoho. The initial events have been described by Richter and Eaton (*5*). "On 13 January strong earthquakes centered near the village of Kapoho, 28 miles east of Kilauea's summit, and an old graben (an elongated block which has subsided between a pair of normal faults) two miles long and half a mile wide, which contained part of the village and most of the farmland that sustained it, began to subside. By nightfall displacements along the faults bounding the graben had grown to several feet. . . . At 7:30 PM the lank eruption began along a line of *en échelon* fissures 0.7 of a mile long, a few hundred yards north of the village. . . . The main fountain area, two miles from the sea coast . . . soon produced a steady stream of lava that slowly flowed down through the graben, reaching the sea. . . ."

By the end of the week the graben had been filled, and lava then spread laterally over the adjacent land surface. The infrared image (Fig. 22) shows that the peripheral part of the flow has reached ambient temperatures, in marked contrast to the vent area at the western end and to the central, thicker part of the flow, which occupies the graben. Temperatures at the surface of a series of small vents, near

Fig. 18. Infrared images of Alae crater. (*a*) Time, 0710, 26 January; spectral region, 4.5 to 5.5 μ; altitude, 1800 meters. (*b*) Time, 0712, 20 February; spectral region, 4.5 to 5.5 μ; altitude, 900 meters. Arrows designate thermal sources visible on image *b* that do not appear on image *a*.

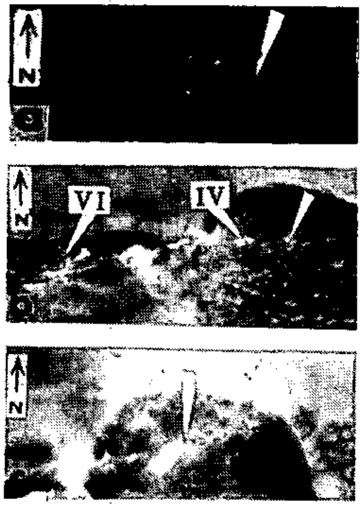


Fig. 19 (left). Infrared images of Napau crater. (*a*) Time, 1657, 1 February; spectral region, 4.2 to 5.5 μ; altitude, 600 meters. (*b*) Time, 0249, 14 February; spectral region, about 0.5 to 5.5 μ; altitude 900 meters. (*c*) Time, 0642, 20 February; spectral region, 4.5 to 5.5 μ; altitude, 360 meters. White arrows designate a thermal source that does not appear on image *a* but is visible on images *b* and *c*. Roman numerals indicate orders of magnitude of apparent temperature.

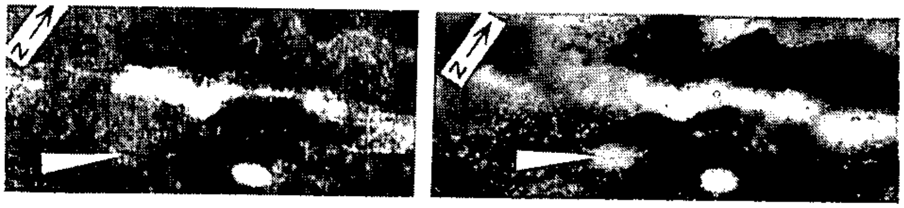


Fig. 20 (left). Infrared images of a part of the east rift zone east of Napau. (*a*) Time, 1800, 12 February; spectral region, about 0.5 to 5.5 μ; altitude, 750 meters. (*b*) Time, 0642, 20 February; spectral region, 4.5 to 5.5 μ; altitude, 750 meters. White arrows designate thermal source visible on image *b* which does not appear on image *a*.

the former site of the village of Kapoho, ranged from 26° to 108°C. Near the center of the Kapoho flow, rocks immediately below the surface have temperatures much higher than the 108°C measured at the surface. A contact pyrometer lowered about half a meter into a small fracture went off scale at 333°C.

Infrared Surveys of Other Hawaiian Volcanoes

During the course of the investigation, one or more flights were made over the rift zones associated with Mauna Loa, Hualalai, and Kohala volcanoes on the island of Hawaii (*7*, *12*). Mauna Loa last erupted in 1950, alalai in 1801; Kohala has not been active in historic time. To facilitate navigation, these flights were made shortly after dawn. No thermal activity was observed on Kohala or Hualalai; some thermal sources, however, were evident on the southwest rift zone of Mauna Loa, and warm springs flowed into the sea near where the rift

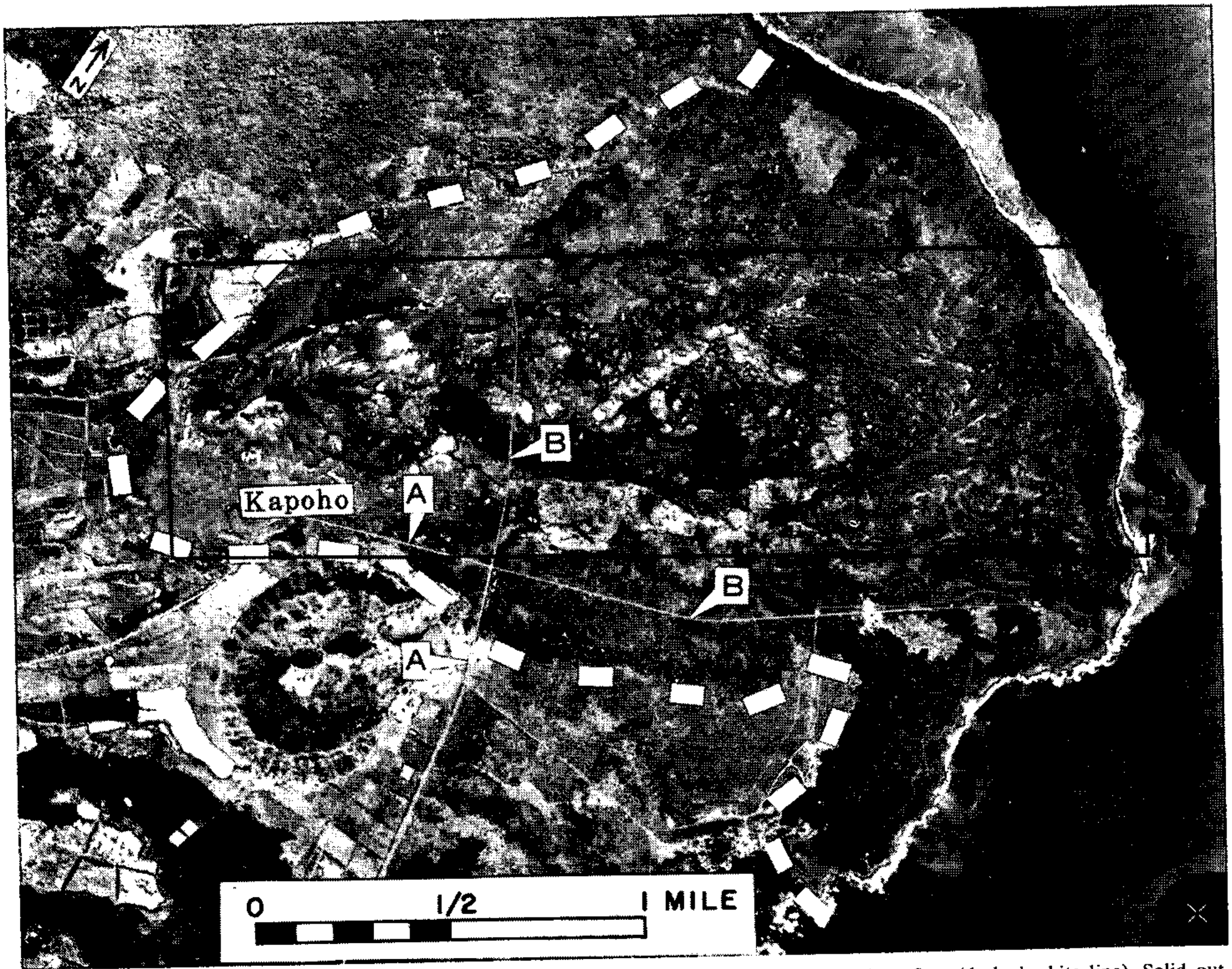


Fig. 21. Conventional aerial photograph of the Kapoho area showing areal extent of 1960 lava flow (dashed white line). Solid outline indicates the area common to Figs. 21 and 22. *A* and *B* are the roads referred to in text, shown in Fig. 25.

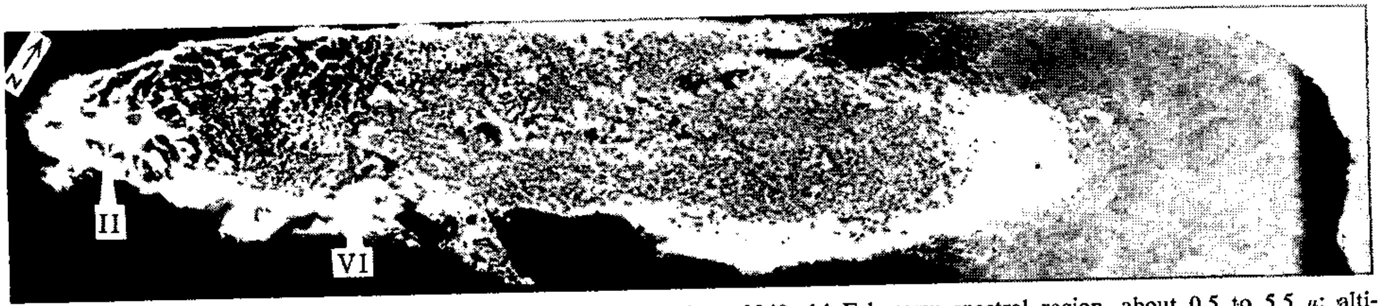


Fig. 22. Infrared image of a part of the Kapoho flow of 1960. Time, 0340, 14 February; spectral region, about 0.5 to 5.5 μ; altitude, 900 meters. Flow originated near vent at west end.

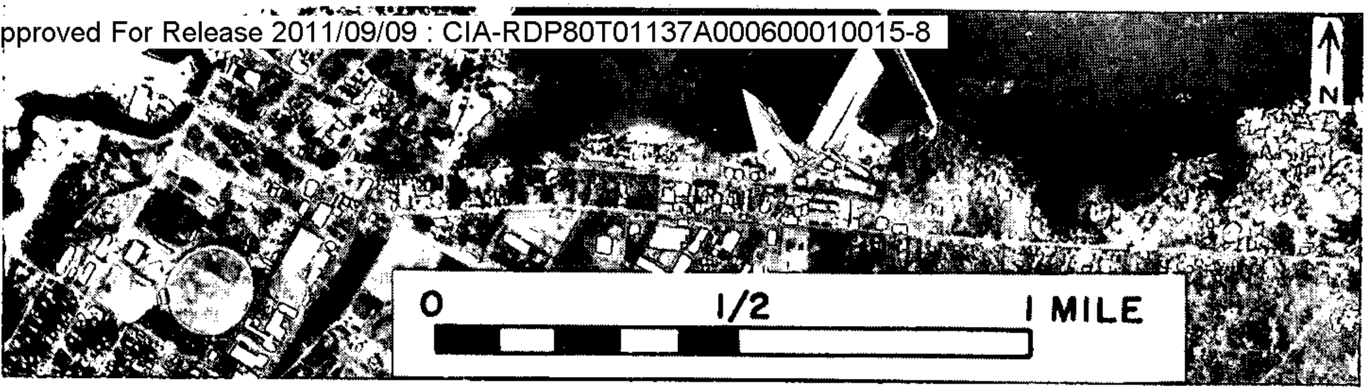


Fig. 23. Conventional aerial photograph of the coastline east of Hilo.

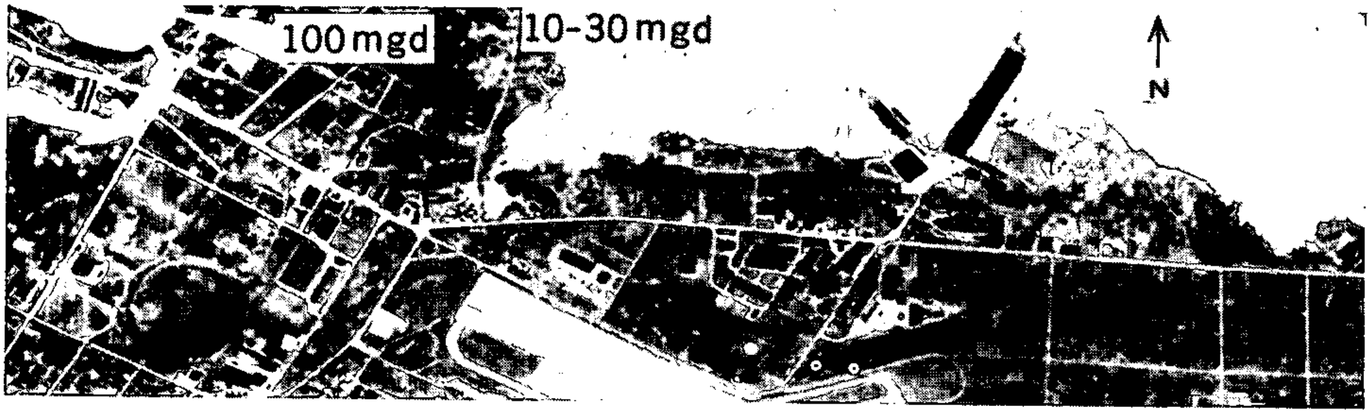


Fig. 24. Infrared image of the part of the coastline shown in Fig. 23. Time, 0723, 19 February; spectral region, 4.5 to 5.5 μ; altitude, 900 meters. Dark areas in the ocean area are believed to represent cool water discharged by springs. Numerals are estimated rates of flow of springs in millions of gallons per day.

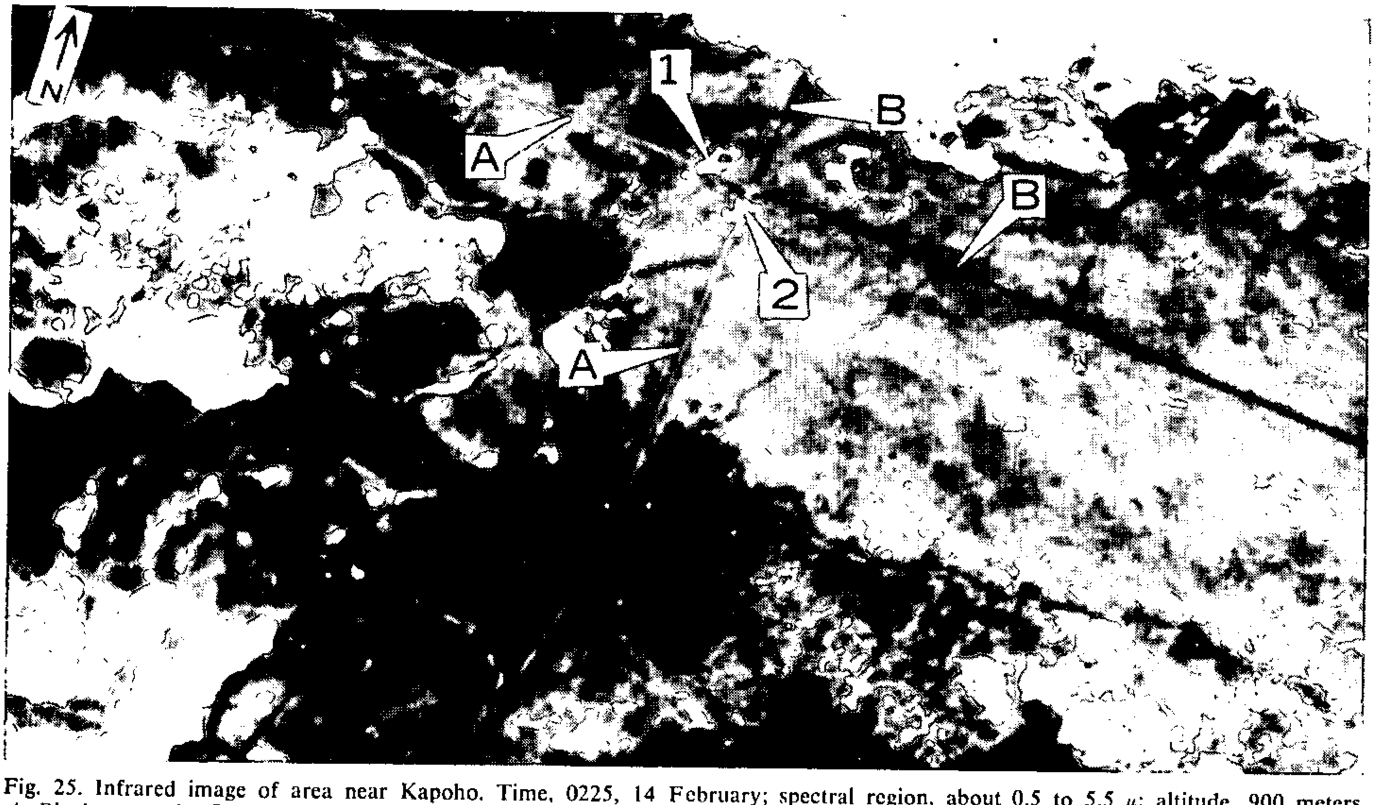


Fig. 25. Infrared image of area near Kapoho. Time, 0225, 14 February; spectral region, about 0.5 to 5.5 μ; altitude, 900 meters. *A*, Blacktop roads; *B*, roads surfaced with cinders. *1* and *2*, Thermal sources that extend beneath the blacktop roads. This area is also shown in Fig. 21.

zone intersects the coast. A single flight was made across the southern flank of Haleakala volcano on the island of Maui (7), which last erupted in 1750. Images produced on this flight, made in mid-afternoon, show no evidence of thermal activity.

Thermal Patterns in Water

There are few well-developed streams on the island of Hawaii, as most rain water percolates downward through the highly permeable volcanic rocks. Because it is less dense than the saline ocean waters, the fresh water "floats" outward and is discharged into the ocean. The ground water commonly has a lower temperature (measurements in caves suggest a temperature of about 15°C) than the ocean (about 20°C).

Because the emissivity of water is essentially uniform and near unity, changes in film density on the infrared images almost certainly relate to changes of the surface temperature of the water, provided the sky temperature is uniform. Thus, large discharges of fresh ground water can be recognized from their thermal contrast with the ocean and from the pattern of discharge. More than 25 major spring areas on the periphery of the island of Hawaii are visible on the infrared images (*13*). Most of these springs have low apparent temperature in contrast to that of the sea water; some, however, adjacent to the northeast and southwest rift zones of Kilauea, have relatively high apparent temperatures.

An infrared image of the coastline east of Hilo shows the cooler (darker) water impounded by a breakwater (Figs. 23 and 24). Darker, northeast-trending streaks are also evident. Their orientation and shape and the fact that they are cooler than the ocean suggest springs discharging large quantities of fresh ground water into the ocean. The flow rates estimated from ground observation (*14*) are given in Fig. 24.

Engineering Geologic Information

Cinders are widely used as a construction material on the island of Hawaii. They can commonly be recognized on infrared images by high apparent temperatures in daylight hours and relatively low apparent temperatures in early morning hours (as at the floor of Keanakakoi, Fig. 16). This characteristic is further illustrated in Figs. 21 and 25. The blacktop roads (*A* in Fig. 21) and roads surfaced with cinders (*B* in Fig. 21) absorb similar amounts of visible solar energy. The infrared image (Fig. 25), however, shows that more radiation is emitted from the roads surfaced with cinders.

Numerals 1 and 2 in Fig. 25 designate thermal sources which extend beneath the blacktop roads and which consequently may have a detrimental long-range effect on the road surface.

The foregoing relationship between absorption of solar energy and emission of infrared energy suggests that these parameters may provide clues to the configuration and physical composition of surficial materials, and that they may be particularly useful where surfaces cannot be adequately resolved on conventional photographs.

Summary

Aerial infrared-sensor surveys of Kilauea volcano have depicted the areal extent and the relative intensity of abnormal thermal features in the caldera area of the volcano and along its associated rift zones. Many of these anomalies show correlation with visible steaming and reflect convective transfer of heat to the surface from subterranean sources. Structural details of the volcano, some not evident from surface observation, are also delineated by their thermal abnormalities. Several changes were observed in the patterns of infrared emission during the period of study; two such changes show correlation in location with subsequent eruptions, but the cause-and-effect relationship is uncertain.

Thermal anomalies were also observed on the southwest flank of Mauna Loa; images of other volcanoes on the island of Hawaii, and of Haleakala on the island of Maui, revealed no thermal abnormalities.

Approximately 25 large springs issuing into the ocean around the periphery of Hawaii have been detected.

Infrared emission varies widely with surface texture and composition, suggesting that similar observations may have value for estimating surface conditions on the moon or planets.

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ORL EXPERIMENT PROGRAM

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Volume A:

Framework for Synthesis

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ORL EXPERIMENT PROGRAM

Volume A

Framework for Synthesis

Contract NASw-1215
21 February 1966

Federal Systems Division
INTERNATIONAL BUSINESS MACHINES CORPORATION
Rockville, Maryland

U. S. Government Agencies and
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PREFACE

This study report, prepared under Contract No. NASw-1215, presents a framework for synthesizing a meaningful earth-orbital experiment program for NASA Orbiting Research Laboratories (ORL's). The results of this study lay the groundwork for the large-scale effort required to implement the experiment program. These results are presented in sixteen volumes, as follows:

- Volume A establishes the need for a user-oriented approach in structuring the earth-orbital experiment program. The volume defines thirteen scientific and technical (S/T) areas that constitute the program and presents a method of synthesizing the experiment program. The synthesis approach yields a framework for deriving—

a. meaningful, interrelated experiments in each S/T area,
b. early identification of the associated equipment, supporting research, and orbital flight characteristics, and
c. a cohesive over-all experiment program which interlaces the individual S/T areas.

By relating prospective individual experiments to the most important national and scientific objectives in each S/T area, the experiment framework provides a focus for prospective experimenters and facilitates obtaining support for their proposed ideas. It thus provides the means for effective participation of the scientific and technical communities. The synthesis approach also provides a means for early and economical implementation of the experiment program: it enables explicit analysis by NASA of program alternatives; it permits development of general-purpose experiment equipment concurrently with, but without the need for awaiting final results of, detailed experiment identification and definition; and it provides for optimum use of existing experiment hardware.

- Volumes B-1 through B-13 illustrate the application of the synthesis approach to the thirteen scientific and technical (S/T) areas identified in Volume A. Each volume develops the scope and characteristics of the program of experimentation for that S/T area, including—

a. objectives to which meaningful experimentation should be directed,
b. functional requirements of the general-purpose equipment required to carry out the experimentation,
c. requirements for supporting research,
d. orbital-flight characteristics of the prospective experiment program, and
e. description of significant individual experiments.

- Volume C interrelates the thirteen S/T area experiment programs derived in Volumes B 1-13. It identifies the equipment and flight characteristics common to the S/T areas, and it sets forth a rationale for grouping prospective experiments into payloads and missions compatible with prescribed constraints. As an example of the approach, Volume C employs the grouping rationale to arrive at guidelines for mission and flight assignments for the initial phase of the manned earth-orbital experiment program, using Apollo Applications Program systems.
- Volume D summarizes the study results.

The Institute of Science and Technology of the University of Michigan assisted IBM, under subcontract, in the study of those experimental areas involving earth observation. Much of the material presented in Volumes B-1 through B-5 is drawn from reports prepared by the faculty and staff of the University of Michigan. Other subcontractors that provided data for the study include:

Lockheed Missile and Space Company—Biomedicine/Behavior
Ling-Temco-Vought, Inc. — Extravehicular Engineering Activities
Environmental Research Associates — Extravehicular Engineering Activities
Hamilton Standard Division of United Aircraft Corporation—Life Support Systems
Decision Systems, Inc.—Payload Grouping and Cost Analysis

In conducting this study, IBM worked closely with elements of NASA, particularly the Manned Earth-Orbital Mission Studies Directorate (MTE). The participation and contributions of Messrs. C. A. Huebner and M. J. Raffensperger and their colleagues are especially acknowledged. IBM is also grateful for the opportunity for profitable discussions with Dr. P. C. Badgley and with many of the scientists participating with him in the ORL program.

Also, during this study IBM secured the valuable consulting services of the following members of the scientific/technical community:

Dr. D. M. Boyd, Research Analysis Corporation
Dr. S. S. Brody, New York University
Dr. G. C. Ewing, Woods Hole Oceanographic Institute
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Dr. C. C. Kiess, Georgetown University Observatory, Washington, D. C.
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Dr. H. E. Skibitzke, U.S. Geological Survey

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I. INTRODUCTION

1.0 OBJECTIVES OF THE STUDY

The Orbiting Research Laboratory provides an unparalleled opportunity to conduct a wide range of earth-orbital space activities and thus represents a powerful new national space capability. The objective of this study was to define a practical procedure for synthesizing and implementing the program of activities—the manned earth-orbital experiment program — which effectively exploits this new capability.

The procedure described herein is applicable to the initial ORL implementation by means of the Apollo Applications Program and to subsequent phases utilizing MORL and later generation space stations.

2.0 STUDY APPROACH

The initial phase of the study encompassed the following principal background activities:

a. Review of the many prospective ORL experiments compiled by NASA
b. Participation in the NASA *ad hoc* efforts, begun in January 1965, to define representative experiments for AES space stations
c. Participation with NASA in studies involving development and application of a logic for assigning experiments to scheduled AES flights, and for costing the experiment program.

These background efforts provided insight and understanding of the procedures currently in use for synthesizing experiment programs and of their associated problems. The systematic procedure set forth in this report was devised specifically to solve these problems.

3.0 CRUX OF THE ORL EXPERIMENT PROGRAM

The crux of the ORL program is not how to package experiment equipment, but what experiments to conduct and what equipment to package. To date, experiment programs have been compiled from among candidate experiment ideas submitted by manifold interested investigators. This approach builds the experiment program "from the bottom up," and has three principal shortcomings:

a. It results in a collection of individual tests, rather than in a cohesive program; the interrelationships of the individual experiments and the extent of their overlap are obscured.
b. It lacks a rationale to determine whether the most important experiments have been identified and are being pursued.
c. Few of the suggested experiments are explicitly tied to requirements or ultimate benefits; as a consequence, the resulting programs frequently fail to demonstrate the value of the space station vis-a-vis its cost.

Efforts to date to devise ORL experiment programs have applied the methods of experiment selection and implementation used in Gemini and earth-orbital Apollo MLLP. A more structured approach is required for ORL experiments because of three fundamental differences between ORL and other programs.

The first major difference is the relative magnitude of the experiment programs. The earth-orbital experiments in Gemini and Apollo MLLP are relatively simple: the number of experiments per flight is generally about a dozen and the average weight is between five and twenty pounds. In contrast, each earth-orbital AAP flight can accommodate complex experiments, in large numbers, with a total experiment payload as high as 50,000 to 70,000 pounds.

The second difference is the interrelationship of the experiments. While most Gemini and Apollo MLLP experiments are independent of each other and utilize their own unique equipment, ORL will capitalize on the opportunity to develop laboratories that meet the requirements common to many different experiments and to increase the usefulness of results through coordinated experimentation.

The third and most significant difference between ORL and Gemini/Apollo is the emphasis attached to the experiment programs. In Gemini/Apollo, the experiment program is secondary to the principal purpose of supporting the national lunar-landing goal. Since the mission is to be flown in any case, the "cost effectiveness" of the experiments is of little concern. For ORL, however, the experiments are its *raison d'être*. The experiments must be selected so that their collective value exceeds program cost.

These differences and opportunities dictate that a more comprehensive and explicit procedure should be adopted for identifying the significant ORL experiments and for interrelating them.

II. NATURE AND SCOPE OF THE ORL EXPERIMENT PROGRAM

Not just a large platform for carrying a multitude of individual experiments, the ORL can be the essential tool for harnessing space for human welfare. The unique capabilities of man as an on-board investigator, coupled with large payload capacity, make ORL a practical workshop for accelerating the development of improved beneficial space systems, for enlightening crucial scientific questions, and for promoting the nation's capability of conducting ever more advanced space missions.

1.0 MAN'S ROLE AS AN EXPERIMENTER

Man's function in ORL is similar to his role in a research laboratory on Earth. However, whereas man's role in terrestrial laboratories is unquestioned, his efficiency as an orbital experimenter hinges on his "cost effectiveness" vis-a-vis preprogrammed and ground-controlled equipment. For many experiments such as those in biomedicine, there is no question as to the essentiality of man's presence. For others, a growing body of experience based on X-15, Mercury, and Gemini flights and on simulation studies of advanced missions evidences his value.

This experience suggests that man's direct participation in complex spaceborne tasks significantly reduces the need for complicated command and control systems, affords greater reliability in calibrating and adjusting equipment, and results in higher overall probability of mission success. Man's ability to erect very large equipment in orbit and to maintain that equipment for long periods affords scope and flexibility greater than can be obtained with unmanned systems. The opportunity to observe experiments at first hand and to correlate results from many sensors enables the on-board scientific specialist to adapt experimental procedures in real time and to edit and select the most appropriate data for transmission to ground.

Perhaps the most important advantage of man is his capability to observe and act upon unforeseen phenomena and events. Research inherently is oriented to the discovery of the unknown and the unanticipated. Situations requiring rapidly devised, new approaches to deal with the unexpected are not amenable to automated equipment. The judgment, experience, and responsiveness of a participating scientist provide the required experiment flexibility.

Notwithstanding present indications of man's advantages as a participant in space research and operations, the question of "effectiveness of man" will not be fully resolved short of trying man in space. One of the most important payoffs of the early generation orbiting research laboratories using Apollo Applications Program systems will be the expanded data and practical experience necessary for resolving this question and for optimally structuring man's role in later-generation space systems.

2.0 CONCEPT OF THE SPECIAL-PURPOSE ORL

ORL's ability to conduct numerous experiments in each flight raises the question of effective experiment grouping. When spacecraft carry few experiments—as typified by Gemini—equipment-sharing has few advantages; as the number of experiments increases, the advantages of equipment-sharing become increasingly significant. This is illustrated in Fig. 1 which shows the number of pieces of equipment, required for 160 separate experiments considered in the MORL study, as a function of number of experiments. The effect of equipment-sharing not only reduces the slope of the curve but makes it asymptotic. Thus, after a core of general-purpose instruments is assembled, the number of incremental items of equipment increases but little as the number of additional experiments increases.

The asymptotic shape of the commonality curve leads to the concept of the special-purpose ORL. The capability of a special-purpose laboratory, for example, for astronomy, containing general-purpose core equipment such as multipurpose optical telescopes will extend beyond that needed for the specific experiments identified to date and will accommodate additional experiments that may be conceived in the future.

The Special-purpose Laboratory concept minimizes the number of items of equipment required and, thus, its weight, volume, and cost; and maximizes the effectiveness of astronaut participation. By concentrating experiments

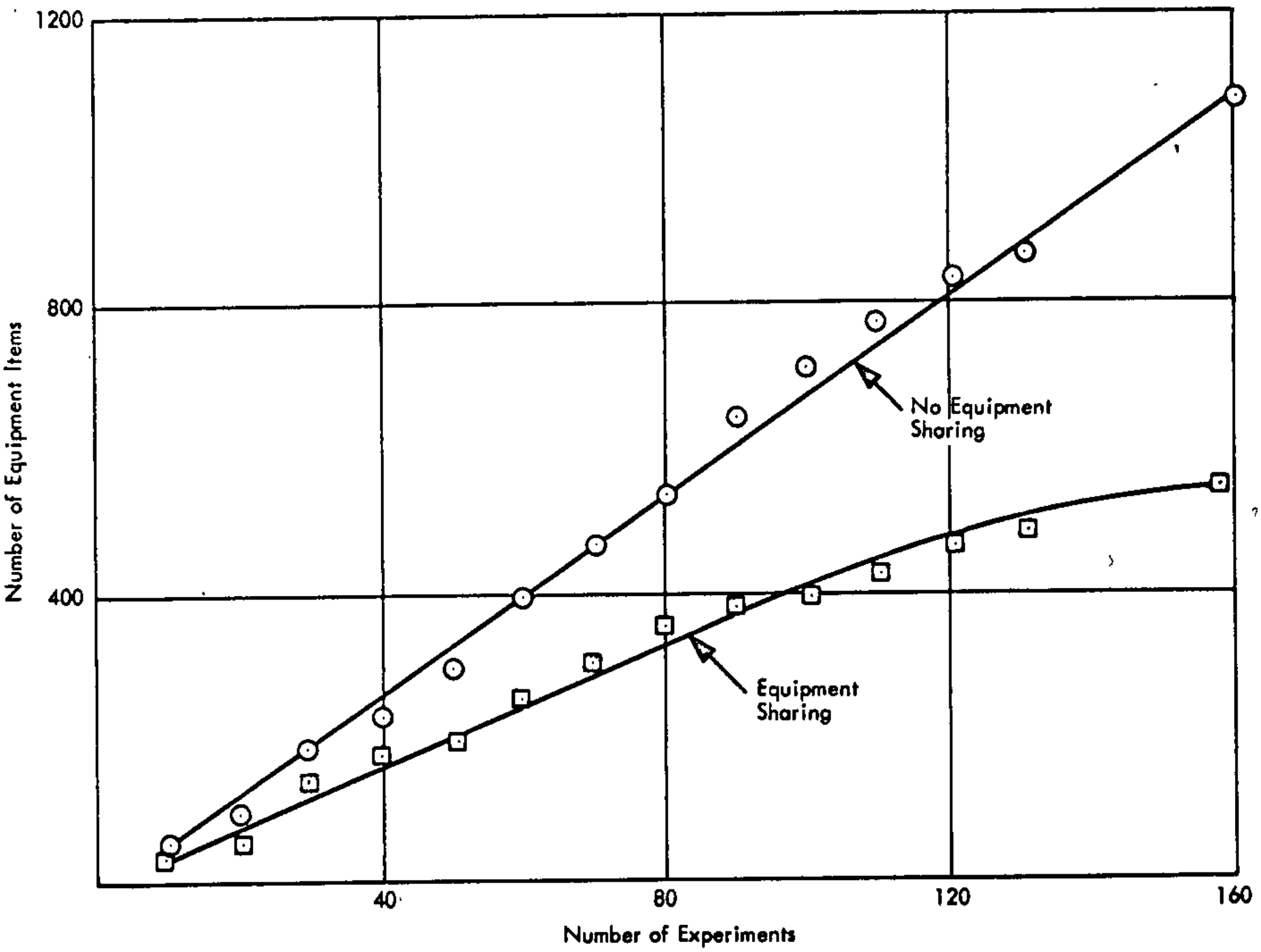

Fig. 1. Effect of Equipment Sharing on Number of Pieces of Equipment for MORL Experiments. (From "Report on the Development of MORL System Utilization Potential, Analysis of Space Related Objectives" SM 48807, Douglas Aircraft Co., Inc.)

by disciplinary area, scientist-astronauts can be selected whose specialized skills match the special purpose of the laboratory.

Beyond these practical advantages, the Special-purpose Laboratory concept has an important management implication: it permits the development and test of experiment equipment to proceed in parallel with the detailed definition of experiments. By comprehensively analyzing the objectives of each disciplinary area, the principal general-purpose core equipment can be identified early in the program. Items of equipment can thus be developed with high probability of accommodating yet-to-be-devised experiments within that area, thus providing the scientist with a laboratory endowed with capabilities to meet his future needs. This reduces the burden on the scientist to assemble specific equipment for each experiment and broadens the opportunities for space experimentation to cover scientists who may not be expert in instrumentation.

As described in Section III, the method of identifying ORL experiments developed in this study is designed to exploit the opportunity for concurrent equipment development.

3.0 PROSPECTIVE SCIENTIFIC AND TECHNICAL APPLICATION AREAS FOR ORL EXPERIMENTATION

The philosophy advanced by this study is that significant earth-orbital experiment activities for ORL can evolve most rapidly and effectively by systematic analysis of the

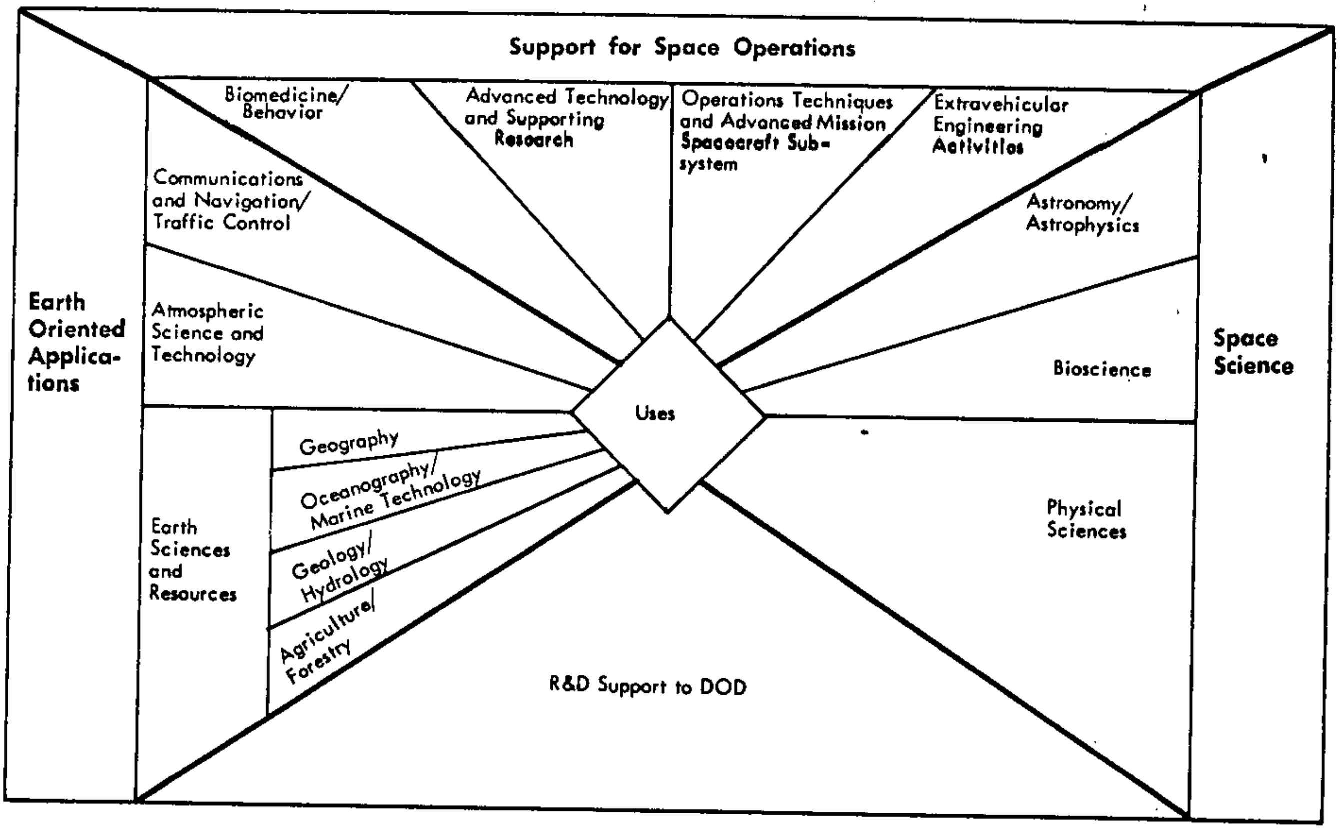

Fig. 2. Scientific/Technical Areas Within the Earth-Orbital Experiment Program.

principal scientific questions they seek to resolve and the potential application that they support, i.e., by analysis of the user-oriented objectives of the experimentation. The earth-orbital scientific and technical applications of space derive from three unique properties:

a. Comprehensive Overview—permits synoptic observation of weather; allows practical and timely survey of the earth's features and natural resources, permits use of orbital relays to overcome limitations in terrestrial communications caused by earth's curvature.
b. Absence of Atmosphere—provides the opportunity to expand astronomical and astrophysical observations to a clarity and breadth not attainable from earth.
c. Weightlessness—affords an opportunity for obtaining new insights into matter, energy, and life through observation and measurement of subtle effects that might otherwise be masked by earth's gravity field.

These properties can be exploited in support of four objectives:

1. Earth-oriented Applications, for which economic and social benefits can be identified.
2. Space Science, undertaken primarily for acquisition and expansion of fundamental knowledge, with incidental concern for possible applications.
3. Support for Space Operations, aimed at developing techniques and technologies for advancing space applications, exploration, and travel to other parts of the solar system.
4. Research and Development Support for DOD.

This report addresses the first three objectives; the methodology set forth is equally applicable to the fourth one. The first three space objectives further divide into the thirteen scientific/technical areas shown in Fig. 2. These represent the potential user-oriented applications, of earth-orbital space systems, by whose systematic analysis a meaningful ORL experiment program can be synthesized. The scope and objectives of each of the S/T areas is summarized in Section IV. Each S/T area is separately analyzed in Volumes B-1 through B-13, according to the procedure set forth in Section III.

III. USER ORIENTED PROCEDURE FOR SYNTHESIZING THE ORL EXPERIMENT PROGRAM

The ORL experiment program is conceived as comprising three major program sequences:

a. Concept, Feasibility, and Definition, which includes—
  (1) Delineation of the end objective of each scientific/technical area and of the knowledge required to achieve the objective
  (2) Selection of those knowledge requirements that can be effectively addressed by space experimentation
  (3) Identification of the functional requirements of the experiment equipment and of the requirements for supporting research; and delineation of completing prospective sets of individual experiments
  (4) Consolidation of experiments and requirements into a cohesive, overall program plan
  (5) Conduct of supporting research and preliminary design of equipment, and detailed definition of experiments.

b. Development and Implementation, which includes—
  (1) Acquisition of experiment prototype and flight hardware
  (2) Integration of hardware into spacecraft
  (3) Preparation of operations support plans.

c. Operations, which includes—
  (1) Launch of payloads
  (2) Conduct of orbital experiments
  (3) Collection, reduction, distribution, and feedback of data.

Items 1 through 4 within the Concept, Feasibility, and Definition sequence are the principal concern of this study. The procedures developed for synthesizing this information builds the ORL experiment program "from the top-down," by systematic analysis of the user-oriented objectives within each S/T area. The procedure identifies significant experiments and their requirements in three steps:

Step I—Identification of S/T area Knowledge Requirements to be Addressed by ORL Experiment Program (Items a1 and a2)
Step II—Derivation of Experiment Requirements of the Individual S/T Areas (Item a3)
Step III—Interlacing* of Experiment Requirements of Individual S/T Areas into an Overall ORL Program Plan (Item a4).

Figure 3 shows the relationship among the three major program sequences and the three synthesis-procedure steps addressed in this study. The "output" of the overall analysis process is depicted in Fig. 4. For each Scientific/Technical area, the objectives of space experimentation are derived by considering, in turn: the ultimate user-oriented objectives of the area; the requirements for new knowledge to achieve these objectives; and the utility of space experimentation in contributing to this new knowledge. By examination of the derived objectives of space experimentation, the three principal elements of the experiment program can be synthesized in parallel. That is: the supporting research program, to prepare the basis for successful conduct of the experiments, can be performed as the set of complementary experiments are individually defined and their sequencing with each other is established. Similarly, the concept of the modular, general-purpose laboratory can be developed concurrently: the functional characteristics of the general-purpose core equipment of the laboratory can be established, the applicability of existing hardware can be assessed, and equipment specifications for initiating the R&D and procure-

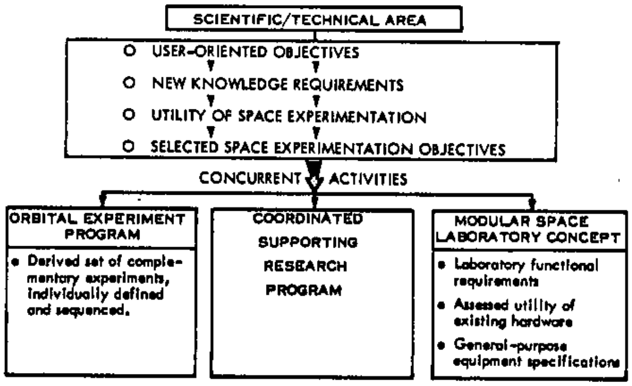

Fig. 4. Information Flow and Output of Overall Analysis Process, Steps I, II, and III.

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* The term "interlacing" is used, rather than "integration," to emphasize the difference between this essentially planning aspect and the physical process of integrating payloads.

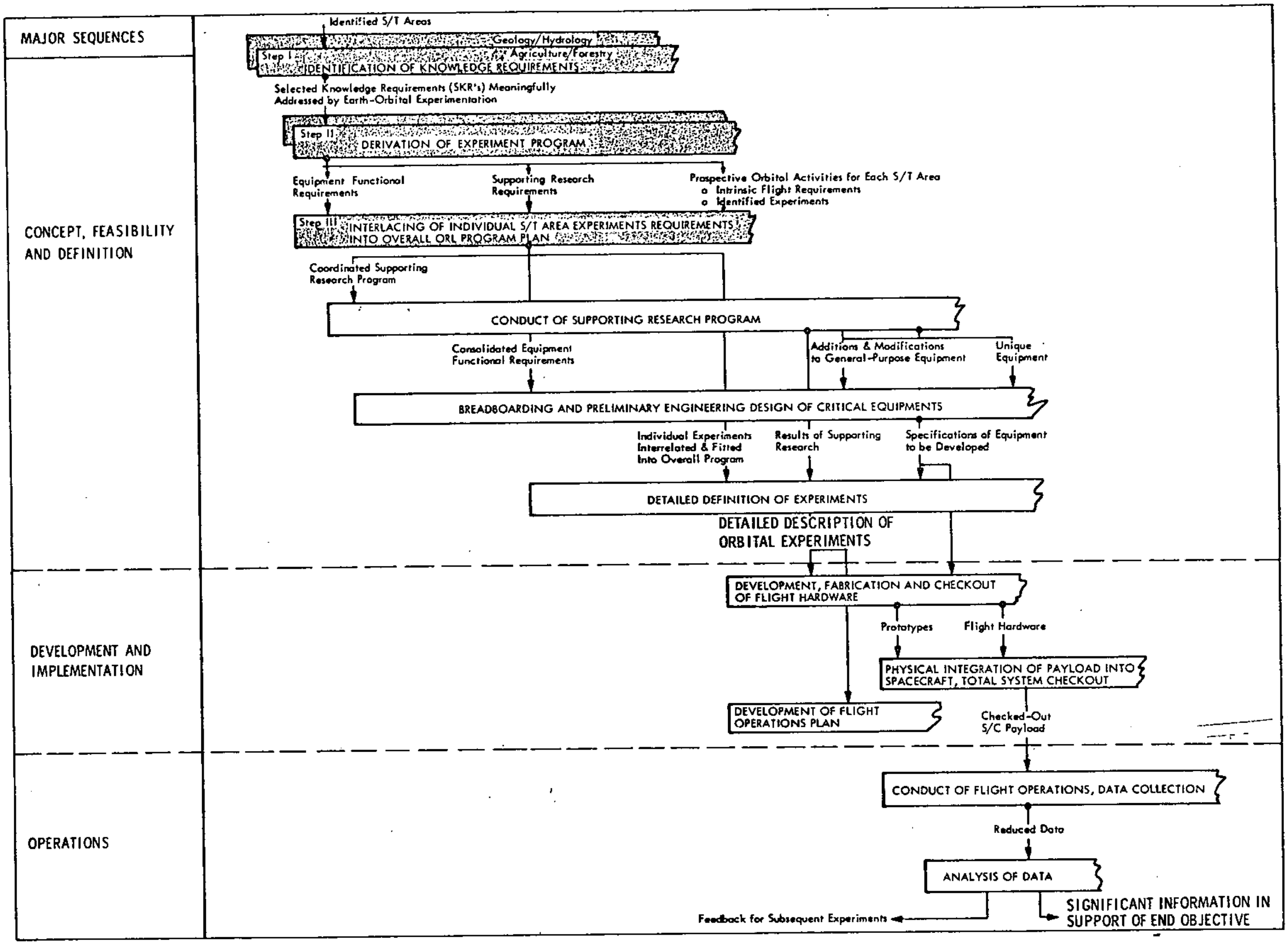


Fig. 3. Major Sequences in the ORL Experiment Program.

ment cycle can be prepared — all in parallel with the supporting research and detailed experiment definition efforts. The three step procedure for achieving these "outputs" are described in the following subsections.

1.0 STEP I: IDENTIFICATION OF S/T AREA KNOWLEDGE REQUIREMENTS TO BE ADDRESSED BY ORL EXPERIMENT PROGRAM

The process for selecting the knowledge requirements to be addressed by ORL experimentation is depicted in Fig. 5 and consists of identifying all the knowledge requirements of an S/T area and explicitly showing their contribution to an end objective:

a. The end objective of each S/T area is defined. For example, the end objective of the Agriculture/Forestry S/T area, as developed in Volume B-1, is ". . . an increase in the output of food, fiber, and forest products ."

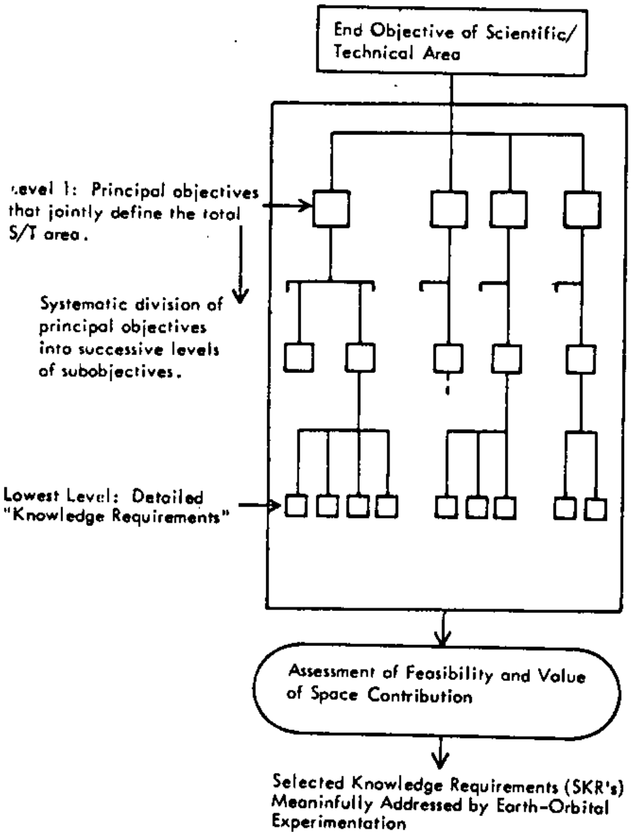


Fig. 5. Definition and Feasibility Sequence Step 1: Identification of S/T Area Knowledge Requirements to be Addressed by ORL Experiment Program.

b. The principal objectives that support the end objective are delineated, for example, the principal objectives of the Agriculture/Forestry S/T area are:
"Increasing yield/quality of lands in cultivation,"
"Decreasing losses in production," and
"Increasing quantity of land in cultivation."

c. The principal objectives (Level 1 of Fig. 5) are resolved into supporting subobjectives in successive levels of increasingly detailed definition, until the S/T area is represented by a set of detailed Knowledge Requirements whose satisfaction is necessary to achieve the principal objectives and end objective of the area.

d. From the totality of Knowledge Requirements, those to which space experimentation can contribute are identified. Of these, the requirements that can be more effectively satisfied by means other than space are filtered out, leaving a residue of Selected Knowledge Requirements (SKR's), toward which the ORL experiment program in the S/T area is to be directed.

This process provides a comprehensive basis for deriving a meaningful experiment program.

The relative importance of the SKR's, as determined by the economic and scientific/technical significance of their contributions, provides a basis for establishing experiment priority. Furthermore, by explicitly showing the reasons for selecting certain Knowledge Requirements and rejecting others, the process highlights important areas for which space experimentation appears unsuited with present technology. It thus focuses attention on these technological deficiencies and stimulates new ideas for novel applications of space.

2.0 STEP II: DERIVATION OF EXPERIMENT REQUIREMENTS OF THE INDIVIDUAL S/T AREAS

The experiment program and experiment requirements of each S/T area are derived by analyzing the Selected Knowledge Requirements, the SKR's in subsequent discussion. The analysis results in (1) functional requirements of the major items of experiment, (2) a plan for carrying out the necessary supporting research to accomplish the SKR's, and (3) an estimate of the number and the orbital characteristics of required flights, and a set of prospective experiments to be detailed.

2.1 Equipment Characteristics

The equipment functional characteristics are derived from the SKR's by the "top-down" approach that considers total requirements of the S/T area, rather than by analysis of individual experiments which address only fragments of the S/T area.

a. For each SKR, the prospective indicative phenomena (for S/T areas involving remote sensing) and the candidate techniques and subsystems to be evaluated (for other S/T areas) are identified.
b. For each indicative phenomenon, the functional equipment characteristics required to perform the observations and measurements are established.
c. Common functional requirements among the SKR's within the S/T area are coalesced. These requirements are compared with characteristics of equipment that is available or is deemed feasible for the projected flight era.
d. Functional equipment specifications are prepared for those common measurement requirements that can be established with high confidence. These define the general-purpose equipment packages which constitute the core of the special-purpose ORL Laboratories.
e. To perform those functions for which no satisfactory equipment is available or projected within the flight era, the requirements are developed for accelerated equipment R&D.

This derivation of general-purpose equipment requirements identifies hardware that represents the total population of potential experiments, and therefore has a high probability of accommodating future, even as yet undefined, experiment requirements. This process provides early, yet confident, identification of the core equipment and thus enables equipment development (breadboarding and feasibility testing) to be started concurrently with conduct of the supporting research and detailed definition of individual experiments. Since the general-purpose core equipment affects the detailed design of most of the experiments in the S/T area, and since core equipment generally includes the most complex items with longest lead times, e.g., a large optical telescope for the Astronomy Laboratory, concurrent development of the core equipment will usually be necessary to meet projected flight dates. Early identification of equipment unique to specific experiments is less critical, and can generally be deferred until the supporting research program is well advanced.

The process of equipment identification results in a preliminary experiment development plan for each S/T area. Coordination of the separate plans to exploit equipment similarities and commonalities is accomplished in Step III.

2.2 Supporting Research

The capability of addressing the SKR's with well-planned orbital experimentation requires preparatory activity referred to as the supporting research program. This activity includes:

a. Laboratory and field research to fully establish the characteristics of the phenomena to be measured
b. Test and evaluation of prospective sensing/measuring techniques under simulated orbital conditions. This may involve low-altitude aircraft flights over controlled ground-truth sites, high-altitude aircraft flights to simulate the perturbing effects of the atmosphere, sounding rocket tests, and tests in unmanned satellites.
c. Planning for effective utilization of the data gathered from orbital experimentation.

The supporting research program for each S/T area is derived from the SKR's by (1) reviewing the status of current research, (2) determining the requirements for additional research, if any, (3) delineating additional methods for obtaining timely results, including acceleration of current programs, expansion to cover new sensing techniques and additional observables (e.g., expansion of the Agriculture field program to include crop types not currently under study, and (4) coalescing all SKR's by similarity to establish a coordinated program, time-phased for compatibility with projected flight dates.

2.3 Prospective Orbital Activities

This assessment includes (1) an estimate of the required number and orbital characteristics of flights that will satisfy the SKR's and (2) a preliminary description of prospective experiments that are to be defined in detail.

2.3.1 Flight Requirements

The anticipated flight characteristics for an S/T area are obtained by coalescing the individual SKR's applicable to that area. The individual flight requirements embrace the following elements: orbital inclination, seasonal dependence, orbital altitude, flight duration, and flight frequency. For each SKR, the preferred value and the sensitivity of each element is established.

The factors dictating the selection of flight elements differ from one S/T area to another. As an example of the procedure, the factors which influence the flight requirements for Agriculture/Forestry are summarized as follows:

a. Orbital Inclination—determined by the geographic location of the significant observables of the SKR's: principal crops, commercially exploitable forest and range areas, and wild game.
b. Seasonal Dependence—determined by the temporal sensitivity of the SKR observables. It may be shown that crops are most sensitive to season; since they also represent the observables of largest economic payoff, their temporal dependence dominates the

selection of time of flight.

c. Orbital Altitude—in the region of 150 to 250 n.m., since projected state-of-the-art of sensor resolution precludes conducting the early Agriculture/Forestry program from near-synchronous altitudes. Within the 150 to 250 n.m. region, the preferred altitude is determined by a tradeoff of low altitude (to maximize resolution) and high altitude (to increase coverage). Within the altitude band of interest, these tradeoffs are not sensitive and an altitude of approximately 200 n.m. represents a good compromise.

d. Flight Duration—minimum flight duration for accomplishing each SKR is established by the inherent growth factors of the observables, i.e., the need, if any, to view the observables at successive stages of growth. In practice, the minimum flight duration is extended by

- Requirements imposed by orbital kinematics, i.e., time to cover the entire area of interest,
- Requirements imposed by sensors for particular lighting conditions,
- Requirements imposed by sensors for particular weather conditions,
- Conflicts between high resolution and broad coverage.

e. Flight Frequency—a function of the periodicity and temporal correlation of the growth patterns of the SKR observables (crops, forests); it is also affected by the time period required between flights for reduction, dissemination, interpretation and feedback of the data.

The derived S/T area flight characteristics are unconstrained at this step of the synthesis, i.e., not limited by detailed characteristics of the available launch vehicles and spacecraft. These practical program constraints are applied in subsequent Step III, wherein potential conflicting requirements between S/T areas are identified and reconciled. A major purpose of deriving unconstrained flight requirements is to provide an invariant baseline for judging the impact of alternative program options and of program revisions which may come about as a result of budget changes, etc.

2.3.2 Candidate Experiments

The first step in detailing experiments is to identify and describe the set of orbital activities that are needed to satisfy the SKR's. For each prospective activity, an initial summary description is prepared; a representative summary description of a prospective experiment in the Agriculture/Forestry S/T area is shown in Table I.

Orbital experiments may be of two types. A Type I experiment directly responds or contributes to a specific SKR. For example, the illustrative experiment (Table 1) regarding identification of wheat from orbit is one of several Type I experiments which directly contribute to the SKR concerned with the ". . . location and identification of major cultivated crops." Type II experiments prove out equipment and procedures for undertaking Type I experiments, for example, calibration of a radar or launch of data capsules; in general, they support several SKR's.

The completeness of a prospective set of experiments can be objectively evaluated by relating the experiments to the end objective of the S/T area. For each S/T area, a matrix of Knowledge Requirements defining the S/T area can be constructed as shown in Fig. 6. The matrix depicts two items of particular significance:

a. The SKR's appropriate for space experimentation.
b. The Knowledge Requirements rejected at this time because of technical unfeasibility or other reasons.

The matrix indicates the extent to which Type I experiments contribute to specific SKR's and the extent to which Type II experiments contribute to several SKR's. The matrix brings out the relative contributions and interrelationships of the prospective set of experiments and highlights "holes" to which additional experiment definition effort should be directed.

The matrix representation is useful not only for initiating a coordinated effort at detailing individual experiments, but also for judging the value of experiments submitted by independent investigators. By indicating the relationship of the independently submitted experiment to one or more SKR's, the experiment can be objectively evaluated vis-a-vis other experiments which support the same SKR's, and action taken to support it, modify it, or reject it.

3.0 STEP III: INTERLACING OF EXPERIMENT REQUIREMENTS OF INDIVIDUAL S/T AREAS INTO OVERALL ORL PROGRAM PLAN

Step III includes (a) identification of similarities in equipment requirements and reconciliation of differences, (b) consolidation of the supporting research programs, and (c) development of guidelines for grouping experiments and for assigning them to flights/missions.

3.1 Identification of Similarities and Reconciliation of Differences in S/T Area Equipment Requirements

In "quasi-operational" systems—for example, for continuously monitoring sea ice—it may be essential to use

TABLE 1. ILLUSTRATIVE EXPERIMENT SUMMARY

No./Title: 1—Identification of Wheat

S/T Area: Agriculture/Forestry

SKR #1—Location and Identification of Major Cultivated Crops

Objective: To recognize and identify different species of wheat in selected ground-truth sites, principally in the U. S., and to measure area of wheat fields. This is the first phase in achieving the capability for surveying wheat on a global basis.

Expected Results: (1) Measures of effectiveness and limitations—probability of detection, false alarm rate, sensitivity to obliquity and atmospheric conditions—of black and white and multi-spectral sensing, from orbit, of wheat fields of different species. (2) Variations in effectiveness of identification and field area measurement, as a function of stage of growth. (3) Perfected procedures for pointing sensors and for quick-look, on-board analysis of data.

Relationship to Other Experiments: This experiment is one of several Type I experiments which jointly achieve the first phase of SKR A/F 1. Other experiments cover oats, barley, rice, corn, potatoes, and other crops determined to be economically significant.

Description of Experiment: Collect multi-spectral imagery, spectrometry, and photometry data over at least two ground-truth sites in the U. S. Perform observations at obliquities from 0° to 45°, at selected sun angles from 5° to 90°. Evaluate astronaut-assisted pointing of sensors and cloud-dodging. Imagery and data will be partially processed aboard ORL, looking for unusual effects requiring immediate checking of conditions of ground-truth sites. Evaluate automatic spectral-matching techniques.

Mission & Orbital Characteristics

Inclination: 45° preferred; 30° acceptable

Altitude: 150 to 250 naut. mi.

Orbital Eccentricity: not critical

Flight Duration: 45 days preferred; 2 weeks marginally acceptable.

Astronaut Involvement

Required Skills: Ability to operate and maintain sensors plus agricultural photo-interpretation experience.

Expected Number and Duration of Operational Periods: 50 periods of 20 min. each, as follows:

Operation	Astronauts	Time (min)	Periods	Total (man-min)
Inflight setup	2	120	1	240
Periodic checkout	1	5	50	250
Standby	1	5	50	250
Planned experimentation	2	10	50	1000
Evaluation of data	1	15	50	750
Unallocated time				
(Additional experimentation and discussion with ground)	1	30	40	1200
			Total	3690

Major Prospective Equipment:

Item	Characteristics: Aperture	Characteristics: Spectral Band	Weight (lbs.)	Volume (ft.^{3})	Power (watts)
Photographic Camera	16″	0.4-0.9 u	420	35	300
Multispectral Camera	2″	0.4-1.2 u	75	2.5	75
Panoramic Camera	4.3″	0.4-0.9 u	300	18	300
Visible Spectrometer (Share)	16″	0.3-3 u	100	3	30
IR Spectrometer (Share)	16″	3 -15 u	80	3	30
			975	61.5	735

equipment that has been specially optimized for the particular measurements involved. A radar for this system, for example, may well be different from that of a radar used for measuring tree height. For the experiments in the early ORL era, however, it may be feasible and desirable—notwithstanding a compromise in performance—to employ a common multipurpose radar system.

Such considerations, of over-all equipment aspects, are addressed in this part of Step III. The commonalities and similarities in equipment functional requirements among different S/T areas are established, and the effects of compromising differences so as to employ common equipment are analyzed. The relative advantages, including savings in development and hardware costs and time, and reduction in total payload complexity, are traded-off against the penalties in loss of performance. The output of this process is a preferred, coordinated, equipment development program.

It is important that the process of reconciling the common equipment should not be done *a priori*, before the individual S/T area requirements are separately established. Because of the complexity of these tradeoffs, the optimum program balance can be effected only after the equipment requirements of the individual S/T areas have been explicitly set forth, in accordance with Step II.

3.2 Consolidation of Individual S/T Area Supporting Research Programs

Supporting research programs are consolidated by systematically identifying the similarities in requirements among S/T areas, e.g., among Earth Sciences and Resources and Atmospheric Science and Technology. The individual supporting research programs are then reformulated or adapted to maximize overall return. As examples, the Geology/Hydrology ground-truth sites may be consolidated with those of Geography; and the field research, aircraft flight test program is structured to accommodate simultaneously as many different S/T area research requirements as possible.

3.3 Development of Guidelines for Mission Assignment

This process examines the intrinsic characteristics of the thirteen S/T areas. The intrinsic characteristics include (1) the need for general-purpose type equipment, (2) orbital characteristics of the required flights, (3) crew skill requirements, and (4) the economic and scientific benefits which accrue from space experimentation in the S/T area. Unlike specific details of individual candidate experiments which undergo considerable change as the experiments are defined, the intrinsic characteristics of an S/T area provide a relatively invariant basis for initial planning of missions. Comparison of the intrinsic characteristics yields groupings of S/T areas having compatible requirements, and indicates which of the S/T areas should be stressed early in the program and which need to be repeated most often. Analysis of the intrinsic characteristic leads to a baseline program of flights which, while evolved in the knowledge of the general national space capabilities that may be applied to the ORL program, is not constrained by specific assignments of spacecraft and launch vehicles.

The unconstrained, baseline flight program represents the most effective way of achieving the desired overall ORL capability and can be used as the objective toward which practical embodiments of ORL hardware should be directed. The baseline program thus provides a guideline for optimally exploiting the specific number and configurations of launch vehicles/spacecraft which may be allocated to ORL, and a basis for selecting from among alternative sets of "real-world" schedules and constraints.

4.0 ADVANTAGES OF SYNTHESIS PROCEDURE

The three-step, user-oriented synthesis procedure described above is an explicit statement of the complex sequence of activities which must be accomplished to identify and implement the manned earth-orbital experiment program. The major outputs of the three-step process are summarized in Table 2.

Admittedly the approach is more structured and formalized than that currently in use for selecting and implementing space experiments. Within the context of the larger scope and magnitude of the ORL program, however, the structured approach represents the most economical and effective, if not the only practical way, of accomplishing the program. Its most significant advantages are summarized below:

a. The "top-down" synthesis procedure provides NASA with a framework for generating significant experiments whose value, in terms of economic benefits and scientific contributions, justifies the cost of the ORL program. The procedure also provides a framework for demonstrative presentation of the program to other Government agencies and to Congress.
b. The procedure, by deriving the experiment requirements of the important general-purpose equipment from overall S/T area considerations, enables a concurrency approach to hardware procurement, and thus reduces the time to implement the program.

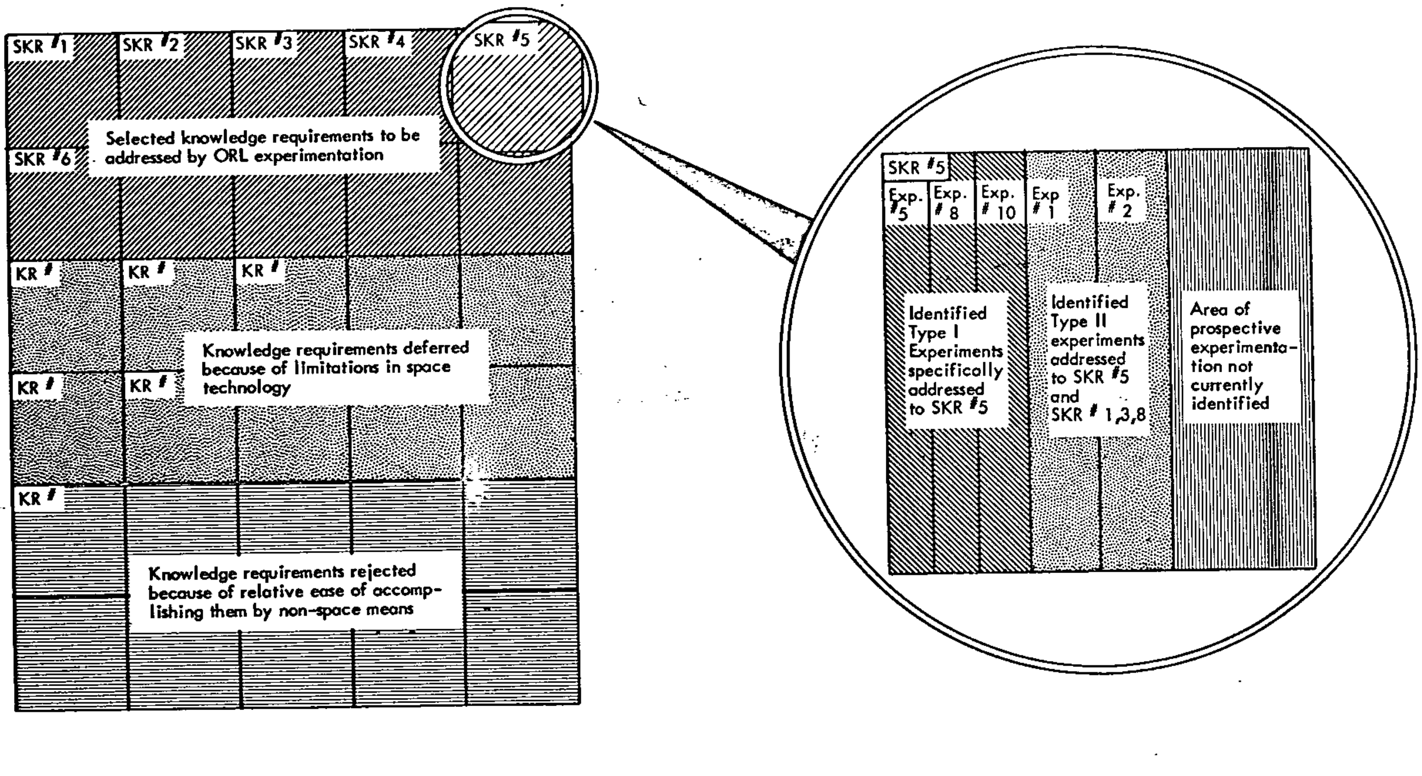


Fig. 6. Representation of Contributions of Individual Experiments.

TABLE 2. OUTPUT OF THE THREE-STEP SYNTHESIS PROCESS

STEP I: IDENTIFICATION OF S/T AREA KNOWLEDGE REQUIREMENTS TO BE ADDRESSED BY ORL EXPERIMENT PROGRAM

Yields

Selected Knowledge Requirements (SKR's) with indicators of their importance in terms of economic benefits or scientific/technical significance.

Identification of important Knowledge Requirements for which advances in technology are needed before they can be addressed by ORL experimentation.

STEP II: DERIVATION OF EXPERIMENT REQUIREMENTS OF INDIVIDUAL S/T AREAS

Yields

Functional requirements of the experiment equipment that makes up the core of the special-purpose ORL Laboratory for the S/T area.

Requirements for supporting research.

Prospective orbital activities

- —estimate of number and orbital characteristics of flights.
- —prospective individual experiments to be detailed.

STEP III: INTERLACING OF EXPERIMENT REQUIREMENTS OF INDIVIDUAL S/T AREAS INTO OVERALL ORL PROGRAM PLAN

Yields

Identification of similarities and reconciliation of differences in equipment and requirements.

Consolidation of individual supporting research programs.

Grouping of prospective experiments and development of guidelines for assigning them to missions.

c. The procedure provides an effective way for incorporating the results of the diverse, ORL-related application and instrument studies currently underway. By consolidating and assessing the results of these independent studies within the overall framework, as shown in Fig. 6, the potential hazard that hardware may be prematurely "frozen" can be avoided; and the directions for re-orienting and expanding current efforts can be established.

d. The steps in the synthesis procedure are milestone events in the overall implementation process and can be used for establishing documentation requirements and overall PERT-type control.

e. The synthesis approach encourages effective participation of the scientific and technical communities. The framework for depicting the relationship between individual experiments and the end objective to which they contribute ensures a balanced overall program which, in fact, demonstrably supports the most important scientific and technical objectives in each S/T area. The framework identifies those areas already well covered by candidate experiments and those which require additional ideas and research effort; thus prospective experimenters can focus their efforts and more readily obtain support for their proposed ideas.

f. Finally, by providing an explicit mechanism for interlacing the individual experiments of the different S/T areas and for relating their combined requirements to launch vehicles, spacecraft, and other practical constraints, the synthesis procedure minimizes the extent to which individual experimenters need be burdened with the myriad of practical details involved with overall experiment integration.

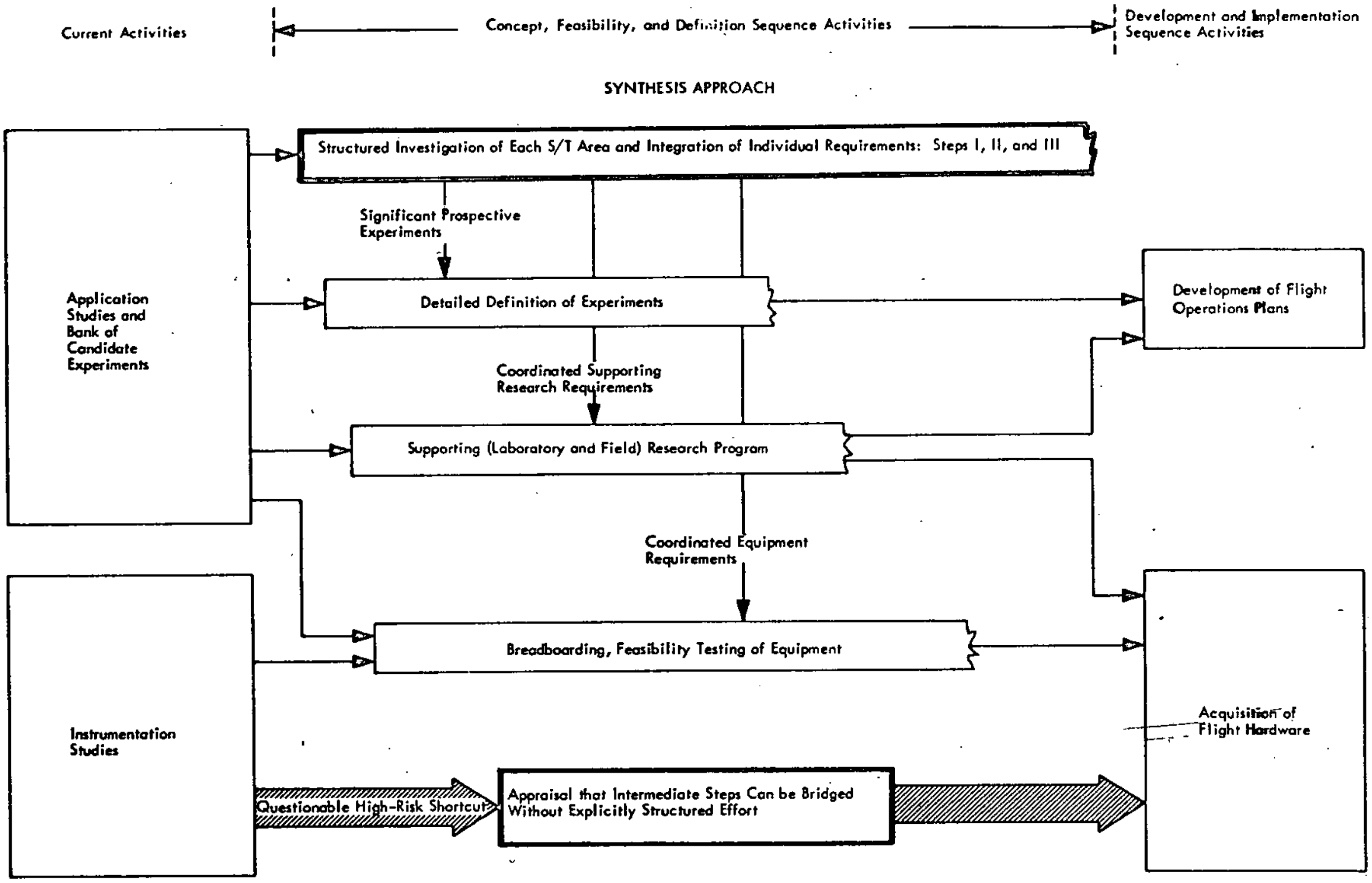


Fig. 7. Relation of Concept, Feasibility and Definition Sequence Activities to Current Activities.

IV. SCIENTIFIC/TECHNICAL AREAS

Insofar as possible, the scientific/technical areas within the ORL program have been selected to be mutually exclusive. Where strongly complementing area interrelationships exist, the boundaries of overlapping interests have been delineated. This minimizes duplication of effort in analyzing the objectives of the S/T areas to identify significant experiments.

The scope and objectives of the thirteen scientific/technical areas are described below.

1.0 EARTH-ORIENTED APPLICATIONS

Earth Sciences and Resources: This grouping of S/T areas comprises the related areas of Agriculture/Forestry, Geology/Hydrology, Oceanography/Marine Technology, and Geography. Their importance stems from the need for better utilization of the earth's resources to provide for the world's burgeoning population, a population that has doubled since 1900 and will double again by the year 2000. Unless resource management methods are improved, population pressures will force a lowering of an already inadequate worldwide standard of living, with profound economic, social, and political consequences. Just as the industrial revolution upset the dire predictions of Malthus 100 years ago, there is need today to marshal science and technology to surmount the twentieth-century problems of resources conservation. Space systems offer new approaches and fresh opportunities. Earth-orbital experimentation in the Earth Sciences and Resources S/T areas will establish the feasibility and demonstrate the practical utility of these space systems.

1.1 Agriculture/Forestry

This S/T area is concerned with, and has as its end objective, an increase in the world's supply of food, fiber, and forest products. Although some developed countries still produce agricultural surpluses, two-thirds of the world's population are inadequately fed. Despite increased effort and expense to alleviate the problem, 1964 per capita food production failed to rise, for the fifth straight year. In many areas it has fallen; for example, current output per capita in Latin America is 16 percent below mid-1930 levels.

Agricultural and forest shortages can be alleviated—

(1) by increasing the yield/quality from lands in cultivation,
(2) by decreasing losses in production, such as from infestation and forest fires, and
(3) by increasing the quantity of land in cultivation.

Space systems can contribute to these objectives. Meteorological satellites, for example, can expand productivity by improving the range and accuracy of weather forecasts. Communication satellites can televise new farming techniques to farmers in remote areas. Observation satellites can survey existing and potential resources and can provide estimates of yield. They may also discover broad-scale ecological relationships not discernible from restricted, piecemeal, ground view: relationships that may be used to improve methods of cultivation.

Much of the scientific information and technical experience needed to bring about the development of these space systems can be obtained most effectively by earth-orbital experimentation. Meteorological experiment requirements are described in the Atmospheric Science and Technology S/T area; those for communication satellites are developed in the Communications and Navigation/Traffic Control S/T area. The Agriculture/Forestry S/T area, as with the other S/T areas in the Earth Sciences and Resources group, is concerned with the application of observational satellites for supplementing and expanding terrestrial techniques for surveys of agriculture and forest resources.

The principal method currently in use for obtaining information on the status of agriculture and forest production is direct on-the-ground survey. This method is deficient because—

a. Many important, underdeveloped areas do not report resource status.
b. When available, such reports are frequently inaccurate; nor are reports from developed regions entirely accurate.
c. Reports from most regions are irregular and infrequent.
d. Different regions use different definitions and interpretive procedures.

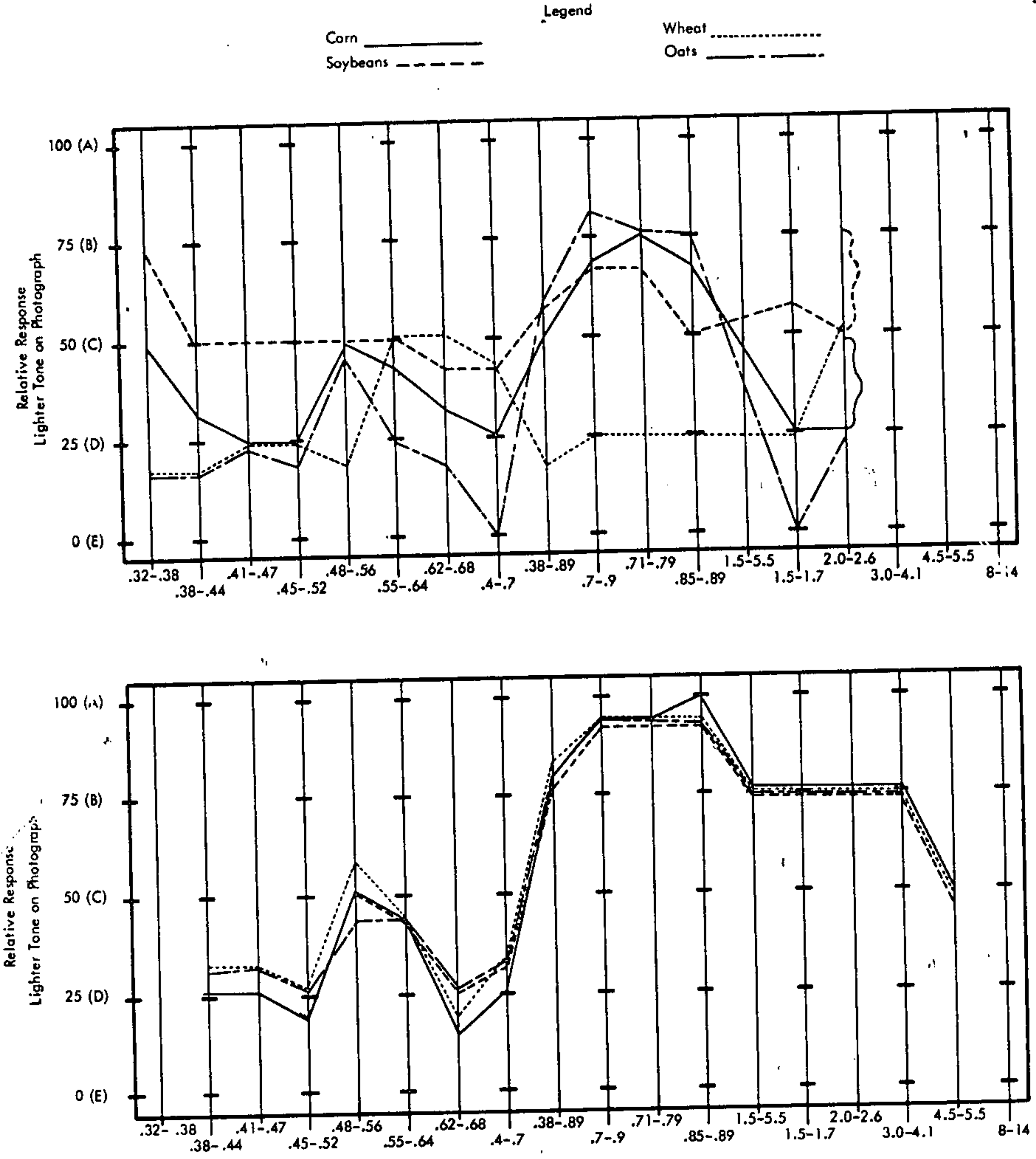


Fig. 8. Multiband Spectral Signature of Field Crops. Fig. 8a shows the energy vs. wavelength curves for soybeans, corn, wheat, and oats. Each has a characteristic shape, akin to a signature that may be used to identify the species of crop. Fig. 8b shows the consistency of the signature for four soybean fields. (From "Applications of Remote Sensing in Agriculture and Forestry," R. N. Colwell and L. R. Shay; Proceedings of AAS 1965 Goddard Day Symposium.)

Aerial photographic survey techniques have been used increasingly to offset some of these limitations. In addition, other remote sensing techniques, which expand the "window" of observation from the visual band to the UV, IR, and microwave bands, are now in development. These techniques, involving correlation of measurements in multiple spectral regions, measure the fine-line structure of the energy emitted and reflected by plants, soils, and animals. Field testing of these techniques with plants, as depicted in Fig. 8, shows that the shape of the energy-versus-wavelength curve is a characteristic signature that may be used to identify the species of the plant. Moreover, deviations in the characteristic signature may indicate the vigor of the plant, as shown in Fig. 9. Based on a series of remarkable tests of diseased orange trees and other plants, agricultural scientists have concluded that ". . . a loss of vigor in many plants can be seen more readily on IR photographs taken from an altitude of two miles or more above the earth than by the expert on the ground as he walks through the same field." *

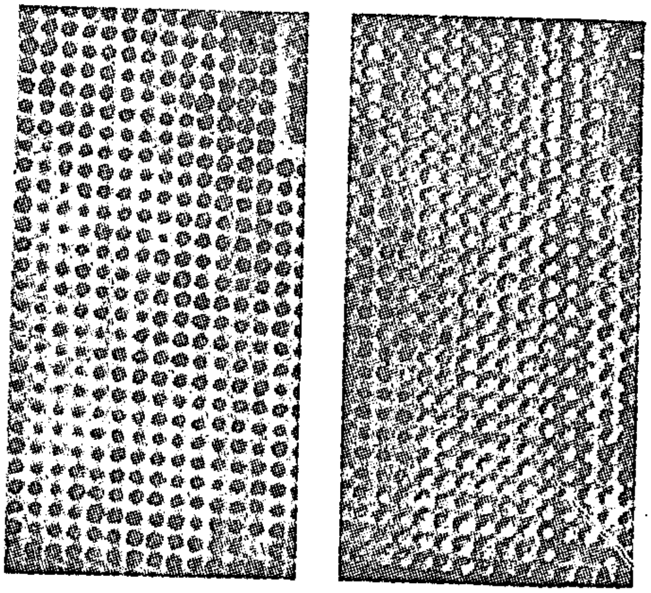
These results have heightened interest in the use of observation satellites for agriculture and forestry. Orbital spacecraft equipped with photographic and multispectral remote sensors portend an economical means for timely, repetitive, and uniformly-interpretable global surveys. In addition to providing the first comprehensive catalog of existing resources, such space sensors would enable accurate yield forecasting and could accomplish other important functions such as detecting forest fires, warning of insect infestations, and locating potentially reclaimable land.

1.2 Geology/Hydrology

This S/T area is concerned with, and has as its end objective, the enhanced utilization of fuel, mineral, and water resources, plus "containing" the adverse effects of dynamic geologic/hydrologic occurrences. In the face of increasing industrialization there is urgent need—

a. To increase the output of fuels and minerals
b. To protect life, property, and resources from volcanoes, earthquakes, and floods
c. To promote economical supply of fresh water
d. To conserve recreation areas and promote the transportation potential of inland waters.

Low-altitude aerial survey techniques, principally photography and magnetometry, have long been used for geologic exploration, and are being used increasingly for hydrologic investigations. With the development of infrared and microwave radiometers, side-looking radars, and other multispectral sensors, the opportunity now exists to carry out global surveys from orbit. Satellites can be used to cover geologically important areas which are all too frequently remote and inaccessible to ground exploration. As an example, spacecraft may be able to detect geological features indicative of mineral and fuel deposits and may thus be able to confine field investigations to particularly promising areas. Project Mercury photo-geology experience indicates the potential of exploration from space; relatively unsophisticated equipment has provided images (Fig.10) from which photointerpreters have identified areas favorable to petroleum accumulations.



a. b.

Fig. 9. Infrared Detection of Diseased Orange Trees. Fig. 9a is a panchromatic aerial photograph and Fig. 9b is an infrared aerial photograph of a navel orange grove in which several trees are dying, as a result of fungus growth. Collapse of the spongy mesophyll tissues of the leaf causes a loss in infrared reflectance long before there is a loss in the normal green coloration of the leaf. While there is no distinguishable tone difference between the diseased and healthy trees on the panchromatic photo, the diseased trees stand out by their dark tone in the IR photo. (Manual of Photographic Interpretation, original photo courtesy of Cartwright and Company and U. S. Bureau of Reclamation.)

Satellites can observe broad-scale geomorphologic features and hydrologic processes not discernible from a low altitude. Information acquired from space can be used in compiling maps showing the worldwide distribution of geomorphological features, especially tectonic land forms,

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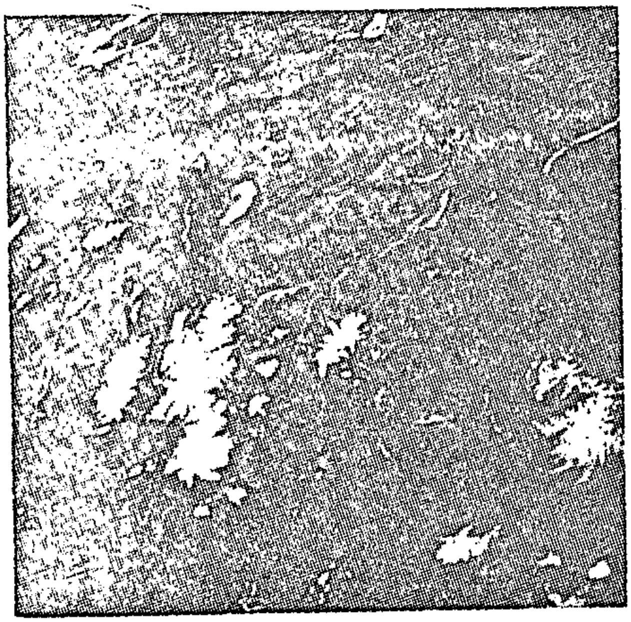
* Colwell, R. N. and Shay, J. R., Applications of Remote Sensing of Agriculture and Forestry, Proceedings of AAS 1965, Goddard Day Symposium.



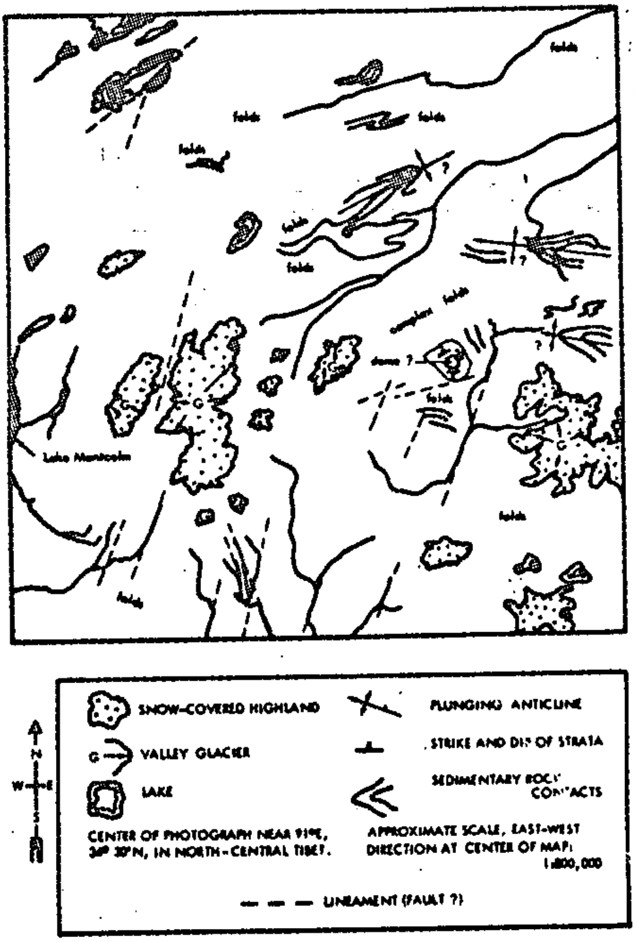


Fig. 10. MA/9 imagery of North-Central Tibet. Fig. 10a, a black and white print of a 70 mm color transparency, shows topographic and geologic detail. Fig. 10b is a geologic sketch map which was prepared from the photography. The domes and anticlines represent potential oil-bearing areas. The intersections of some of the lineaments might be the loci of mineral deposits. (From "A Review of Photography of the Earth from Sounding Rockets and Satellites," Paul D. Lowman, Jr. NASA Technical Note D-1868, December 1964.)

such as folds, faults, and eroded or exhumed igneous masses. This information, needed to clarify mechanisms responsible for deformation of the earth's crust, can help to explain the triggering of earthquakes and volcanos and the extent to which diastrophic forces are displacing land masses relative to one another. Aside from its purely scientific interest, this information—which cannot be obtained by conventional means—may lead to practical surveillance techniques for timely warning of earthquake and volcano activity.

Satellites can also help in managing increasingly important water resources. Repetitive, region-wide surveys from space of stream conditions, and of extent and depth of snow and ice packs and frozen soils can provide short-term forecasts of water availability. As an example of the economic benefits of such forecasts, a single, medium-sized, Canadian hydroelectric plant saves 1 million dollars for each 1 percent increase in accuracy in predicting April-to-August flow. This amount of power revenue would otherwise be lost because of the need to waste water to provide room for unanticipated flood conditions.

1.3 Oceanography/Marine Technology

This S/T area is concerned with, and has as its end objective, the exploitation of ocean resources, and the containment of its adverse effects. Covering 70% of the earth's surface, the oceans represent a vast storehouse of potential food and minerals which may be tapped to relieve growing pressures on land resources. In addition, improved understanding of oceanographic phenomena is required:

a. To promote safety and economy of ocean transportation
b. To utilize the oceans as safe sinks for waste
c. To protect life, property, and coastal resources from tides, sea state, and other damage-producing ocean phenomena.

As a consequence of growing recognition of the importance of oceanography, there has been a major effort to survey the oceans, cataloging their features and characteristics:

Waves, currents and tides
Sea state
Sea ice
Coastal geological features
Distribution of marine life
Distribution of patterns of pollution.

It is to this end that space systems present a new capability; orbiting spacecraft make it practical for the first time to obtain frequent, synoptic surveys of the entire ocean surface.

Heretofore, surveys made by ship have been spot samples, widely discontinuous in time and space; coverage has necessarily emphasized the vertical rather than the horizontal distribution of properties, even though the horizontal dimensions of the oceans are 5000 times the vertical. Large areas of the oceans have been surveyed by ship only once in a century, and some have never been explored.

A typical research vessel can survey about 10,000 square miles a day, at a cost of about $3000. At this rate, a single, complete ocean survey would cost $38,000,000 and would require 35 ship-years. By contrast, a satellite could cover the area in a matter of days. Although present technology is such that observations from space cannot acquire all the information that can be obtained by ship measurements *in situ*, satellites equipped with multispectral remote sensors, and, perhaps, with provisions for "reading" data from fixed and free-floating buoys provide a potent supplement to ships in a coordinated oceanographic program.

1.4 Geography

This S/T area is concerned with the interaction between man and his environment, and has as its end objective the fostering of man's effective utilization of the earth's resources.

In the broad sense, geography is an amalgam of disciplines, including, among others, agriculture and forestry, geology and hydrology; and oceanography. For the purpose of deriving the knowledge requirements to which the ORL experiment program can contribute, these areas—because of their special importance—are treated separately. The principal objectives reserved for and addressed in the analysis of the Geography S/T area are:

a. To extend knowledge of global topography.
b. To provide information relative to planning for cultural facilities.
c. To improve understanding of cultural growth patterns.

These objectives encompass cartography — compilation, analysis and graphic presentation of environmental data—and the fields of demography, urban development, and transportation economics.

To a greater extent even than the previously discussed Earth Sciences and Resources S/T areas, geography depends on a global viewpoint. One of the most important applications of spacecraft is the potential to improve world mapping. Adequate maps exist for less than 50% of the world's land area. Proven, aerial photographic techniques and newer multispectral techniques can be directly extrapolated to space to cover present mapping voids and to update maps, depicting dynamic changes in special areas of interest such as the developing nations.

Spacecraft observations can be used to obtain a global population census and to determine patterns of land use, including growth and development associated with urban settlements. Satellites can establish dynamic patterns of trade routes, and may be able to provide economists and sociologists with more accurate assessments of level of economic activity and organization than the measures currently in use; e.g., measurement of man-induced energy output may be a better indicator than available, generally imprecise estimates of gross national product.

1.5 Atmospheric Science and Technology

The end objective of this S/T area is to enhance man's ability to predict and to control atmospheric processes. Affecting virtually all aspects of life, this capability is required—

a. To increase efficiency in the production of goods and performance of service
b. To protect life and property from effects of meteorological phenomena such as severe storms
c. To protect life and property from effects of man-made atmospheric contamination.

In one of the first applications conceived for space, experience with twelve unmanned meteorological satellites has demonstrated the ability to locate hurricanes and other severe storms. The Weather Bureau uses satellite data, to date principally cloud photography, on a routine basis. However, since cloud photography yields only a part of the measurements needed for accurate weather prediciton, the TIROS and Nimbus satellites represent only an initial step in exploiting space for meteorology.

Currently, general weather forecasts have an accuracy of about 85% and cover a time span of about one day. Improvements in forecasting—a national goal is to extend the time span to five days with greater accuracy—depend on frequent, globally-distributed observations of wind velocity, pressure, temperature, and water vapor, all at many altitudes. These observations are now limited to populated regions in the northern hemisphere and are inadequate for long-range prediction or for developing the better meteorological models upon which forecasts are based.

Satellites are well-suited for collecting the needed measurements on a global, repetitive, and timely basis. Advanced meteorological satellites equipped with UV, IR, and radio/radar sensors, as well as with camera systems, can observe atmospheric phenomena across the entire spectrum. Used individually and correlated with each other, these multispectral measurements could provide all the important atmospheric-state parameters needed for forecasting. Moreover these satellites would afford meterologists hitherto unobtainable opportunities to observe broad-scale atmospheric phenomena and to appraise their effects on weather.

Space systems also have application to the problem of air pollution. To date, air pollution control efforts have been restricted to isolated measures in particularly distressed industrial areas. These efforts have concentrated almost exclusively on measures to reduce pollutant emissions at their source. A broader attack on the problem can be undertaken through use of satellites. Equipped with remote sensors, satellites could be used to trace the dispersion patterns of air pollution and to discover natural purging mechanisms. They could monitor the distribution of pollution over broad areas, something not now practical; detect unexpected releases; and provide warning of pollution episodes.

The economic significance of the improved ability to predict weather and to control air pollution which may be afforded by advanced space systems is enormous. Annual losses in the U.S. alone due to air pollution are estimated to be 11 billion dollars. The economic gain to the U.S. of extending the general forecast to five days is estimated to exceed 5 billion dollars per year; world-wide benefits would be many times greater.

The purpose of earth-orbital experimentation in support of the Atmospheric Science and Technology S/T area is to speed the development of these advanced satellites; by improving understanding of atmospheric phenomena and by establishing the utility of prospective remote sensing systems. Whether these advanced satellites will ultimately be manned or unmanned, the ability to conduct preoperational experimentation with meteorologist-astronauts will accelerate and reduce the cost of their development.

1.6 Communications and Navigation/Traffic Control

This S/T area is concerned with development of global communications and related services to meet the public and national needs of the U.S. and other countries.* By Act of Congress, the establishment of a communications satellite system to develop these services is a national policy.

Use of satellites to overcome line-of-sight limitations of ground-based communications techniques has been demonstrated by a variety of experimental systems. First-generation, privately-owned systems are already in use. These have shown the feasibility of services hitherto unachievable, such as real-time intercontinental TV, and have indicated the cost-effectiveness of communication satellite links vis-a-vis conventional links. Although originally conceived for intercontinental service, satellite relays also offer advantages for regional communications; U.S. broadcasting networks are already planning to establish distribution communication satellites for domestic operations, to replace land cables and microwave links.

Significant improvements can be anticipated in later-generation communication satellites, including longer operating life, wider channel and greater multiple-access capability, and reduction in cost of ground terminals. In addition to providing common-carrier services, new uses can be anticipated. Examples:

a. With the development of high-powered sources and large, directional antennas, satellites will be able to broadcast voice and TV directly to simple, home-type receivers. Among other uses, the broadcast satellite has enormous potential for education in developing regions. Television can be used in areas of low literacy for vocational training; and, most important, TV can bring about the condition where the need for change and progress is recognized and accepted by the populace. Studies of the TV broadcast satellite have shown that it is both practicable and more economical than alternative methods of providing wide-area service. Figure 11 shows an indicative cost comparison of alternative systems.

b. Communication satellites that can relay information to manned satellites, e.g., Gemini, can provide global tracking and communications for space operations, covering areas for which it is not practicable to install ground terminals and long-distance ground-ground links to the mission control center. (Such communication satellite systems could also be used

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* As one of the Earth-Oriented Applications, this S/T area covers terrestrial applications, i.e., earth-to-earth communications; and navigation and control of ships and aircraft. Related areas concerning space operations, such as data links with space probes and spacecraft navigation and guidance, are treated in the S/T areas within the Support for Space Operations group.

as relays in effecting communications between earth and lunar and deep space vehicles.)

Closely related to communications is the use of satellites for controlling ship and aircraft traffic. Satellites can provide craft with all-weather, world-wide, position determination. Although it is technically feasible for a ship or aircraft to establish its position merely by receiving signals emitted by a satellite, except for special military situations, it is preferable to combine the position-fixing function with a communications link, between the craft and the satellite. In this way optimal routing information, computed at a central traffic control facility, can be provided to the craft, thereby reducing travel time and operating costs, particularly those arising from congestion in terminals and harbors. Although current navigation doctrine involves relatively autonomous operation of each ship or aircraft, the need for centralized traffic control is becoming more critical as the number of craft increases and as their speed increases. A central control facility could transmit weather information to the craft and warn of other hazards such as icebergs (for ships) and high intensity radiation bursts (for high-flying supersonic aircraft). The ship-to-satellite-to-control center communications link could also be used for collecting weather information and other data from the using craft and for supporting search-and-rescue operations.

Several promising techniques are currently under study for navigation and traffic control satellites. As with advanced communication satellites, further R&D on both components and systems will be required to make these systems practical. Although much of the R&D can be performed in ground-based facilities that simulate the space environment, many aspects can best be accomplished by actual testing in space: for example,

a. Determination of the reflection, refraction, and interference characteristics of the propagating medium
b. Deployment and erection of large antennas
c. Determination of degradation of components after prolonged exposure to space, either through in-space inspection or through retrieval and return of samples to ground
d. Appraisal of feasibility of effecting maintenance and repair of operational satellites.

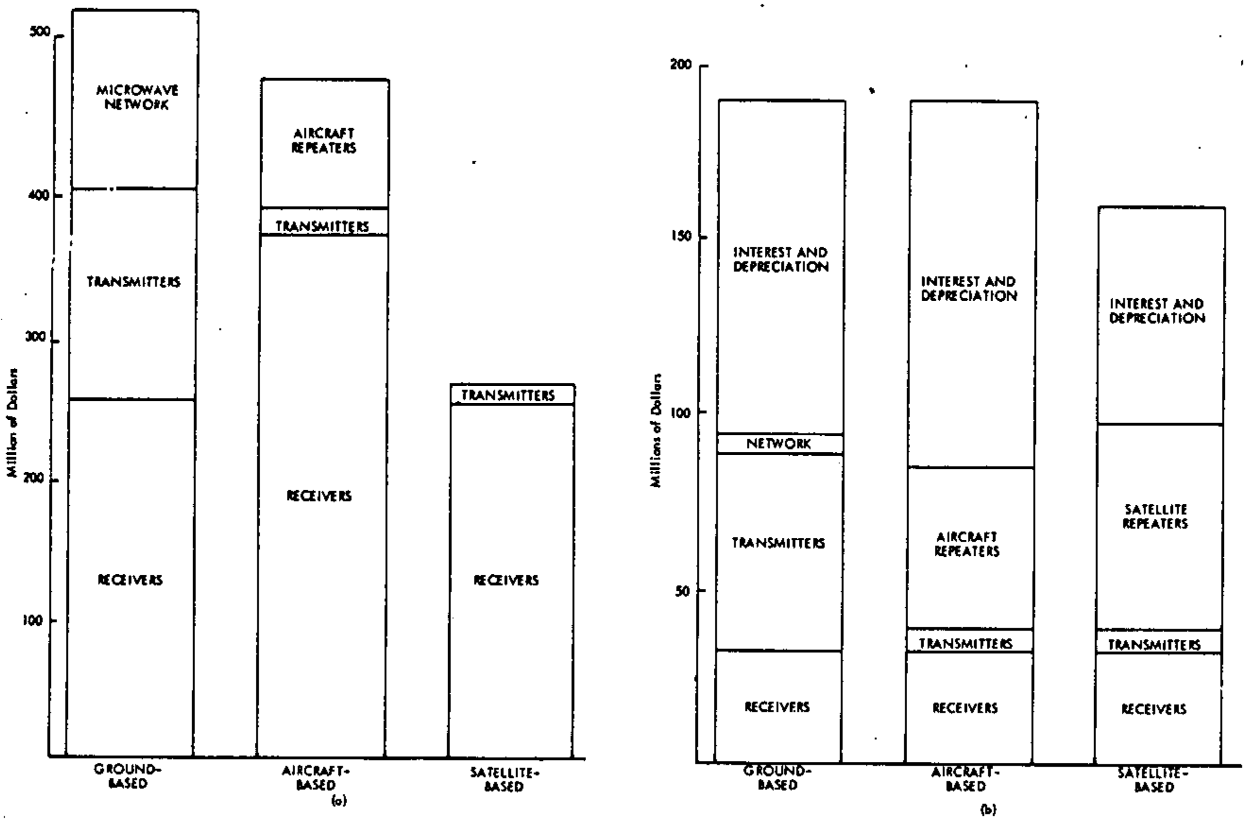


Fig. 11. Indicative Cost Comparison of Methods of Providing TV Coverage of India — Fig. (a) shows the initial costs of providing nine channels of TV to 570,000 community receivers by: 1) a network of 224 broadcast stations; 2) a system of 40 aircraft-based transmitters; and 3) a system of three satellites. Fig. (b) shows the annual operating costs. The life of the satellite is taken to be only one year. The cost of the satellites is treated as an operating cost. (From "Television Broadcasting from Satellites," N. I. Korman and A. Katz, American Rocket Society, 2722-A-62.)

The ability to perform research and development on critical subsystems aboard manned spacecraft and to use the ORL as a test bed for evaluating the effectiveness of contemplated systems will hasten their realization.

2.0 SUPPORT FOR SPACE OPERATIONS

2.1 Biomedicine/Behavior

This S/T area is concerned with man's physiological integrity and capacity to withstand prolonged exposure to the space environment and to operate effectively in future space missions—including ORL missions and longer-term missions of planetary exploration.

Results of the Mercury, Gemini, and Russian space programs appear to show that, for durations up to two weeks, man suffers no major impairment from space flight. However, even for these relatively short flights, deconditioning is evident in the cardiovascular, musculoskeletal, and other vital physiological systems (Fig. 12). Future missions of much longer duration will likely require remedial measures for these effects and for other negative effects—in particular, behavioral (performance) problems—which may be uncovered.

The purpose of the ORL experiment program in the Biomedicine/Behavior S/T area is to contribute to the development of these remedial measures: to enable man to travel and operate in space at will. The experiment program will provide the quantitative basis for effective planning of man's role in future missions. By extending exposure times well beyond those which will have been achieved in Gemini and Apollo; by using more sophisticated equipment; and, especially, by taking advantage of the opportunity to place a physician on board, the ORL experiment program will provide detailed understanding of man's physiological capabilities and limitations. It will also establish a much needed compendium of knowledge regarding man's behavioral adjustment to space flight. Collectively, the information obtained from the Biomedicine/Behavior program will contribute a major input to a "design handbook of human factors for space flight", covering such factors as:

—Criteria for astronaut selection
—Standards for hygiene and habitability
—Standards for establishing work/rest cycles and guidelines for structuring interpersonal relationships among crew members
—Mechanisms of deconditioning and adaptation of affected body systems
—Measures of effectiveness of alternative countermeasures
—Standards of sensory, mental, and motor performance
—Standards for design of displays and other I/O devices
—Indices for predicting effects of exposures in excess of ORL flight durations.

2.2 Advanced Technology and Supporting Research

This S/T area is aimed at establishing a base of fundamental engineering knowledge underlying the design of advanced space systems. Bridging the gap between basic scientific research and its practical applications, ATSR complements the Operations Techniques and Advanced Mission Spacecraft Subsystems (OTAMSS) S/T area, which is concerned with validating and qualifying mission-configured equipment.

Much of the technology for advanced space systems can be extrapolated directly from terrestrial experience; however, many aspects, particularly those that are gravity-dependent such as heat transfer by convection, will require reformulation for space application. For these aspects, experimentation on research models is required to evolve practical design principles for operational equipment. Because of the limitations of ground facilities in simulating

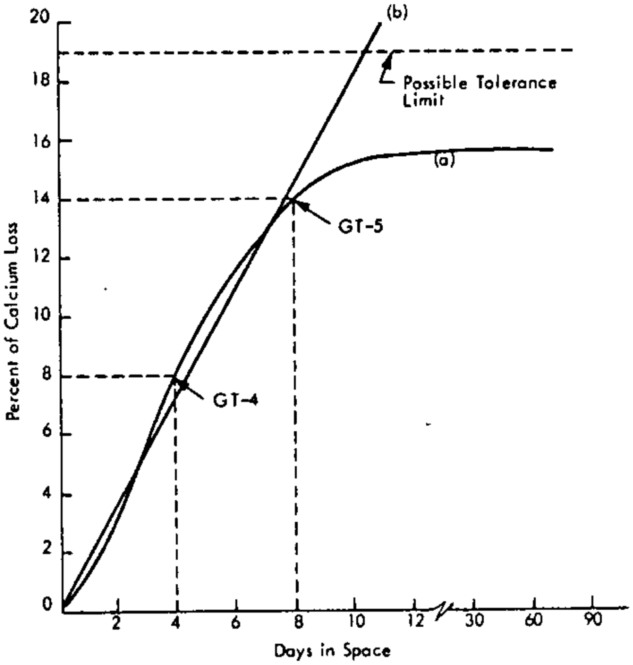


Fig. 12. **Calcium Loss in Weightlessness. Current knowledge, based on GT-4 and GT-5, is inadequate to predict whether effect will level off as in (a) or increase as in (b). ORL will establish the precise nature of the curve and relate it to tolerance limits. If tolerance limits will be exceeded for missions of the future, ORL will develop and evaluate the effectiveness of countermeasures.**

the space environment, development of advanced technologies that are environment-critical necessitates extensive testing in space.

ATSR experimentation will include the following areas:

a. Mechanical design data acquisition—determination of effects of weightlessness, radiation, hard vacuum, and micrometeoroites on materials and mechanisms; for design of structures and devices suitable for the space environment
b. Fluid system design data acquisition—verification of zero-g principles of hydrostatics and hydrodynamics; for design of systems for storage, transport, and control of fluids in space
c. Chemical and nuclear engineering design data acquisition—to develop design criteria for equipment dependent on chemical interactions, such as advanced life support components; and on nuclear reactions, such as prime power devices for operating electrical generators
d. Heat transfer design data acquisition—for design of boilers, condensers, and other heat-exchange components for use in space
e. Electrical/electronic design data acquisition—for design of advanced power, communications, and guidance systems.

Through investigation of research models, principles and empirical guidelines will be established for design of spaceborne equipment. This data will be the basis for development of a "handbook of applied engineering principles for space."

2.3 Operations Techniques and Advanced Mission Spacecraft Subsystems

This S/T area is concerned with in-flight development, evaluation, and qualification of (1) operational techniques and procedures and (2) flight-configured equipment, for advanced space missions. This S/T area complements ATSR and is closely related to the Extravehicular Engineering Activities area that considers those aspects of development and qualification requiring extensive extravehicular activity.

Ground-based methods for developing operating procedures for space involve exercising of equipment and training of crews under simulated conditions. Experience with aircraft systems has shown that, while flight trainers are valuable aids, man cannot become proficient in flying solely through their use. Terrestrial simulation of the orbital environment is even more limiting. Ground-based simulation facilities cannot provide a long-duration low-gravity environment, nor can they realistically represent the spatial extent or range of possible contingencies associated with many operations of interest.

Ground-based methods for testing equipment are limited by uncertainty as to all the relevant parameters of the space environment and by inability to faithfully reproduce the environment for extended periods. Final development and qualifications of equipment in space will supplement ground-based testing and will ensure equipment safety and effectiveness.

Representative operations and procedures to be developed by OTAMSS earth-orbital experimentation include—

a. Orientation maneuvers, rendezvous, and docking
b. Acquisition, pointing, and image compensation
c. Alignment, maintenance and repair of advanced experiment payloads
d. Methods for coping with emergency situations, such as fire, explosion, and decompression
e. Simulation of elements of advanced missions such as planetary approach, survey from orbit, landing, and return to mother craft.

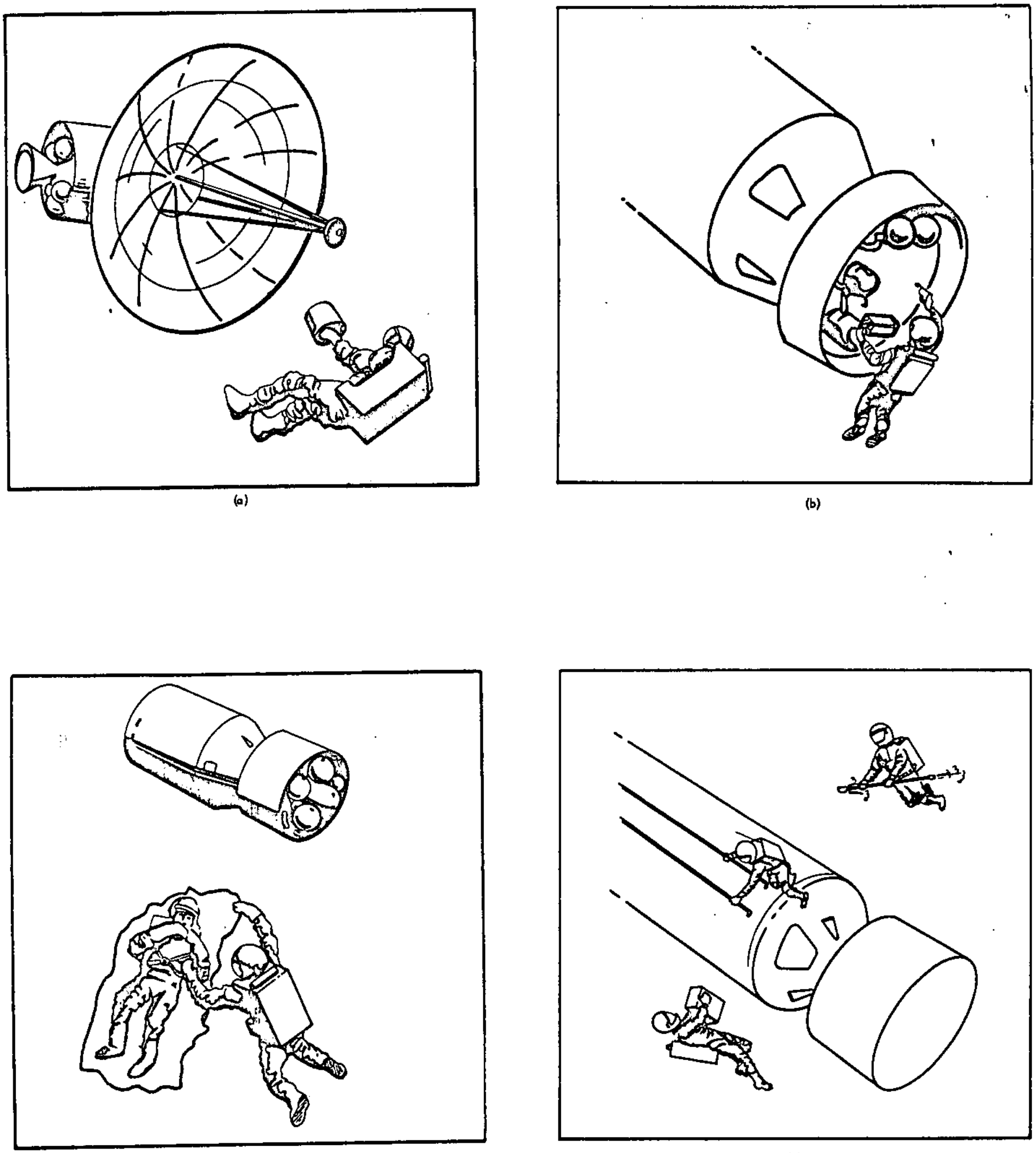
Representative equipment to be evaluated and qualified includes components of basic spacecraft subsystems: life support, power, structure, altitude control, environmental control, communications, guidance and navigation, and propulsion.

2.4 Extravehicular Engineering Activities

This S/T area is concerned with development of extravehicular equipment, techniques, and procedures required for (1) performance of experiments in the other earth-orbital S/T area, and (2) preparation for advanced planetary exploration.

Many items of prospective experiment equipment, such as large antennas and telescopes, are too large or too delicate to be launched as complete entities. These items need to be assembled outside the spacecraft, aligned, and checked out in orbit. As shown in Fig. 13, astronauts will also have to operate outside the spacecraft to maintain externally-mounted equipment, to retrieve a satellite, to recover a disabled astronaut, to transfer fuel and supplies from one vehicle to another, and to conduct orbital launch operations. Studies have shown that these tasks are too complex to be accomplished remotely by automatons.

The experiment program in the EVEA S/T area will appraise and develop man's extravehicular capabilities. The results of the EVEA experiments will pave the way for effective conduct of the overall experiment program; for example, the capability for assembling and aligning a telescope will have been perfected by EVEA S/T area activity before the astronomy package is deployed. The EVEA experiment results will also play a major role in selecting mission modes (e.g., earth-orbit rendezvous versus direct launch) for advanced space exploration.



(a) (b)

(c) (d)

Fig. 13. Extravehicular Engineering Activities. Participation of the astronaut will be required for (a) assembly of large structures, (b) maintenance and repair, and (c) recovery/rescue operations. Experiments in the EVEA S/T area will develop (d) basic locomotion and maneuvering capability, and will perfect equipment and procedures required by the orbital activities of the other S/T areas.

3.0 SPACE SCIENCE

3.1 Astronomy/Astrophysics

This S/T area is concerned with expanding man's knowledge of the universe. The results of the ORL experiment program will broaden the basis for theories of the structure, origin, and evolution of celestial bodies and galaxies, and will clarify the question of existence of extraterrestrial life.*

Until recently, the ability to resolve many of the most important questions in astrophysics was limited by the poor "visibility" caused by the earth's atmosphere. Of the total spectrum of radiation emitted by cosmic bodies, the atmosphere blocks all but a few narrow bands in the visible, IR, and radio regions. As indicated in Fig. 14, even within these narrow windows the ability to discern fine detail is limited by randomly fluctuating atmospheric reflection and refraction effects that set a lower bound to the angular resolution achievable with ground-based instruments. Further, airglow and scattering of sunlight and starlight in the upper atmosphere set a lower limit on the brightness of objects that can be detected from the ground.

These limitations are avoided by making observations from above the atmosphere. Since the first rocket-launched UV spectrographs were obtained in 1947, the value of space astronomy has been amply demonstrated. Fundamental discoveries have already been made by exploiting the X-ray and gamma-ray windows; with the launch of the unmanned Orbiting Astronomical Observatory (OAO) opportunities for important new research involving the visual and UV bands will soon be presented.

The ORL Astronomy/Astrophysics experiment program will follow up and expand the OAO experience. With its large payload capacity, the ORL will be able to make simultaneous observations in many spectral bands; by correlating these observations, the astronomer will better understand cosmic processes and their underlying laws. With their increased resolving power, the ORL instruments will allow the astronomer to discern fine surface features of planets and to separate closely packed star fields in distant clusters.

In addition to addressing fundamental scientific questions of immediate concern to the astronomical community, the initial phases of ORL experimentation will also contribute to the development of very large (greater than 100-inch telescope) space observatories. ORL experience will accelerate the solution of the multitude of difficult engineering problems associated with very large observatories and will pinpoint man's role in such systems.

3.2 Bioscience

This S/T area* is concerned with the origin and nature of life and seeks to enlighten fundamental questions regarding its evolution, function, and response:

a. How did life originate and evolve?
b. What affects the vital processes of living organisms?
c. What is the mechanism of the responses of living organisms?

These questions have immense significance to mankind not only because of their scientific and philosophical impact, but also because of the possibility that their answers may enable man to gain a measure of control of heredity, growth, and development.

Ground-based research has revealed abnormal effects in the shape and growth of living organisms exposed to artificially-produced increased gravity. Theory suggests that abnormal biological processes will also occur in the absence of gravity. Similarly, absence of normal earth periodicities and differences in environment brought about by the absence of the shielding atmosphere are expected to affect biological processes. The limited space experience obtained to date confirms some of these effects; the Russians, for example, have reported that cell division proceeds faster in space than on the ground. Additional experiments in space are needed to gather further proof of these suppositions.

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* Search for extraterrestrial life is included in the Astronomy/Astrophysics S/T area inasmuch as the largest part of the exobiology experiments which can be accomplished in ORL will employ remote-sensing, astronomical instruments. Other aspects of exobiology which depend upon *in situ* observations are included in the Bioscience S/T area.

* The scope of the ORL Bioscience S/T area is somewhat different from that of the NASA Bioscience program. For purposes of logical development of earth-orbital experiments, the Bioscience S/T area covers only the purely scientific aspects; its analysis yields experiments aimed at obtaining crucial pieces of fundamental knowledge. Other application-oriented bioscience experiments that directly support space operations are included within and are derived by analysis of the Support for Space Operations group of S/T areas. Thus, for example, bioscience experiments that seek to clarify man's physiological response to weightlessness stem from analysis of the Biomedical/Behavioral S/T area. Similarly, the need for biotechnology experiments, such as qualifying advanced life support systems, derive from the Operations Techniques and Advanced Missions Spacecraft Subsystems S/T area.

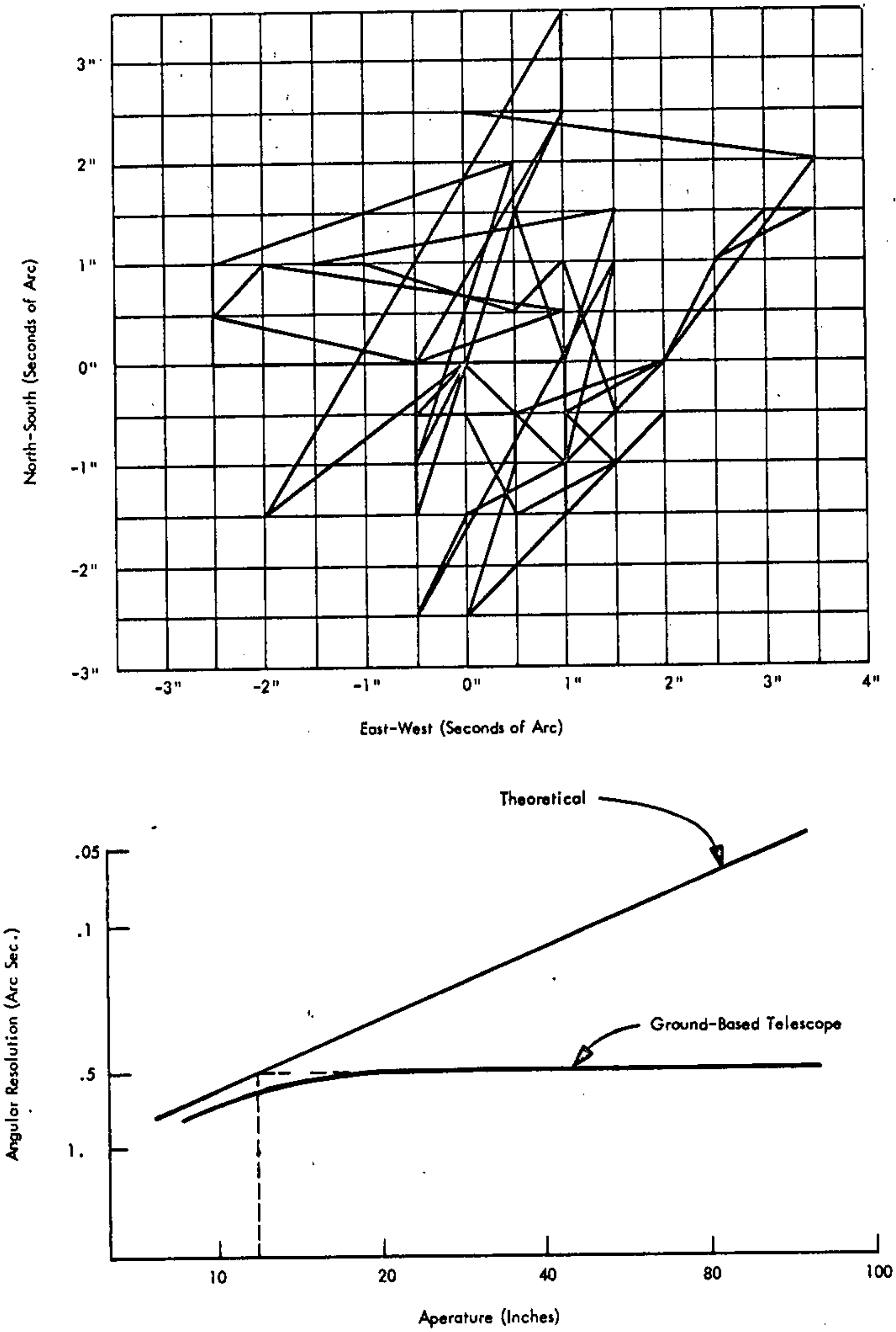

Fig. 14. Effect of Atmosphere in Limiting Ground-Based Observations. Turbulence of the atmosphere varies the apparent brightness of objects and distorts their apparent bearing. The first effect is called image scintillation; the second, image "dance". Fig. 14a shows the variation in apparent angle of Capella during two seconds of time; each point represents an increment of 1/32 second in time. (From "On the Effects of Image Motion on the Accuracy of Measurement of a Flashing Satellite," J. Allen Hynek, Smithsonian Institution Astrophysical Observatory, February 1960.) Fig. 14b shows the effect of image "dance" in limiting resolution. The upper curve represents the theoretical angular resolution achievable in the absence of atmosphere. The lower curve represents the actual performance of ground-based telescopes. The 200" telescope at Mt. Palomar has a theoretical resolution of 0.03 arc sec. In practice the attainable resolution seldom exceeds 0.5 arc sec., equivalent to a 12" telescope operating in space.

The ORL affords a unique opportunity to expand on the biological space research conducted by unmanned satellites. For example, the search for extraterrestrial life can be supported by experimentation *in situ* to establish whether microorganisms or remnants of living matter exist in near-earth orbit. For all areas of bioscience research, the ability of an on-board scientist to manipulate preparations, to fix specimens, to alter procedures, to select data to be recorded, and to observe experiments at first hand to uncover unsuspected effects will enable a range of experiments beyond the capability of automated satellites.

3.3 Physical Sciences

This S/T area encompasses two categories of experimentation: (1) experiments of a fundamental nature, which complement the Astronomy/Astrophysics and Bioscience S/T areas in advancing knowledge of matter and energy and their relationship, and (2) investigations of the properties of the earth-orbital environment.

Fundamental experimentation takes advantage of weightlessness and space vacuum to overcome the masking effects of normal earth conditions. Subtle instrumentation errors due to friction and unbalance can be eliminated, and ultra-precise measurements can be made that are not achievable on earth. For example, precise measurements of torque-free gyroscope precession can help verify the general theory of relativity. Moreover, by varying gravity forces at will, down to zero, the effects of gravity on such complex phenomena as thermodynamic change of state and processes of fluid mechanics can be assessed.

Investigations of the earth-orbital environment are concerned with—

a. Composition, density, and dynamics of the neutral atmosphere and the geomagnetic field
b. Nature of impinging particulate and electromagnetic radiation of solar and galactic origin
c. Interaction of particulate/electromagnetic radiation with neutral atmosphere and geomagnetic field.

A particularly promising experimental technique would use a maneuverable subsatellite launched from the ORL to investigate such phenomena as the propagation of hydromagnetic waves. With its large payload capacity and the opportunity to involve an on-board experimenter, the ORL can supplement space physics research performed by unmanned satellites by making practical many experiments that are too complex to be fully automated.

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

HYDROLOGIC INVESTIGATIONS
ATLAS HA-218

FRESH-WATER SPRINGS OF HAWAII FROM INFRARED IMAGES

INTRODUCTION

The discharge of water from the island of Hawaii into the sea consists of ground-water flow at sea level from rock along the shore, flow in perennial streams, and occasional flow in ephemeral streams. From Hilo (pl. 1) clockwise around the island to the vicinity of Kawaihae, virtually all the discharge is ground-water flow at sea level. Around the rest of the island, the discharge is partly ground-water flow and partly streamflow. Perennial streams enter the sea from Kohala Mountains along the stretch of shore between Pololu Stream and Waipio Bay and from the northeastern slope of Mauna Kea between Laupahoehoe and Hilo.

Most of the discharge of ground water at sea level is diffused along rocky shores exposed to the waves; consequently, the flow can be measured at only a few places and many springs have gone unrecognized. Measurements indicated that the ocean waters surrounding the island are commonly warmer than the ground water discharging into them, thus suggesting that spring discharges might be located by observation of thermal patterns in the nearshore waters.

In an effort to gain further information on the location and flow of these springs, infrared images showing the distribution of apparent temperatures in the waters surrounding the island were obtained in January and February 1963 (Fischer, et al, 1964). These images, in the form of positive prints from negatives produced with electro-optional scanning radiometers (Harris, D. E., and Woodbridge, C. L., 1964), show differences in apparent temperatures as distinctions in shades of gray; relatively warm objects are recorded with lighter shades of gray than relatively cool objects. Figure 26B is a representative example of one of the images.

The infrared images, obtained in the course of these investigations, do show numerous features that contrast in apparent temperature with the surrounding ocean (fig. 26B). The pattern of these features and their thermal contrast with adjacent ocean waters suggest that they result from the spring discharge of fresh, relatively cool or relatively warm ground water into the ocean.

DATA GATHERED

Airborne data.—Aerial infrared imagery (recording energy in the part of the electromagnetic spectrum) between 4.5 and 5.5 microns and conventional aerial photographs were taken of nearly all coastline of the island. Areas imaged are shown on pl. 1. More than half the coastline was imaged more than once. Most flights were made during daylight hours.

Surface temperature measurements.—Measurements of the temperature of sea water were made throughout the period of investigation, principally in the vicinity of Hilo, Kalapana, and Punaluu. The maximum ocean temperature recorded was 28.5°C, the minimum 21°C, and the mean 23.1°C. The temperature of water pumped from wells near Kona ranged from 18° to 22°C. Temperature measurements made in caverns on the east flank of Kilauea suggest that these caverns, and the water that percolates through them, have a relatively constant temperature of approximately 16°C.

Ground-water discharge and its relation to thermal anomalies.—The average rainfall on the island of Hawaii amounts to more than 10 billion gallons of water per day, of which a substantial part discharges as perennial ground-water flow at the shore. The ground-water flow would be expected to be greatest along the shore of island sectors where rainfall is heavy. This pattern is illustrated to some degree by the number, size, and density contrast of the anomalies outlined on figures 1-26A and 27-29. These figures are ordinary aerial photographs rather than infrared images. Loss in clarity that occurs in halftone printing made it impractical to reproduce most of the infrared images, though figure 26B, in which the tonal contrasts are most distinct, is included as an example.

The most striking sector of apparently large discharge is the Hilo area (figs. 26A, 26B, and 27), where the mean annual rainfall is 100 to 200 inches. Large ground-water flows have been observed and measured along the Hilo coast. These measurements confirm the large discharges suggested by the anomalies on the infrared images. The greatest ground-water discharge in the Hilo area is at the outlet of Waiakea Pond into Hilo Bay (spring 165, figs. 26A and 26B). Waiakea Pond is estuarine, and the flow fluctuates with the tide and includes varying amounts of sea water. A series of measurements made during a 27-hour period in June 1930 showed an average discharge from the pond of 146 mgd (million gallons per day). In a series of 16 measurements made between November 1959 and May 1960, the flow varied between 120 and 238 mgd and averaged about 160 mgd. The flow is estimated to be at least two-thirds fresh ground water that issues from lava flows at the bottom and around the shore of Waiakea Pond.

A large ground-water discharge is visible at the head of Reeds Bay just east of Hilo Bay (spring 170, figs. 26A and 26B). The flow is difficult to measure by conventional methods but has been estimated to be 10 to 20 mgd.

In the Kau area, measurements of a part of the discharge have been made at Ninole and Kawaa Springs. The measurable flow at Ninole Springs (spring 61, fig. 7) was about 27 mgd in July 1961 and about 29 mgd in September 1963. The flow at Kawaa Springs (spring 64, fig. 7), a mile southwest of Ninole Springs, was about 13 mgd in October 1963. Unknown amounts flowed into the sea outside the measureable sections at both springs.

A contrasting sector of low discharge is the western shore of the island, covered by figures 20, 21, and 22, where the annual rainfall in the tributary area is generally less than 50 inches. Density anomalies in the infrared images here are few and scattered, are small in area, and have a relatively low contrast.

Areas of thermal anomaly suggesting discharge of water warmer than the ambient sea are numerous along the southeastern shore of the island (figs.. 1, 2, 4, 5, and 6). These anomalies can be attributed to the heating of ground water by volcanic activity. The cause of warm spots along the Kona coast (figs. 15 and 16), however, cannot be explained by information now available.

METHODS OF STUDY

Measurements of image tone (apparent temperature).—Positive transparencies of the infrared images were scanned to locate all nearshore areas having apparent thermal contrast with the image tone of the open sea. Images including thermal anomalies were compared with correlated conventional aerial photographs to identify and eliminate from further consideration those anomalies which clearly correspond to partially submerged rocks or surf. The contrast in film density between ambient ocean water and apparent nearshore thermal contrasts was measured with a MacBeth-Ansco densitometer. Density contrast is expressed, on figures 1-26A and 27-29 and in table 1, by a number which represents the maximum relative difference in film density between the anomaly and the ambient ocean water. The thermal contrast of warm anomalies is shown as a negative number. Where the area was imaged more than once, the image showing the maximum thermal contrast was used for this measurement.

Measurement of size of anomalies.—Contrast in film density between thermal anomalies and the ambient ocean seemingly relates to the temperature contrast between them. The areal extent of some anomalies on the imagery, however, is smaller than the minimum area that can be measured with the densitometer; thus, this measurement may not provide a reliable estimate of the thermal contrast of the smaller anomalies. Nevertheless, if one assumes that the temperatures of the smaller springs are relatively uniform, this measurement may serve to assist in estimating the relative flow of the springs causing the smaller anomalies.

The size of each of the thermal anomalies, as shown on figures 1-26A and 27-29 and in table 1, is considered to relate, in part at least, to the rate of flow of the springs. This size was determined by a combination of densitometer measurement and visual inspection. The outlines of the anomalies, shown on figures 1-26A and 27-29, represent the edges of detectable tone contrasts. Where multiple images were available, the image showing the maximum areal extent of the anomaly was used to derive the outline.

Differences between massive images of the same area may relate to changes in sea condition or tidal stage, but they may be due also to differences in gain settings of the infrared equipment (gain settings must be adjusted in flight to accommodate varying levels of energy emitted from the earth).

REFERENCES

Fischer, W. A., Moxham, R. M., Polcyn, F., and Landis, G. H., 1964, Infrared surveys of Hawaiian volcanoes: Science, vol. 146, no. 3645, p. 733-742.

Harris, D. E., and Woodbridge, C. L., 1964, Terrain mapping by use of infrared radiation: Photogramm. Eng., 30, no. 1, p. 134-139.

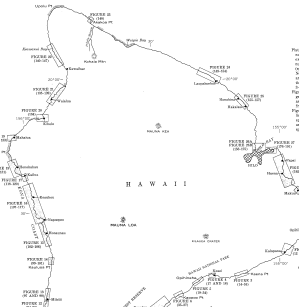

PLATE 1.— *Location map of spring areas*

EXPLANATION

☐ Outline of figure coverage

▨ Coastal springs area not imaged

ILLUSTRATIONS

Plate 1. Index map of the island of Hawaii. Figure numbers and brackets show location and areal extent of aerial-photograph mosaics (figs. 3-29); numerals in parentheses identify thermal anomalies (springs) located from infrared images; anomaly No. 1 is south of Kumukahi Point; other anomalies are numbered consecutively in a clockwise direction. Anomaly numbers are common to figures 3-29 and table 1.

Figures 1-26A and 27-29. Mosaics of aerial photographs showing location, film density contrast, and areal extent of thermal anomalies as interpreted from infrared images.

Figure 26B. Infrared image of a part of the coastline east of Hilo, taken at 0723, 19 February 1963; spectral region 4.5-5.5. Dark areas in the ocean are believed to represent cool water discharged by springs.

TABLE 1.—*Table showing spring number, area of thermal disturbance, and descriptive information*

[Under "Reliability", a question mark indicates doubt whether the anomaly represents a discharge of ground water. Under "Density contrast", a minus sign indicates ground water warmer than the ambient sea]

Spring No.	Reliability	Approximate area (sq. ft.)	Density contrast	Remarks	Figure
1		260,000	−0.62	Hot	1
2		30,000	.30		
3	?	30,000	.05		
4	?	10,000	.15		
5	?	10,000	.10		
6		50,000	.60		
7	?	30,000	.10		
8	?	2,000	.06		
9	?	3,000	.10		
10	?	10,000	.10		
11		130,000	−.10		
12	?	255,000	−.05	do	2
13	?	2,890,000	−.10		
14	?	10,000	.30	do	3
15	?	10,000	.30		
16	?	20,000	.30		
17	?	205,000	−.20	do	4
18	?	100,000	−.20		
19		15,000	−.20	do	5
20		15,000	−.40		
21		15,000	−.20		
22		20,000	−.30		
23		15,000	−.20		
24		25,000	−.30		
25		15,000	−.20		
26		15,000	−.30		
27		15,000	−.20		
28		20,000	−.20		
29		65,000	−.30		
30		55,000	−.30		
31		20,000	−.50		
32		30,000	−.30		
33		20,000	−.20		
34		15,000	−.20		
35	?	10,000	−.20	do	6
36	?	40,000	−.30		
37	?	30,000	−.30		
38	?	30,000	.30		7
39	?	10,000	.30		
40		15,000	.30		
41	?	30,000	.30		
42	?	100,000	.40		
43		50,000	.36		
44	?	50,000	.40		
45		30,000	.30		
46	?	25,000	.20		
47		55,000	.30		
48		15,000	.30		
49		40,000	.30		
50	?	10,000	.20		
51	?	10,000	.30		
52	?	15,000	.30		
53		30,000	.40		
54	?	30,000	.10		
55	?	10,000	.30		
56		15,000	.24		
57		80,000	.20		
58	?	160,000	.30		
59	?	10,000	.30		
60		20,000	.50		
61		80,000	1.48		
62		30,000	.70		
63	?	10,000	.20		
64	?	25,000	.34		
65	?	5,000	.20		
66	?	5,000	.20		
67	?	5,000	.20		
68	?	5,000	.20		
69	?	5,000	.20		
70	?	5,000	.20		
71	?	5,000	.20		
72	?	5,000	.20		
73	?	5,000	.20		
74	?	20,000	.20		
75	?	65,000	.10		8
76	?	60,000	.15		
77	?	30,000	.10		
78	?	15,000	.10		
79	?	10,000	.16		
80	?	10,000	.16		
81	?	10,000	.10		
82		30,000	.14		
83	?	10,000	.14		
84	?	50,000	.14		9
85	?	20,000	.14		
86	?	50,000	.14		
87	?	145,000	.05		10
88	?	15,000	.05		
89	?	35,000	.05		
90	?	110,000	.05		
91	?	115,000	.05		
92	?	215,000	.05		
93	?	100,000	.10		11
94	?	35,000	.10		12
95	?	65,000	.10		
96	?	10,000	.10		
97	?	10,000	.10		13
98	?	100,000	.30		
99	?	25,000	.10		14
100	?	10,000	.10		
101	?	80,000	.10		
102	?	90,000	−.05	Hot	15
103	?	5,000	.10		
104	?	5,000	.10		
105	?	50,000	−.05	do	
106	?	15,000	.10		
107	?	35,000	.20		16
108	?	290,000	−.25	do	
109		50,000	−.20	do	
110		250,000	−.20	do	
111	?	35,000	−0.10	Hot	16
112	?	70,000	−.05	do	
113	?	140,000	.20		
114	?	110,000	−.10	do	
115	?	110,000	−.05	do	
116	?	45,000	−.05	do	
117	?	215,000	−.05	do	
118	?	10,000	.10		17
119	?	10,000	.10		
120		665,000	.21		
121	?	25,000	.05		18
122	?	10,000	.20		
123		10,000	.38		
124		15,000	.44		
125		10,000	.44		
126		10,000	.24		
127		40,000	.24		
128		15,000	.18		
129		65,000	.10		
130		100,000	.14		
131	?	10,000	.20		
132	?	115,000	.10		19
133	?	55,000	.10		
134	?	55,000	.10		20
135	?	505,000	.20		21
136	?	200,000	.16		
137	?	305,000	.15		
138	?	2,025,000	.20		
139	?	150,000	.10		
140	?	10,000	.06		22
141	?	15,000	.06		
142	?	10,000	.06		
143	?	15,000	.06		
144	?	10,000	.06		
145	?	10,000	.06		
146	?	20,000	.06		
147	?	25,000	.06		
148		110,000	.10		23
149	?	1,010,000	.10		24
150	?	405,000	.12		
151	?	150,000	.12		
152	?	100,000	.12		
153	?	1,420,000	.30		
154	?	1,010,000	.30		
155		200,000	.10		25
156	?	200,000	.14		
157		1,420,000	.20		
158	?	2,455,000	.24		26
159	?	1,155,000	.20		
160	?	2,020,000	.30		
161		1,590,000	.38		
162	?	2,310,000	.44	Diffuse flow; difficult to determine boundaries	
163	?	5,200,000	.50		
164	?	4,765,000	.60		
165		127,940,000	.62		
166		6,790,000	.34		
167		10,540,000	.42		
168		6,790,000	.44	do	
169	?	360,000	.44		
170		30,610,000	.70	do	
171		13,000,000	.64		
172		1,820,000	.62		
173		4,455,000	.60		
174		3,180,000	.60		
175		720,000	.34		
176		11,500,000	.66	do	27
177		8,665,000	.68		
178		1,445,000	.54		
179	?	110,000	.10		
180		375,000	.54		
181		300,000	.68		
182		360,000	.68		
183		2,890,000	.40	do	
184		2,310,000	.60		
185		1,010,000	.50		
186		435,000	.38		
187		290,000	.15		
188		145,000	.15		
189		80,000	.15		
190		865,000	.40		
191		360,000	.36		
192	?	75,000	.10		28
193	?	150,000	.04		
194		100,000	.70		
195		405,000	.70		
196		365,000	.20		
197	?	150,000	.20		
198	?	150,000	.30		
199		1,115,000	.30		
200	?	75,000	.10		
201	?	80,000	.10		
202	?	202,000	.04		
203	?	405,000	.10		
204	?	810,000	.20		
205	?	250,000	.46		
206		150,000	.10		
207		100,000	.10		
208	?	50,000	.10		
209	?	100,000	.10		
210	?	210,000	.10		
211	?	500,000	.10		
212	?	200,000	.10		
213	?	150,000	.10		
214	?	150,000	.10		
215	?	160,000	.10		
216	?	405,000	.10		
217	?	100,000	.10		
218	?	72,000	.20		29
219	?	470,000	.10		

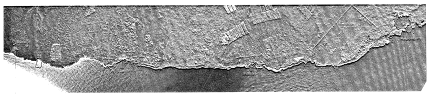
FIGURE 1
(1-11)

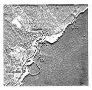

FIGURE 2
(12 AND 13)

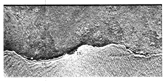

FIGURE 3
(14-16)

FIGURE 4
(17 AND 18)

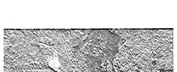

FIGURE 5
(19-34)

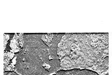
FIGURE 6
(35-37)

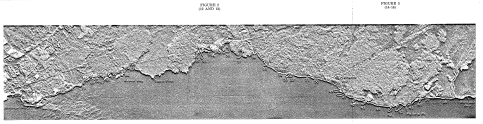

FIGURE 7
(38-74)

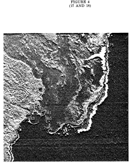
FIGURE 8
(75-83)


FIGURE 9
(84-86)

FIGURE 10
(87-92)

FIGURE 11
(93)

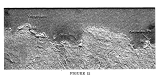

FIGURE 12
(94-96)

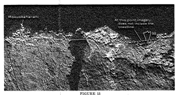

FIGURE 13
(97 AND 98)

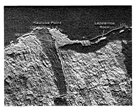

FIGURE 14
(99-101)

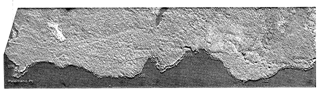
FIGURE 15
(102-106)

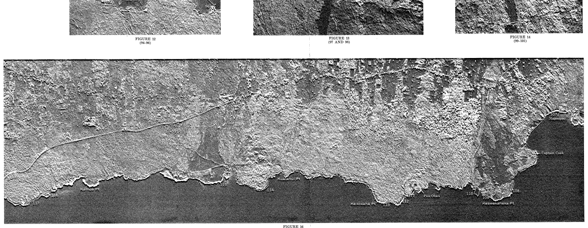
FIGURE 16
(107-117)

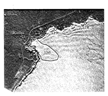
FIGURE 17
(118-120)

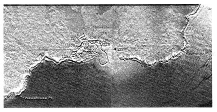
FIGURE 18
(121-131)

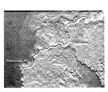
FIGURE 19
(132 AND 133)

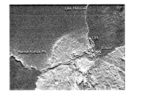
FIGURE 20
(134)

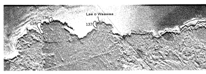

FIGURE 21
(135-139)

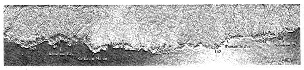
FIGURE 22
(140-147)

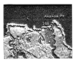
FIGURE 23
(148)

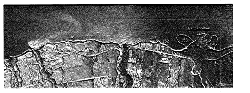
FIGURE 24
(149-154)

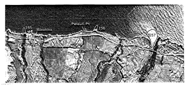
FIGURE 25
(155-157)

FIGURE 26A
(158-175)

FIGURE 27
(176-191)

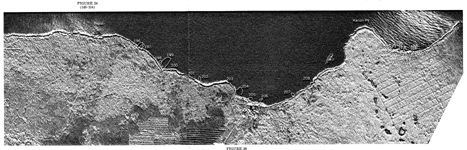

FIGURE 28
(192-217)

FIGURE 26B

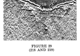

FIGURE 29
(218 AND 219)

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FRESH-WATER SPRINGS OF HAWAII FROM INFRARED IMAGES

By

William A. Fischer, Dan A. Davis, and Theresa M. Sousa

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