DEMONSTRATION OF AN EXPLORATION TECHNIQUE INTEGRATING HIGH-RESOLUTION HYPERSPECTRAL REMOTE SENSING DATA, SOIL GAS SURVEYS, AND FRACTURE INTENSIFICATION DOMAINS FOR THE DETERMINATION OF SUBSURFACE STRUCTURE IN NEW YORK STATE

FINAL REPORT

NYSERDA PROJECT # 4713

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NOTICE

ABSTRACT

Zones of intense fracturing that are associated with fault zones at depth may be identified using hyperspectral remote sensing data obtained from a fixed-wing aircraft-mounted spectrometer. The fracture zones are the surface expression of structures that may produce fractured reservoirs. Normally the surface expressions of these structures are difficult to recognize due to both limited exposure and difficulty of recognition of offset in the thick sequence of interbedded sands and shales. However, extensive data from previous geologic and geophysical studies demonstrated the exisitence and location of fracture zones in Allegany County, New York State. This research project demonstrates that lineamens observed in the hyperspectral data are coicident with the previously identified fractures zones. The principal value of the low-altitude flight hyperspectral data is high resolution (about 3 m per pixel), which allows clear discrimnation between cultural and natural origins of lineaments, and promotes the ability to enhance the recognition of fracture zones through a numerical treatment of the spectral data.

KEY WORDS

Remote sensing, hyperspectral analyses, lineaments, New York State, soil gas analyses, fractures

ACKNOWLEDGMENTS

We are pleased to acknowledge the assistance by our able field crews for collection of soil gas data and structure data. We thank Dr. Smith for assistance in assembling this final report, and we especially thank Dr. John Martin for his support and his viewpoints that added considerably to our discussions.

TABLE OF CONTENTS

LIST OF FIGURES

SUMMARY

The importance of structural control on oil and gas reservoir quality, and in some cases, on even the presence of a play, is well known. However, mapping structural trends by conventional techniques, based on well logs and high resolution seismic data, is often prohibitively expensive, especially 3-D seismic or reconnaissance high-resolution seismic. A primary objective of the research was to test the efficacy of hyperspectral image analyses for identifying lineaments that are associated with fracture intensification domains (FIDs). If such lineaments could be identified in the hyperspectral data, then the location of FIDs that were recognized in outcrop or in soil gas data could be extended away from the outcrop or soil gas spike. Such lineaments provide a rapid, relatively inexpensive method for determining the extent of fractured reservoirs and for determining target areas for more expensive exploration technologies, such as seismic profiling or exploratory drilling.

The specific study area for this research project was in Allegany County, New York State, where Jacobi and Fountain had previously identified faults through an integrated approach that included surface stratigraphy, structure, soil gas analyses, VLF, lineament analyses of images such as Landsat, air photos, topographic maps and SLAR, and subsurface seismic reflection analyses and well log analyses. Subsurface structures identified by this integrative methodology included N-, NE- and NW-striking faults.

The result of the present research showed that low-level flight (high resolution) hyperspectral images do display lineaments, and that the origin of these lineaments can be discriminated between cultlural and natural origins, unlike many of the lineaments identified in the coarser resolution Landsat 7 images. Most of the hyperspectral lineaments correspond to FIDs recognized in the earlier Jacobi and Fountain study, but a few additonal lineaments were found in the hyperspectral data that were never recognized from the previous data sets. Ths present study demonstrates that an integration of hyperspectral lineaments, surface structure and soil gas is an extremely effective method for recognizing subsurface structure and mapping the patterns of these subsurface structures. The method is essentially a "poor-person's 3-D seismic", especially if combined with a confirmation seismic line.

The report that follows is slightly modified from an earlier publication that appeared in 1999; the reference for this earlier publication is: Fountain, John C., Jacobi, Robert D., and Fountain, Matthew J., 1999, Detection of fracture intensification domains using hyperspectral remote

sensing data: A case study in Allegany County, New York: Ontario Petroleum Institute (London, Ontario), 38th Annual Conference, Technical Paper13, 10pp.

INTRODUCTION

This paper describes an enhanced method of utilizing remote sensing data to aid in locating fractured reservoirs. In western New York, as in other portions of the Appalachian Basin, gas production from many units is controlled by the extent of fracturing of reservoir rocks. Thus, recognition of zones of intense fracturing is an essential aspect of exploration and resource evaluation. Although regional fracture sets cut virtually the entire basin, zones of high productivity in fractured reservoirs are restricted to areas of unusually intense fracturing; these zones are typically associated with fault zones. In western New York, the displacement associated with the fault zones has traditionally been thought to die away above the Silurian Salina Group (e.g. Fakundiny et al., 1978), consistent with the apparent minor surface expression of most faults. Although we believe significant offsets at the surface are more common than generally believed (Jacobi and Fountain, 1996), the long-lived perception that most faults in the region have little surface expression is evidence of the difficulty of recognizing the faults at the surface. The surface expression of typical fault zones is confined to zones of intense fracturing, or minor faults with an offset of a few centimeters. These zones, which may be narrow in outcrop (less than 100 m in many cases) and segmented, are difficult to locate with conventional techniques. Such zones have been termed fracture intensification domains (FIDs; Jacobi and Fountain, 1996; Jacobi and Xu, 1998). In this paper, a new procedure for identification of FIDs using hyperspectral analysis is described.

BACKGROUND/APPROACH

It has been well established that remote sensing can be used to help identify fault zones, through recognition of lineaments (e.g., Sabins, 1987). Faults can produce lineaments by many processes; large offsets may juxtapose dissimilar rocks across the fault, vertical offset may cause linear fault scarps, and highly fractured rock may result in high rates of erosion along the fracture trend. Thus topographic lows and streams are often aligned along faults, all of which form lineaments. Of course lineaments may have many other origins, including roads, property boundaries and dozens of other anthropogenic influences. Nonetheless, remote sensing has had much success in finding major fault systems.

In western New York, however, recognition of faults through lineament analysis is difficult, not only due to the weak surface expression of many fault systems but also due to complications resulting from the fact that there are typically at least two, and often more, regional fracture systems in each area, each of which may produce lineaments.

The method described in this paper has thus been designed to address two major problems with the traditional remote sensing approaches:

1: Fault zones in western New York have been shown to be characterized by narrow (in cases less than 10 m) outcrops of intense fracturing (fracture intensification zones or FIDs), and may not always form long persistent zones. Thus a resolution on the scale of a few m is necessary to detect some FIDs.

2: A rigorous lineament analysis usually finds many (hundreds to thousands) of lineaments, discrimination of which, if any, correspond to the desired fault zone is an onerous task. As the resolution of the lineament analysis increases, the number of lineaments found in a given area increases. Thus high-resolution remote sensing methods typically identify more lineaments than can readily be field checked.

HYPERSPECTRAL DATA

For this project, Jacobi and Fountain used hyperspectral data collected from a fixed-wing aircraft-mounted spectrometer from GER (Geophysical & Environmental Research, Corp., Millbrook, NY, see Appendix A). The goal was to test whether a procedure could be developed to reduce the number of lineaments identified, but still maintain appropriate scale and sensitivity. Jacobi and Fountain employed the low-altitude aircraft-mounted spectrometer technique in order to obtain the desired resolution. Jacobi and Fountain wanted to have the potential of resolving fracture zones as narrow as 10 meters, requiring a pixel size of the same order. In addition, the high resolution would provide easier determination of the origin of many of the lineaments.

The spectrometer used a continuous scanning hyperspectral analyzer with 30 channels covering the visual and infrared spectrum. Data were obtained at two flight elevations (height above average ground surface), 885 m (2,900 ft) and 8,900 ft. At an elevation of 885 m (2,900 feet), the scan width was approximately 1,530 m (5,030 ft), with 512 pixels per scan, resulting in a pixel width of approximately 3 m (10 ft). At an elevation of 2,710 m (8,900 ft), the swath width was about 4,700 m (15,400 ft), yielding a pixel width of about 9 m (30 ft). In comparison, conventional Landsat TM data has a resolution of about 30 m (Sabins, 1987).

STUDY AREA

Data were acquired in two portions of Allegany County, New York (Figure 1), an area in which Jacobi and Fountain (1996) recently completed an intensive structural study. Also shown on Figure 1 is the trend of one of the main branches of the Clarendon-Linden Fault System which resulted in many of the north-trending structures in the study area. Data acquired in Jacobi and Fountain's (1996) earlier study included detailed structural and stratigraphic measurements on more than 1200 outcrops, 75 miles of seismic lines, well log and soil gas data, as well as topographic lineament analysis (Figure 2). Over 75,000 fractures were measured in the study. Two flight lines were selected for this study (Figure 3) to cover areas of multiple FIDs that were recognized in the earlier study; the flight lines were also planned so that they crossed at least one seismic line. The extensive existing studies thus allowed detailed verification of lineament identified in this reserch project.

An existing study by Earthsat (Earthsat, 1997) utilized Landsat TM imagery for identification of fractures in the New York State. This study, which has provided a high quality lineament analysis of the Appalachian Basin in New York, gives an idea of the number of lineaments that one obtains through remote sensing (Figure 4). The lineaments reported by Earthsat's (1997) study for Allegany County are shown in Figure 5. Although this study was on the scale of entire state it still found a formidable number of lineaments to evaluate, even when considering only a small area.

The major lineaments noted on the Earthsat (1997) study on the western edge of the county correspond to the Rawson Valley area, where one of the two flight-lines was planned for this study, and in which Jacobi and Fountain (1996) found FIDs on the ground. The area over which the second flight was made, in the north central part of the county (Figure 3), does not correspond with an area of north-south fractures on the Earthsat (1997) study. However seismic, outcrop and well log data (discussed in a later section) have confirmed the presence of a fault zone and related FIDs in this zone (Jacobi and Fountain, 1996). Apparently the lineaments associated with the FIDs in this area were not detected by the Landsat analysis.

METHOD DEVELOPMENT

A lineament analysis can be made using existing techniques that could identify smaller features. However, if the lineament analysis is refined with a higher resolution image, for example by using a 7.5' topographic map as the image for lineament analysis, the density of the lineaments becomes proportionately higher (Figure 6). This figure contains topographic lineaments of one 7.5' topographic quadrangle in Allegany County (Houghton quadrangle; Wawrznski and Jacobi, 1992; Jacobi and Fountain, 1996). Although lineament analysis of 7.5' topopgrpahic maps can easily identify topographic lineaments as short as 100m, there is no rapid way to evaluate the origin of the thousands lineaments thus identified. This increase in number of lineaments with increased sensitivity illustrates the need for the paired objectives of this study, to develop a method that is both sensitive and selective.

Hyperspectral analysis utilizes more channels of data (the dataset for this study included 30 channels covering the visible and infrared spectrum, compared to 7 for Landsat TM). In theory this provides more sensitivity than data with fewer channels since individual channels may show much stronger response to various factors than the averaging that rsults with the wider bands of more traditional imaging. However it also poses a greater problem of processing the data, for there is so much more data to evaluate. There are many approaches at developing a scheme for lineament recognition. The methodology in this study was formulated for the specific objectives of this study, to recognize the FIDs in the study area.

The approach was to select several areas on the flight lines where Jacobi and Fountain (1996) have established from previous studies that FIDs exist, then select a processing procedure that made the FIDs highly recognizable on the images. This procedure was then applied to the remainder of the study area. The raw data was first corrected for aircraft motion by GER and then processed by the University at Buffalo Rock Fracture Group using the program ENVI (Better Solutions Consulting Limited Liability Company, Lafayette, CO). Three bands (#13, 14 and 15: 670, 689 and 708 nm respectively) showed each FID clearly, while band 30 (infrared, 10,000 nm) did not show the FIDs. Bands 13, 14 and 15 are all within the red portion of the visual spectrum. The three bands were thus summed and band 30 subtracted. The images were then edge-enhanced with a non-directional edge-enhancement routine in ENVI. The contrast of the resulting image was adjusted by stretching. This technique was then applied to each image.

To determine if this technique is capable of identifying FIDs, the technique was then applied to each of the flight lines. An operator who was not familiar with the geology of the area was instructed in the technique and asked to identify all lineaments that were prominent after processing, and that were not associated with an obvious non-geologic origin (field edges, roads etc.). Prior to this test, a list of known FIDs in the area was compiled. In evaluating the origin of the lineaments, the high-resolution images were of immense help. It is clear on these images which lineaments are associated with cultural features such as field boundaries, roads, and other non-geologic origins.

RESULTS

The resolution of the data is compared to Landsat TM data in Figures 7 and 8. Figure 7 shows the north shore of Rushford Lake on a Landsat image; Figure 8 shows the same scene using the data from this study. In each case, a single channel, selected for the best resolution of this image, was used. It may readily be seen from these two figures that while many lineaments may be recognized in the LandSat data, it is usually difficult to determine the origin of the lineaments. In contrast, one can see in Figure 8 that the origins of most lineaments are readily apparent in the hyperspectral image.

A demonstration of the increased ability to recognize lineaments in the hyperspectral data compared to the Landst 7 data can be seen in Figure 9. This figure diplays an unprocessed hyperspectral image from an area with a FID previously identified by Jacobi and Fountain (1996). This FID cannot be recognized in Landsat images, but a number of lineaments can readily be seen in figure 9. Although the high-resolution of the image allows identification of many of the lineaments as field edges, about a half dozen strong lineaments would require further evaluation. Figure 10 shows the same image with our processing applied. Here there are only two strong lineaments, one of which is clearly related to a field boundary, the other is apparently not related to any obvious origin. The second lineament, marked by the arrow in Figure 10, is an FID. The very strong lineament of the FID is obvious, and the lineament is not associated with any obvious cultural cause such as a road or field edge. As a further check of lineaments, the topography can be compared with the lineament by overlaying a digitized USGS topographic map. The FIDs are almost invariably associated with topographic lineaments, whereas many of the field boundaries and other man-made lineaments are not.

The correspondence of lineaments identified by this study's method and faulting is confirmed by a seismic line shot across the lineament (see Figure 3 for the location of the seismic lines). Figure 15 is a seismic section along the lineament, which shows clear offset at depth (Jacobi and Fountain, 1996; 1998). It is important to note that there was no outcrop near this lineament, thus it could not have been identified as an FID by conventional mapping techniques.

Another example of the processing technique developed for this study is shown in Figure 11, which is an image of another area with two known FIDs. Although a NE-trending lineament can be seen (marked by an arrow in Figure 11), a NW-trending lineament (which is evident on the ground as a dry valley) cannot be seen, even on a large high-resolution print of this image. After processing (Figure 12), one can see that there are two intersecting lineaments (the lines on figure

12 are added for clarity; they are parallel to the lineaments, but offset slightly so that they do not obscure the anomalies). A seismic line (not shown) from a study by the New York State Geological Survey (Fakundiny et al., 1978), located very near these valleys found about 77m of offset of the basement, confirming these lineaments are associated with major faulting.

Similar results were found on the Rawson Valley flight line. In this case several areas of known FIDs were located too far from the flight path to be imaged by the low level flight (which has about a 1 mile swath) and thus the high elevation data was used. Figure 13 shows an unprocessed image of one area with known FIDs. After processing, distinct lineaments may be seen on both sides of the valley (Figure 14: again for clarity the lines are offset the lineaments). Excellent outcrop on the valley sides allowed direct comparison of the lineaments to fracture orientation and density. The master fractures, which elsewhere in the area area are NW- or NE-striking, were oriented north-south in Rawson Valley, as were the lineaments. The lineament on the right side of the photo corresponds to one of the zones with the highest frequency of N-strking frcatures (Figure 16), and the lineament on the left to the other zone. A seismic line shot across the valley confirmed that the FIDs found in outcrop, topographic lineaments, and the lineaments found by our processing, all correspond to faulting at depth (Figure 16).

To evaluate the process we compiled a list of 12 known FIDs along the flight lines. Our analysis of the hyperspectral data found all 12 of these FIDs. In addition, several other lineaments were identified in areas with little other data. These lineaments occured in zones defined by north-south topographic lineaments that are probably also FIDs. It should be noted that the flight lines were selected to follow bands of known FIDs, thus the probability of a hypewrspectral lineament being associated with FIDs was higher than normal. However, the superb visual resolution of the images was primarily responsible for the ability to eliminate most cultural-related lineaments from further consideration.

CONCLUSIONS

The use of high resolution (approximately 3 m per pixel) hyperspectral images, combined with simple processing, allows rapid identification of zones of intense fracturing. The technique works even where outcrop is poor to nonexistent and where the surface expressions of the faults are not well developed.

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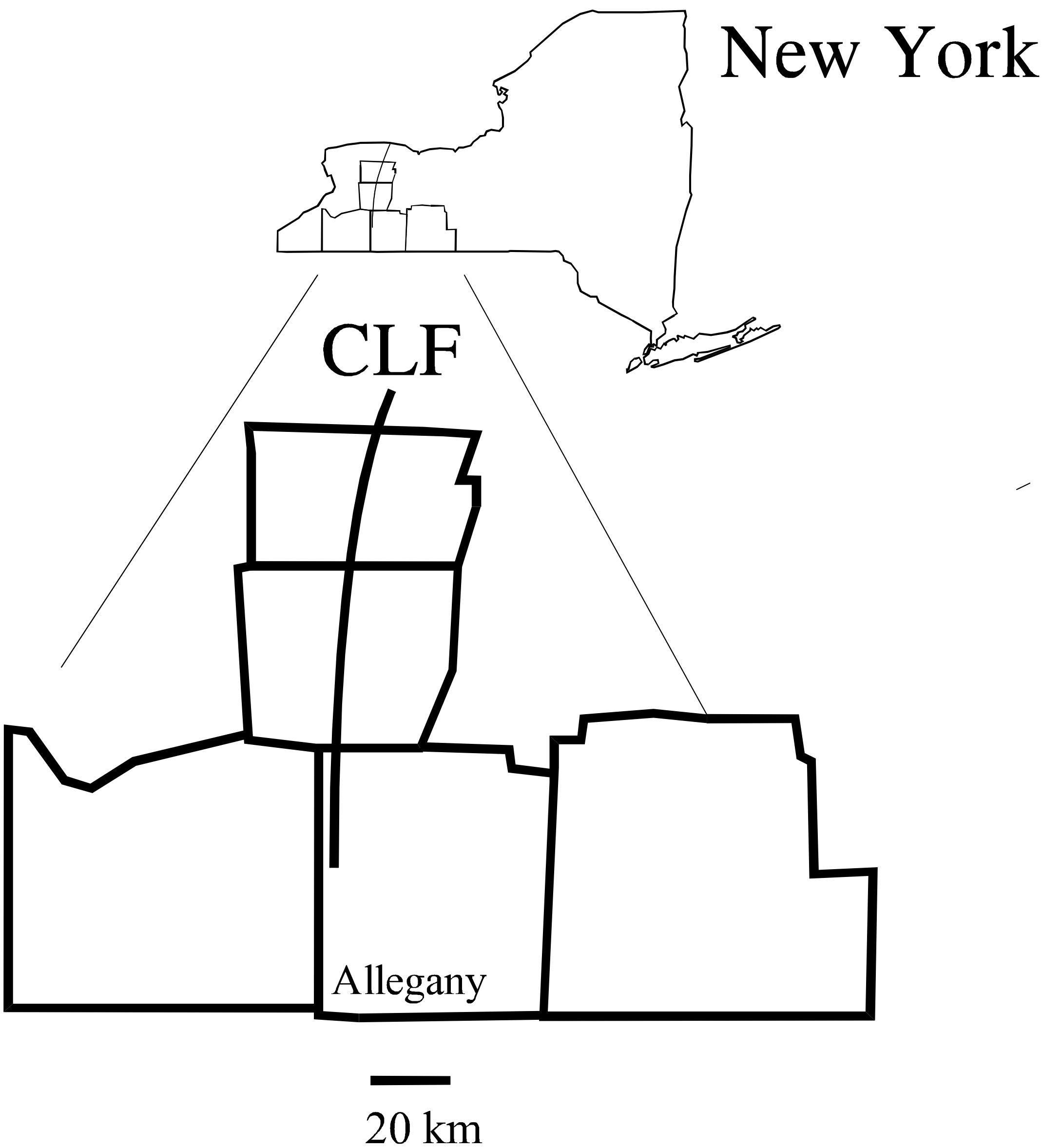

Figure 1. Location of Allegany County, New York. The Clarendon-Linden Fault System is labeled CLF.

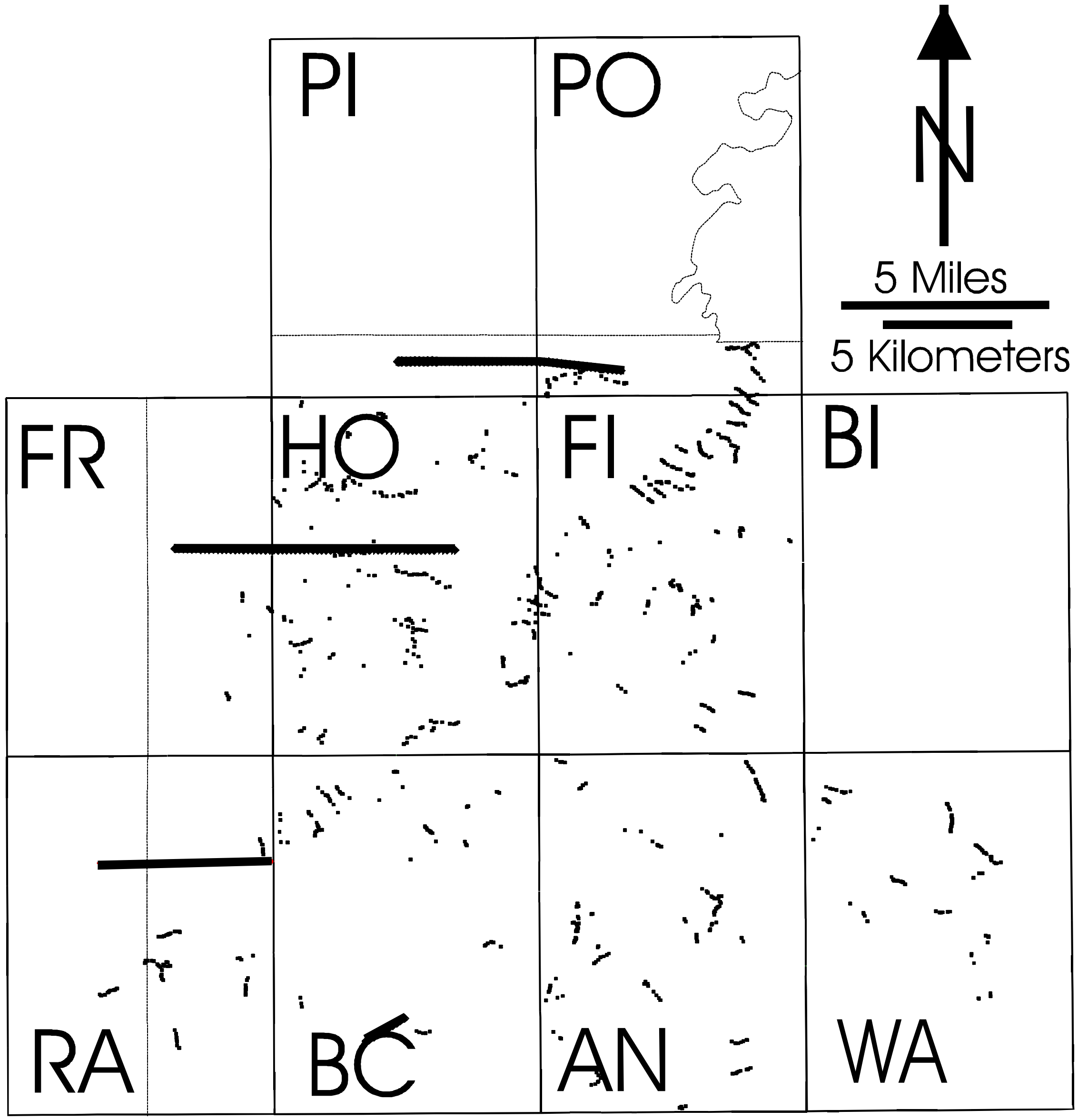

Figure 2. Location of sites in Allegany County for which structural and stratigraphic data are available (Jacobi and Fountain, 1996). Dashed lines are county lines, heavy black lines are seismic lines. The northern line is Wiscoy (Figure 15) and the southern line is Rawson (Figure 6).Quadrangles: PI: Pike, PO Portageville, FR: Freedom, HO: Houghton, FI: Fillmore, BI: Birdsall, RA: Rawson, AN Angelica, BC: Black Creek, WA: West Almond.

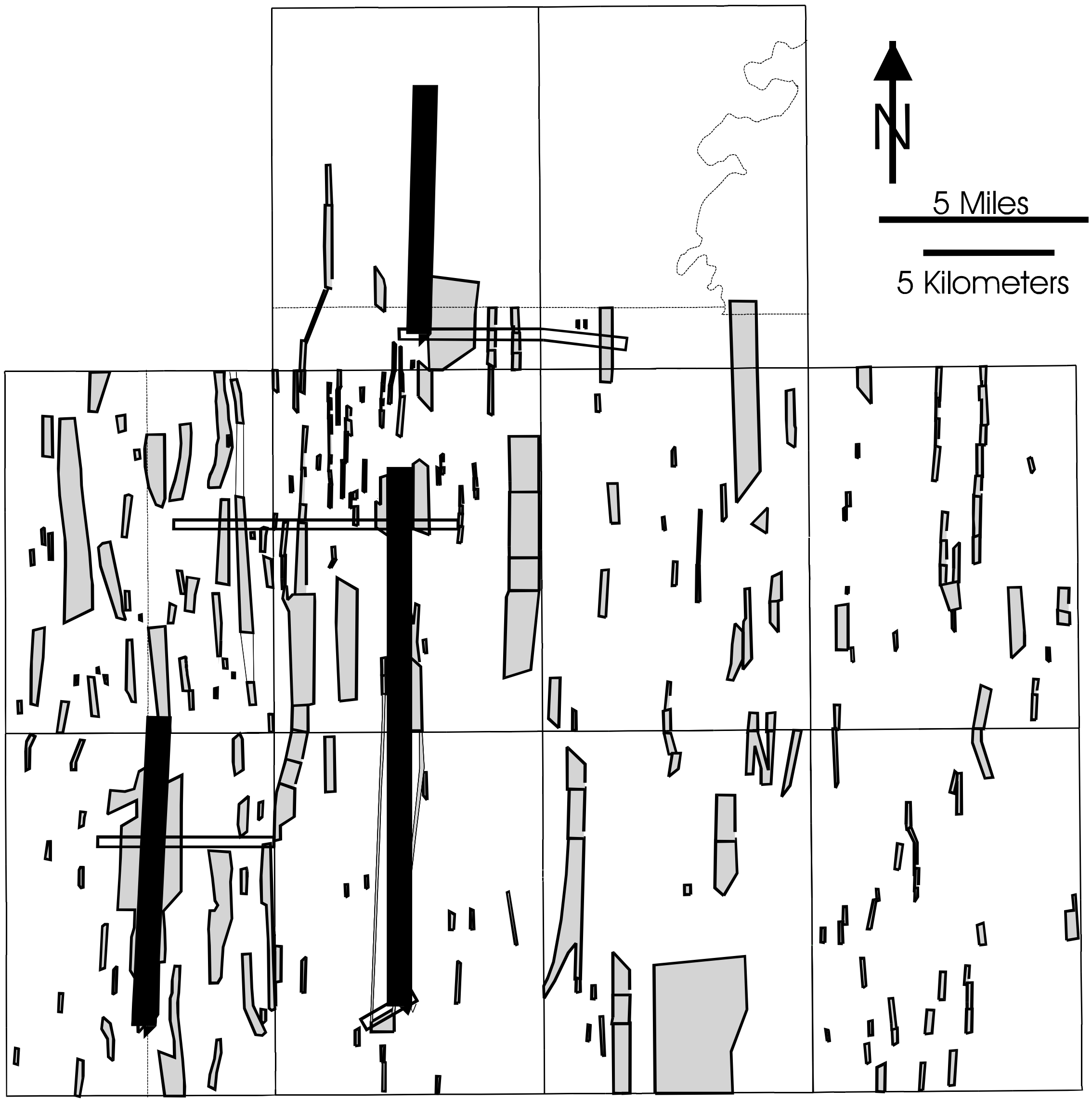

Figure 3. Location of Flight Lines (heavy black lines). The gray boxes are north-trending FIDs (Jacobi and Fountain, 1996; Peters and Jacobi, 1997; Zack and Jacobi, 1997; Jacobi and Xu, 1998). Open boxes are seismic lines.

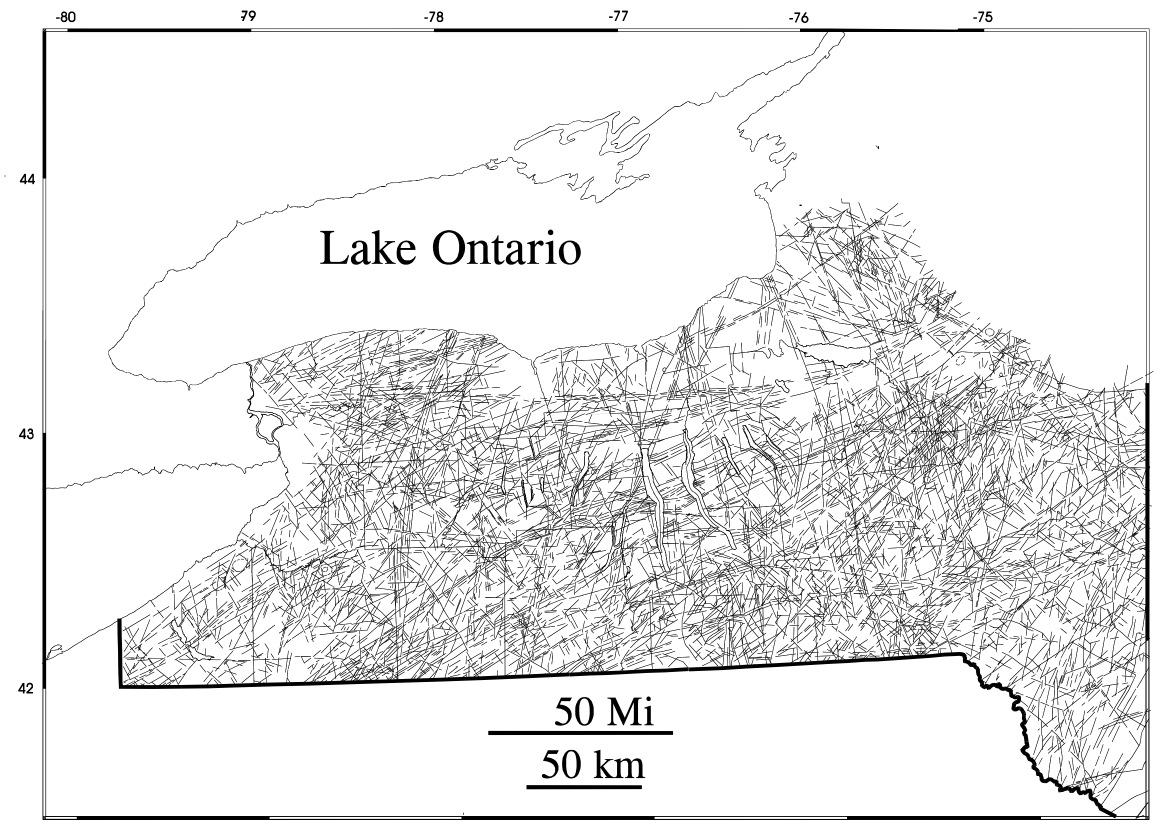

Figure 4. Lineaments in New York State from Earthsat (1997).

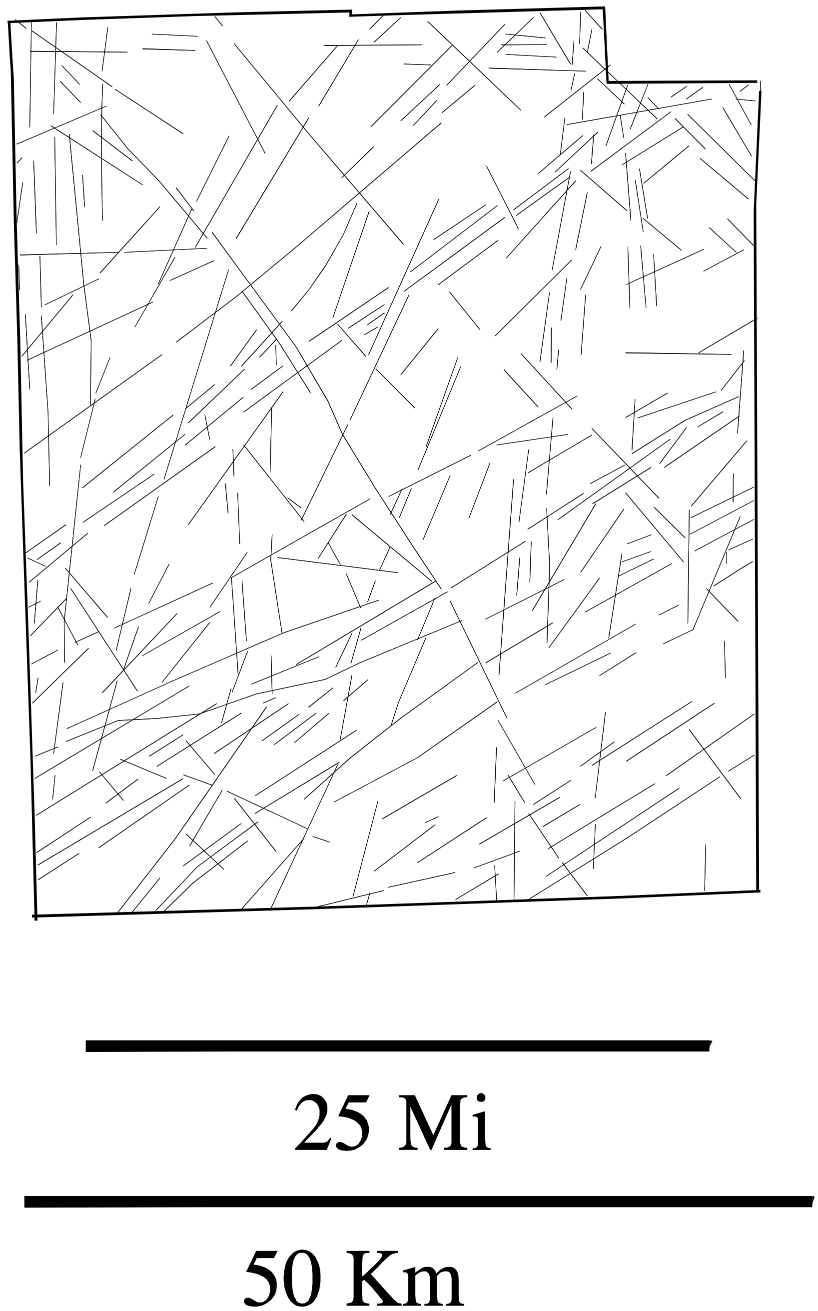

Figure 5. Earthsat (1997) Lineaments in Allegany County. North at top of figure.

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Figure 6. Topographic lineaments in the 7.5' Houghton Quadrangle (from Wawrzynski and Jacobi, 1992). North at top of figure. Distance across base of map is 10.2 km (6.36 mi).

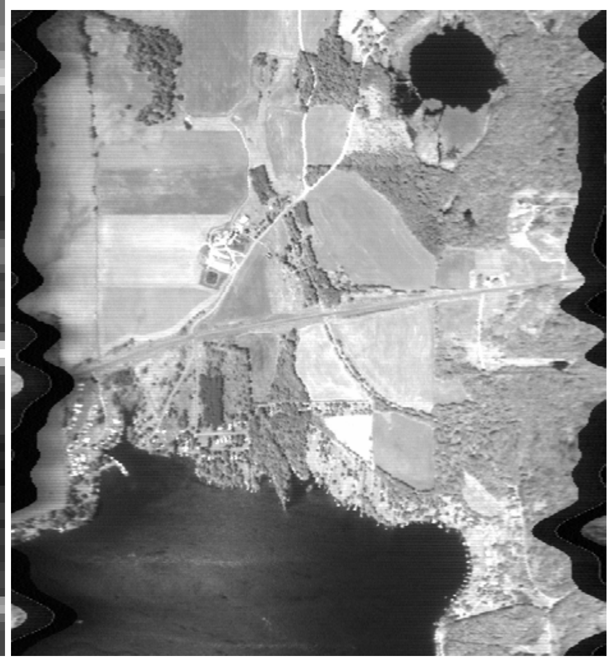

Figure 7. Landsat TM Image of the north shore of Rushford Lake. Image is approximately 1.6 km (1 mi) across. North at top of image.

Figure 8. Hyperspectral image of the north shore of Rushford Lake. Image is approximately 1.6 km (1 mi) across. North at top of image.

Figure 9. Hyperspectral image. Width of image approximately 1.6 km (1 mile). North at top of image.

Figure 10. Area shown in Figure 9, after processing. Arrow is aligned with FID. Width of image approximately 1.6 km (1 mi).

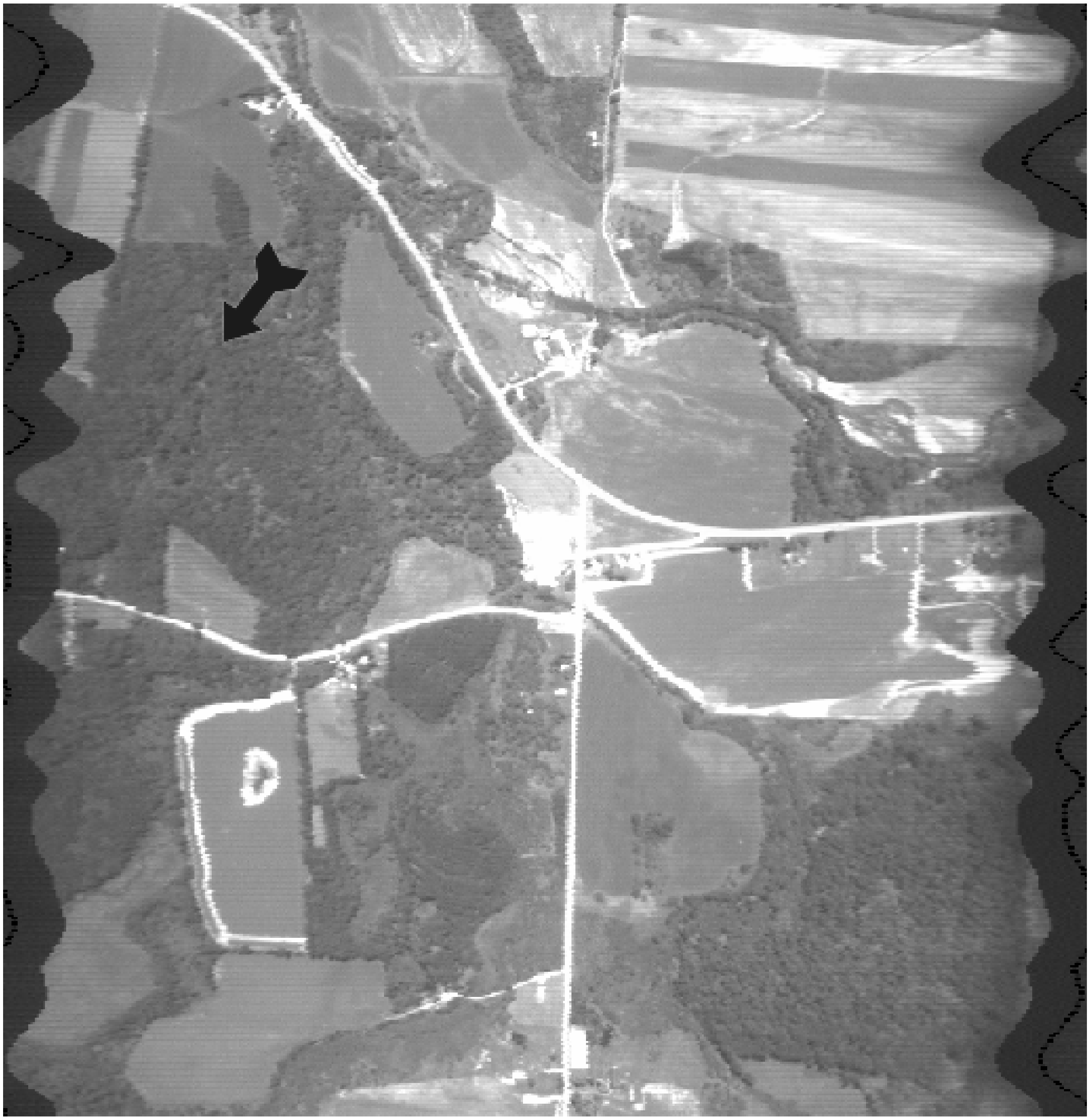

Figure 11. Hyperspectral Image near Pike, New York. North is at base of image. Arrow points to lineament. Width of image is approximately 1.6 km (1 mi).

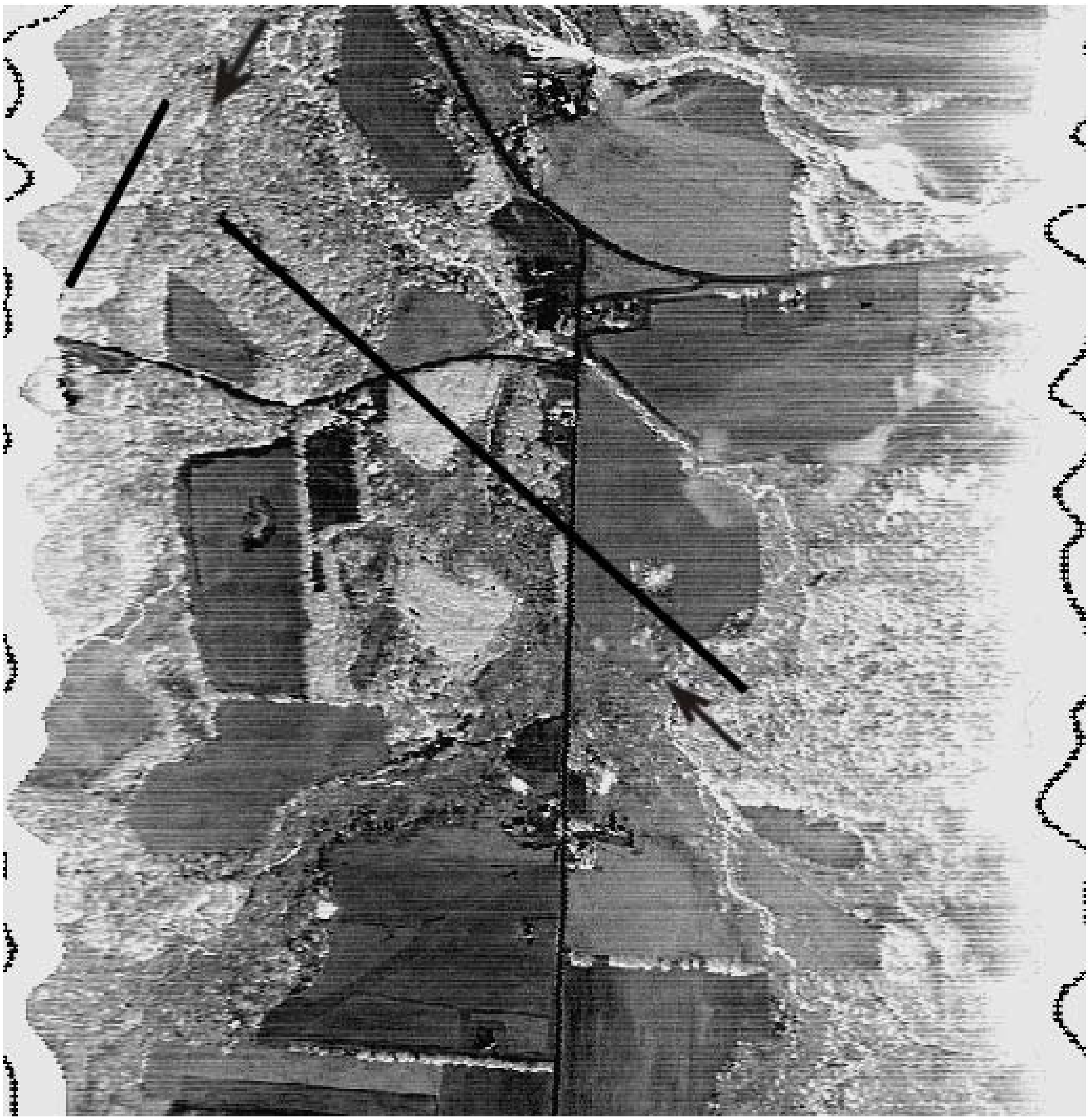

Figure 12. Scene in Figure 12 after processing. North is at base of the image. Image is approximately 1.6 km (1 mi) wide. Note that for clarity the black lines denoting lineaments are offset from actual lineaments on the image. Arrows point to locations of the actual lineaments

Figure 13. Hyperspectral high-elevation image of Rawson Valley. North is at the base of the image. Width of image is approximately 4.8 km (3 mi).

Figure 14. Processed version of Figure 13. North at base of image. Width of image is approximately 4.55 km (2.8 mi). Note that for clarity the black lines denoting lineaments are offset from actual lineaments on the image.

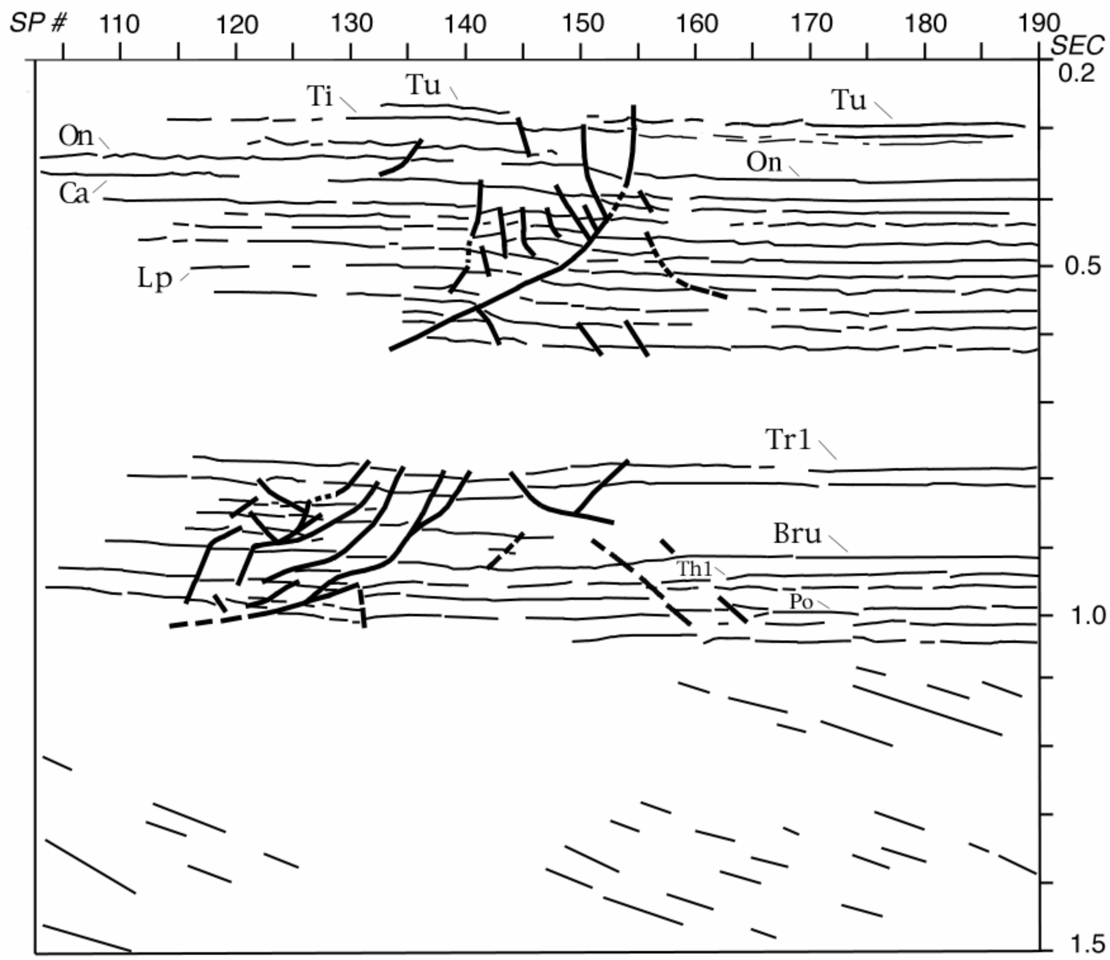

Figure 15. Wiscoy interpreted seismic section. (From Jacobi and Fountain, 1998)

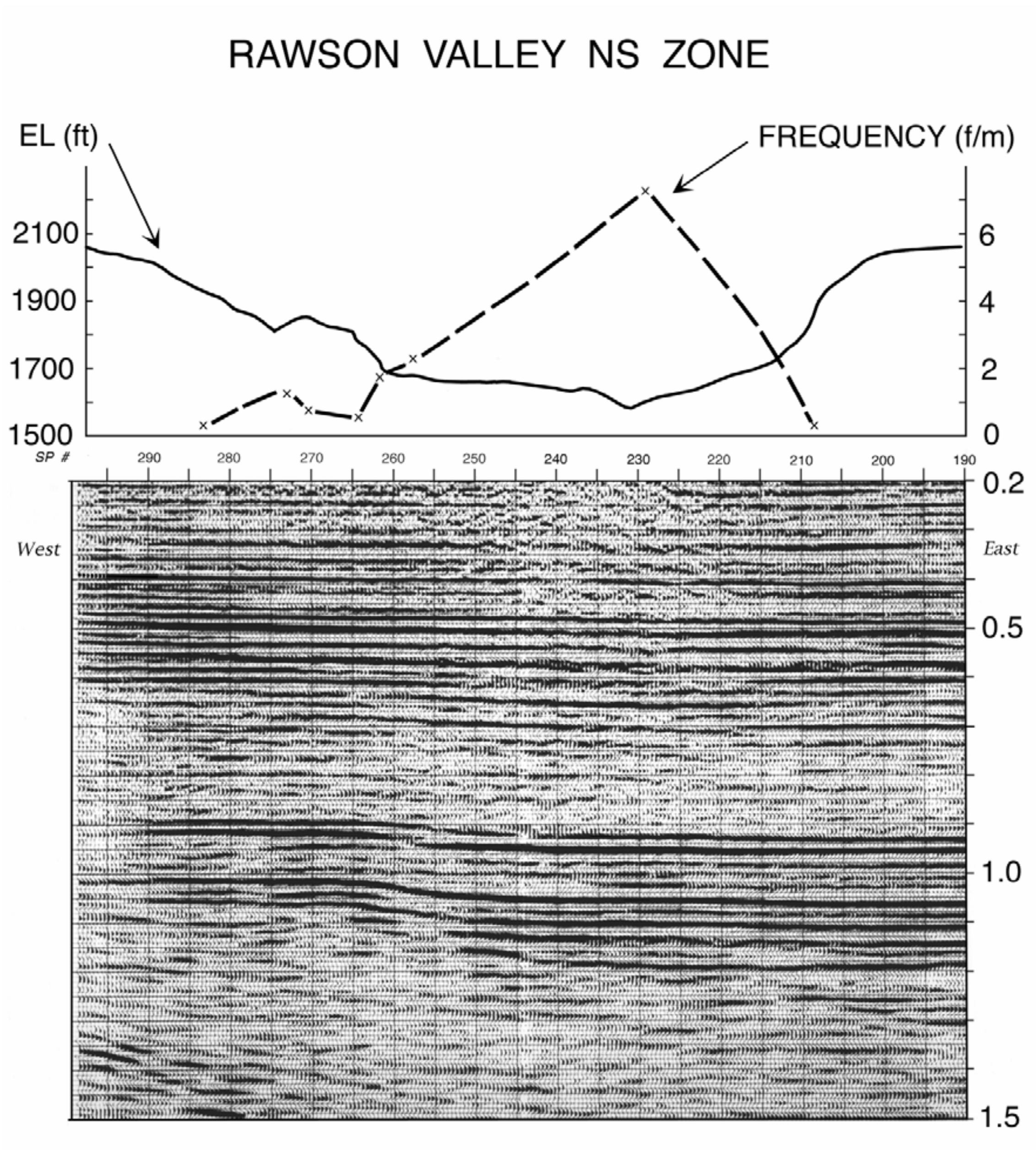

Figure 16. Rawson seismic section. Topography and fracture frequency across Rawson Valley also shown. (From Jacobi and Xu, 1998)

APPENDIX A

AIRBORNE REMOTE SENSING SURVEY REPORT

from

GEOPHYSICAL AND ENVIRONMENTAL RESEARCH CORPORATION

to

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AIRBORNE REMOTE SENSING SURVEY REPORT

The Research Foundation of State University of New York

Purchase Order Number R92213

1 April, 1999

Mission Summary

Following is a list of the flight lines flown in July 1998. The accompanying maps show the associated waypoints and their coordinates

Line 1	Rawson	Low altitude
Line 2	Pike	Low altitude
Line 3	Rawson	High altitude
Line 4	Houghton	High altitude
Line 5	Pike	High altitude
Line 6	Houghton	Low altitude

All flight lines were flown at a groundspeed of 110 knots, and in a south to north direction. The low altitude lines were flown at a height of 2900' above average ground elevation giving a resolution of about 2.5 m. The high altitude lines were flown at a height of 8900' above average terrain elevation for a pixel size of about 8.5 m. The corresponding swath widths are approximately 1530 and 4700 m (5030 and 15440')

Data CD-ROMs

Enclosed please find 7 CD-ROMs with the data files from the July 1998 airborne remote sensing survey. The files on the CD-ROMs are listed below:

Processed data

CD-1 NYSERDA-1

file 1	g37.980713.t1f01.bgps	Rawson low
file 2	g37.980713.t1f01.bgps.hdr	
file 3	g37.980713.t2f01.bgps	Pike low
file 4	g37.980713.t2f01.bgps.hdr	

CD-2 NYSERDA-2

file 1	g37.980713.t2f02.bgps	Rawson high
file 2	g37.980713.t2f02.bgps.hdr	
file 3	g37.980713.t2f03.bgps	Houghton high
file 4	g37.980713.t2f03.bgps.hdr	
file 5	g37.980713.t2f04.bgps	Pike high
file 6	g37.980713.t2f04.bgps.hdr	

CD-3	NYSERDA-3	
file 1	g37.980714.t1f01a.bgps	Houghton low south half
file 2	g37.980714.t1f01a.bgps.hdr	
file 3	g37.980714.t1f01b.bgps	Houghton low north half
file 4	g37.980714.t1f01b.dgps.hdr	

raw data

CD-4	NYSERDA-4	
file 1	g37.980713.t1f01.32.raw	Rawson low
file 2	g37.980713.t1f01.32.raw.hdr	
file 3	g37.980714.t1f01.32.raw	Houghton low
file 4	g37.980714.t1f01.32.raw.hdr	
CD-5	NYSERDA-5	
file 1	g37.980713.t2f01.32.raw	Pike low
file 2	g37.980713.t2f01.32.raw.hdr	
file 3	g37.980713.t2f02.32.raw	Rawson high
file 4	g37.980713.t2f02.32.raw.hdr	
file 5	g37.980713.t2f03.32.raw	Houghton high
file 6	g37.980713.t2f03.32.raw.hdr	
file 7	g37.980713.t2f04.32.raw	Pike high
file 8	g37.980713.t2f04.32.raw.hdr	

waveform data

CD-6	NYSERDA-CH-1	
file 1	g37.980713.t1f01.vch	Rawson low
file 2	g37.980713.t1f01.vch.hdr	
file 3	g37.980714.t1f01a.vch	Houghton low south half
file 4	g37.980714.t1f01a.vch.hdr	
file 5	g37.980714.t1f01b.vch	Houghton low north half
file 6	g37.980714.t1f01b.vch.hdr	
CD-7	NYSERDA-CH-2	
file 1	g37.980713.t2f01.vch	Pike low
file 2	g37.980713.t2f01.vch.hdr	
file 3	g37.980713.t2f02.vch	Rawson high
file 4	g37.980713.t2f02.vch.hdr	

file 5	g37.980713.t2f03.vch	Houghton high
file 6	g37.980713.t2f03.vch.hdr	
file 7	g37.980713.t2f04.vch	Pike high
file 8	g37.980713.t2f04.vch.hdr	

Please note that due to its size the Houghton Low files have been split into north and south halves in the processed and waveform data.

File nomenclature

The fields of the file name are assigned as follows:

field 1	g37	scanner name GER DAIS 3715
field 2	980713	date July 13, 1998
field 3	t1f01	original as recorded tape and file number on that tape these are for GER internal purposes and do not match the file numbers on the CD-ROMs.
field 4	32.raw	32 bands of raw data
	bgps	30 bands of processed data
	vch	27 bands of waveform transform data
field 5	hdr	ENVI header associated with corresponding data file

Data Processing Steps Performed on the Data

The following steps are performed on the raw data, in sequence:

Baseline subtraction.

The average value of pixels 533 to 540 is subtracted from each scan line.

Gyro roll correction.

The image is corrected for aircraft roll using the roll gyro data recorded in channel 31 as follows:

- gyro count of each scan line is calculated by averaging the channel 31 gyro data of pixels 100 through 350
- an average gyro count for the whole image is calculated using the average gyro count for each scan line, and established as the reference point for line shifting
- the difference between the average value for the entire flight line and the value for each individual scan line is used to shift the scan line to its proper location
- the conversion factor is 42 gyro counts for a one pixel shift

Panoramic correction.

Each scan line is resampled so that each pixel is converted from a fixed scan angle datum to a fixed ground distance datum. The scan angle is 81.92° and is sampled by 512 pixels.

Waveform transform

GER proprietary waveform analysis is applied to the processed data.

GER DAIS 3715 System Specifications

The GER DAIS 3715 Spectrometer is an airborne unit designed to acquire spectral information for mineral exploration, vegetation mapping, environmental monitoring, and thermal imaging. A Kennedy type scanner is used to acquire the images; which are formed at the entrance slit to the spectrometer. A schematic of the instrument is shown in Figure 1.

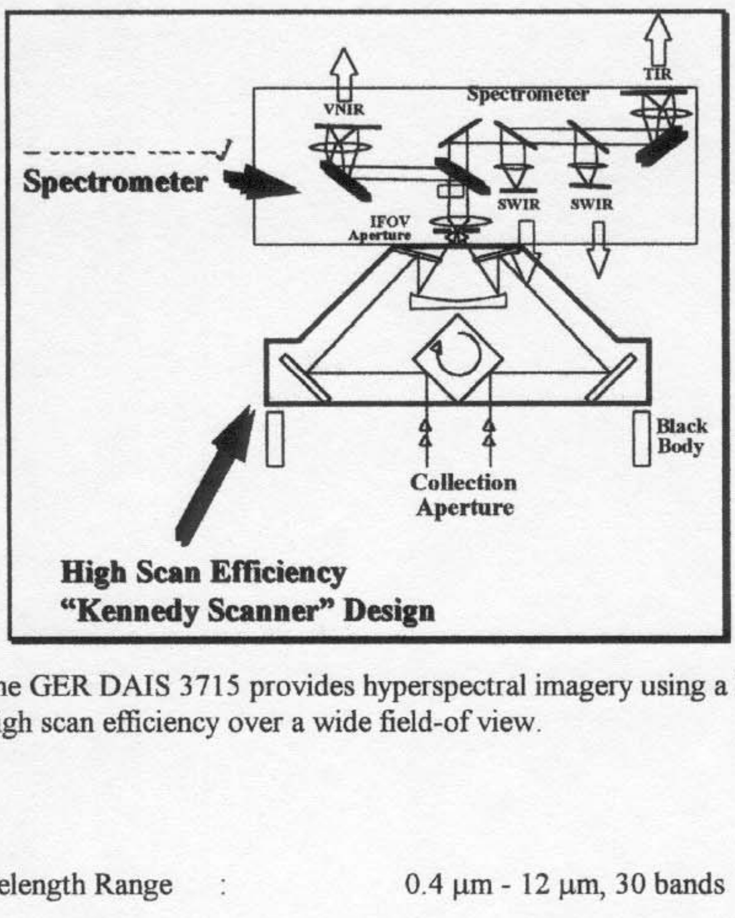


Figure 1. The GER DAIS 3715 provides hyperspectral imagery using a Kennedy Scanner to achieve high scan efficiency over a wide field-of view.

Wavelength Range : 0.4 µm - 12 µm, 30 bands

a.	0.4 µm - 1.0 µm	:	28 bands	bandwidth = 16 nm
b.	1.0 µm - 1.8 µm	:	1 band	bandwidth = 800 nm

c. 8.0 μm - 12.0 μm : 1 band bandwidth = 4000 nm

The appropriate band positions are shown in the accompanying calibration report.

Aperture	:	6.0 mrad IFOV at 3.3 mrad sampling
Swath Angle	:	81.92° (8 km swath at 5 km altitude)
Scan Speed	:	up to 33 Hz
Detectors	:	Si, InSb, and MCT
Recorder	:	DLT cartridge tape drive

Wavelength Calibration

Raw Data Channel Number	Processed Data Channel Number	Wavelength Center (nm)
1	1	460.66
2	2	476.85
3	3	493.27
4	4	509.92
5	5	526.80
6	6	543.91
7	7	561.25
8	8	578.81
9	9	596.61
10	10	614.64
11	11	632.90
12	12	651.38
13	13	670.10
14	14	689.04
15	15	708.22
16	16	727.62
17	17	747.26
18	18	767.12
19	19	787.21
20	20	807.54
21	21	828.09
22	22	848.87
23	23	869.88

24	24	891.12
25	25	912.59
26	26	934.29
27	27	356.22
28	28	978.38
29	29	1300
30	30	10000
31		roll gyro
32		pitch gyro and GPS

GPS Data

GPS data were downloaded from the aircraft's Trimble TNL-2000T via RS-232 and are recorded on channel 32 of the raw data.

When retrieving the GPS data, channel 32 should be read as byte data instead of integer data. Each scan line has 1088 bytes. The GPS data start at byte 1017.

Due to space limitations, only the first 10 fields of data from the Trimble are recorded. These are Item Designators A (latitude) through J (active leg number) in the accompanying Trimble data output documentation.

The following table lists the byte number corresponding to the Trimble Item Designators.

Trimble Item Designator	Channel 40 byte number
A	1017
B	1030
C	1042
D	1045
E	1052
F	1060
G	1066
H	1071
I	1080
J	1086

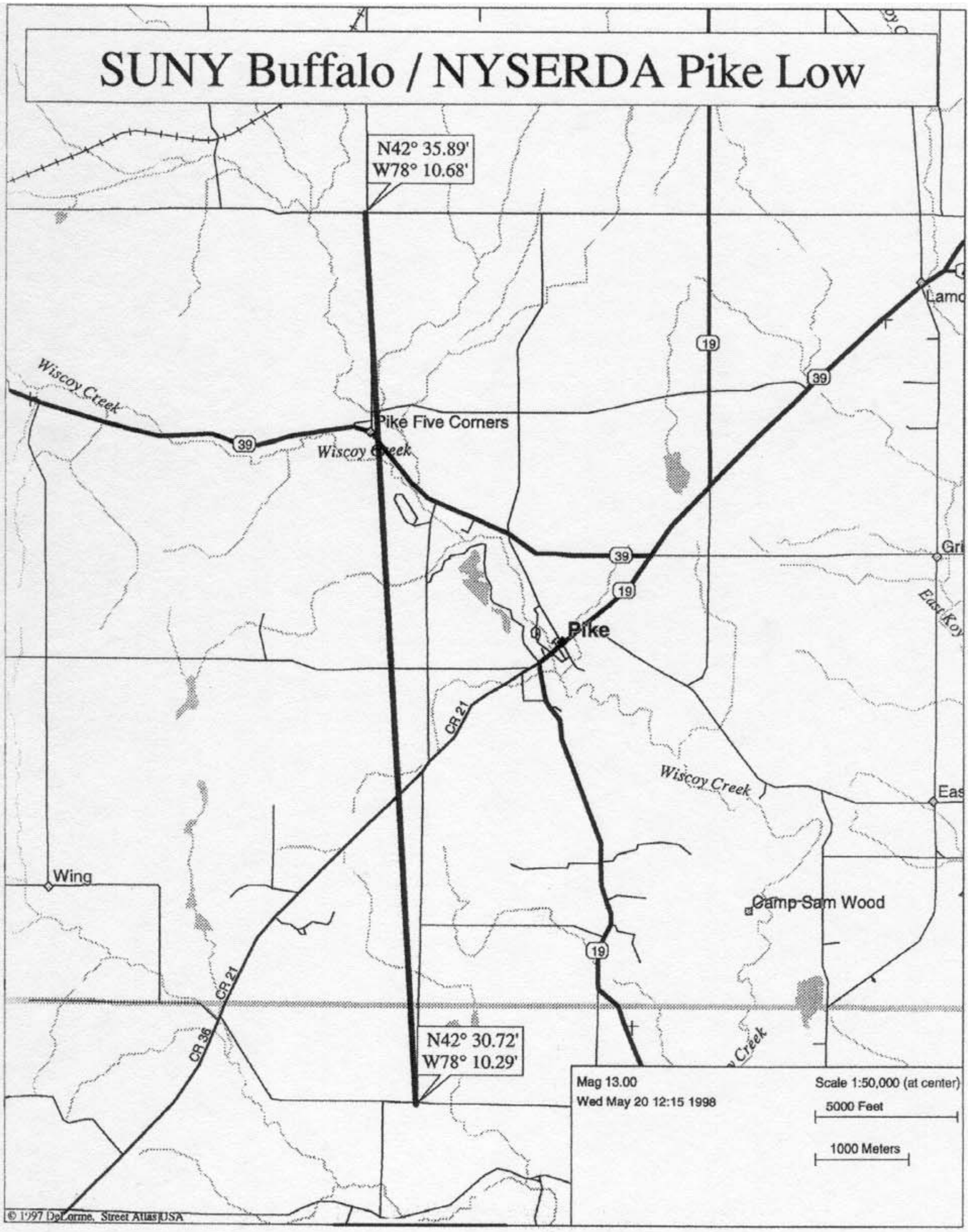
Gyro Data

Roll gyro in channel 31

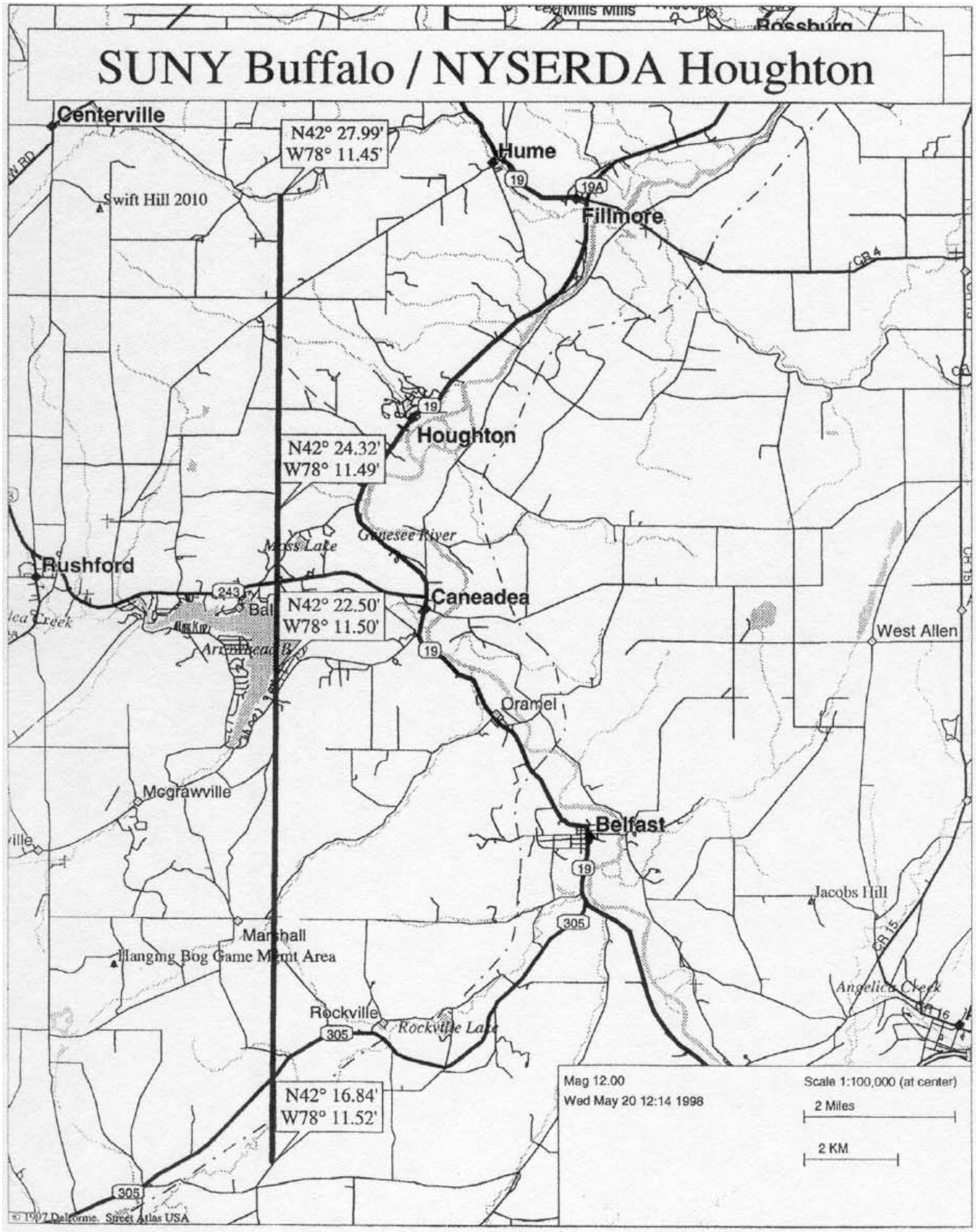
The roll gyro signal is recorded in channel 31 of the raw data, in synchronization with the image data. The processing of the roll gyro data is described in the Data Processing section.

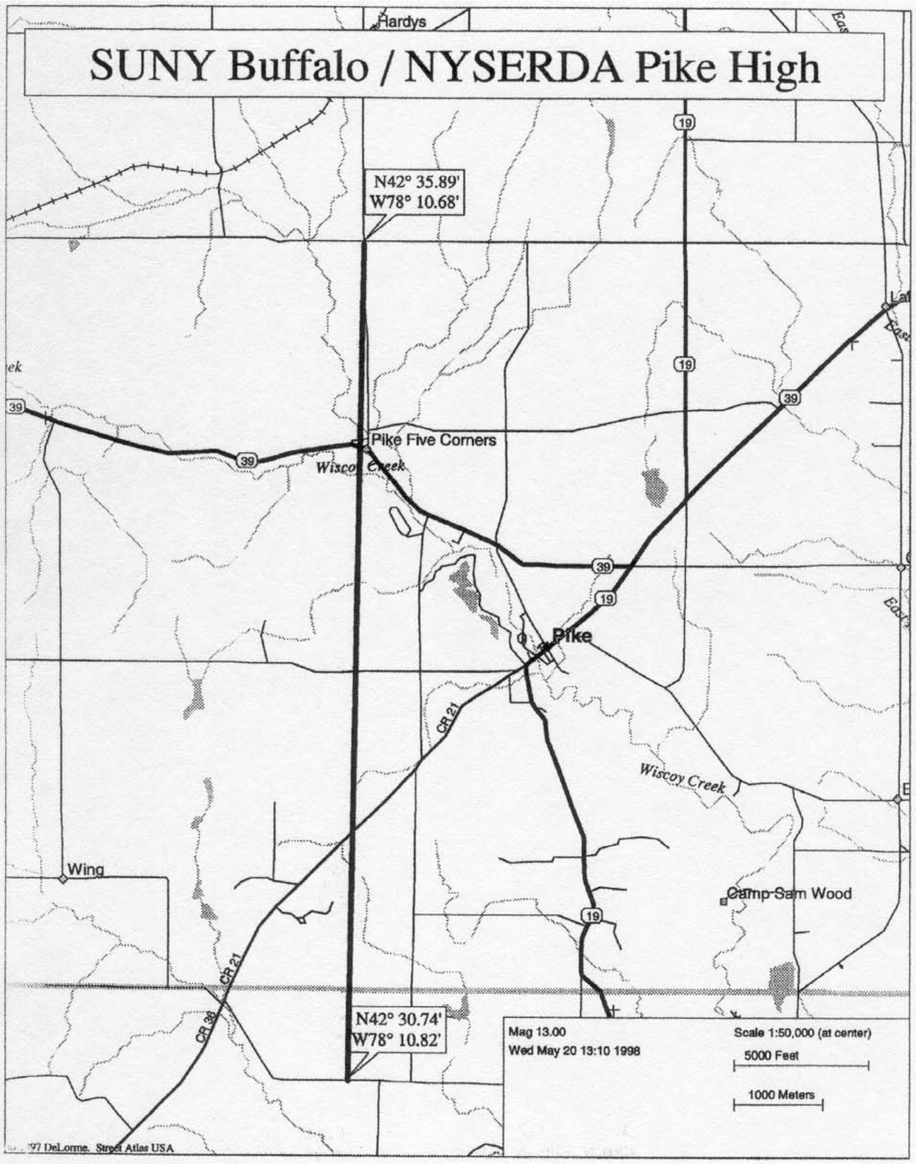
Pitch gyro in channel 32

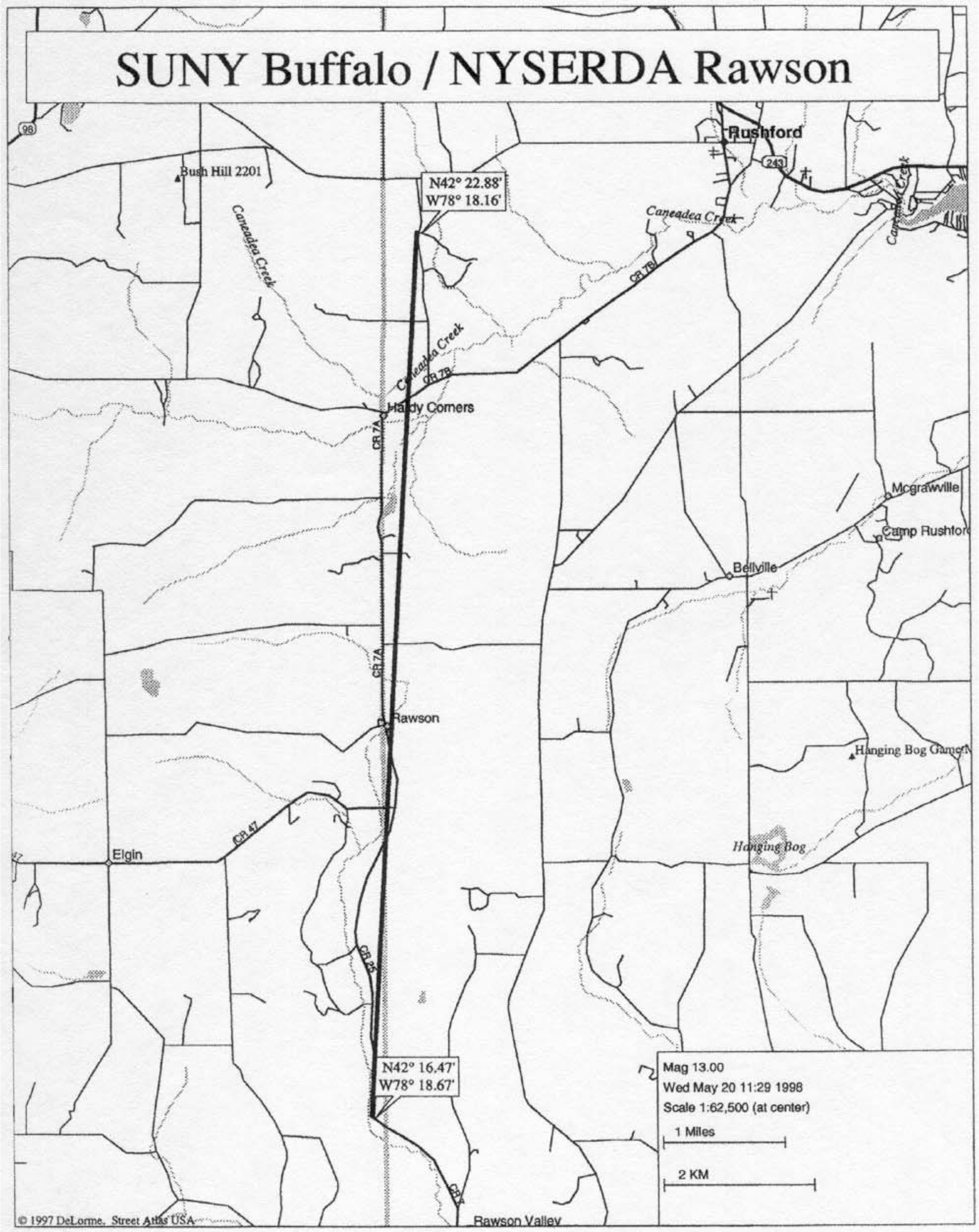
The pitch gyro signal is recorded in channel 32 of the raw data, in synchronization with the image data. However GPS data are also recorded in this channel. In pixels 509 through 544 the pitch gyro data are replaced by GPS data. The number of digital counts per degree of pitch is uncalibrated.



SUNY Buffalo / NYSERDA Pike Low
N42° 35.89'
W78° 10.68'
Wiscoy Creek
Pike Five Corners
Wiscoy Creek
39
19
Pike
CR 21
Wiscoy Creek
Wing
Camp-Sam Wood
CR 36
N42° 30.72'
W78° 10.29'
Mag 13.00
Wed May 20 12:15 1998
Scale 1:50,000 (at center)
5000 Feet
1000 Meters
© 1997 DeLorme, Street Atlas USA


SUNY Buffalo / NYSERDA Houghton
Centerville
N42° 27.99'
W78° 11.45'
Hume
Swift Hill 2010
Fillmore
CR 4
Houghton
N42° 24.32'
W78° 11.49'
Genesee River
Rushford
Caneadea
N42° 22.50'
W78° 11.50'
West Allen
Oramel
Mcgrawville
Belfast
Jacobs Hill
Marshall
Hanging Bog Game Mgmt Area
Angelica Creek
Rockville
Rockville Lake
N42° 16.84'
W78° 11.52'
Mag 12.00
Wed May 20 12:14 1998
Scale 1:100,000 (at center)
2 Miles
2 KM
© 1997 DeLorme. Street Atlas USA


SUNY Buffalo / NYSERDA Pike High
Hardys
N42° 35.89'
W78° 10.68'
Pike Five Corners
Wiscoy Creek
Pike
Wiscoy Creek
Wing
Camp Sam Wood
N42° 30.74'
W78° 10.82'
Mag 13.00
Wed May 20 13:10 1998
Scale 1:50,000 (at center)
5000 Feet
1000 Meters
'97 DeLorme. Street Atlas USA


SUNY Buffalo / NYSERDA Rawson
Rushford
Bush Hill 2201
N42° 22.88'
W78° 18.16'
Caneadea Creek
Caneadea Creek
CR 78
Caneadea Creek
CR 78
Hardy Corners
CR 7A
Mcgrawville
Camp Rushford
Bellville
CR 7A
Rawson
Hanging Bog
Elgin
CR 47
Hanging Bog
N42° 16.47'
W78° 18.67'
Mag 13.00
Wed May 20 11:29 1998
Scale 1:62,500 (at center)
1 Miles
2 KM
Rawson Valley
© 1997 DeLorme. Street Atlas USA

TRIMBLE NAVIGATION
TNL 2000/GPS RECEIVER
TNL 3000 GPS/LORAN RECEIVER

The data output is as follows: <STX><id><dddd><it><id><dddd><it>....<id><dddd><it><ETX>

Where: STX = ASCII Start of Text Character
id = Item Designator (Single Alphabetic Character)
dddd = Item Data
it = Item Terminator: (CR) or (CR)(LF)
ETX = ASCII End-of-Text Character

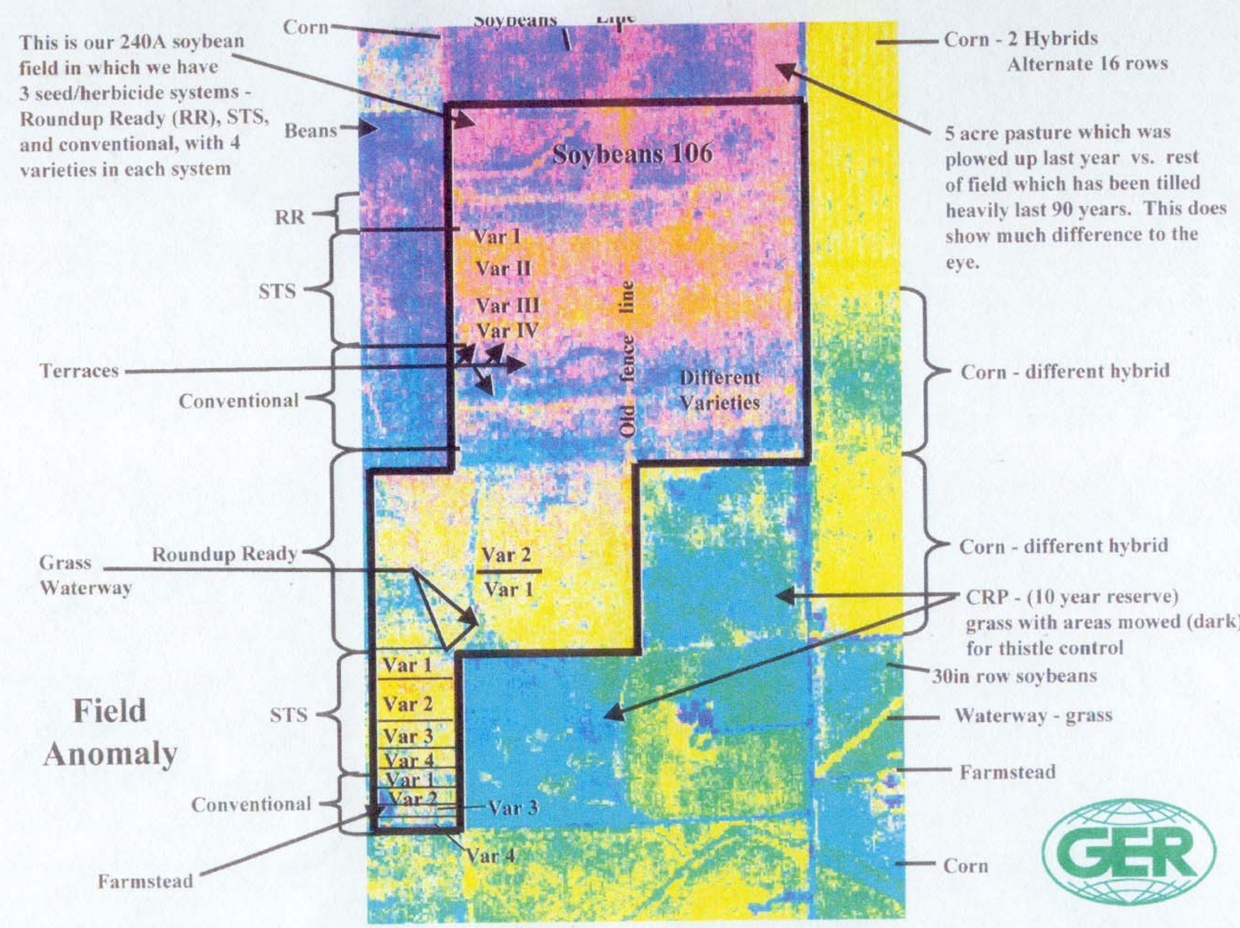
The following information is output:

INFORMATION	OUTPUT
Latitude (LAT)	North or South degrees
Longitude (LON)	East or West degrees
Track (TK)	Magnetic degrees
Ground Speed (GS)	Knots
Distance to Destination Waypoint (DIS)	Nautical miles
Estimated Time Enroute (ETE)	Hours and Minutes
Cross-Track Error (XTK)	Right or Left nautical miles
Track Angle Error (TKE)	Right or Left degrees
Desired Track (DTK)	Degrees
Active Leg Number (LEG)	Flight Plan Leg Number, Direct = 21, Heading = 22
Destination Waypoint Identifier (IDENT)	ASCII Characters
Bearing To Destination Waypoint (BRG)	Degrees
Parallel Offset (PTK)	Right or Left nautical miles
Estimated Position Error	Nautical miles
Magnetic Variation	East or West degrees
Time Since Solution	Seconds and tenths
Warnings	Character in Designated Field
Minimum Safe Altitude (MSA)	Thousands of feet
Minimum Enroute Safe Altitude	Thousands of feet
Date	Month, day and Year
Time of Day	Hours minutes and seconds
Software Code	Six digit number

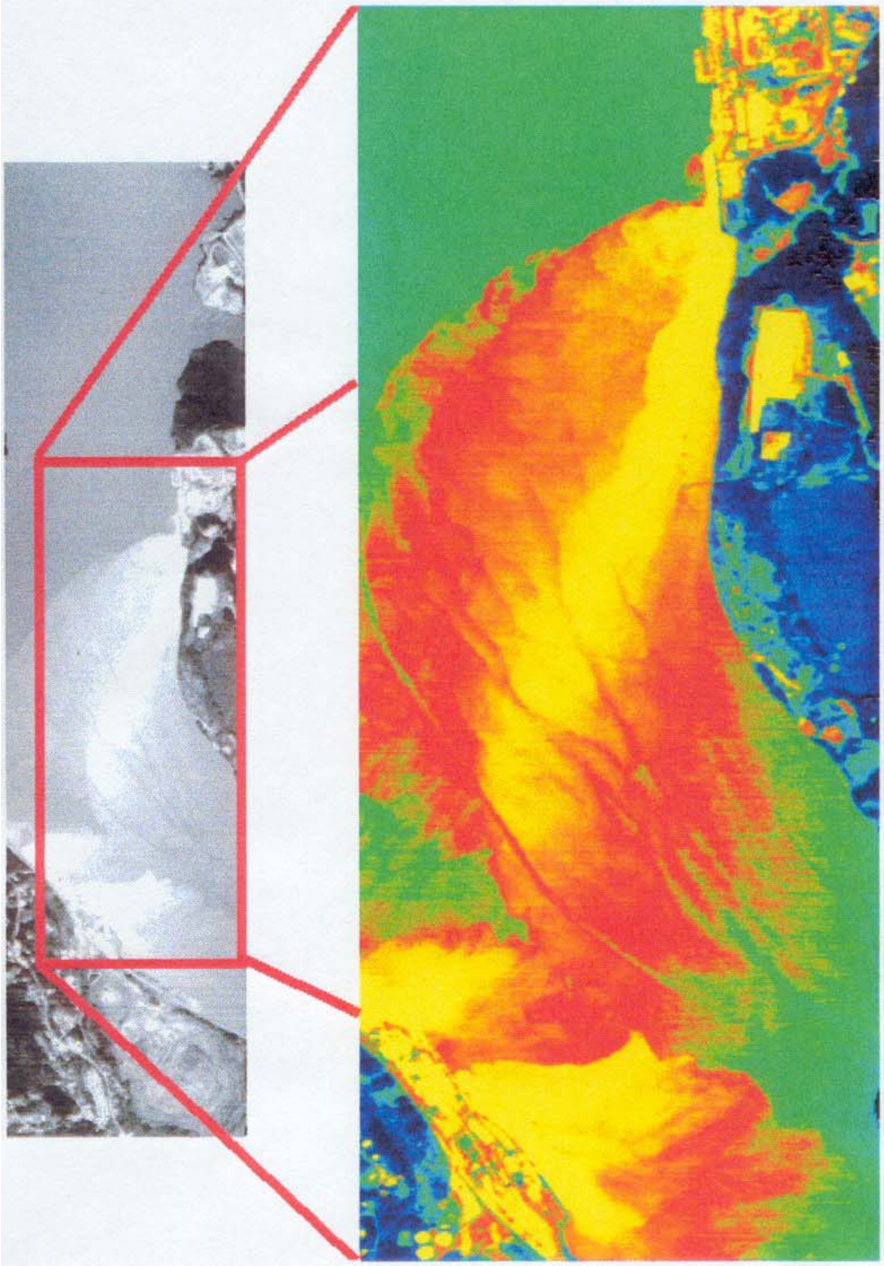
TRIMBLE NAVIGATION
TNL 2000/GPS RECEIVER
TNL 3000 GPS/LORAN RECEIVER

The following table describes the contents of the R0 and the R1 data formats:

ITEM DESIGNATOR	ITEM FORMAT	FIELD WIDTH	ITEM DESCRIPTION
A	N dd mmmm	9	LAT (N or S, deg, min x 100)
B	W ddd mmmm	10	LON (E or W, deg, min x 100)
C	ddd	3	TK (deg)
D	sss	3	GS (kts)
E	dddddd	6	DIS (nm x 100)
F	hhmm	4	ETE (hrs and mins)
G	Lnnnn	5	XTK Error (L or R, nm x 100)
H	Ldddd	5	TKE (L or R, deg x 10)
I	dddd	4	DTK (deg x 10)
J	ll	2	LEG
K	ccccc	5	IDENT
L	dddd	4	BRG (deg x 10)
M	Lnnnn	5	PTK (L or R, nm x 10)
P	nnn	3	Estimated Pos Error (nm x 100)
Q	Eddd	4	VAR (E or W, deg x 10)
c	ttt	3	Time Since Last Solution (s x 10)
T	---A-------	11	Warnings in Effect
d	fff	3	MSA (kft x 10)
e	fff	3	MESA (kft x 10)
i	mm/dd/yy	8	Date
j	hh:mm:ss	8	Time
s	cccccc	6	Software Code


This is our 240A soybean field in which we have 3 seed/herbicide systems - Roundup Ready (RR), STS, and conventional, with 4 varieties in each system
Corn
Beans
RR
STS
Terraces
Conventional
Grass Waterway
Roundup Ready
STS
Conventional
Farmstead
Field Anomaly
Soybeans 106
Var I
Var II
Var III
Var IV
Old fence line
Different Varieties
Var 2
Var 1
Var 1
Var 2
Var 3
Var 4
Var 1
Var 2
Var 3
Var 4
Corn - 2 Hybrids Alternate 16 rows
5 acre pasture which was plowed up last year vs. rest of field which has been tilled heavily last 90 years. This does show much difference to the eye.
Corn - different hybrid
Corn - different hybrid
CRP - (10 year reserve) grass with areas mowed (dark) for thistle control
30in row soybeans
Waterway - grass
Farmstead
Corn

Indian Point Power Plant, Hudson River, New York



$NE\Delta T \approx 0.1^{\circ}$

GER