N O T I C E

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An Investigation of Vegetation and Other Earth Resource/Feature Parameters Using Landsat and Other Remote Sensing Date

I. Landsat
II. Remote Sensing of Volcanic Emissions

Semi-Annual Status Report (#2)
August 1, 1980 to January 31, 1981

Dartmouth College
Hanover, NH 03755

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Stanley Williams, graduate student

Undergraduate Student Assistants

(E81-10133) AN INVESTIGATION OF VEGETATION AND OTHER EARTH RESOURCE/FEATURE PARAMETERS USING LANDSAT AND OTHER REMOTE SENSING DATA.
1: LANDSAT. 2: REMOTE SENSING OF VOLCANIC EMISSIONS Semiannual Status (Dartmouth G3/43 00133)
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.

NCC 5-22 supports work which was started in 1974 under NSG 5014. The work described below I. B., (Geology and Geobotany) will in the future be supported under another Cooperative Agreement or Grant.

I. 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.

A. Forestry

I. Introduction

In the past half year, we have had some changes in personnel, have worked on applications of Landsat data, developed applications techniques, and have maintained and established contacts with remote sensing colleagues. We have noticed an increased awareness of and interest in the use of Landsat data in New England:

II. Changes in Personnel

Kevin Doran has replaced Ken Sutherland as forestry advisor from the UNH Cooperative Extension Service and has quickly taken
hold of these responsibilities. Emily Bryant has entered the Computer and Information Sciences Program as a Master's candidate and has been working on this project half time. Gibb Dodge's role has remained the same. Undergraduate assistants were Mark Heuberger (fall), and Sally Johnson and Paul Fisher (winter).

III. Applications Projects

A. Investigation of the fanning algorithm as applied to Maine forests was completed, written up as an abstract, submitted, and accepted as a poster for the 15th ERIM Symposium in May, 1981. (Enclosure 1)

B. Deer yard habitat. Mark and Kevin field-checked areas in southwestern New Hampshire which the NH Fish and Game Department had indicated were deer yards. Mark used these areas (largely softwood) to develop signatures for potential deer yard habitat. In a field trip to Canaan, signs of deer were found in two out of four or five areas that had printed out as deer yard. Printouts of three towns in southwestern NH were made with these signatures. Reaction from the Fish and Game Department was positive. We are refining these signatures and developing output appropriate to their needs (e.g. overlays of topography).

C. Gypsy moth defoliation mapping. Tapes were finally acquired, but since they are in the wrong format, there is a delay in using them.

D. Recent report by Cooperative Extension Service (sub contract) is at Enclosure 2.

IV. Techniques

We are writing a program on the Dartmouth computer to calculate pixel coordinates given latitude and longitude and vice versa. Mark
determined ground control point coordinates for a significant portion of New Hampshire; Em and Paul have been writing code for the program.

V. **Maintaining Contacts** - spreading the word.

Em went to GISS in September to meet with Arch Park in regards to his project mapping biomass.

Gibb, Em, and Kevin attended the RSGNNE meeting in Burlington in September.

Gibb and Em gave a guest lecture for Dave Lingren's (Geography) remote sensing class.

Kevin and Em met with Kurt Olson (UNH) to see how his work is going and to catch up on news.

At our invitation, Helen Mustafa and Bob Edwards from the New England Area Remote Sensing System (NEARSS) visited Dartmouth. We discussed NEARSS and remote sensing in New Hampshire.

Gibb, Kevin, and Em visited Bob Barker of St. Regis Paper Company in Jacksonville, Florida. We saw their Forest Resource Inventory System which is being put together now. It incorporates Landsat data as one of many levels of information in their forest inventory.

Article "Landsat for Practical Forest Type Mapping: A Test Case" was (finally) published in *Photogrammetric Engineering and Remote Sensing* Magazine, December, 1980. (Reprint, Enclosure 3)

VI. **Increased Awareness.**

Over the past year or so, a number of projects involving Landsat have cropped up in New England. A Landsat Demonstration
Project backed by ERRSAC has been initiated in New Hampshire.
Maine has a similar project started within the last year.
Vermont's demonstration project has been underway for a couple of years. The NEARSS group, whose concern is largely with access to real-time ocean and coastline remote sensing data, started gathering information and making plans last spring. The New England Inovation Group (funded by NSF) has a contract from NASA Headquarters to investigate the use of Landsat data on the local and regional government level. All in all, things are starting to cook!

B. Geology and Geobotany

The geobotany group have been involved in refining the data collected over the Mesatchee Creek prospect. A Chi squared statistical test was applied to the aircraft multispectral scanner data and it confirmed the extremely high correlation (>99.9%) of the anomalous spectral data to the mineralized zone. This data has been included in a revised paper sent to Economic Geology. (see previous semi-annual report) This paper has been accepted for publication.

II. Remote Sensing of Volcanic Emissions

This research group consists of Professor Richard Stoiber and Graduate Assistants Lawrence Malinconico, Stanley Williams (Ph.D. candidates) and David Sussman. During the period of this report (August 80 - January 81) they were concerned with:

b. Monitoring volcanic activity in Nicaragua, El Salvador and Guatemala (Foreign travel supported by others)
c. Testing a Mini-Cospec.
d. Reporting various activities at Scientific Meetings.

1. Mt. St. Helens

The RAVE Mission is described in Enclosure 4. Professor Stoiber participated with the group, in the remote sensing of SO$_2$. This report was presented at a symposium on the Mt. St. Helens Eruption in Washington, DC, November 18-19, 1980 (Enclosure 5). At this meeting, a paper was presented (Enclosure 6) to which Stoiber, Malinconico and Williams contributed. A similar paper was presented at the 1980 AGU Fall Meeting (see below and Enclosure 8, V 39).

2. The group visited Central America again in November - December, 1980. This activity continues the field proofing of the Cospec loaned by Barringer Research, the manufacturer, Toronto, Canada. The field expenses, including travel, for this work, are supported by others (esp NSF) but the work contributes generally to the expertise and reputation of the group. Recent activities have been reported in the SEAN (Scientific Event Alert Network of the Smithsonian Institution) Bulletin #12, Dec. 31, 1980 (Extract at Enclosure 7) and at the 1980 AGU (American Geophysical Union) Fall Meeting Dec. 10-15, 1980 in San Francisco (Abstracts of 3 papers V 132, V 133, V 136, Enclosure 8).

Encl. 1-8, a/s
I. Introduction

Most Landsat classification algorithms used today separate land cover into discrete categories on the basis of presence or absence of a land cover type: "wheat vs. non-wheat". Most landscapes, however, include a mixture of types: trees plus grass in an orchard, or corn plus soy along a field boundary. These would be better classified on the basis of the proportion of the area covered by each type. The "fanning" algorithm was developed at the Goddard Institute for Space Studies by Stephen Ungar, to accommodate mixture landscapes. It quantifies the varying proportions of two "pure" land cover types within a pixel.

II. Description of Algorithm

Assume each pixel to be composed of a mixture of cover type A and cover type B. "Pure" pixels of cover type A have a mean spectral signature specified as $A_1, A_2, A_3, A_4$ where $A_i$ is the energy received at the satellite in the $i$th spectral band. The energies in each of the four Landsat MSS bands may be thought of as the components of a 4-dimensional observation vector $\mathbf{A}$. In a similar manner $\mathbf{B} = (B_1, B_2, B_3, B_4)$ represents the spectral signature of a "pure" pixel of cover type $\mathbf{B}$. In principle, the signature of a pixel composed of a mixture of cover types $\mathbf{A}$ and $\mathbf{B}$ may be expressed as

$$\mathbf{S} = \eta \mathbf{A} + (1 - \eta) \mathbf{B}$$
where \( n \) represents the fractional area occupied by cover type \( A \). As \( n \) varies from 0 to 1 a "fan" of vectors is formed, ranging in direction from \( \vec{B} \) to \( \vec{A} \) and terminating on the line joining \( \vec{B} \) and \( \vec{A} \).

In a real situation, the observed signature of a mixture pixel will generally not terminate on this line. Our technique determines which value of \( n \) minimizes the difference between observed signature and a theoretical signature terminating on the line. Geometrically, this is equivalent to finding the end point of the theoretical mixture vector by dropping a perpendicular from the observed signature to the line joining the pure types.

The problem may be analytically stated as follows:

If, \( \delta S = |\vec{S}_{\text{obs}} - [(\eta \vec{A}) + (1 - \eta)\vec{B}]| \); find \( \eta \) such that \( \frac{\partial}{\partial \eta} (\delta S) = 0 \). The formal solution is simply the least squares fit determination of \( \eta \) among the four values obtained by considering each Landsat band independently.

The fanning algorithm is available in both an unsupervised and supervised mode. In the unsupervised mode, the GISS chaining algorithm is used to allow pixels to chain together into clusters and fans. The algorithm selects the signatures for the pixel pair with the largest separation in each fan as the endpoints or "pure" types. A value of \( \eta \) is then determined for each remaining pixel in the fan in terms of these pure types. In the supervised mode, the user specifies the pure type signatures which are applied to a category of pixels defined from some previous supervised or unsupervised classification.
In both modes, the algorithm tests: (a) the value of \( n \) derived for each pixel for physical reasonableness (i.e., \( 0 < n < 1 \), if the fractional area hypothesis for a two component mixture is correct); and (b) the goodness of fit of the observed signature to the fan (i.e., \( \delta S = 0 \) if the observed vector is close to a theoretical vector lying in the fan).

This study uses only the supervised mode.

III. Application of the Fanning Algorithm in Forestry

One goal of the Earth Resources Group at GISS is to make useful forest type maps with Landsat data. Forest types used in current practical forest inventories in the northeastern U.S. are defined by the proportion of hardwood (deciduous) and softwood (evergreen) trees in an area. Definitions and their interpretation vary from user to user. If the fanning algorithm could provide objective and consistent quantification of forest type proportions, Landsat maps could meet or even surpass users' inventory specifications.

IV. Results to Date

As a test of the fanning technique, a classification was compared with a detailed inventory of ¼ million acres of forest land in northern Maine, managed by the Seven Islands Land Company, Bangor, Maine. Landsat data was recorded in August, 1976. The inventory, done the same year, breaks out four general forest types:
A scale for the fan was set up where 0.0 represented pure hardwood and 1.0 pure softwood. One would expect, therefore, to partition the forest types at values of 0.25, 0.50, and 0.75 on the scale. To match inventory acreages on the 29 subareas (townships) of the applications area, however, the scale had to be partitioned at mean values of 0.294 (± 0.046), 0.536 (± 0.044), and 0.642 (± 0.043). Although these values were significantly different from expected, they were consistent across the applications area. This suggested that actual partition values could be determined quite confidently from a sample area. The partitioning determined from two sample townships (10% of the area) was used to make acreage estimates for the four forest types in the applications area. Differences between classification and inventory were within 5½% over the area as a whole, and within an average of 22% by township. These differences are similar to those observed in a classification of the same area using a "discrete categories" algorithm.

To test temporal consistency, the fanning algorithm was also applied to Landsat data from July, 1976. Over an application area which was limited by clouds, August partition values were 0.271, 0.522, and 0.638; July values were 0.212, 0.500, and 0.647. Slope of the regression line between dates was close to 1, and correlation was high (0.997).
It can be concluded from the project that the fanning algorithm provides consistent quantification of mixtures of two forest types. Partition values for specific ratios of pure types, however, have to be derived empirically at this point.

V. Advantages of Approach

Several approaches which treat pixels as two component mixtures have appeared in the literature. Two strong points of the GISS approach are:

1) The technique is based on a simplistic physical model rather than a statistical approach, and readily allows for improvement by model refinement (e.g., a more recent version of the algorithm takes into account shadowing and slope effects by permitting the fractional areas of the two components to sum to less than one).

2) In unsupervised mode "pure" type signatures are extracted for the end points in a group of pixels and the mixture ratio is determined for each remaining pixel in terms of these pure types. The algorithm automatically rejects pixels which are inconsistent with the two component mixture hypothesis.

The practical application outlined in this paper provides perhaps the first quantitative evaluation of a mixture classification algorithm for large area inventories.
PROGRESS REPORT

APPLYING LANDSAT MEASUREMENTS
TO FOREST RESOURCE INVENTORIES

May 31, 1980 through December 31, 1980

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

SITE SELECTION

1. Finished developing field maps of deer yard areas in the towns of Washington, Stoddard and Henniker for the N.H. Fish and Game Department. Will deliver to the Department and test usefulness.

2. Select gypsy moth defoliation training sites.

3. Select new spruce-fir defoliation training sites

GUIDANCE AND EVALUATION

a) GISS on making changes in computer programs to produce better products continued.

b) Dartmouth work-study students - mapping techniques, observing ground truth sites, development of rotation and scale change program.

c) Private landowners with large ownership - using computer maps as field tools

d) Revise and update 1981 work plans

e) Evaluation - analyze computer outputs resulting from GISS program changes

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 Group, GISS, ERRSAC, GSFS, Remote Sensing Group of Northern New England, New Hampshire Fish and Game Department and Office of State Planning and NEARS personnel.

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

4. Met with N.H. Office of State Planning personnel on New Hampshire Landsat demonstration project with ERRSAC.

Enclosure 2
TECHNOLOGY TRANSFER AND REPORTING

1. Landsat presentations to classes of Dartmouth

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

SUBMITTED BY:
Kevin Doran, Program Assistant
Arthur "Gibb" Dodge, Jr., Program Leader
Landsat for Practical Forest Type Mapping: A Test Case

Computer classified Landsat maps agreed to within 5 percent of a conventional inventory of forest lands in northern Maine.

INTRODUCTION

Many people have used Landsat data in mapping natural resources and cultural features (Bauer et al., 1978; Dejace et al., 1977; Gaydos and Newland, 1978; George et al., 1977; Krebs and Hoffer, 1976; Mukai and Takeuchi, 1979; Odenyo and Pettry, 1977). In particular, researchers across North America have reported use of Landsat data in mapping forest resources (Beaubien, 1979; Dodge and Bryant, 1976; Harding and Scott, 1978; Johnson et al., 1979; Kalensky et al., 1979; Kirby et al., 1975; Kourtz, 1977; Mead and Meyer, 1977; Sayn-Wittgenstein, 1977; Titus et al., 1975; Williams and Haver, 1976).

The goal of the Dartmouth forestry section of the Goddard Institute for Space Studies is to use computer classification of Landsat data to make forest type maps which are useful to the field forester. Thus, the person who cruises the forest rather than the upper level manager is the "user" for whom the Landsat maps are being developed.

SEVEN ISLANDS PROJECT

The Seven Islands project developed from a contact with a potential Landsat data user employed by the Seven Islands Land Company, Bangor, Maine. Seven Islands manages 690 thousand hectares (1.7 million acres) of forest land in northern Maine and New Hampshire. They require information about forest types on their lands for management decisions and for taxation purposes. (The state of Maine taxes forest land by applying different values to softwood, mixed wood, and hardwood forest areas.) A detailed inventory of the Seven Islands lands was underway at the time the contact was made. This presented a rare opportunity to test Landsat's ability to meet practical user information needs: the user requirements were well defined (in the inventory specifications) and there was a product, the standard inventory, against which to measure Landsat mapping performance.

With the cooperation of the Seven Islands Land Company, the Landsat maps were compared with the recent inventory of forest lands in northern Maine. Over the 196,000 hectare (485,000 acre) area mapped, estimates of area of softwood, mixed wood, and hardwood forest types by the two methods agreed to within 5 percent. Cost of the Landsat maps is estimated at 6.5 cents per hectare (2.6 cents per acre). Although the information derived from Landsat is not yet refined enough to be incorporated in current forest inventories, the techniques used are worth developing.
Company, a project was started. The goal was to match their inventory specifications as closely as possible using computer classification of Landsat data, and to create, quickly and inexpensively, a product suitable to submit to the Bureau of Taxation. There is a difference between this and some other Landsat applications projects. Success is measured by agreement with a given inventory, not by agreement with "ground truth" gathered by the Landsat investigators. A positive aspect of this approach is the elimination of biases which Landsat investigators might introduce in gathering their own ground truth.

More specific goals of the project were

- To map the Ashland District portion of the Seven Islands lands (Figure 1);
- To match computer-classified Landsat categories with Seven Islands inventory categories: softwood, mixed wood, and hardwood forest types, non-forest areas, water, and roads;
- To calculate area for each category in each Seven Islands management unit (units are usually townships or parts of townships); and
- To produce geometrically corrected computer printout maps of the area at 1:24,000 scale.

The following constraints were put on the project in order to approximate an operational situation:

- Minimize the amount of ground truth used in creating and checking the Landsat classification (methods dependent on large amounts of ground truth are suitable only for research situation);
- Keep track of expenses—human and computer time, cost of data and supplies—to give an estimate of cost per unit area.

THE ASHLAND DISTRICT

The Ashland District, managed by Seven Islands Land Company, consists of land in 29 townships in northern Maine located between 46 and 47 degrees north latitude. In most of the area, the political subdivisions are "unincorporated townships" where there is very little permanent human settlement.

The individual parcels or townships in the Ashland District are not always contiguous and range in size from 400 to 10,500 hectares (1,000 to 26,000 acres). The District comprises a total of 196,356

![Fig. 1. Ashland District portion of Seven Islands Land Company lands, an area of about 196,000 hectares (485,000 acres). Individual parcels are not always contiguous and range in size from 400 to 10,500 hectares (1,000 to 26,000 acres).](image1)

![Fig. 2. Oblique (above) and vertical (below) views of a portion of the Ashland District. The vertical view is an example of the black-and-white infrared photos used in the Seven Islands inventory (original scale 1:15,840, photos taken in May, 1976).](image2)
hectares (485,310 acres) (Figure 1). The most
common forest types in this area are

- spruce-fir (Picea sp.—Abies balsamea)
- maple-beech-birch (Acer saccharum—Fagus
  grandifolia—Betula alleghaniensis)
- northern white cedar—black spruce (Thuja
  occidentalis—Picea mariana)

Figure 2 shows oblique and vertical views of
part of the Ashland District.

THE SEVEN ISLANDS INVENTORY

The Seven Islands inventory is based on aerial
photo-interpretation, "3-P" (probability propor-
tional to prediction) field sampling, and the
Giss computer program (a standard forest measure-
ment program). Figure 2 includes an example of the
photos used in the inventory. The inventory con-
ists of type maps, acreage tallies, and volume esti-
mates. This project concentrated on matching the
maps and acreage tallies, leaving volume estimation
to other techniques.

The Seven Islands maps distinguish vegetation
by type, size, and density to a 10 acre mini-
mum. Acreage is determined for each forest stand, and
totals are computed by type for each township. For
tax purposes, the many forest types distinguished
in the inventory are grouped into three more gen-
eral types according to the proportion of softwood
(conifer) to hardwood (deciduous) trees in an area:

- softwood—at least 75 percent of the trees are
  softwood.
- hardwood—at least 75 percent of the trees are
  hardwood.
- mixed wood—the proportion of softwood to
  hardwood trees lies between those of the
  softwood and hardwood categories as defined
  above.

The above are the general forest categories that
were to be matched in the Landsat classification.

PROCEDURE

GENERAL OUTLINE

The project employed computer programs to
make maps and acreage tallies from Landsat mul-
tispectral scanner (MSS) digital data. A supervised
classification approach was used. It was de-
veloped at the Goddard Institute for Space Studies
(Giss) by Stephen G. Unzar and is described in
Merry et al. (1977). With the Giss classification al-
gorithm, the program use defines a volume in
four-dimensional color space around an average
signature for each land cover category. The signa-
ture is usually the average reflectance of a land
cover type as taken from a representative sample
of the MSS data (a "training site"). The user can
create a classification category for which there is
no training site, if there is another source of sig-
atures.

Fig. 3. MSS band 6 image of the 11 August 1976 Landsat
scenes used in classifying the Ashland District (scene
identification numbers 5480-14040 and 5480-14043).
Ashland District is outlined, sample townships are
labeled 1 and 2. Water is black, softwood dark gray, and
hardwood light gray.

DETAILS OF THE SEVEN ISLANDS PROJECT

Landsat data used in the Seven Islands project
was recorded on 11 August 1976. Scene identifi-
cation numbers are 5480-14040 and 5480-14043
(Figure 3).

Ground truth consisted of

- Representative copies of the photos used in the
  Seven Islands inventory (Figure 2);
- Seven Islands inventory maps and acreage tallies
  for two of the 29 townships in the District;
- Personal knowledge from an overflight of the
  area;
- Prints of photo-mosaics used for location of forest
  harvests (scale 1:31,680); and
- Topographic maps (scale 1:62,500).

There was no ground checking except indirectly
through the inventory information.

We chose signature training sites in the MSS data
(usually 10 to 30 pixels in size) for softwood,
hardwood, water, bog, and open categories using
the aerial photographs. Mixed wood signatures
were made by interpolating between hardwood
and softwood signatures.

The tolerance parameters for the forest cate-
gories were adjusted so that the acreage tallies
would agree with the Seven Islands inventory on
two sample townships (Table 1). Discrepancy in
acreage figures on the two townships taken to-
gether was under 3.5 percent; it was under 10 per-
cent when they were considered separately. The
two townships comprise 19,000 hectares (47,000
acres), about 10 percent of the Ashland District
(Figure 3).
TABLE 1. FOREST TYPE AREA ESTIMATES FOR SAMPLE TOWNSHIPS FROM SEVEN ISLANDS LAND COMPANY AND LANDSAT INVENTORIES.*

<table>
<thead>
<tr>
<th>Forest Type</th>
<th>7 Islands Tally (ha)</th>
<th>Landsat Tally (ha)</th>
<th>Percent Diff.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total For.</td>
<td>8 481</td>
<td>8 596</td>
<td>+1.4%</td>
</tr>
</tbody>
</table>

Sample Township #1

<table>
<thead>
<tr>
<th>Forest Type</th>
<th>7 Islands Tally (ha)</th>
<th>Landsat Tally (ha)</th>
<th>Percent Diff.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Softwood</td>
<td>4 331</td>
<td>4 573</td>
<td>+5.6%</td>
</tr>
<tr>
<td>Mixed Wood</td>
<td>3 320</td>
<td>3 117</td>
<td>-6.1%</td>
</tr>
<tr>
<td>Hardwood</td>
<td>830</td>
<td>906</td>
<td>+9.2%</td>
</tr>
</tbody>
</table>

Sample Township #2

<table>
<thead>
<tr>
<th>Forest Type</th>
<th>7 Islands Tally (ha)</th>
<th>Landsat Tally (ha)</th>
<th>Percent Diff.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Softwood</td>
<td>4 247</td>
<td>4 017</td>
<td>-5.4%</td>
</tr>
<tr>
<td>Mixed Wood</td>
<td>3 286</td>
<td>3 591</td>
<td>+9.3%</td>
</tr>
<tr>
<td>Hardwood</td>
<td>826</td>
<td>1 667</td>
<td>-8.8%</td>
</tr>
</tbody>
</table>

Sample Townships #1 and #2 Combined

<table>
<thead>
<tr>
<th>Forest Type</th>
<th>7 Islands Tally (ha)</th>
<th>Landsat Tally (ha)</th>
<th>Percent Diff.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Softwood</td>
<td>8 578</td>
<td>8 591</td>
<td>+0.2%</td>
</tr>
<tr>
<td>Mixed Wood</td>
<td>6 606</td>
<td>7 070</td>
<td>+1.5%</td>
</tr>
<tr>
<td>Hardwood</td>
<td>2 656</td>
<td>2 572</td>
<td>-3.2%</td>
</tr>
</tbody>
</table>

Boundaries of the management units (townships) were superimposed on the Landsat data using a masking program. They were taken from topographic maps, using water bodies as control points.

RESULTS

RESULTS RELATIVE TO THE GOALS

Map the District. A printout map and acreage tally by category was made for each management unit in the Ashland District.

Match Seven Islands categories. Area comparison is one measure of how well the Landsat categories match Seven Islands categories. Area tallies for the entire district are shown in Table 2 and Figure 4. Differences between Landsat and Seven Islands forest type acreage estimates are under 5 percent. As is to be expected, they are larger for the individual township tallies. Figure 5 shows Seven Islands versus Landsat acreage estimates for the individual townships for softwood, mixed wood, hardwood, total forest, water, and open categories. Both the Landsat and the Seven Islands inventory acreage tallies were normalized so that the total acreage in each township matched

TABLE 2. AREA ESTIMATES OF FOREST TYPES AND RELATED FEATURES IN THE ASHLAND, MAINE DISTRICT DERIVED FROM SEVEN ISLANDS LAND COMPANY INVENTORY AND LANDSAT COMPUTER CLASSIFICATION.

<table>
<thead>
<tr>
<th>Forest Type</th>
<th>Seven Islands Hectares</th>
<th>% of Total</th>
<th>Landsat Hectares</th>
<th>% of Total</th>
<th>Difference Hectares</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Softwood</td>
<td>87 104</td>
<td>44.4%</td>
<td>88 884</td>
<td>45.3%</td>
<td>+1 780</td>
<td>+2.0%</td>
</tr>
<tr>
<td>Mixed Wood</td>
<td>215 285</td>
<td>36.7%</td>
<td>219 683</td>
<td>37.9%</td>
<td>+4 398</td>
<td>+1.9%</td>
</tr>
<tr>
<td>Hardwood</td>
<td>177 895</td>
<td>14.0%</td>
<td>184 127</td>
<td>13.3%</td>
<td>+6 232</td>
<td>+3.8%</td>
</tr>
<tr>
<td>Water</td>
<td>27 482</td>
<td>3.0%</td>
<td>4 695</td>
<td>2.4%</td>
<td>-1 261</td>
<td>-20.4%</td>
</tr>
<tr>
<td>Open Land</td>
<td>14 609</td>
<td>0.4%</td>
<td>11 605</td>
<td>0.3%</td>
<td>-3 004</td>
<td>-20.6%</td>
</tr>
<tr>
<td>Bog</td>
<td>2 035</td>
<td>1.6%</td>
<td>1 639</td>
<td>0.1%</td>
<td>-2 818</td>
<td>-92.1%</td>
</tr>
<tr>
<td>Unclassified*</td>
<td>7 562</td>
<td>0.0%</td>
<td>599</td>
<td>0.0%</td>
<td>-1 963</td>
<td>-20.6%</td>
</tr>
<tr>
<td>Total Forest</td>
<td>186 562</td>
<td>95.0%</td>
<td>189 503</td>
<td>96.5%</td>
<td>+2 941</td>
<td>+1.6%</td>
</tr>
<tr>
<td>Total Area**</td>
<td>485 310</td>
<td>100.0%</td>
<td>485 310</td>
<td>100.0%</td>
<td>+7 267</td>
<td>+1.6%</td>
</tr>
</tbody>
</table>

* The Seven Islands inventory included no "unclassified" category.
** Both Seven Islands and Landsat tallies were normalized so that total area in each township matched the deeded acreage as listed in the Seven Islands records.
Fig. 5. Seven Islands inventory tallies for each management unit (township) are plotted against Landsat computer classification results for six land cover classes. Discrepancies in one township could be attributed to differences in classification of partially cut areas (data point is circled).
its deeded acreage as listed in the Seven Islands records.

Agreement in locations of features on maps was desired as well as area agreement. An informal comparison of Landsat maps and Seven Islands inventory maps shows that the positions and shapes of the forest stands generally coincide (Figure 6). As a more formal test of locational agreement, 130 sample pixels in one ground truth township were selected at random, and their Landsat and Seven islands categories were compared. Results are in Table 3. The overall agreement (diagonal entries in the table divided by the total number of samples; 83/130) is 63 percent. While this seems rather low, other Landsat applications studies involving forest types have similarly low overall agreement, depending on exactly what the categories are, how they are aggregated, and how the samples are chosen (Table 4). Overall agreement ranges from 43 percent to 98 percent.

This single pixel method of measuring classification accuracy has inherent problems. Minimum feature size classified on the ground truth maps is often greater than one pixel (0.4 hectares or 1.1 acres); in this case it was 4 hectares (10 acres). Exact location of one-pixel samples on ground truth maps is uncertain. Each of these problems can lower the measured accuracy of a classification, regardless of its actual accuracy.

In the non-forest categories, it was found that roads were not located with enough accuracy to be useful; also, bogs were often classified as forest, and small streams were not identified.

**Tallies for each township.** Acreage by township and category is in Figure 5 as mentioned above. Locating township boundaries was very time consuming but essential for comparison with the standard inventory results.

**Geocorrected data.** The Landsat geometric correction used was a systematic correction applied to the entire Landsat scene, using a nearest neighbor resampling scheme. The accuracy was acceptable over the one-township size units (8000 hectares or 20,000 acres) used in the Seven Islands project.

**Remarks on the constraints**

**Minimize ground truth.** Originally, the Seven Islands inventory of the two sample townships
LANDSAT FOR PRACTICAL FOREST TYPE MAPPING

TABLE 3. COMPARISON OF SEVEN ISLANDS AND LANDSAT CLASSIFICATIONS.
THE 130 ONE-Pixel SAMPLES WERE SELECTED AT RANDOM FROM ONE SAMPLE TOWNSHIP.

<table>
<thead>
<tr>
<th>Landsat Category</th>
<th>Soft</th>
<th>Mixed</th>
<th>Hard</th>
<th>Water</th>
<th>Open</th>
<th>Other</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Softwood</td>
<td>41</td>
<td>12</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>3</td>
<td>58</td>
</tr>
<tr>
<td>Mixed Wood</td>
<td>16</td>
<td>23</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>44</td>
</tr>
<tr>
<td>hardwood</td>
<td>0</td>
<td>8</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>15</td>
</tr>
<tr>
<td>Water</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>12</td>
<td>0</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td>Open</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Other</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>57</td>
<td>43</td>
<td>11</td>
<td>13</td>
<td>0</td>
<td>6</td>
<td>130</td>
</tr>
</tbody>
</table>

Sum of diagonal entries = 82, or 63% of the 130 samples total.

was not included in ground truth. Preliminary results, however, showed a large discrepancy between Landsat and inventory maps. The only way to match given categories was to have a sample of them, not just the inventory specifications. Since the size of the ground truth sample townships was large, the original goal was expanded from mapping three townships to mapping the entire district.

Costs. The cost estimates for this project are listed in Table 5. The overall cost of 6.5 cents per hectare (2.6 cents per acre) includes human time at ten dollars per hour, computer time at 600 dollars per hour (on an IBM 360/95), and ground truth. The cost of ground truth for the two sample townships is 37 percent of the total cost—2.4 cents per hectare (0.99 cents per acre). The cost also reflects inefficiencies which would be eliminated in subsequent projects. The estimate excludes cost of software development, depreciation on the computer, photo-mosaics, topographic maps, and geocorrection of data. Classification of a larger area would reduce the per area cost; estimated cost for 800,000 hectares (2 million acres) is 2.4 cents per hectare (0.96 cents per acre). Table 6 compares this cost estimate with those from other Landsat applications projects. They vary from 0.078 to 8.6 cents per hectare (0.032 to 3.5 cents per acre). Much of this variation is due to differences in the items included in the estimates (sometimes ground truth is excluded) and the cost assigned to the items (cost of human time varies from 5 to 21 dollars per hour).

The information derived by computer-classification of Landsat data could also be derived from standard photo-interpretation techniques. The company that did the Seven Islands inventory gave a ball-park estimate of the cost as 11.0 to 16.0 cents per hectare (4.5 to 6.5 cents per acre). (Rate for the Seven Islands inventory itself would be higher because it is more detailed).

DISCUSSION

Although acreage results on the forest categories were within 5 percent, those for the remaining categories (water, bog, open land) had much larger discrepancies (Table 2; Figure 5). Possible explanations of these discrepancies follow. First, there is a smaller sample: together the open, bog, and water categories comprise only 5 percent of the

TABLE 4. COMPARISON OF LOCATIONAL AGREEMENT RESULTS.

<table>
<thead>
<tr>
<th>Reference</th>
<th># Categories</th>
<th># Diagonal Entries (Pixels)</th>
<th>Total # of Samples (Pixels)</th>
<th>Overall Agreement (Percent)</th>
<th>Sample Selection Scheme</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bryant et al.</td>
<td>6</td>
<td>82</td>
<td>130</td>
<td>63%</td>
<td>Random</td>
</tr>
<tr>
<td>Harding and Scott 78</td>
<td>5</td>
<td>142</td>
<td>302</td>
<td>47%</td>
<td>Stratified</td>
</tr>
<tr>
<td>Johnson et al. 1979</td>
<td>6</td>
<td>107</td>
<td>200</td>
<td>54%</td>
<td>Grid</td>
</tr>
<tr>
<td>Johnson et al. 1979</td>
<td>6</td>
<td>169</td>
<td>200</td>
<td>85%</td>
<td>Grid</td>
</tr>
<tr>
<td>Kalensky and Scherk 1975</td>
<td>4</td>
<td>1119</td>
<td>1342</td>
<td>83% (4-date)</td>
<td>*</td>
</tr>
<tr>
<td>Kalensky and Scherk 1975</td>
<td>4</td>
<td>*</td>
<td>*</td>
<td>67%-82% (1-date)</td>
<td>*</td>
</tr>
<tr>
<td>Kalensky et al. 1979</td>
<td>9</td>
<td>4024</td>
<td>4123</td>
<td>98%</td>
<td>Control Areas</td>
</tr>
<tr>
<td>Kalensky et al. 1979</td>
<td>9</td>
<td>4061</td>
<td>4123</td>
<td>98%</td>
<td>Control Areas</td>
</tr>
<tr>
<td>Kalensky et al. 1979</td>
<td>9</td>
<td>3978</td>
<td>4123</td>
<td>96%</td>
<td>Control Areas</td>
</tr>
<tr>
<td>Kirby et al. 1975</td>
<td>6</td>
<td>401</td>
<td>676</td>
<td>59%</td>
<td>Pixel Columns</td>
</tr>
<tr>
<td>Mead and Meyer 1977</td>
<td>11</td>
<td>590</td>
<td>1305</td>
<td>43%</td>
<td>Pixel Rows</td>
</tr>
<tr>
<td>Mead and Meyer 1977</td>
<td>11</td>
<td>779</td>
<td>1478</td>
<td>53%</td>
<td>Pixel Rows</td>
</tr>
<tr>
<td>Williams and Haver 1976</td>
<td>6</td>
<td>162</td>
<td>232</td>
<td>70%</td>
<td>Random</td>
</tr>
<tr>
<td>Williams and Haver 1976</td>
<td>3</td>
<td>208</td>
<td>232</td>
<td>90%</td>
<td>Random</td>
</tr>
</tbody>
</table>

* Information not provided.
area classified; the rest is forested. Next, the resolution of Landsat (80 metres) is coarse relative to streams and narrow roads. These features are absorbed into the surrounding forest types. This may account for the Landsat underestimation of water and open categories.

Confusion in Landsat categories may account for the underestimation of the bog category. Bogs were often classified as mixed wood or hardwood.

Forest acreage tallies for some individual townships had noticeably large discrepancies. In one case (circled in Figure 5) this could be attributed to difference in classification of partially cut areas which included many small softwood trees and a few large hardwood trees. The photo-interpretation in the Seven Islands inventory, which is based on numbers of trees, indicated softwood; the computer classification, based on average reflection, indicated mixed wood.

A factor influencing forest classification is sun illumination. Classifications of forest areas within terrain shadows have a bias toward softwood. Merging of digital topographic data and Landsat data could improve this situation (Krebs and Hoffer, 1976; Strahler et al., 1979). Over a large enough area, these differences balance each other out.

There are some problems which researchers cannot solve. One is New England weather, which is relatively cloudy. It is possible that in some years there would be no Landsat coverage at the desired times of year. Another problem is the acquisition of data. At this point there is a long turnaround time in ordering Landsat computer compatible tapes (cct's). Also some private organizations do not want to depend on government sources for their data.

CONCLUSION

Bearing in mind the objective to give quick, inexpensive, and accurate acreage estimates of forest types to the Bureau of Taxation, the following conclusions are drawn. Results were very good on the district as a whole, but were not good for the individual townships. Each township has unique records of accounting and ownership and must have proven and precise forest type information. In some cases this is needed for portions of a township that are as small as 400 hectares (1000 acres). The 400 hectare tract requires the same level of precision that was reached in this project with the tallies for the 200,000 hectare tract.

On the other hand, the energy situation is becoming more burdensome, and satellite information will become more important as a supplement to aerial photographs and other information sources. Further research in satellite data processing techniques could bring the information to a more useable level and is worth pursuing.

RECOMMENDATIONS

More experience using satellite data in practical situations is recommended. Computer classification may currently be as reliable as photo-

---

**Table 5. Seven Islands Project Cost Estimates.**

Size of Area Classified: 196,400 hectares (485,310 acres).

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost (Dollars)</th>
<th>% of Total</th>
<th>Cost/ha (Cents)</th>
<th>Cost/acre (Cents)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Materials¹</td>
<td>$690</td>
<td>3.4%</td>
<td>0.36¢</td>
<td>0.14¢</td>
</tr>
<tr>
<td>Field Expenses²</td>
<td>780</td>
<td>3.1</td>
<td>0.40</td>
<td>0.16</td>
</tr>
<tr>
<td>Inventory of Sample Townships³</td>
<td>800</td>
<td>37</td>
<td>2.4</td>
<td>0.99</td>
</tr>
<tr>
<td>Signature Development⁴</td>
<td>490</td>
<td>35</td>
<td>2.3</td>
<td>0.99</td>
</tr>
<tr>
<td><strong>Subtotal: Initial Costs</strong></td>
<td>$10,789</td>
<td>84%</td>
<td>5.5¢</td>
<td>2.2¢</td>
</tr>
<tr>
<td>Run-off and Tally of Ashland District⁵</td>
<td>$2,070</td>
<td>16%</td>
<td>1.1¢</td>
<td>0.43¢</td>
</tr>
<tr>
<td><strong>Total Cost</strong></td>
<td>$12,859</td>
<td>100%</td>
<td>6.5¢</td>
<td>2.6¢</td>
</tr>
</tbody>
</table>

Projected Cost Estimate for 800,000 hectares (2,000,000 acres)

| Initial Costs (As Above) | $10,789 | 56% | 1.3¢ | 0.54¢ |
| Run-off and Tally | 860 | 44% | 1.1¢ | 0.43¢ |
| **Total Cost** | $11,649 | 100% | 2.4¢ | 0.97¢ |

¹ Includes air photos, Landsat images, Landsat CCT's, and computer supplies.
² Includes travel and labor costs. (Labor valued at $10 per hour.)
³ Estimated cost for 10,000 hectares (40,000 acres) at 25¢ per hectare (10¢ per acre).
⁴ Includes 355 hours labor and 144 minutes computer time (valued at $10 per minute).
⁵ Includes 106 hours labor and 90 minutes computer time.
interpretation, but there are differences, and they need to be identified. Perhaps some of the information missing in the current Landsat maps can be extracted from higher resolution data such as the quarter acre resolution projected for Landsat D (Williams and Stauffer, 1979). Already, examination of Landsat 3 m X-ray imagery suggests that woods roads will be much more distinct with 30 metre resolution.

**SUMMARY**

Landsat classification maps were made for a forested area in northern Maine, managed by the Seven Islands Land Company. Over the 200,000 hectare (half million acre) district, results agreed with a standard inventory to within 5 percent on area of general forest types. Cost was estimated at 6.5 cents per hectare (2.6 cents per acre). Accuracy measurements and cost estimates were comparable with other Landsat forestry applications projects.

The techniques described here are promising, but are not yet practical for Seven Islands Land Company's needs. Further research and perhaps better spatial resolution are needed to ensure reliable Landsat results on smaller geographic areas.

**ACKNOWLEDGMENTS**

This project was supported by NASA Science Grant 5014. We wish to thank Seven Islands Land Company for their cooperation and for the use of inventory data.

**REFERENCES**


George, T. H., W. J. Stringer, and J. N. Baldridge, 1977. Reindeer Range Inventory in Western Alaska from Computer-Aided Digital Classification of


(Received 30 May 1979; revised and accepted 5 June 1980)
RESULTS OF THE SEPTEMBER 22, 1980 RAVE STUDY
OF THE MOUNT ST. HELENS PLUME

Jarvis Moyers
University of Arizona

This paper presents a description of the joint University-NASA research project RAVE (Research on Atmospheric Volcanic Emissions) and preliminary results from a recent Mount St. Helens expedition. The RAVE scientific team consists of scientists from Drexel University, Dartmouth, Michigan Technological Institute, University of Arizona, University of Maryland, and NASA. A Lockheed Orion P-3 four engine turbo-prop aircraft has been outfitted with active and passive instrumentation for monitoring and sampling gases and aerosols in volcanic plumes. The first field study in this project was performed on September 22, 1980 at the Mount St. Helens volcano. Measurements made in this study include remote sensing of SO2 and aerosol burdens and fluxes; in plume analysis of SO2, H2S, NO, NO2, O3 and particle size distribution; and the filter collection of aerosols and reactive gases for subsequent laboratory analysis. There was a very successful integration and operation of all onboard equipment and experiments. Available results obtained in this are presented and discussed.

*Chemistry Department, Tucson, AZ 85721*
ABSTRACT DIGEST
SYMPOSIUM ON
MOUNT ST. HELENS ERUPTION:
ITS ATMOSPHERIC EFFECTS AND
POTENTIAL CLIMATIC IMPACT

Washington, D.C.
November 18-19, 1980

Sponsored by:
NASA-Office of Space and Terrestrial Applications

On behalf of:
U.S. National Climate Program

Organized by:
Institute for Atmospheric Optics and Remote Sensing

Institute for Atmospheric Optics
and Remote Sensing,
P.O. BOX P • HAMPTON, VA 23666

Enclosure 5
CONTRIBUTIONS OF CO₂ AND SO₂ TO THE ATMOSPHERE FROM VOLCANIC ACTIVITY AT MOUNT ST. HELENS

D. M. Harris, T. J. Casadevall, and D. A. Johnston
U.S. Geological Survey

W. I. Rose, Jr.; and T. J. Bornhorst
Michigan Technological University

R. E. Stoiber, L. L. Malinconico, and S. N. Williams
Dartmouth College

The resumption of volcanic activity at Mount St. Helens in March 1980 prompted measurements and study of CO₂ and SO₂ emission rates. The objective of these studies is to provide information about the degassing of the subsurface magma body. Although the principal propellant of the explosive eruptions at Mount St. Helens is probably H₂O vapor, emission rates for CO₂ and SO₂ may also be useful indicators of volcanic activity. Significant changes in emission rates for these gases may occur as a result of various factors such as migration of gases from deeper magma, intrusion of magma toward the surface, changes in the concentrations of CO₂ and/or SO₂ in the silicate liquid, changes in the degassing rate of the silicate liquid, and changes in the permeability of the vent. Aside from providing information relevant to eruption mechanisms, the measurements of sustained gas emissions together with the pre-eruption volatile concentrations provide a basis for inferring the presence of a magma body and for estimating the volume of degassed silicate liquid remaining at depth. The total amounts of CO₂ and SO₂ released to the atmosphere by magma degassing during non-eruptive periods at Mount St. Helens can be estimated from the more than 70 measurements of emission rates. One must increase these numbers by the amounts released during explosive eruptions.

Reston, VA 22092
Vancouver, WA 97663
Menlo Park, CA 94025 (deceased)
Houghton, MI 49931
Hanover, NH 03755
Figure 3: Monthly numbers of days in which eruptions occurred (top); harmonic tremor events (center); and recorded earthquakes (bottom) at Tarumai, January 1978 - December 1980.

Mayon Volcano, SE Luzon Island, Philippines (13.26°N, 123.62°E). All times are local (= GMT + 8 hours).

A moderate quantity of dirty white steam rose weakly to 200 m above the crater rim on 4 December at 1247, accompanied by short-duration harmonic tremor on the Mayon Resthouse Observatory seismograph. Faint crater glow was first noted at 2315 the same day. Additional steam emission was observed 12 and 14 December.

Harmonic tremor was first recorded at Mayon on 16 August (see SEAN Bulletin v.5, no. 8). Episodes of tremor and discrete earthquakes continued through December. Similar seismic activity preceded the 1978 eruption (see SEAN Bulletins v.3, nos. 2, 5, and 8) and accompanied crater glow in July 1979 (see SEAN Bulletin v.4, no. 8).

Information Contact: Olimpio Peña, Acting Commissioner, Commission on Volcanology, 5th Floor, Hizon Bldg., Quezon Blvd., Ext., Quezon City, Philippines.

Volcanic Activity in Nicaragua, El Salvador, and Guatemala, late 1980

Geologists from Dartmouth College, the Instituto Geográfico Nacional of Guatemala, and the Instituto de Investigaciones Sismicas of Nicaragua observed 8 Nicaraguan, 2 Salvadoran, and 2 Guatemalan volcanoes between mid-November and early December. Dartmouth geologists provided the following report.

Nicaragua

Cerro Negro (12.52°N, 86.73°W) - Summit crater fumaroles remained at temperatures as high as 300°C. A small vapor plume was intermittently visible. Seismic activity had dropped from the high level of June.

Cosiguina (12.97°N, 87.58°W) - No fumarolic activity was visible from the rim.
Volcanic Activity
Nicaragua, El Salvador, Guatemala, (cont.)

Las Pilas (El Hoyo) (12.48°N, 86.68°W) - A small continuous vapor plume was still being emitted from the top of the km-long crack in the summit.

Masaya (11.95°N, 86.15°W) - Emission of a very large gas plume has continued without interruption since fall, 1979. Remote sensing of SO₂ revealed continued high level flux, with 1,500 - 2,000 tons/day average for the entire year. The hole through the surface of the lava lake was larger than in previous years and a great deal of sublimation was occurring around its edge. No lava or red glow was visible during daylight. Acid gas and rain continued to cause considerable damage downwind.

Mombacho (11.83°N, 85.98°W) - A small, intermittent plume was visible, rising from the SE section of the summit.

Momotombo (12.42°N, 86.55°W) - The summit crater fumaroles continued to be very hot with temperatures measured up to 735°C and reported to >900°C. A small vapor plume continued and remote sensing revealed very low rates of SO₂ emission. Portions of the crater were seen to glow red and orange when observed at night, with the highest temperatures on the steep S wall of the crater. No seismic activity has occurred recently at Momotombo.

San Cristóbal (12.70°N, 87.02°W) - A moderate-sized vapor plume rose continuously from the summit. Remote sensing of SO₂ revealed increased flux since June 1980, but SO₂ emission remained far below the levels of the mid-1970's.

Telica (12.60°N, 86.87°W) - A moderate-sized but continuous vapor plume rose from the summit crater. SO₂ flux was remotely measured and found to be approximately 150 tons/day.

El Salvador

Observations were made during a flight over the country.

Santa Ana (13.85°N, 89.63°W) - A moderate plume rose from a bank of fumaroles on the SE wall of the inner crater, very similar to its appearance in November 1978.

San Miguel (13.44°N, 88.27°W) - A small, continuous vapor plume rose from the summit crater.

Guatemala

Pacaya (14.38°N, 90.60°W) - A very small cinder cone had grown inside MacKenney Crater in the last 2 months. A large gas plume rose continuously from the summit.

Santiaguito (14.76°N, 91.55°W) - Ash and gas eruptions from Caliente vent (at the E end of Santiaguito Dome) occurred irregularly over the 3-day period of observation, with intervals of 1/2 hour to 4 hours between eruptions. Most eruptions lasted 2-3 minutes and sent ash and gas columns to heights of several hundred m to 1 km above the vent. Five mm of ash accumulated at the foot of the dome over one 12-hour period. Eruptions
Volcanic Activity
Nicaragua, El Salvador, Guatemala (cont.)

occasionally threw 10-cm blocks several hundred m and ejected tephra to well above the summit of Santa María. Although not directly observed, the plug dome and blocky lava flow that was seen being extruded from Caliente vent in February was apparently still very active. Large avalanches of glassy material could be heard from Caliente vista many times per hour. Debris from these avalanches was visible in the barranca below Santiaguito.

Information Contacts: Richard E. Störmer, Stanley N. Williams, H. Richard Naslund, Lawrence L. Malinconico, and Mark Conrad, Department of Earth Sciences, Dartmouth College, Hanover, New Hampshire 03755 USA.

Samuel Bonis, Instituto Geográfico Nacional, Avenida las Américas, 5-76, Zona 13, Guatemala City, Guatemala.

Arturo Aburto and Douglas Fajardo, Instituto de Investigaciones Sismicas, Apartado Postal 1761, Managua, Nicaragua.

SEISMIC EVENTS

<table>
<thead>
<tr>
<th>DATE</th>
<th>TIME (GMT)</th>
<th>MAGNITUDE</th>
<th>LAT.</th>
<th>LONG.</th>
<th>DEPTH OF FOCUS</th>
<th>REGION</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 Dec.</td>
<td>1737</td>
<td>5.7 Ms</td>
<td>36.02°N</td>
<td>1.23°E</td>
<td>10 km</td>
<td>N Algeria</td>
</tr>
<tr>
<td>17 Dec.</td>
<td>1622</td>
<td>6.7 Ms</td>
<td>49.41°N</td>
<td>129.61°W</td>
<td>10 km</td>
<td>W of Vancouver Is., Car.</td>
</tr>
<tr>
<td>19 Dec.</td>
<td>0117</td>
<td>6.1 Ms</td>
<td>34.54°N</td>
<td>50.70°E</td>
<td>Shallow</td>
<td>N-central Iran</td>
</tr>
<tr>
<td>22 Dec.</td>
<td>1251</td>
<td>5.5 m</td>
<td>34.39°N</td>
<td>50.49°E</td>
<td>32 km</td>
<td>N-central Iran</td>
</tr>
</tbody>
</table>

The Algeria event injured 20 persons in the El Asnam area, devastated by earthquakes 10 October that killed thousands and left about 400,000 homeless (see SEAN Bulletin v.5, no. 10). There were no reports of casualties or damage from the 17 December shock. The 19 December earthquake killed 26 persons. The nearby event 3 days later caused 3 deaths and 139 injuries according to official reports.


United Press International.

The Associated Press.

Earthquake Swarm
Siquijor Island, Philippines.

A swarm of earthquakes began to be felt at Lazi, on the S coast of Siquijor Island, on 17 December. By 19 December, recorded events averaged 102/hour and several may have reached magnitude 4-5. Loud detonations reportedly accompanied the seismicity. The next day, 95 strong earthquakes
1980 AGU FALL MEETING

December 10-15, 1980, San Francisco
rest on a fan of earlier 1980 pyroclastic flow deposits. The path of the basal portions of the flows were controlled by topography. Bilaterally brecciated and tuffaceous sheet flows were generated from the fluidized mass by escaping gasses. This movement is similar to that described by Mount St. Helens, which had basaltic topography. The flow was controlled by topography. 10.

I.6ptacemk)nt, which generally determined on a flowage deposit Soon aft, incorporated Air may have been in impo, CO

MINERAL CHEMISTRY

V 35

The Mt. St. Helens lava dome, composed shortly

in a large eruption, is a pile of ash that may be

form a pyroclastic dome. Plagioclase (32 model 4) dominates the phenocrysts and molarite assemblage. nephrine is the most abundant phase in the major

expected increase in the flow velocity, and volumetric flow rate. The lowermost flow had the largest volume and may have been in impo, CO

V 37

RHEOLOGICAL PROPERTIES OF MUDFLOWS ASSOCIATED WITH LATE Eruptions OF MOUNT ST. HELENS

J. Fish

H. Malini (Geology Department, Arizona State University, Tempe, AZ 85281)

The rheological properties of three superposed mudflows on the south side of Mount St. Helens were calculated using techniques based on the geometry of the flowage deposit. The mixtures of the sizes and densities of suspended blocks, thicknesses, and other parameters were determined on the flowage deposit. The flow velocities, and volumetric flow rates. The two lower flows (A1) had larger grain sizes (800-1000 N/m), whereas the upper flow (A2) had finer grain sizes (200-400 N/m). An upper bound of 200 N/m was placed on plastic viscosity of the lowermost flow; estimates for the upper flow could not be obtained. The lowermost flow was probably caused by the catastrophic eruption of May 18, when large volumes of ice and rock were mobilized. Later, smaller mudflows were observed formed by failure of the dome and ash-covered slopes on the south rim of the mountain by mid-June.

Yield strength measurements are being used in conjunction with rainfall, topography, and seismicity to predict areas of high susceptibility to new mudflow formation during the upcoming rainy season.

The 1980 Eruption of Mt. St. Helens IV

Emerald Room HI

Tuesday PM

Robert L. Christiansen (USGS), Stephen D. Malone (U of Washington), Presiding

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V 126
PEMBRE-POOR EQUILIBRIUM IN SILICATE LIQUIDS AT 1 K

R. E. Lack (Dept. of Geology & Geophysics, University of Washington, Seattle, WA 98195)

The concentration of FeO and Fe2O3 has been determined in 37 silicate liquids, covering virtually the whole natural range of liquids, quenched from supercooled temperatures (1200–1300°C), and with nobble systems from the KI and PNO. In conjunction with published data, the linear relation between the concentration of the silicate liquid and the composition of the liquid is as follows:

\[ \log_{10} C = \log_{10} C_0 + \frac{E}{R T} \]

where \( C_0 \) refers to total iron calculated as FeO, Oxygen fugacity calculated for the analysis samples of the Nakajima lavas is low by 0.4 to 0.5 ppm, depending on temperature, but the corresponding values in natural rocks containing FeS only are 0.4 to 0.7 ppm higher than in the supercooled liquids. The higher intrinsic activity of FeS in natural rocks is consistent with the activity of FeS in the supercooled liquids, and the difference is significant.

V 127
ACIDIC FIRST PRINCIPLES: Isotherms for NaCl to 300 kilobars

H. G. W. Brown (Dept. of Geology and Geophysics, University of California, Berkeley, CA 94720)

Baker's equation of state for NaCl, frequently used for pressure calibration, has satisfactory accuracy to pressures of the order of 100 kilobars. We report an attempt to generate accurate theoretical isotherms for NaCl that are reliable to 300 kilobars.

The NaCl isotherm of NaCl is computed with the aid of a first principles calculation of the entropy of the NaCl structure. The Augmented Plane Wave Method was used to obtain the self-consistent band structure. The volume and correlation integrals were approximated by the Multi-Landau potential, and the adjustable parameters were modified. The predicted lattice constant of NaCl is in excellent agreement with the experimental estimates, as are the zero pressure bulk modulus and its pressure derivative. Since the accuracy of the theoretical methods improved with computation, we feel that we have a very accurate NaCl isotherm.

Airborne Sampling of Eruption Clouds of Explosive Volcanoes

Gold Rush B

Friday AM

R. D. Cadle, W. I. Rose, Jr. (Michigan Tech.), Presiding

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ash eruptions in 1970, coincident with the highest SO2 flux of thousands of metric tons per day. In 1970 the rate had dropped to 70 tons per day. Meanwhile, we have measured the beginning of a dramatic new trend. SO2 output is now almost an order of magnitude greater than it was in the 1970's. Simultaneously, the eruptions occurred approximately 20, 50 and 70 years ago and lasted from 5 to 10 years. We are continuing to study this event. These gradual changes in SO2 flux contrast with short-term increases in flux of hours or days, which have preceded ash eruptions at Mt. Etna, Sicily.

V 133 INVITED PAPER

SHINSEI AND CONCENTRATIONS OF VOLCANIC PLUMES MONITORED IN CENTRAL AMERICA AND WESTERN UNITED STATES
RICHARD H. STEINER
Lawrence C. Wellington
Shinley W. Williams (all at Dept. of Earth Sciences, Dartmouth College, Hanover, NH 03755)
M.E. Nunner (Dept. of Biological sciences, Stanford University, Stanford, CA 94305)

The correlation spectrum (COSEP and SO2 detector) have been used both eastward and southward to measure the rate of production and concentration of SO2 in volcanic plumes in Nicaragua, Guatemala, and Washington State. A method of flying at successively lower elevations at a distance downwind from an actively degassing volcano has been developed to determine the pipe thickness and lateral dimensions. These data are the bases for construction of SO2 emitting areas and for cross sections of volcanic plumes at various distances from the vent, the work which will show that the plume usually has a larger cross section than that of the visible vapor plume. Discrete SO2 plumes have been observed at distances greater than 80 km from the volcano.

We have previously used the COSEP for determining the rate of SO2 emission from volcanoes. In addition, we have developed complete concentration profiles horizontally throughout the plume. The concentration directly measures SO2 concentration and has been used simultaneously with the COSEP, the data interpreted, and compared with the COSEP data. The results agree very well.

Concentration distribution in cross sections of the plumes, Nicaragua volcanic plume near areas of 0.6 µgm as per downwind at 37 km. In the actively erupting cloud, newly formed SO2 concentration decreased very slowly due to conversion into SO2.

V 134 INVITED PAPER

GAS ANALYSES OF AIRBORNE SAMPLES FROM ST. HELENS ERUPTION PLUME
R.A. Cates (Air Pollution Research Section, Department of Civil and Environmental Engineering, University of Washington)

Whole air gas samples have been collected in the numerous volcanic eruption plumes of Mt. St. Helens during 1980 and 1981. Air samples were collected using a 2- meter aircraft in collaboration with the U.S. Geological Survey, Scientific Labs and the Department of Energy. The samples have been analyzed for a variety of trace gases with gas chromatography on components such as CO2, C2H2, CO, and CH4, that occur in volcanic emissions. After collection for sample transfer, GC levels ranged from 0.2 to 0.5 ppm. GC levels were further reduced to concentrate the sample, such as CO2, CH4, and CO, as well as other gases of interest, obtained by the various collaborators.

V 135 INVITED PAPER

P. V. HAYES
L. K. TURCOT
D. A. HESS
R. W. ELLIOTT
Jr. F. TULL (all at Cloud and Aerosol Research Group, Dept. of Atmos. Sci. UC-AD, University of Washington)

Extensive airborne measurements have been obtained of the particles and gases emitted during the explosive eruptions of Mt. St. Augustine, Alaska, in 1975 and Mt. St. Helens, Washington, in 1980. Both produced gas-rich plumes representing a range of source materials from gaseous to tephra. The Mt. St. Augustine consisted of three periods of eruption, each with progressive activity (March to April, 1975). Our measurements were made during the period of activity following measurements in April, 1975. Our measurements of the Mt. St. Helens eruption have covered the entire eruption phase and do not include pre-eruptive, eruptive, and post-eruptive phases, and include several of the five major eruptive phases.

The size distributions of particles measured during the two eruptions are remarkably similar. In both cases the particles consist mainly of micron-sized particles (with a small water soluble component). Strongly acidic emissions with a major sub-micron characteristic of the post-eruptive phases of both volcanoes. The largest emissions from Mt. Augustine entered largely 50, until after 1 week after the 25 week entry and this was released 5 at 10 m/s indicated high emission of the sulfur emissions from the volcanic plume was generally similar.

Unlike Mt. St. Augustine, the SO2 emissions from Mt. St. Helens have been monitored at several altitudes and the SO2 concentrations were high in the intra-eruptive phase.

V 136 INVITED PAPER

MAKARAT VULCANO, NEPAL: A MAJOR SOURCE OF THIOURIC SULFUR DURING 1980 AND ITS IMPACT ON THE ADJACENT ENVIRONMENT
D.W. Maunder

The greatest natural contribution of NOx and aerosol to the troposphere in 1980 was believed to have been emitted from Makarot Volcano, Nepal, in late July when similar plume was seen. NOx and the chlorine fluoride gases that react in the atmosphere to form NOx (at 100 pm) NOx from Mt. St. Augustine, the SO2 emissions from Mt. St. Helens have been monitored at several altitudes and the SO2 concentrations were high in the intra-eruptive phase. The largest emissions from Mt. Augustine entered largely 50, until after 1 week after the 25 week entry and this was released 5 at 10 m/s indicated high emission of the sulfur emissions from the volcanic plume was generally similar.

Unlike Mt. St. Augustine, the SO2 emissions from Mt. St. Helens have been monitored at several altitudes and the SO2 concentrations were high in the intra-eruptive phase.

V 137 INVITED PAPER

GAS CHROMATOGRAPHIC DETERMINATION OF SOME CONSTITUENTS OF VOLCANIC GASES
J.P. Cogill
(USGS; 18614, Colorado Springs, CO 80905)

Gas chromatographic analyses have been made of the gases collected from sulfur dioxide during or eruptive eruptions from Basaltic andesite (1978) and Basaltic andesite (1976) in the Yellow River region of China. Gas chromatographic analysis of the gases collected from sulfur dioxide during or eruptive eruptions from Basaltic andesite (1978) and Basaltic andesite (1976) in the Yellow River region of China.

Along the conclusions reached are that the Mt. St. Helens emitted various gases even during the the post-eruptive phase of the eruption. The gases were mainly observed in volcanic gases to almost certainly of no source, and that volcanic gases are only a minor source of carbonaceous matter in the atmosphere.

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V 138

COMPARISON OF AEROSOLS FROM Eruptions OF EASTERN AND WESTERN MT. ST. HELENS
J. P. Cogill (Kernslech Corporation, Costa Mesa, CA 92626)
D. C. Maunder (Cloud Langley Research Center, Hampton, VA 23666)

The results of direct airborne aerosol sampling of eruption clouds from Santalitupa in 1970, are compared with those from the Mt. St. Helens eruptive phase in 1980. There is no measurable (less than 0.1) increase in these samples from Santalitupa in 1970, or from the Mt. St. Helens in 1980. We found to produce a nearly monodisperse aerosol, large (40 µm) to small sizes (1-2 µm), mainly of feldspar. The eruption phase from the Mt. St. Helens in 1980 produced a nearly monodisperse aerosol, large (40 µm) to small sizes (1-2 µm), mainly of feldspar.

V 139

CHARACTERIZATION OF ATMOSPHERIC ASH AND EJECTION FROM Eruptions OF EASTERN AND WESTERN MT. ST. HELENS
J. P. Cogill (NASA Langley Research Center, Hampton, VA 23666)
D. C. Maunder (Kernslech Corporation, Costa Mesa, CA 92626)

Aerosol data on sulfur and aerosol and its distribution, concentration, composition, and optical properties have been obtained in the atmosphere over volcanoes. The aerosol over volcanoes and its distribution, concentration, composition, and optical properties have been obtained in the atmosphere over volcanoes.