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Activities in Geological Remote Sensing: August 1984 - Late 1985

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by

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Introduction:

Activities in geological remote sensing from August 1984 to late 1985 included development of new sensors, acquisition of exciting new terrestrial and extraterrestrial data, holding of several symposia and workshops, publication of numerous articles and image maps, and further merging of research activities of terrestrial (continents and sea floor) and extraterrestrial remote sensing. This article describes the diverse activities in geological remote sensing; significant scientific advances are not addressed directly. For these, the reader is referred to the many publications noted which became available during the past year. The commercialization of the U.S. federally-run Landsat remote-sensing program was finally consummated during the year. The Earth Observation Satellite Company (EOSAT) was awarded the contract on 26 September for Landsat data continuity and the marketing of data. EOSAT will distribute images from the existing data base in addition to new acquisitions and will apply a commercial "confidential" classification to all Landsat data that they sell. EOSAT plans to launch Landsat 6 in 1988 and Landsat 7 in 1991 as successors to the current Landsat 4 and 5 systems. As a new start in the planetary arena, the first dedicated remote sensing satellite for Mars (the Mars Observer) was approved. It will reach Mars in 1991 and operate for 1 Martian year (687 Earth days).

New Data and Studies:

Landsat 5 continues to provide multispectral scanner (MSS) and thematic mapper (TM) data; Landsat 4 provides only MSS data. As of April 1985, the Landsat 4 and 5 TM data archive at the National Aeronautics and Space Administration (NASA) Goddard Space Flight Center contained more than 50,000 scenes. More than 6,900 TM scenes have been processed and are available from EOSAT, c/o EROS Data Center (EDC), Sioux Falls, SD.

The Space Shuttle Columbia Space Transportation System (STS) Mission 41-G, in October 1984, acquired the first high-resolution stereoscopic photographs of the Earth available to the civilian geological community. The Large Format Camera (LFC) acquired 2,160 frames during 80 data passes with black-and-white (8 to 14 m/line pair resolution), color (14 to 25 m/line pair resolution), and high-resolution color-infrared film (20 to 40 m/line pair resolution). The film format is 23 cm by 46 cm, with the long dimension in the direction of flight. The stereoscopic coverage provides varying degrees of vertical exaggeration for use in both regional geomorphic analysis and the preparation of topographic maps at scales as large as 1:50,000 and has the potential for revolutionizing studies of tectonic geomorphology in many regions. In fact, the Chinese Academy of Sciences Institute of Remote Sensing Applications has already produced a 1:80,000-scale, 50-m contour-interval topographic map of Mount Everest and environs by using LFC photographs. Microfiche and microfilm of LFC data are available from the EDC. More than 200 U.S. and foreign investigators have requested LFC photographs from the EROS Data Center.

Also on Mission 41-G, the Shuttle Imaging Radar (SIR-B) acquired less than half of the anticipated multiple-incidence-angle data because of a faulty antenna. Eight hours of optical data and eight hours of digital data, encompassing 15.5 million square kilometers, were acquired worldwide. Stereo radar of selected areas was successfully obtained (for example, Mount Shasta, CA). Coverage maps and data are available from National Space Science Data Center (NSSDC), GSFC, Greenbelt, MD.

During the reporting period, more than 18,000 photographs of the Earth have been acquired during 10 Shuttle missions by hand-held Hasselblad 70-mm-format and Linhof 100- X 130-mm-format cameras, mostly with Ektachrome film. The areal coverage and spatial resolution of the Hasselblad and Linhof photographs, taken under a variety of solar illumination conditions and viewing angles, are comparable to Landsat (MSS and TM) images and LFC photographs, respectively. All photographs are archived at EDC and are available without restriction.

New data were acquired by the NASA-funded Jet Propulsion Laboratory (JPL)-developed 128 spectral band Airborne Imaging Spectrometer (AIS), a 6 spectral band thermal-infrared multispectral scanner (TIMS), a thematic mapper simulator (Daedalus AADS 1268 MSS), and a 2 spectral band active infrared CO_2 laser absorption spectrometer (LAS). Additional high-resolution airborne spectrometric data were acquired by Geophysical Environmental Research, Inc. As more narrow-band spectral data in the visible (VIS) (0.4 to 0.7 μm); near-infrared (NIR) (0.7 to 2.5 μm), including short-wavelength infrared (SWIR) (1-2.5 μm); and mid-infrared (MIR) [2.5 to 40 μm, synonomous with thermal-IR (TIR)] regions is acquired, improved identification of specific minerals and bulk composition of geologic materials should be possible, as well as identification of changes in reflectance of vegetation related to the presence of underlying mineral deposits.

Additional airborne MSS data were acquired by using a 15 spectral band Carr Boyd Mineral, Ltd. (Australia) scanner and the Canadian Centre for Remote Sensing's (CCRS) 8 narrow spectral band imaging system, the Multispectral Electro-optical Imaging Scanner-II (MEIS-II). To date, Système Probatoire d'Observation de la Terre (SPOT) simulation data over more than 100 test sites in the U.S. were acquired by the Daedalus AADS 1268 MSS. These data, as well as 18 technical sheets and slides describing the characteristics of the SPOT system, are available from SPOT Image Corporation, Reston, VA.

The U.S. Geological Survey's (USGS) side-looking airborne radar (SLAR) program continued acquisition of X-band (3.1 cm) SLAR image and digital data to support regional geologic investigations. To date, 48 1:250,000-scale (1° x 2° quadrangle map) controlled radar image mosaics of the Appalachian region and New England, 47 1° x 2° quadrangle SLAR image maps of the North Slope and Peninsula of Alaska, and 19½ 1° x 2° quadrangle SLAR image maps of the central and western U.S. are available from the EDC. When the current acquisition of 29 additional quadrangles in the central and western U.S. is completed, radar-image mosaics will have been compiled for over 20 percent of the conterminous U.S.

The USGS-sponsored multi-federal agency National High-Altitude Photography (NHAP) program continues to acquire medium-altitude black-and-white (1:80,000-scale) and color-infrared (1:58,000-scale) aerial photographs of the conterminous U.S. The first cycle (NHAP 1), acquired during non-foliage conditions, is now 90 percent complete, with an expected completion date in 1986. The second cycle (NHAP 2), to be acquired during foliage conditions, is already underway, with 7 percent contracted for acquisition. Laser altimetry and laser-equipped airborne surveying systems, such as the Aerial Profiling of Terrain System (APTS), have produced centimeter-scale resolution of the topography of land and ocean surfaces.

The past year showed a marked increase in the amount of side-scan sonar (SSS) imagery and related data of the sea floor. The impetus for acquisition of SSS images is the increased research emphasis within the Exclusive Economic Zone (EEZ) of the U.S., in addition to mapping of submarine volcanic and tectonic features. Geologists from many institutions are now using an array of instruments for these studies, including the Sea MARC I side-looking sonar imager, which can resolve morphologic features about 3 m in size and simultaneously acquire bottom and subbottom acoustic profiles; the Sea Beam multi-narrow-beam echosounder, which produces accurate bathymetric contour maps; the Sea MARC II side-looking sonar imager, which produces both images and bathymetric contours; the GLORIA II side-scan sonar imager, which is used to produce images and image mosaics of large areas (for example, part of Gulf of Mexico in late 1985) at coarser spatial resolution (20 m) than the Sea MARC I; and a variety of photographic and video cameras designed to acquire photographs and images in the deepest parts of the oceans. The USGS has mosaicked GLORIA images of areas off the West and Gulf Coasts of the U.S., as well as around the Commonwealth of Puerto Rico and the Virgin Islands, as part of a program to prepare SSS image maps of the EEZ. Marine geologist Bob Ballard of Woods Hole Oceanographic Institution, and his French colleagues used sonar and then a video camera mounted on a towed sled (ARGO) to locate and image the wreck of the R.M.S. Titanic in 4,000 m of water in the western North Atlantic Ocean in September 1985. Once the wreck was located, he used a set of 4 cameras mounted on a towed sled (ANGUS) to acquire photographs of the wreck. In December 1985 he used the same instruments to survey 240 km of the East Pacific Rise. The ARGO/ANGUS system represents an important new capability to marine geologists for acquiring high-resolution photographs of morphologic features on the sea floor.

Geologists involved in terrestrial and extraterrestrial remote sensing are finding increasing overlaps in research interests and more opportunities for cooperative investigations. A short course, "Introduction to Planetary Geology," and a "Workshop on the Earth as a Planet," which included a session on new directions in remote sensing, were held at the Geological Society of America Annual Meeting in Orlando, Florida, in October 1985. Scheduled missions by the U.S. and the Soviet Union in the late 1980's and early 1990's to Mars, Venus, and the Moon will provide important new synoptic remote sensing data on their surface characteristics. In June 1985, the Soviet Vega Landers landed on the plains of Venus and discovered rock formations similar to basic igneous (olivine-gabbro-norite) rocks on Earth, possibly enriched in sulphur (or sulphate). A major objective of the Mars Observer Mission, scheduled for 1990-91, is the determination of the global elemental and mineralogical character of the surface as well as the planets topography and surface electrical properties. The Mars Observer will have a large array of remote sensing and other geophysical instruments, including a visual/infrared mapping spectrometer, ultraviolet imaging photometer, radar altimeter/radiometer, gamma-ray spectrometer, magnetometer, etc. The Galileo Mission to Jupiter, its moons, and the asteroid Amphitrite will be launched in 1986 by NASA. Including both an orbiter and a probe it will arrive at Jupiter in 1988. The Venus Radar Mapper will provide radar images of the Venusian surface similar to the SIR-A and SIR-B images of Earth, although spatial resolution will be 500 percent less (120-480 m pixel). It will also obtain 23-cm-wavelength microwave radiometry and 25-km-footprint altimetry with 30-m accuracy. The recently released Soviet Union Venera Orbiter 15 and 16 synthetic aperture radar (SAR) image mosaics of Venus revealed the complex volcanic-tectonic patterns of the northern highlands, many of which indicate plastic deformation and compression. Altimetry and microwave radiometry (0.5- 10-, and 15-cm wavelengths) of the Venusian surface were also acquired. The Voyager 2 spacecraft will pass by Uranus in late January 1986 on its way to a rendezvous with Neptune in August 1989. Soviet planetary exploration plans now call for a lander/remote sensing mission to one of Mars' moons, Phobos, in 1988, including a rich array of instruments (for example, deep-sounding radar, laser mass-spectrometer), as well as a 16-instrument lunar geoscience orbiter in 1989-90. Beyond these missions, the Soviets have plans for a flight to the asteroid Vesta and landings in the mountainous terrain of Venus' equatorial highlands (Aphrodite Terra) in the early 1990's.

Meetings and Publications:

The Environmental Research Institute of Michigan (ERIM) sponsored two symposia: the Fourth Thematic Conference, "Remote Sensing for Exploration Geology," in San Francisco, CA, in April 1985, and the Nineteenth International Symposium on Remote Sensing of the Environment, in Ann Arbor, MI, in October 1985. NASA and the American Society for Photogrammetry and Remote Sensing (ASPRS) (new name adopted in 1985) sponsored the Final Landsat Image Data Quality Assessment (LIDQA) Symposium "Use of Landsat 4 and 5 MSS and TM data," in conjunction with ASPRS' fall convention, September 1985, in Indianapolis, IN. The proceedings of the first LIDQA were published in the Journal of the ASPRS in September 1985 (v. 51, no. 9). The Institute of Electrical and Electronics Engineers (IEEE) International Geoscience and Remote Sensing Symposium (IGARSS '84) was held in August 1984 in Strasbourg, France. IGARSS '85 was held in October 1985 at Amherst, MA. The Ninth William T. Pecora Memorial Symposium was held in October 1984 in Sioux Falls, SD. Archibald Park of Globex was the recipient of the 1984 Pecora Award. The Tenth Pecora Symposium was held in August 1985 in Ft. Collins, CO. Charles Elachi, JPL, was the recipient of the 1985 Pecora Award for his pioneering work on SIR-A and SIR-B. The Sixth International Conference on Basement Tectonics was held in September 1985 in Los Alamos, NM. The Fifth Geosat Workshop, "Remote Sensing: Goals and Directions for Research and Development," was held in November 1985 in Flagstaff, AZ. A NASA-and International Union of the Geological Sciences-sponsored Workshop on Global Mega-Geomorphology was held in Oracle, AZ, in January 1985. Thirty U.S. and foreign geomorphologists discussed the use of satellite imagery of the Earth for regional and global geomorphological and comparative planetary studies. R.S. Hayden edited the proceedings of the workshop, available as NASA Conference Publication 2312. Ten of the workshop participants are also collaborating on a NASA Special Publication, "Geomorphology from Space: A Global Overview of Regional Landforms." NASA's Earth Science and Applications Division sponsored several workshops in 1985, including the workshop "Geologic Applications of Remote Sensing to the Study of Sedimentary Basins" in Lakewood, CO, in January; the workshop "Geologic Applications of Remote Sensing to the Study of Ophiolites and Ultramafic Terrains" in Washington, D.C., in March; the "Airborne Imaging Spectrometer (AIS) Data Analysis Workshop" in Pasadena, CA in April; and the "Thermal Infrared Multispectral Scanner (TIMS) Users Workshop" in Bay St. Louis, MS, in June.

A number of publications and image maps were published during the past year. Text books include "Image Processing of Geological Data" by Andre Fabbri (Van Nostrand Reinhold), "Photometry and Polarization in Remote Sensing" by W.G. Egan (Elsevier), "Laser Remote Sensing, Fundamentals and Applications" by R.M. Measures (John Wiley and Sons), "Remote Sensing in Civil Engineering," T.J.M. Kennic and M.C. Matthews, eds. (John Wiley and Sons), the 4th edition of "Interpretation of Aerial Photographs" by T.E. Avery and G.L. Berlin (Burgess Publishing Co.), and "Satellite Microwave Remote Sensing" edited by T.D. Allan (Ellis Horwood Limited). "Remote Sensing for Geological Mapping," edited by Paul

D. Teleki and C.C. Weber, International Union of Geologic Sciences (IUGS) Publication 18, was also released. "Frontiers for Geological Remote Sensing from Space", edited by F.B. Henderson III and B.N. Rock, is the report of the Fourth Geosat Workshop. The Committee on Space Research (COSPAR) published "Advances in Space Research," the Proceedings of the XXVth Meeting, Graz, Austria (Pergamon Press), which includes "Remote Sensing from Satellites," vol. 4, no. 11, edited by W.D. Carter and E.T. Engman. The long awaited Joint NASA/Geosat Test Case Project Final Report, edited by M.A. Abrams, J.E. Conel, and H.R. Lang, was published by the American Association of Petroleum Geologists in October 1985 as two volumes and an executive summary. It contains comprehensive analyses of remotely sensed data of 8 test sites containing known deposits of petroleum, porphyry copper, and uranium. As a follow-on to the NASA/Geosat Test Case Project, the Geosat Committee has created a subcommittee to evaluate Thematic Mapper (TM) data of the original 8 test sites. Modular Opto-electronic Multispectral Scanner (MOMS) data will also be evaluated for 14 test sites. In November 1985, the National Geographic Society released its "North American Atlas: Space Age Portrait of a Continent." "Images of Earth" by Peter Francis and Pat Jones (Prentice-Hall) was also released. "Remote Sensing, A Geophysical Perspective" by Ken Watson appeared in the 50th Anniversary issue of the Society of Exploration Geophysicists (SEG) in late 1985. NASA publications for the year included "Proceedings of the Airborne Imaging Spectrometer Data Analysis Workshop, April 8, 9, 10, 1985" (JPL 85-41); "Imaging Spectrometry: The Next Step in Remote Sensing" (JPL 400-243); "The Geology of the Terrestrial Planets" (NASA SP-469); "Planetary Geology in the 1980's" (NASA SP-467); "Planetary Cartography in the Next Decade (1984-1994)" (NASA SP-475); "The Earth Observing System, Science and Mission Requirements, Working Group Report," Volume 1, Parts 1 and 2 (NASA Technical Memorandum 86129); and "Report of the Workshop on Geologic Applications of Remote Sensing to the Study of Sedimentary Basins" (JPL 85-44). The National Oceanic and Atmospheric Administration's (NOAA) National Environmental Satellite, Data, and Information Service (NESDIS) released NOAA Technical Report NESDIS 19, "The Space Station Polar Platform: Integrating Research and Operational Missions." Symposium proceedings which were published include ERIM's Third Thematic Conference, "Remote Sensing for Exploration Geology," Colorado Springs, CO; IGARSS '84, Strasbourg, France; and IGARSS '85, Amherst, MA. The proceedings of the 1984 SPOT symposium, "SPOT Simulation Applications Handbook," and a special issue on results of analyses of SPOT simulation data (ASPRS-Journal, September 1985, v. 51, no. 8) were published by ASPRS. Publications dealing with remotely sensed data bases include USGS Bulletin 1631, "Characteristics and Availability of Data From Earth Imaging Satellites" by C.S. Southworth; "Catalog of Space Shuttle Earth Observations Hand-Held Photography, (STS) 41-G Mission" from the Johnson Space Center (JSC-20639); "MOMS-01 Experimental Missions on Space Shuttle Flights STS-11 (41-B) Data Catalog" from the German Aerospace Research and Test Institute (Deutsche Forschungs und Versuchsanstalt für Luft-und Raumfahrt or DFVLR); Proceedings of the Metric Camera Workshop from DFVLR and European Space Agency (ESA SP-209); "Looking Down. Looking Forward (Earth Observation - Sciences and Applications - A Perspective)" (ESA SP-1073); and a Landsat "user" poster published by NOAA.

The USGS published several unique image maps of interest to geologists during the past year. A 1:125,000-scale TM image map of Great Salt Lake and vicinity, Utah, acquired when the water in the lake was at its highest level in 107 years, includes water-level contours, and cultural and geodetic data. A 1:50,000-scale image map of Salt Lake City and Ogden, Utah, was produced by integrating TM imagery and LFC photography. An innovative, color "Geologic Map of Cape Cod and the

Islands, Massachusetts," by Robert N. Oldale and Roger A. Barlow (I-1763) delineates 36 geologic units on a 1:100,000-scale Landsat 3 return beam vidicon (RBV) image base. Twelve SLAR-image maps of the Aleutians were printed with the corresponding topographic map on the reverse side. Lithographic copies of the radar-image mosaics of the Tonopah, NV, and Harrisburg, PA, $1^{o}x2^{o}$ quadrangles were also published. "Ugashik, Alaska, Side-Looking Airborne Radar (SLAR) Image Map Set" is a training set consisting of 7 sheets of image maps, image mosaics, stereo image strips, and explanatory text. An experimental image map of the Central Appalachian region was produced by optically merging SLAR imagery and a geologic map. Also in progress by the USGS is planimetric mapping of Antarctica with digitally enhanced Landsat MSS images. These enhanced images show exceptionally well-defined, never-before-observed glaciological features on glaciers, ice streams, and ice shelves. An image mapping program initiated by the USGS resulted in the production of 1:250,000-scale Landsat MSS image maps of Tonopah and Goldfield, NV. Landsat TM image maps at 1:100,000-scale were produced of the following 9 quadrangles: Kansas City and Olathe, KS; Richmond and Roanoke, VA; Mariposa and Needles, CA; Cactus Flat and Pahute Mesa, NV; and Denali National Park, AK.

Future systems:

The launch of the French satellite SPOT in late 1985 will make 10-m pixel resolution digital image data available, including some limited stereoscopic coverage. Future SPOT 2, 3 and 4 satellites, which will provide SPOT data continuity through 1998, are currently under study. Eighteen percent of the SPOT assessment program is devoted to geologic research. In 1987, the LFC and SIR-B' are expected to be payloads on the first civil polar-orbiting shuttle mission. Canada's Radarsat, a C-band (10-cm) radar designed to provide worldwide stereoscopic coverage, is planned for a shuttle launch in 1990. NASA is also developing several important sensors for deployment in the late 1980's and 1990's. The sensors of immediate interest to geoscientists include the shuttle thermal-infrared multispectral scanner (STIMS), the airborne visible/infrared imaging spectrometer (AVIRIS), the shuttle imaging spectrometer experiment (SISEX), a high-resolution imaging spectrometer (HIRIS), and a laser atmospheric sounder and altimeter (LASA). STIMS will provide spectral data sensitive to Si-O minerals while AVIRIS, SISEX, and HIRIS will provide spectral data sensitive to Fe^{3+} Nd^{3+} CO_3, Al-OH, OH, CO_3 and Mg-OH. The European Space Agency plans to launch ERS-1 in the late 1980's. Among the instruments it will carry of interest to geologists are a SAR and a radar altimeter, specially designed to acquire image and elevation data over land areas. Also, by the late 1980's, the U.S. global positioning satellite (GPS) system will become fully operational. Field measurements of geographic position and elevation, with accuracies of a few centimeters, will become routine with the GPS system, offering an important new source of data to geologists involved in studies of crustal deformation and geomorphology.

NASA's Earth Observing System (EOS) Science and Mission Requirements Working Group identified concepts for an Earth Observing System on a polar platform of a space station slated for the 1990's. Two out of three EOS instrument packages are of interest to geologists: 1) Surface Imaging and Sounding Package (SISP), which includes imaging spectrometers, a multifrequency microwave radiometer, and a LASA and 2) Sensing with Active Microwaves (SAM), which includes a SAR, a radar altimeter (ALT), and a radar scatterometer (SCAT). The improved sensor capabilities afforded by the EOS instrument packages, if implemented in the proposed information system network, will allow increased understanding of global geologic processes. The NASA/Lunar and Planetary Institute (LPI)-sponsored Geology Working Group of the Earth Systems Science Committee's (ESSC) draft report on Continents from Space is an exceptionally fine review of the expected future direction of geological remote sensing as evaluated by 23 geologists under the direction of Kevin Burke (LPI). Among the topics addressed were remote sensing and tectonics, remote sensing and climatic variation, remote sensing in monitoring geological processes, practical applications of remote sensing, global change in the geological environment, geobotanical goals, and remote sensing requirements for rock and mineral discrimination and for structural and morphological observations from space. The Geology Working Group specifically recommended high-resolution stereoscopic images, MSS and spectroscopic systems which permit identification of minerals from space, space-borne SAR and photographic cameras, global topographic mapping, and development of co-registration of digital data sets to fulfill 3 broad goals for studying global geology by observation and measurements made from space. The 3 goals are 1) to understand the origin and evolution of continents, 2) to obtain geological data of direct practical benefit, and 3) to monitor processes responsible for global change. These goals echo the three objectives of the National Academy of Sciences' "A Strategy for Earth science from space in the 1980's; Part 1: Solid Earth and Oceans."

Progress continues in co-registration and geometric projections of already existing geological, geophysical, and geochemical data bases, and, in conjunction with global data bases such as PETROS (rock chemistry), national uranium resource evaluation (NURE), Magsat, etc.. Multiparameter intercomparisons of data for many regions on Earth and other planets and moons can now be accomplished from such data bases. Such approaches require access to micro- and mini-computers, now becoming more widely available. The possibilities for adopting digital-optical disks as a (write-once) high-density recording media (540 megabytes per disk) are now real and will lead to greater use and dissemination of digital remote sensing data in the next few years, if the cost of such data for research purposes is affordable.