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NSG 5014

An investigation of Vegetation and Other Earth Resource/Feature Parameters Using Landsat and Other Remote Sensing Data

A. Landsat

B. Remote Sensing of Volcanic Emissions

Semi-Annual Status Report (#11)

July 1 to Dec. 31, 1979

Dartmouth College

Hanover, NH 03755

Principal Investigators:

Richard W. Birnie

Richard E. Stoiber

Researchers:

Emily Bryant

A.G. Dodge, Ken Sutherland (UNH)

Joseph Francica

Lawrence Malinconico

Student Assistants

(E80-10158) AN INVESTIGATION OF VEGETATION AND OTHER EARTH RESOURCE/FEATURE PARAMETERS USING LANDSAT AND OTHER REMOTE SENSING DATA. A: LANDSAT. B: REMOTE SENSING OF VOLCANIC EMISSIONS Semiannual Status (Dartmouth

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Dartmouth College

Semi-Annual Status Report - NSG 5014 - Dec. 31, 1979

This report covers activities of the Landsat Sensing Research Group (Earth Resources) and of the Volcanic Gas Sensing Research Group (Planetary Science) which work in collaboration with the Goddard Institute for Space Studies, New York; Dr. Robert Jastrow, Director. Dr. Stephen Ungar of GISS is the Technical Officer for this project.

A. Landsat

The Dartmouth Landsat Research Group continued application studies for Landsat data under the general category of analysis of vegetation cover, especially forestry and geobotany, that is, the effects of soil/earth mineral content on vegetation.

1. Agricultural Crop Studies. No research activities in period. (No funds allocated).

2. Forestry (Emily Bryant). This work includes the effort of Ms. Bryant and her student assistants, in collaboration with A.G. Dodge, Area Forester, Cooperative Extension Service, University of New Hampshire, and Ken Sutherland, Assistant County Forester with the Grafton County Extension Service, whose services are furnished under a task order to UNH by Dartmouth.

2a. Research. This half year had three general emphases: continued investigation into signature extension techniques, forestry applications of current mapping capabilities, and development of new programs and skills to be incorporated into our forest mapping projects.

1. Signature extension. (Formerly called "fudge factor".)

Chris Harris, an undergraduate assistant, worked on extending the signatures used in Coos County from one Landsat orbit to the adjacent one. Results from Androscoggin County, Maine were compared with Forest Service forest type acreage estimates, and were not in close agreement. This could be due to discrepancies in forest type definitions and/or to less than adequate signature extension techniques.

We also applied the signature extension technique to mapping the town of Madison, N.H. in 1973 and 1978. Acreages by type were not very close, but qualitative changes (forest harvests, increase in size of gravel pit) could be located.

The area covered by the 7 1/2 minute Concord, N.H. U.S.G.S. quadrangle map was classified in 1973 and 1978 using signature extension. We found that an increase from 8 to 50 or 75 in the number of training sites used to estimate the correction needed between passes improved the consistency of the categories from one pass to the other. Perhaps such a change would improve results for the Madison and Androscoggin County projects mentioned above.

2. Applications of mapping capabilities.

Amy Haak and Caroline Stoops, undergraduate assistants for the fall term, made classifications with 1973 and 1978 Landsat data of the part of the White Mountain National Forest which is in N.H. This is an area of about 800,000 acres. The purpose was to demonstrate Landsat mapping capabilities to managers of the WMNF and to get their reactions on the practicality of using Landsat as one source of information for their inventory needs. Only the area within the WMNF boundaries was classified; this was also segmented to correspond with the 15 minute U.S.G.S. quadrangle sheets. A general cost estimate (including human and computer time, excluding cost of developing signatures) is 0.8 cents per acre. This will be presented to WMNF managers in February.

We made a preliminary product for use by NH Forest Fire Service personnel: a Landsat classification map of the area covered by the Rumney, N.H. 15 minute quad. It was reduced to the 1"=1 mile scale photographically. Similar products will be tested in the field this summer. David Crampton, undergraduate asistant, is putting the finishing touches on this.

Ken Sutherland worked on producing an acceptable map for Groveton Papers Company of one of their tracts of land, and it is almost complete. This involves superimposing compartment boundaries and roads on the Landsat printout using the line program which was recently released by GISS.

3. Development of new programs and skills.

We have begun to familiarize ourselves with the operation of "Wylbur", an interactive remote job entry system that allows us to edit and enter jobs through the Decwriter rather than the card reader.

Elizabeth at GISS wrote the "line program" for us, which allows us to superimpose linear features (such as property boundaries and streams) on the Landsat printout. Thus features which can be distingished only from auxiliary sources can be combined with Landsat data on one printout. The program also includes such niceties as a legend and extra overprint characters. Although these may seem like luxury items to researchers, we believe they will prove to be almost essential to potential data users.

A program called REGISTER was written on the DTSS system. Given pixel coordinates of a ground feature on one Landsat pass, it will calculate them for another pass. The user must first indicate the coordinates of three ground control points for both passes. It has been tested on a limited area, and looks as if it will speed up and make more accurate future efforts to register Landsat data.

4. Pine vs. Spruce distinction. (A small effort). Carl Henderson, undergraduate assistant in the summer term, worked on discrimination of pine-hemlock and spruce-fir forest types using Landsat data from June, 1978 and August, 1976. Single-pass data in both cases still showed confusion between mixed spruce-fir-hardwood and pine-hemlock type. Multitemporal classification is the next step in this investigation.

2b. Spreading the Word.

We have attended several meetings, visited other researchers, and had contact with GISS and with some New Hampshire and Maine state agencies.

In July, Ken and Em visited Gary Smith at the University of Vermont, and saw that their Landsat project is moving into operational status.

In August, the three of us went to GISS to catch up on work being done there, and to express our desires for the line program.

In August, also, Ruth Whitman, Steve Ungar, and Sam Goward visited Dartmouth. We gave them summaries of our current projects.

Ken, Em, and Gibb attended the annual meeting of the Remote Sensing Group of Northern New England in September, and put up the poster which had been presented this spring at the ERIM conference.

Ken and Em attended the first ERRSAC conference in Maryland, in October, and gave a short talk on Landsat Forestry Applications in New Hampshire. Proceedings of the conference will include a write-up of this. While there, we established contacts with the New Hampshire Fish and Game Department and Office of Comprehensive Planning and some Maine state agency representatives.

Jim Connors of the Maine Land Use Regulatory Commission invited Ken and Em to talk about Landsat applications results at the semi-annual November meeting of the Remote Sensing Interest Group in Augusta, Maine. Representatives of various Maine state and private organizations were present.

Em gave a lecture on Landsat digital data to Dave Lindgren's remote sensing class (Geography Department) in November. Also in November, Ken, Gibb, and Em met with Kurt Olson, Paul Bruns, and John Szajgin, who have a remote sensing project at the University of New Hampshire. Their classification program is being used on a test area of digitized U-2 imagery, but will also be compatible with Landsat data. They are expecting to set up another classification system with the aid of ERRSAC.

Ken, Gibb, and Em were present at the Workshop on Remote Sensing - Application for New Hampshire, sponsored by the New Hampshire State Office of Comprehensive Planning, in early December. Em and Ken gave a talk on our Landsat aplications in NH and Maine. Gibb lead a wrap-up session.

We started a monthly meeting, formed to give remote sensors associated with the Dartmouth NASA Grant a chance to keep up with each others' work and to exchange ideas.

3. Land Use. No research activities in period. (No funds allocated).

4. Water Quality. No research activities in period. (No funds allocated).

5. Mineral Resources. Work under this heading is undertaken by Prof. Birnie with Graduate Student Joseph Francica, and student assistants.

A. Research.

1. The Mesatchee Creek Prospect experiment has been completed, written up, and submitted to Economic Geology (Abstract, Enclosure #2).

2. Prof. Birnie and Francica presented a paper describing the Mesatchee Creek Prospect experiment at the annual meeting of the Geological Society of America, San Diego, Nov. 1979. (Enclosure #3).

3. Prof. Birnie was invited to present a lecture on Remote Sensing of Geobotanical Anomalies for Mineral Exploration at the October meeting of the Maine Mineral Resources Association in Bangor, Maine. At this time, Birnie had discussions with several groups working in mineral exploration in northern Maine to set up aircraft experiments for the summer of 1980.

4. Prof. Birnie, in conjunction with Adjunct Prof. Posmentier, has undertaken a study of the Lower Hudson River Estuary using

Landsat digital data. Lateral spectral contrasts are clearly distinguished on the Landsat data and these contrasts can be exploited for circulation and hydrologic mapping. This work will be reported at the 14th International Symposium on Remote Sensing of Environment, April 1980, San Jose, Costa Rica. (Abstract Enclosure #4).

5. The final write-up on the Landsat work done by Prof. Birnie and former grad. student Dykstra has been published in the American Assoc. of Petroleum Geologists Bulletin. (Abstract Enclosure #5).

6. Research by Graduate Student Francica in July and August consisted of generating a base geologic classification map of the Indus Suture zone in the Ladakh Himalaya. Several new techniques, such as band ratioing, were used in an attempt to obtain better results for my classification scheme.

In late August and September, field work was undertaken in the Ladkakh Himalaya and in Baluchistan, Pakistan, to check training areas that had been chosen before entering the field.

After the field season, work began on new data from a new LANDSAT scene acquired for the area which has proven to be quite an improvement compared with data that had been used previously.

In mid-December, the RAMTEK at Goddard (GISS) was used to obtain qualitative information regarding training area sites as well as to establish the capabilities of the RAMTEK and its application to the study of Ladakh.

A paper, discussing the results of this research, will be presented at the 14th International Symposium of the Environment sponsored by the Environmental Research Institute of Michigan to be held in San Jose, Costa Rica in April, 1980. (Abstract, Enclosure #6).

B. Remote Sensing of Volcanic Emissions

This work was undertaken by Professor R.E. Stoiber, Research Assistant Lawrence Malinconico and undergraduate student assistants.

1. Lawrence Malinconico spent the months of June, July, August, and part of September monitoring the SO_2 emissions from Kilauea Volcano. The work was partly supported by NASA. The work allowed us to produce a long-term SO_2 emission curve for a quiescent volcano. Monitoring was done 6 days a week. SO_2 averaged $160td^{-1}$ with a standard deviation of 40t.

2. Professor Stoiber used the GASPEC to measure the HCl emission from Kilauea. There was no observed HCl response in the plume and calculations based on condensate samples taken suggest that the amount of HCl is below the detectable limits of the instrument.

3. Professor Stoiber and Malinconico presented a paper at the Hawaii Symposium on Intraplate Volcanism and Submarine Volcanism, July 16-22, 1979. The title of the paper is "SO_2 Monitoring by Remote Sensing at Kilauea Volcano, Hawaii". (Abstract Enclosure #7).

4. In September, Lawrence Malinconico presented one paper and was co-author on another paper dealing with volcanic gas emissions. These papers were given at the NW regional meeting of the AGU with the Association of North American volcanologists meeting at the same time. The papers (Abstracts, Enclosures 8 and 9) were entitled "Volcanic Gas Studies in Hawaii: 1978-1979"

and "Budget of S and Cl released from shallow magma bodies at Fuego volcano, Guatemala".

5. During the fall, Professor Stoiber and Lawrence Malinconico had a paper they co-authored with William Rose accepted for inclusion in a book entitled Orogenic Andesites and Related Rocks. The paper dealt with gases from explosive volcanoes and was entitled "Eruptive gas compositions and fluxes of explosive volcanoes: problems, techniques and initial data".

6. In November the GASPEC was taken to Guatemala. This was not supported by NASA. It was important, however, because the machine apparently detected HCl in two separate eruption plumes of Santiaguito volcano. Amounts of HCl have not yet been determined, but the machine finally seems to be in good working order.

7. In December, the COSPEC was returned to Barringer Research for Tuning up. This was the first time in five years of use that it has gone back to the firm. Improvements were made on baseline drift and instrument sensitivity.

8. At the end of December, the COSPEC was sent to Denver for mounting in the NCAR aircraft in preparation for the February 1980 trip to Guatemala.

Enclosures 1-9

PROGRESS REPORT

APPLYING LANDSAT MEASUREMENTS TO
FOREST RESOURCE INVENTORIES

May 1, 1979 - October 31, 1979

Ken Sutherland and Gibb Dodge, Cooperative Extension Service, coordinated their activities with Emily Bryant, Dartmouth College, and other representatives of GISS.

Site Selection

1. Continued developing field maps of Groveton Papers (Diamond International) test compartment.

2. Assisted in developing criteria and categories for mapping White Mountain National Forest by districts.

3. Developed maps (assisted) of the towns of Rumney and Madison for use by N.H. Forest Fire Service and RC&D project assistant.

4. Took ground truth photos on White Mountain National Forest.

Guidance and Evaluation

1. Guidance to:

   a) GISS on making changes in computer programs to produce better output products (polygon, legend, scale change, line, smoothing, etc.)

   b) Dartmouth work-study students - mapping techniques and observing ground truth sites.

   c) N.H. Forest Fire Service - using computer maps as field tools.

   d) RC&D and County Extension Foresters - comparing land use change (activity) over time.

   e) Revise and update 1980 work plans.

2. Evaluation:

   a) Analyze computer outputs resulting from GISS program changes.

   b) Changes indicated on Landsat maps by comparing 1975 and 1978 data.

Collaboration

1. Serving on Cooperative Extension Service National Task Force for remote sensing - advice to Extension Committee on policy related to Extension activity in remote sensing technology transfer.

2. Update information to the University of Vermont, University of New Hampshire, Maine Forestry Planning Group, GISS, ERRSAC, GSFC, Remote Sensing Group of Northern

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New England, New Hampshire Fish and Game Department and Office of State Planning.

3. Remote sensing meetings with New Hampshire Office of State Planning, UNH, and Dartmouth.

Technology Transfer and Reporting

1. Landsat presentations to ERRSAC Conference/Workshop, Easton, Maryland and classes at Dartmouth.

2. Generate remote sensing technology to New Hampshire Fish and Game Department and Division of Forests and Lands.

Submitted by,

Arthur G. Dodge, Jr.
Program Leader

Kenneth E. Sutherland, Jr.
Program Assistant

clg

SUBMITTED TO
ECONOMIC GEOLOGY
Sept 1979

Remote Detection of Geobotanical Anomalies Related to Porphyry Copper Mineralization

by

Richard W. Birnie and
Joseph R. Francica

Dept. of Earth Sciences
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Hanover, NH 03755

August 6, 1979

Enclosure 2

ABSTRACT

Visible and near infrared (450-1000nm) reflected radiance spectra of Douglas-fir trees were measured at the Mesatchee Creek porphyry copper prospect in Washington. Analysis of the reflected radiance data indicates that the vegetation growing within the pyrite halo of the copper deposit has anomalously high reflected radiance values at 565nm and low reflected radiance values at 465nm. Six flight lines were flown on each of two days. Taking one flight line from the first day's data as the control line, individual spectra with a 565nm/465nm reflected radiance ratio value greater than 1.7 fall predominantly within the pyrite halo. When this threshold value is applied to all flight lines from the first day, 36.7% of the spectra within the pyrite halo and 5.4% of the spectra outside the pyrite halo are classified as anomalous. The zone of mineralization is clearly defined by the cluster of anomalous spectra. There is an 87% probability of an anomalous spectrum lying within the mineralized zone. The same technique was applied to the second day's data. The threshold ratio value was optimized at 1.6 and the resultant probability of an anomalous spectrum lying within the mineralized zone is then 93%. Higher cutoffs improve the probability of an anomalous spectrum falling in the mineralized zone, but fewer spectra are classified as anomalous and the extent of the mineralized zone is not as well defined. The geobotanical anomaly correlates with the pyrite halo and is not preferentially concentrated within the high

Cu soil geochemical zones. Comparison with results obtained in lodgepole pine at Heddleston, Montana show that different vegetation types manifest geobotanical anomalies in different spectral regions.

accepted for presentation Nov 8, 1979
Geol. Soc. Am. Annual Meeting San Diego

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ABSTRACT FORM

Exact format shown on instruction sheet must be followed.

REMOTE DETECTION OF GEOBOTANICAL ANOMALIES: A METHOD FOR MINERAL EXPLORATION

BIRNIE, Richard W.; FRANCICA, Joseph R. Jr.;
Dept. Earth Sciences, Dartmouth College,
Hanover, NH 03755

Visible and near infrared (450-1000nm) reflected radiance spectra of Douglas Fir trees were measured at the American River porphyry copper prospect in western Washington State. These measurements were made with an airborne spectrometer with a 18m spacial resolution and a 1.4nm spectral resolution. Analysis of the spectral data indicates that the vegetation growing within the pyrite halo of the copper deposit has anomalously high reflected radiance values at 560nm. At 460nm, the mineralized and nonmineralized spectra show no difference. Six flight lines were flown on each of two days. Taking one flight line from the first day's data as the control line, individual spectra with a 560nm/460nm reflected radiance ratio value greater than 1.7 cluster within the pyrite halo. When this threshold value is applied to all flight lines on the first day, 37% of the spectra within the pyrite halo and 5% of the spectra outside the pyrite halo are classified as anomalous. The zone of mineralization is clearly defined by the cluster of anomalous spectra. There is an 87% probability of an anomalous spectrum lying within the mineralized zone. The same technique was applied to the second day's data. The threshold was optimized at 1.6 and the resultant probability of an anomalous spectrum lying within the mineralized zone is than 93%.

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- archaeological geology
- coal geology
- X economic geology
- engineering geology
- extraterrestrial geology
- general geology
- geochemistry
- geology education
- geomorphology
- geophysics
- geoscience information
- history of geology
- hydrogeology
- marine geology
- mathematical geology
- mineralogy/crystallography
- paleontology/paleobotany
- petrology
  - experimental
  - igneous
  - metamorphic
- Precambrian geology
- Quaternary geology
- sedimentology
  - sedimentary petrology
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- OTHER

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3/79

Identification of Lateral Spectral Contrasts in the Lower Hudson River Estuary Using Landsat Digital Data

by Richard W. Birnie
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and

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A study has been made of the Landsat digital data for the Lower Hudson River Estuary (Scene E-1096-15074, Oct. 27, 1972). The study area includes the region of the Upper Bay from 6km south of the Verrazano Narrows up the river about 60km to Upper Nyack, New York.

The data show easily discernable spectral differences between east side and west side water, and these differences persist over most of the 60km stretch of the river that was studied. The western water is from 10 to 42% brighter, depending on the Landsat bands, than the eastern water. The average signature for western water is 0.439, 0.224, 0.117 and 0.115 $mW \cdot cm^{-2} \cdot sr^{-1} \cdot ch^{-1}$ for Bands 4, 5, 6, and 7 respectively; and the average signature for eastern water is 0.400, 0.196, 0.093, and 0.081 $mW \cdot cm^{-2} \cdot sr^{-1} \cdot ch^{-1}$ for Bands 4, 5, 6, and 7 respectively.

Until recently, it has been assumed that there are no lateral gradients of the water properties in the Lower Hudson Estuary. However, recent theoretical and observational evidence supports the presence of the lateral gradients that are seen in the Landsat

14th International Symposium: Remote Sensing of Environment
[illegible] April 1980, San Jose, Costa Rica
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data.

Salinity measurements have been made on the river, and these measurements indicate that there is a salinity gradient of ≈1ppt across the river with the eastern water being more saline. However, the spectral properties of four fresh water reservoirs on the western shore of the Hudson were also studied; and three of these fresh water reservoirs have spectral characteristics consistent with the more saline eastern river water. One of the reservoirs, Lake Tappan, had distinctly brighter, western water spectral characteristics. The water in the Lake Tappan reservoir was very silty because of on-going construction at the time of the Landsat overpass. It appears, therefore, that salinity is not the controlling factor in the spectral differences observed laterally across the Hudson, but that turbidity controls the spectral differences. This observation is consistent with other studies that report increased turbidity with increased reflected radiance values. It should also be noted that the lateral spectral gradient does not correlate with depth alone.

The Landsat digital data were classified according to a supervised classification scheme developed by S. Ungar at NASA's Goddard Institute for Space Studies. The classification algorithm is primarily based on direction cosines in the four dimensional Landsat color space with the user specifiying the degree to which color and brightness are to be weighted. A volume for each control area is described about the average of the four Landsat spectral bands. This volume, whose specific shape and orientation change depending on the weighting factors, is a distorted hyper-ellipsoid inscribed within a truncated cone.

Four discontiguous control areas of 36 pixels each were chosen for each of the two water types. Signatures for these two water types were calculated by averaging all 144 pixels in the 4 control areas. The brightness and color weighting factors were optimized for the two water types by studying the distribution of pixels in the Landsat color space and determining which combination most completely enclosed the pixels of one water type and excluded the pixels of the other water type. The classification was so successful that nearly all of the water in this 60km stretch of the Hudson is uniquely classified into only one category; there are very few pixels that classify in both water types, and also very few pixels that are not classified.

One area where the lateral contrast breaks down is the northern part of the Upper Bay, north to 34th Street in Manhattan. Large volumes of sewage effluent dumped into the east side of the river in this area may cause the disruption of the lateral gradient.

This analysis of the Landsat data leads us to conclude that there is a strong downstream flow on the west side of the river, and that this western water is more turbid and less saline than the eastern water. On the east side of the river, there is a weaker downstream flow with saline water making its way farther upstream on the eastern shoreline. It is clear that differences in the spectral properties of the Landsat digital data can be mapped and used as indicators of circulation and dispersion in the Hudson Estuary.

The American Association of Petroleum Geologists Bulletin
V. 63, No. 9 (September 1979), P. 1490-1503, 10 Figs., 2 Tables

Reconnaissance Geologic Mapping in Chagai Hills, Baluchistan, Pakistan, by Computer Processing of Landsat Data[1]

JON D. DYKSTRA[2] and RICHARD W. BIRNIE[3]

Abstract A Landsat spectral classification map of the Chagai Hills, Baluchistan, Pakistan, has been produced by computer processing of Landsat-1 digital data. A supervised classification algorithm was used which employed the Mahalanobis distance as a maximum-likelihood discriminant. A Landsat geologic map has been interpreted from the spectral classification by use of a set of interpretation rules specifically formulated for the Chagai Hills. The Landsat geologic map shows an overall close agreement with a photogeologic map produced by the Hunting Survey Corp. Areas of disagreement have been studied and evaluated as to the reasons for and validity of the discrepancies.

Each pixel of the Landsat data was classified as one of the preselected pixel populations which represent chosen surface types within the Chagai Hills. Pixel populations generated from the control areas of each of the mapped surface types were represented as "characteristic lines" in the Landsat four-dimensional color space. A characteristic line is defined as the line which parallels the pixel population's principal component and passes through the population's center of gravity. The characteristic lines were used to thin out surface types to which the pixel being tested could not be reasonably classified. The Mahalanobis distance classification discriminant was based on the position of a test pixel within the density distributions of the populations. The individual pixel classifications were smoothed by reclassifying the central pixel of a 3 × 3 array on the basis of the classification information contained in all nine pixels.

A discriminant similar to one of a tightly constrained parallelepiped was used to classify hydrothermal alteration. The alteration classifications were smoothed by considering only those areas where two or more pixels of a 3 × 3 array were classified as altered. Approximately 100 areas classified as hydrothermally altered were located on the Landsat geologic map. Four of these are known to be altered rock. Two of the known areas of alteration were used as control areas; the correct classification of the other two increases the confidence in the alteration classifications across the Chagai Hills.

INTRODUCTION TO GENERAL GEOLOGY

The objective of this study was to use Landsat digital data to produce a geologic map of the Chagai Hills, Baluchistan Province, Pakistan. The arid climate and rugged topography of the Chagai Hills severely restrict travel and complicate mineral exploration. The paucity of vegetation and limited access to interior regions provide opportunity for a Landsat remote-sensing study to make a valuable contribution to geologic mapping and mineral exploration programs.

The Chagai Hills are located along the Pakistan-Afghanistan border in the Baluchistan Province of Pakistan. A mosaic of six Landsat frames (Fig. 1) whose outline appears on the location map (Fig. 2) shows the Chagai Hills as an elliptical physiographic feature approximately 170 km long and 40 km wide. The average elevation is approximately 2,000 m, more than 1,000 m above base level in the Mirjawa-Dalbandin trough on the south. The Ras Koh Ranges roughly parallel the Chagai Hills and are approximately 75 km south of them. The Ras Koh are separated from the Chagai Hills by the Mirjawa-Dalbandin trough which extends west to the Iranian border. The part of the Chagai Hills mapped in this study is located in Pakistan, south of the border with Afghanistan. The only previously available geologic map of the Chagai Hills was a 1:253,440 photogeologic map produced by Hunting Survey Corp. (Jones, 1961) shown in generalized form in

[1]Manuscript received, January 6, 1978; accepted, March 3, 1979.

[2]Dartmouth College, Hanover, New Hampshire; present address, Earth Satellite Corp., Washington, D.C., 20015.

[3]Dartmouth College, Hanover, New Hampshire 03755.

The writers gratefully acknowledge the help of Robert G. Schmidt of the U.S. Geological Survey. It was at his suggestion, and with his support, that this study was undertaken. Stephen Ungar and the staff of the Goddard Institute for Space Studies, and Gerald Carlson of the Department of Earth Sciences, Dartmouth College, provided valuable help with the development of the classification algorithms. Victor McGee of the Amos Tuck School of Business, Dartmouth College, supplied extremely valuable guidance in the concepts and applications of multivariate analysis. Close cooperation with the staff of the Resource Development Corp. of Pakistan, in particular S. A. Bilgrami, made this study possible. We also wish to acknowledge the valuable assistance of the Geological Survey of Pakistan.

The computer used for the study is located at the Goddard Institute for Space Studies in New York City, and is accessed by a remote installation on the Dartmouth campus.

Most of the funding for the project was provided by NASA Grant NSG 5014. Transportation and logistic expenses to and within Pakistan were funded by National Science Foundation Grant INT77-07767.

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Enclosure 5

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Geologic Mapping of the Ladakh Himalaya by Computer Processing of Landsat Data

Joseph R. Francica
Richard W. Birnie
Gary D. Johnson

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Landsat digital data have been used to construct a geologic map of portions of the Ladahk Himalaya of Northern India and Pakistan. This area, encompassing the Indus Suture Zone, is tectonically significant as a probable zone of collision between the Eurasian and Indian lithospheric plates. The area is particularly suited to a geologic study using Landsat data because the paucity of vegetation provides a clear exposure of the bedrock geology. The high relief and limited accessibility of the terrain make geologic mapping by conventional techniques difficult.

The Ladakh Himalaya are located between the Karakorum Range to the north and the Zanskar Himalaya to the south. Ophiolitic melange in the region is convincing evidence of a collisional plate boundary. In addition to the ophiolites, the Landsat data have distinguished five major geologic units: the Ladakh Intrusives, a biotite-hornblende granite with associated granodiorites, norites and gabbros; the Ladakh Molasse, an interbedded complex of conglomerates, sandstones, and mudstones; the Dras Volcanics, primarily andesites and volcanoclastics; the Indus Flysch, a thick sequence of contorted silty shales; and unconsolidated Quaternary deposits, a series of alluvial, colluvial, flacio-fluvial, lacustrine and aeolian valley fill deposits.

Control areas of known geologic units were identified from published reconnaisance geologic maps of the area. Spectral signatures for each control area were determined. These signatures were then used to recognize similar geologic units in adjacent unmapped areas and to improve the detail of mapping in those areas previously mapped at the reconnaisance scale. Following this preliminary computer mapping exercise, field work was undertaken in the Ladakh Himalaya in order to 1) confirm the geology of sites chosen as control areas;

Enclosure 6

2) check the validity of the classification of the geologic units outside the control areas; and 3) identify problems associated with incorrect geologic classifications. The preliminary computer classification map was refined and improved using the observations made during the field investigations.

The Landsat digital data were classified using a supervised classification scheme developed by S. Unger at NASA's Goddard Institute for Space Studies. This algorithm is primarily based on direction cosines in the four dimensional Landsat color space and permits specification of the degree to which color and brightness differences are to be weighted in the classification. The fundamental volume and unit described by these specifications is a distorted hyper-ellipsoid inscribed within a truncated cone.

Control areas varied in size from 25 to 100 pixels. Brightness and color weighting factors were optimized by determining which combination most completely enclosed the pixels of individual control areas and excluded pixels of other areas. Computer programs developed at Dartmouth for this purpose were used to determine the optimum values of the weighting factors which were later applied to the Landsat data. The result is a Landsat geologic map of the Ladakh Himalaya.

One problem encountered with applying the Landsat data in the Ladakh Himalaya is the extreme relief. The 47° sun elevation associated with scene E-2598-04404 (September, 1976) data used in this study combined with the relief to create large shadow zones on west-northwest facing slopes. Initially it was assumed that there would be no color differences between the sunlit and shaded exposures of the same geologic unit. Therefore it was anticipated that this problem of relief shading could be eliminated by basing the descrimination of the major geologic units solely on color differences. Band ratio plots show that there is definite color as well as brightness differences between shaded and sunlit areas of the same unit. All shaded regions, independent of the geology, exhibit a similar signature. Data from scene E-30135-04495 (July, 1978) with a 58° sun elevation eliminates most shading effects.

The application of computer processing techniques in this study shows that Landsat digital data can be used to assist in geologic mapping. The use of Landsat technology in this remote region allows rapid and relatively inexpensive compilation of a geologic map (here at a nominal scale of 1:125,000) accurate enough to be used as a basis for subsequent detailed studies. It should be recognized, however, that a Landsat analysis is no panacea and it should be used in conjunction with careful field work.

SO_2 Monitoring by Remote Sensing at Kilauea Volcano, Hawaii

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The SO_2 mass flow from Kilauea Volcano during the period 3 to 7 October, 1978 averaged 220 metric tons per day.

The SO_2 emission was monitored using a remote sensing correlation spectrometer, which operates by measuring the amount of absorption by SO_2 molecules at specific wavelengths in the ultraviolet. The instrument was used in the mobile mode; mounted in a vehicle with a right angle mirror attached to the telescope and then driven under the plume. The values obtained are considered minimums, as the spectrometer is a pathlength dependent device and is susceptible to scattering and dilution of the absorption signal. Also, any SO_2 oxidized to other sulfur species or dissolved in water is effectively lost to the spectrometer.

Twenty-two traverses were made during the five day period of the investigation. Traverses were also made completely around the crater and down the Chain of Craters road. This showed the Kilauea crater was the only detectable source of SO_2 within the measuring area. The volcano was in a "quiet" state of activity at the time, with no effusive lava and only gas being emitted from fumaroles in the crater.

Over a six day period in February, 1975 an average of 280 metric tons per day of SO_2 was measured by Stoiber and Malone. In February, 1975 and October, 1978 the volcano was in a state of quiescence so it seems reasonable to assign an average emission level of 200 to 400 metric tons of SO_2 gas per day to a quiescent Kilauea.

The implications of this output relative to degassing of subsurface magma is examined and the ratio of other gases to SO_2 are used to estimate daily output of other gases.

SO_2 measurements from other volcanoes suggests that the SO_2 emission levels reflect the activity of the volcano. A similar situation should exist at Kilauea, and monitoring variations in the mass flow of SO_2 might even provide short term premonitory signs of activity.

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Enclosure 7

VOLCANIC GAS STUDIES IN HAWAII: 1978 - 1979

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The past 2 years of quiescence at Kilauea and Mauna Loa have provided an opportunity to carry on a systematic study of the degassing of Hawaiian volcanoes during a period of no eruptive activity. Recent addition of a hydrogen gas probe, a field gas chromatograph, and a correlation spectrometer has made it possible to monitor gas emission nearly continuously. The goals of this work are to develop reliable gas monitoring techniques that may be useful in forecasting volcanic activity, and to evaluate the contribution of Hawaiian volcanoes to the global volatile budget.

An inventory of thermal areas shows that most Kilauea solfataric activity occurs at Halemaumau crater, along caldera border faults, and along recently active eruptive fissures in the summit caldera and in the two rift zones. Three hydrogen gas probes and one carbon dioxide gas probe are in continuous operation on Kilauea and Mauna Loa. Changes in hydrogen and carbon dioxide concentrations have been observed to accompany shallow seismic activity at the summit of Kilauea. Daily monitoring of SO_2 emission using a correlation spectrometer indicates an average daily flux of 170 ± 40 td^{-1} of SO_2 from vents located at Kilauea caldera. The 1975 fissure in the Mauna Loa summit caldera produces less than 5 td^{-1} SO_2. Direct field measurements of gas composition using a portable gas chromatograph indicates that the chemistry of gas from the 1971 fissure in Kilauea caldera is variable, caused in part by changes in temperature of the fumaroles and by variation in rainfall. The ratios of various gases (i.e. CO_2, CO, H_2, H_2S, HCl) to SO_2 allows us to calculate the daily emission of these gases from Hawaiian volcanoes during a period of no eruptive activity.

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Enclosure 8

BUDGET OF S AND CL RELEASED FROM SHALLOW MAGMA BODIES AT FUEGO VOLCANO, GUATEMALA

1. 017386 ROSE JR

2. 1979 FMAGU Bend, Ore. July.

3. Volcanology (volcanic gases symposium)

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Because of the force of such eruptions, direct eruptive gas determinations in major explosive eruptions have not been obtained. Nevertheless the S and Cl budget of explosive eruptions can be constrained by several measurements including: 1) microprobe analyses of glass inclusions in phenocrysts, 2) scavenged acids on fresh ash, 3) residual S and Cl trapped in tephra, 4) remote correlation spectrometry of gases emitted by volcanoes in quiet intervals between eruptions, 5) determination of gas/particle ratios of S and Cl by airborne sampling inside small eruption clouds, and 6) direct measurements of Cl/S in passive emissions from craters.

We have assembled all of the above data, some of which were obtained at a low level of activity, for the recent activity at Fuego Volcano, Guatemala. The large eruption of October 1974 released $>2.2 \times 10^{14}$ g of ash. Constrained extrapolation allows us to estimate that it also released 1.5×10^{12} g of S and 6.2×10^{10} g of Cl. The flux of S and Cl for three years of passive emission following October 1974, when added to the eruptive gases, make the emission totals equal 1.9×10^{12} g S and $4.7\text{-}11 \times 10^{11}$ g Cl. Based on the pre-eruption S and Cl content of Fuego magma estimated from glass inclusions, the mass of magma required is 1×10^{15} g, about 5 times the amount erupted. Most of the S released and only a small fraction of the Cl was in the short-lived 1974 eruption. S is thus preferentially emitted during explosive eruptions and Cl during low-level activity. The data suggest that rates of S emission during major eruptions are more than 100 times the largest measured rates during low-level emissions.

Enclosure a