AIRBORNE INFRARED MINERAL MAPPING
SURVEY OF MARYSVALE, UTAH

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Preliminary report on Marysvale study in cooperation with U.S. Geological Survey. This paper has not been approved for publication.

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INTRODUCTION

Infrared spectroradiometer survey results from recent flights over the Marysvale, Utah, district show that hydrothermal alteration mineralogy can be mapped using very rapid and effective airborne techniques. The airborne spectroradiometer system is able to detect alteration mineral absorption band intensities in the infrared spectral region with very high sensitivity. The higher resolution spectral features and spectral differences characteristic of the various clay and carbonate minerals are also readily identified by the airborne infrared instrument allowing the mineralogy to be mapped as well as the mineralization intensity.

The Marysvale survey shows very conclusively that high spectral and radiometric resolution systems can perform mineral exploration and mapping functions that have not been possible by any other means. The airborne survey methods acquire much more and comprehensive data than can be obtained by ground sampling and mapping techniques, and the mapping can be accomplished in a matter of days. As an exploration technique, the airborne infrared spectroradiometer is the most sensitive system available. For mapping and developing known mineral properties, the airborne application can save considerable time and expense.

Previous flights by the newly developed infrared spectroradiometer system were designed for quick reconnaissance of several scattered sites in western Neavada (Collins, Chang and Kuo, 1981). These flights were very successful in showing the 2.0 to 2.5 micron infrared spectral properties of various hydrothermally altered sites and other sites of unaltered clay and carbonate lithologies. The present survey over Marysvale marks the first time that a detailed grid survey has been flown over a mineral site using a high spectral resolution infrared system. The present results show that airborne surveys in rectangular grid patterns will provide very good coverage and allow accurate mapping of geologic terrain.

The Marysvale site was flown on October 9, 1981 in a grid pattern as shown in Figure 1. The flight traverse pattern in this case was designed to cover earlier ground traverses by the U.S. Geological Survey. The aircraft was flown at 2000 feet above the terrain and at 110 miles per hour.

The airborne spectroradiometer acquired data in two spectral windows. In the visible and near IR the instrument acquired 512 channels of data in the 350nm to 1.0nm region at 1.3nm bandwidth in each channel. The infrared data was acquired in 64 channels between 2.0 micron and 2.5 micron. The bandwidth is 8nm in the infrared region. The data are acquired in 20 meter square fields of view in a contiguous sequence along the ground track. Storage is on digital tape. The data are calibrated in radiance received at the front aperture. Data processing and analysis are done on the computer.

Survey Site

The Marysvale district is in south western Utah. It is one of the major volcanic centers that surround the Colorado Plateau. The exposed rocks are mostly oligocene to miocene volcanic flows and tuffs with some quartz monzonite and granite intrusions (Kerr, 1968). Hydrothermal alteration has resulted in heavy alunite mineralization with surrounding kaolinite and montmorillonite. Metalic mineralization is gold, silver, base metals, uranium, and molybdenum.

ALTERATION AND MINERALOGIC MAPPING

The alteration in the Marysvale region has been mapped both for mineralization intensity and mineral type. The intensity is measured with respect to the total absorption intensity in the mineral bands. This absorption intensity can be measured in several ways such as by taking the ratio of bands inside and outside the absorption feature, or by integrating the energy within the absorption band window. These techniques have the disadvantage that, in data taken over natural terrain, there are many spectral and intensity variations that are not related to the mineral bands.

The Marysvale data were analyzed using techniques specially developed for high spectral resolution aircraft data. Spectral variations in the data are recognized using a "waveform analysis" technique in which the spectral curves for each field-of-view measurement in the radiance/wavelength domain are transformed into a series of polynomial terms using the Chebyshev method. The appearance of various absorption features in the data along the aircraft traverses is seen as a change in the polynomial terms. This technique has proven more reliable and noise free than other analysis methods.

The results of the mineralization intensity analysis are mapped on the aerial photo mosaic in Figure 1. The mineralization intensity along each aircraft traverse is mapped in color with yellow and red the most intensely altered areas, as measured by the strength of the mineral bands. The areas mapped in orange show moderately strong absorption features. The areas mapped in brown have weak but still very obvious mineral features. The areas mapped in blue show no mineral features or very weak ones. These areas are considered background.

The mapping results show four hydrothermal cells in the survey area. The outer contours enclose the zone of weak to moderate mineralization as mapped in brown and orange. The inner contours with cross hatching mark the more intensly altered areas mapped in yellow, red, and orange. The more intensly altered zones in each cell are well defined areas within the larger zones of alteration. The mapping results also show that the alteration within each site is quite pervasive.

<u>Alteration Intensity Analysis</u>

The waveform analysis results used to determine the mineral absorption band intensities are shown in Figure 2. These data are from aircraft traverse 5 (Figure 1), which runs north-south through the largest alteration cell in the center of the survey

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ALTERATION INTENSITY MAP

MARYSVALE, UTAH

COLOR	PATTERN	EXPLANATION
YELLOW		Very Strong Clay Alteration
RED		Strong Clay Alteration
ORANGE		Moderate Clay Alteration
BROWN		Weak Clay Alteration
BLUE		No Clay Alteration

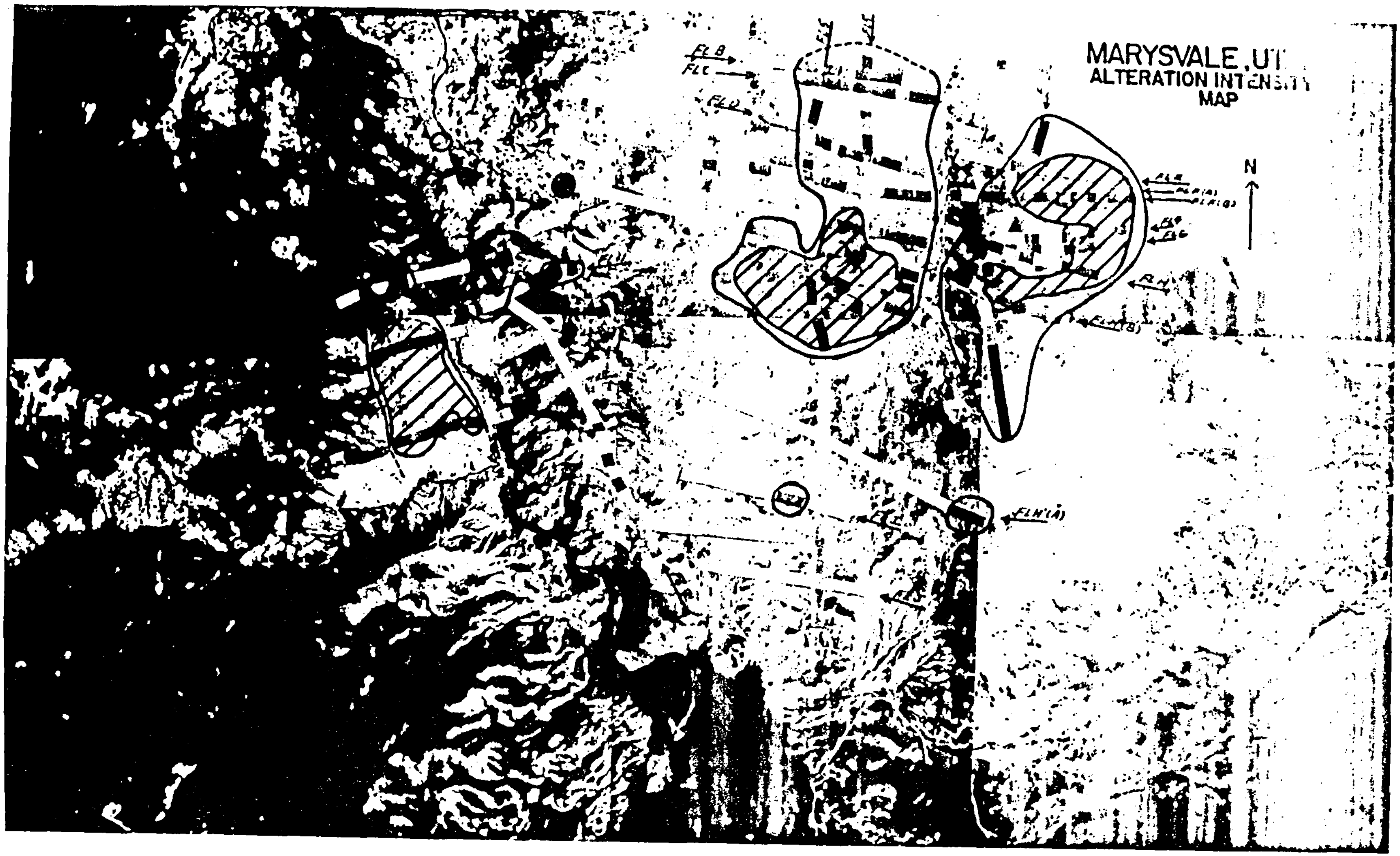

Figure 1. Alteration intensity map of marysvale, Utah. Contures outline four major hydrothermal cells with intensly altered cores.

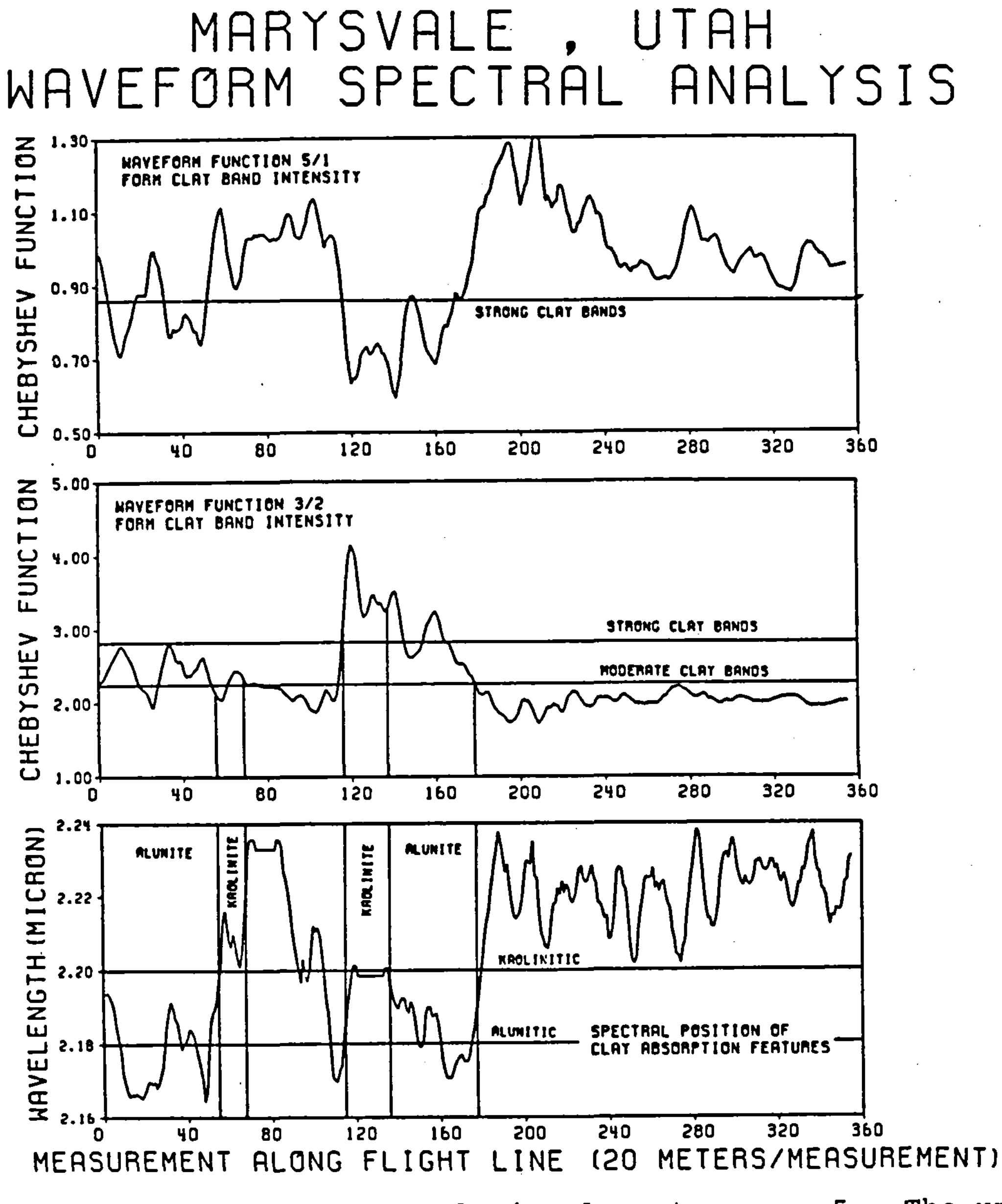

Figure 2. Waveform and mineral analysis along traverse 5. The upper waveform analysis results quantify the clay absorption intenstity along the traverse, with the most intense zone near measurement 120. The lower curve shows the spectral position of the clay feature, which can indicate the difference between kaolinite and alunite.

area. The traverse is about four miles long; running from the top of the survey site, through the alteration zone for about two miles, and through background areas of no alteration for the last two miles.

The data in Figure 2 are from 360 measurements taken in sequence along the aircraft traverse each measurement is a 64 channel infrared spectrum of the type shown in Figure 3. Each measurement is made up of the integrated energy, in radiance, reflected from a 20 meter square field-of-view. Waveform functions 5/1 and 3/2 are sensitive to the clay absorption bands. Function 3/2 is used mainly to measure the clay band intensity, while function 5/1 is an indicator of carbonate versus clay features. The 5/1 function when low indicates clay absorption in the 2.15 to 2.2 micron region.

The waveform function 3/2 is very sensitive to the intensity of the clay absorption features. Higher values indicate more intense absorption. The values of waveform function 3/2 show moderate to weak clay mineralization between measurements one and 70 in Figure 2. This area is mapped in orange and brown for the first 3/4 of a mile of traverse 5 on Figure 1. Between measurement 70 and 115, the function 3/2 values are low indicating no alteration. This area is mapped in blue.

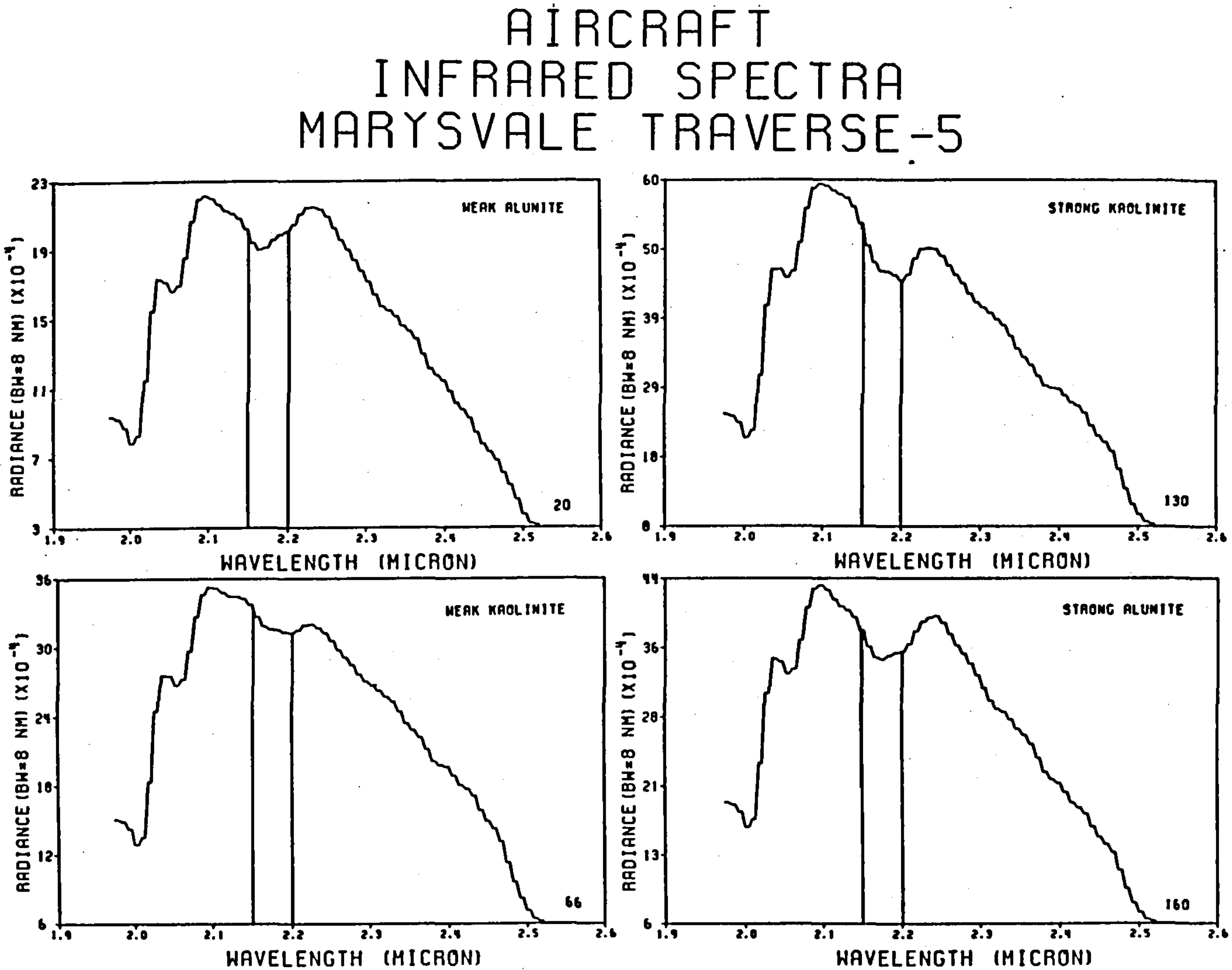

Figure 3. Spectral measurements along traverse 5. The numbers in the lower right corner identify the measurement number. These numbers correlate with the x-axis scale in Figure 2. The spectra show the differences in alteration intensity and mineral species.

From measurement 115 to 180, the waveform results indicate strong alteration. This section of traverse 5 is mapped in red and orange. After measurement 180 the data show no alteration minerals along the traverse. This "background" area has waveform function 3/2 values well below those over the altered zone.

Spectral Data

Eventually the computer analysis will also include pattern recognition of various mineral spectra based on a stored library of reference curves. This technique, however, will require an extensive data base of known curves, which is now being assembled from the survey data. At present the analysis of aircraft infrared data includes visual inspection.

Selected infrared spectral curves from traverse 5 are shown in Figure 3. The spectra are measured in 64 channels between 2.0 and 2.5 microns. The numbers in the lower right corner of each diagram indicate the measurement number along the flight path. In Figure 3 the spectra are from measurements 20, 66, 130, and 160 along the traverse. These numbers can be related back to the flight line measurement in Figure 2 and to the mapping in Figure 1.

The two spectra labeled weak alunite and weak kaolinite are from the beginning section of traverse 5, which is mapped in brown and orange in Figure 1. This is the northern section of the hydrothermal cell where the alteration appears weaker. The mineral bands, as can be seen in Figure 3, are less intense in this zone of the alteration cell. The spectra from measurements 130 and 160 show strong absorption features between 2.15 and 2.20 microns. These measurements are from the zone in Figure 2 with high waveform function 3/2 values and low function 5/1 values. The spectra are from the areas mapped in red in Figure 1, and where the traverse crosses the strongly altered zone in the southern part of the hydrothermal cell.

Mineral Mapping

Identification of mineral species can be accomplished using infrared spectral data providing that the instrument spectral resolution is sufficient to resolve the spectral features that distinquish the various minerals. The 8nm band width of the airborne system is quite adequate to allow mineral identification. This identification at present is being accomplished by comparison of the airborne results with known laboratory measurements (for example Hunt, 1979) and with airborne surveys over known terrain (for example Collins, Chang, Kuo, 1981).

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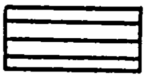
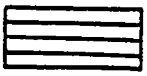
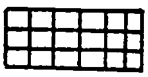
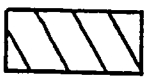
MARYSVALE, UTAH

MINERAL MAP

COLOR	PATTERN	EXPLANATION
YELLOW		Alunite
RED		Kaolinite
ORANGE		Mixed Alunite and Kaolinite
CHERRY RED		Montmorillonite
BLUE		Clay plus Gypsum
GREEN		Alunite/Kaolinite plus Gypsum
VIOLET		Kaolinite/Montmorillonite plus Jarosite?
BROWN		Kaolinite/Montmorillonite

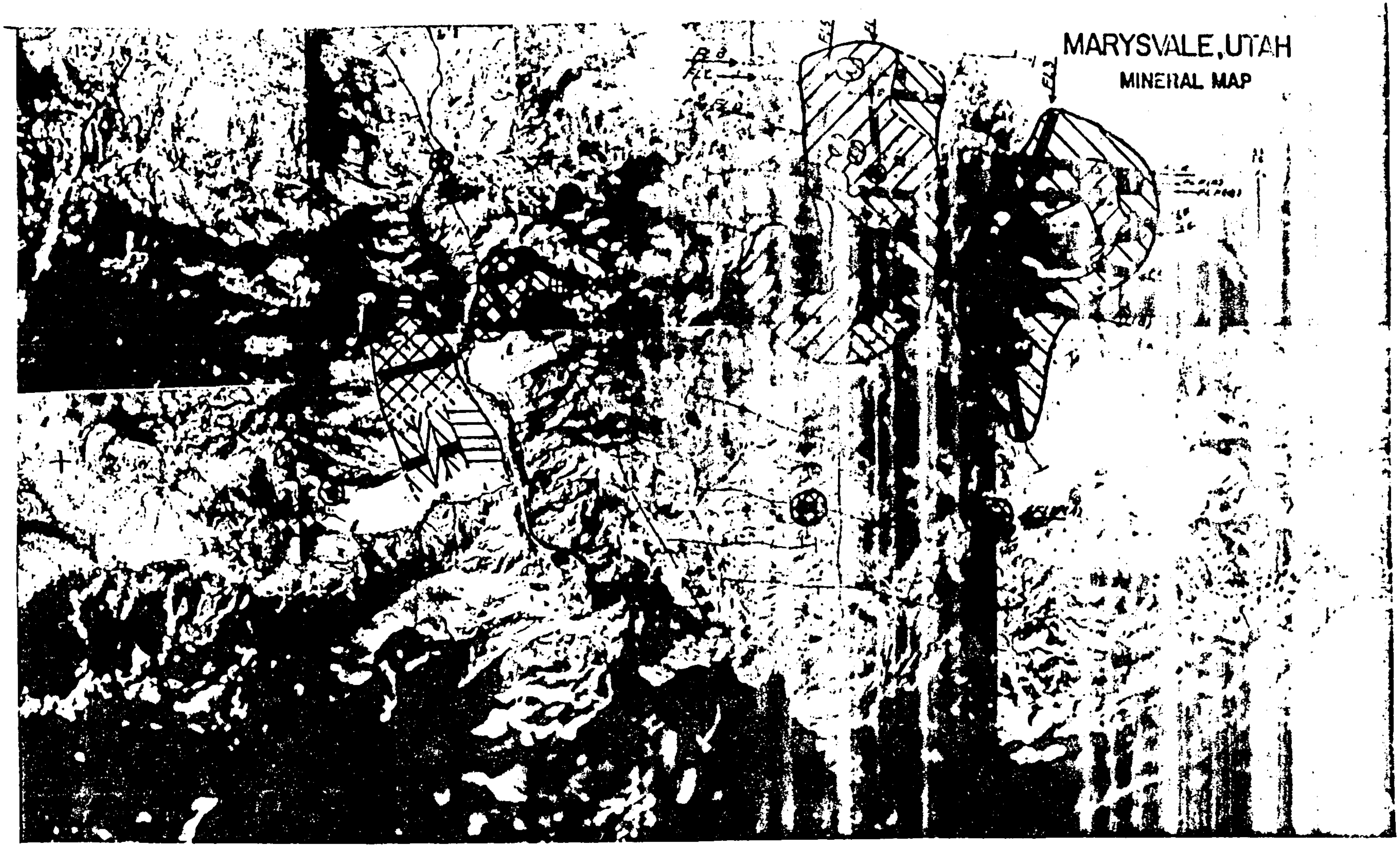


Figure 4. Mineral map of Marysvale, Utah. The various hydrothermal alteration minerals are mapped in each of the four cells.

The results of the mineral identification and mapping are shown in the map overlay of Figure 4. The mineral mapping was done only within the hydrothermal cells. The main hydrothermal mineralogy of alunite, kaolinite, and montmorillonite occurs in a very interesting pattern that is well defined by the infrared spectral mapping.

The alunitic zones are mapped in yellow with single cross hatched pattern, and the kaolinitic zones are mapped in red with single cross hatching pattern. The montmorillonite zones are mapped in cherry red with double cross hatching. Some smaller areas that contain other minerals as well are mapped in other colors and patterns, as explained in the index for Figure 4. The other minerals appear to be gypsum and possible jarosite or chlorite. Ground measurements and sampling are required to establish this mineralogy.

The alunite and kaolinite infrared spectral properties can be seen in the spectra of Figure 3 from traverse 5. The kaolinite clays have a well defined doublet absorption band with the minimum at 2.2 microns and a shoulder feature at 2.17 microns. The alunite band has a strong minimum at 2.1 to 2.18 microns and is generally broader than the kaolinite band. The variations in the position of the absorption minima along traverse

5 are shown in the lower diagram of Figure 2. The upper horizontal line through the wavelength value of 2.20 microns, and labeled kaolinitic, marks the wavelength position of the kaolinite minimum. The lower horizontal line through 2.18 microns marks the approximate limit of the minimum shift in alunite spectra. The mineral determination is done within the limits of significant alteration intensity as indicated by the waveform function 3/2 values (vertical boundary lines). The data in Figure 2 have been smoothed in the flight direction. This brings out the general trend in alteration. The point-to-point variation in mineralogy is greater than is indicated by the curves in Figure 2. The finer variations would be useful in mapping specific sites on a much more expanded scale.

The mineralization in the two larger, eastern, cells occurs in a well defined pattern of three alunite "core zones" with outer zones of kaolinite. Two of the alunite zones fall within the zones mapped as intense alteration in Figure 1. The largest alunite zone occurs in the northern section of the larger central cell. The mineralization appears less intense in this area. In summary the two eastern hydrothermal cells show a more or less central zone of intense alteration with alunite zones coinciding with the more intense mineralization. A third zone of alunite does not correllate with the most intense alteration. The two eastern cells are current molylbdenum prospects.

The two western cells show a different mineralogy; which is dominantly montmorillonite, or a similar clay. This preliminary classification of montmorillonite from the spectral data requires ground sampling for initial correllation of infrared spectral properties as measured from the air. The spectral data are shown in the following section. The pattern of distribution of montmorillonite indicates that the western cells, at the surface level, are zones of lower temperature alteration.

INFRARED SPECTRAL DATA

Inspection of the infrared spectral data shows conclusively that there are very distinct and consistent differences in the high spectral resolution features of the alteration minerals. The following data show these spectral features of the Marysvale site. Many additional and distinctive spectral properties have been observed over other sites (Collins, Chang, Kuo, 1981). These results from the airborne infrared spectroradiometer surveys indicate that a wide variety of information is available in applying this survey technique.

The spectral curves from traverse G are shown in Figures 5, 6, and 7. The spectra in Figure 5 are from the first 40 measurements where the traverse crosses the medium to strongly altered zone of kaolinite and alunite on the east edge of the eastern hydrothermal cell.

The spectra in Figures 6 and 7 are from traverse G across the central hydrothermal cell. The traverse is broken because of the offset in the photo mosaic. Traverse G is the straight east/west traverse that begins as the second traverse up from the southeast corner of the hydrothermal cell. The lower traverse crosses G near traverse 5. Traverse G extends the farthest west

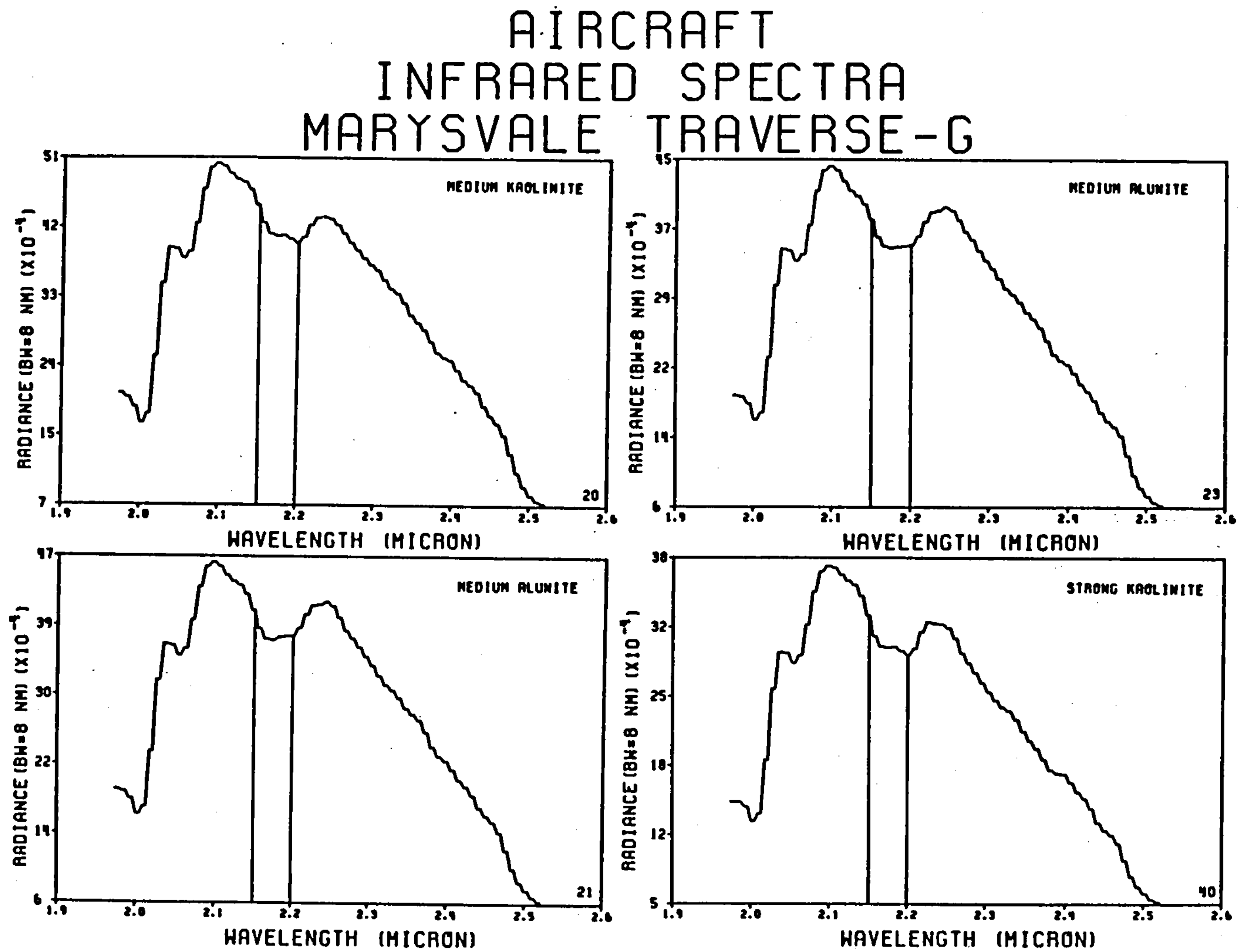


Figure 5. Spectra from traverse G where it crosses medium and strong intensity kaolinite and alunite mineralization in the large eastern hydrothermal cell.

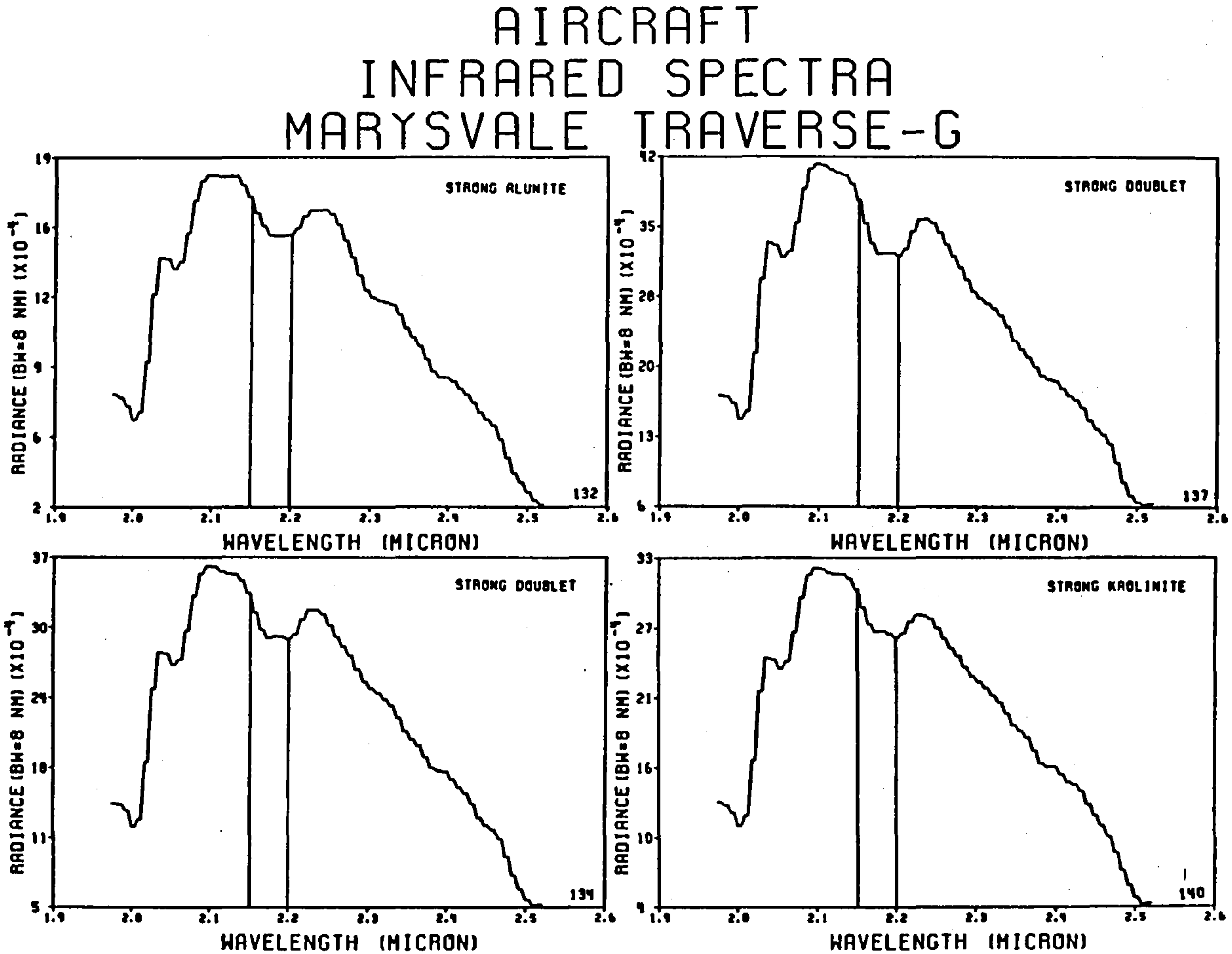


Figure 6. Spectra from traverse G where it corsses strong alunite and kaolinite mineralization in the central hydrothermal cell. Spectra labeled strong doublet appear to be a mixture of kaolinite and alunite. These areas are mapped in orange on the mineral map.

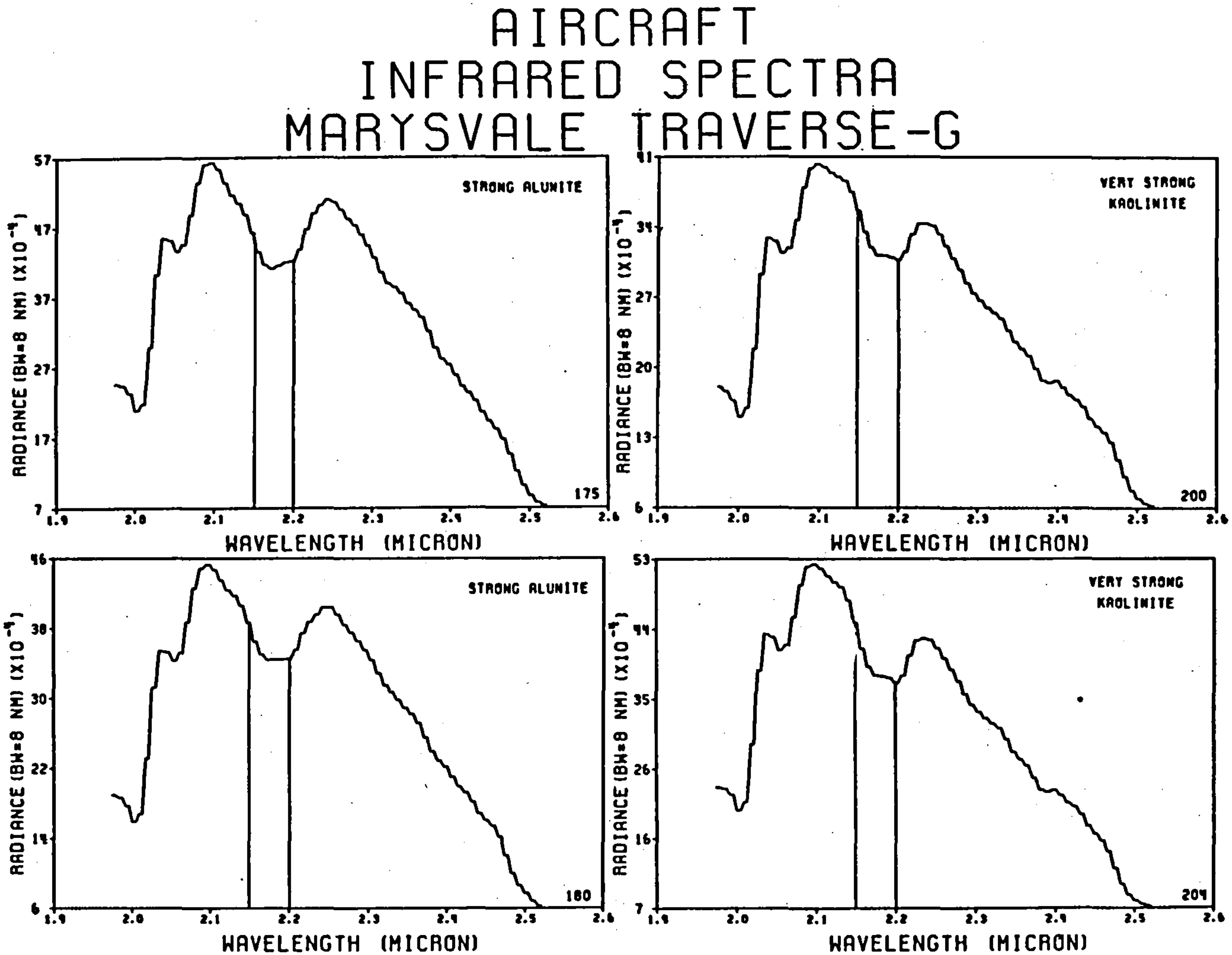


Figure 7. Spectra from the intensly altered zone of the central hydrothermal cell. The kaolinite and alunite bands are strongest in this zone. In addition to the minimum shift in the alunite band, there is a widening of the shoulder between 2.10 and 2.15 microns.

and is the southern most traverse at the southwestern corner of the hydrothermal cell.

The spectra in Figure 6 show a predominant strong doublet of mixed kaolinite and alunite. This area is mapped in orange (Figure 4) at the southeast edge of the hydrothermal cell. The traverse then passes into an area of strong kaolinite mapped in red. A spectrum from this zone is shown in Figure 6, measurement 140.

Traverse G crosses the eastern side of the intensly altered alunite zone (Figure 4) in the area of measurements 175 and 180. These spectra are shown in Figure 7. Near measurements 200 and 204, (Figure 7), the traverse crosses one of the zones in which the kaolinite bands are noticeably more intense than in other kaolinitic zones. These areas are mapped in yellow in Figure 1.

The infrared spectral features of the other traverses through the two large eastern cells are very consistent and similar to the spectral features shown for traverse G.

Outside of the two eastern cells, the spectral properties change markedly. The spectra in Figure 8 are from the background

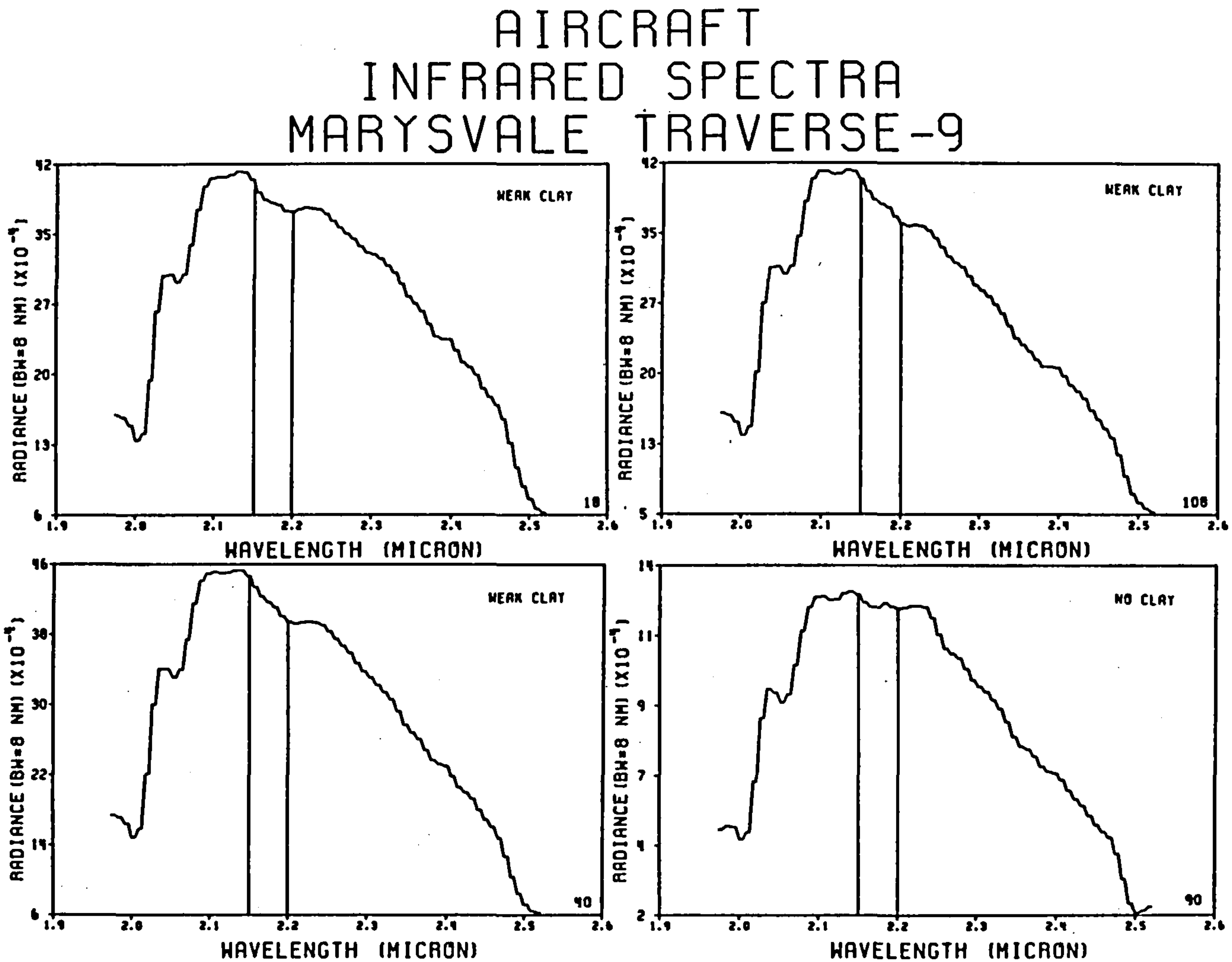


Figure 8. Spectra from the first half of traverse 9, which crosses background terrain of no alteration. The spectra show mostly very weak 2.2 micron clay bands.

area in the southern half of traverse 9. This area is mapped in blue in Figure 1. The spectral features in these areas are predominantly very weak clay bands. Spectrum 90 shows a strong shoulder at 2.25 microns and no clay bands.

The spectra in Figures 9 through 12 show a very different alteration pattern and mineralogy. These data are from the two smaller western hydrothermal cells. The mineralogy in these cells is very mixed, but mostly a clay mineral with a strong 2.21 feature that appears to be montmorillonite. The spectra in Figure 9 are from traverse 11 along the eastern section across the smaller alteration cell. The spectra show a mineral with strong absorption at 2.25 to 2.3 microns. Jarosite has a strong band in this region (Hunt, 1979) Ground measurements and sampling are required, however, to establish the correlation. This zone also shows some strong kaolinite (spectrum 18). Spectrum 21 shows the strong 2.21 micron feature of montmorillonite. In this spectrum the long wavelength shoulder is suppressed and there are weak features at 2.25 and 2.35 microns. This appears to be gypsum mineral mixed with the clay. Stronger gypsum can be seen in Figure 12. Figure 10 shows measurements along traverse 9 where it crosses traverse 10 at measurements 176 and 177. In this area there appears to be mixed strong jarosite and strong

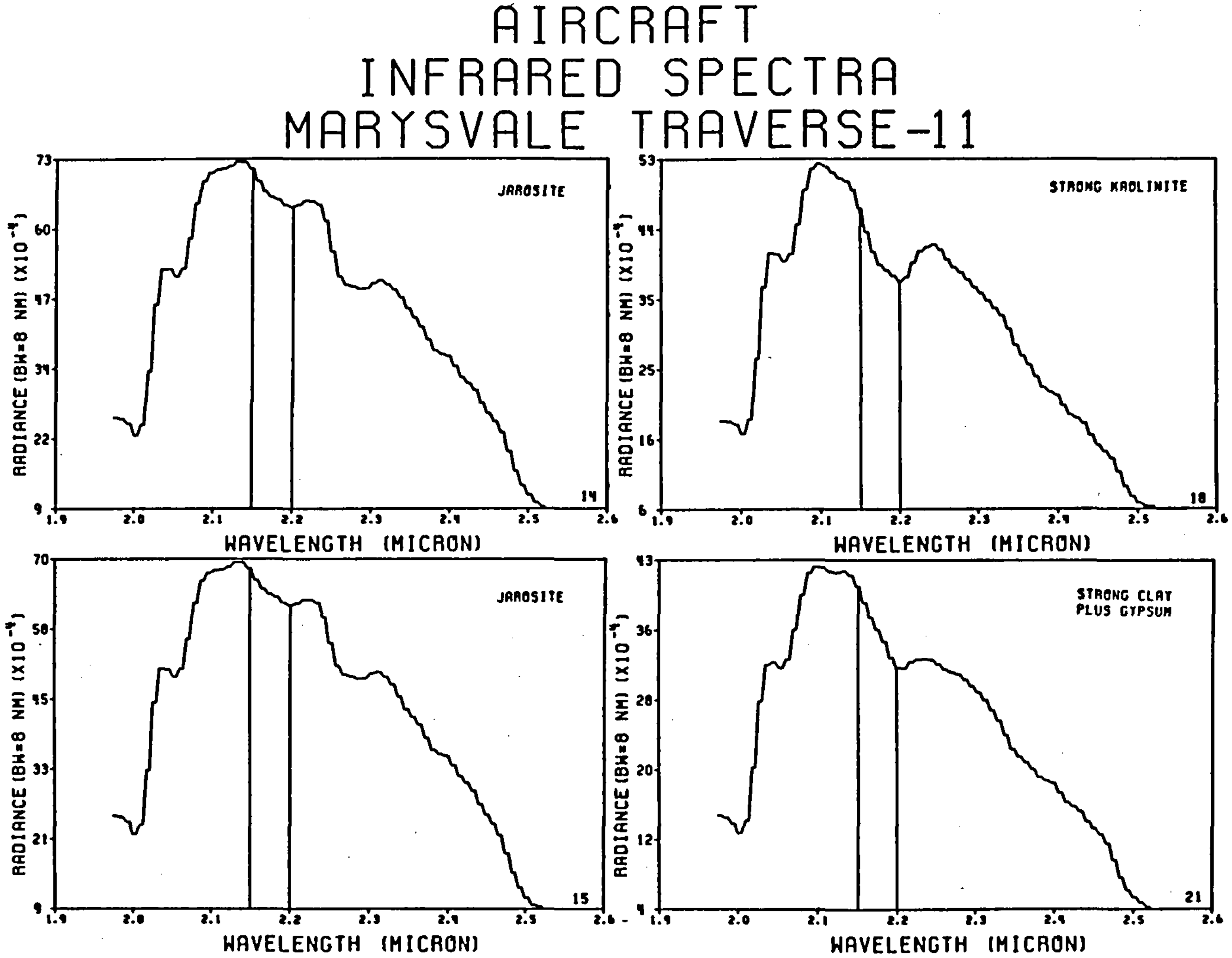


Figure 9. Spectra from the section of traverse 11 where it crosses the smaller of the two western alteration cells. This zone shows very mixed mineralogy.

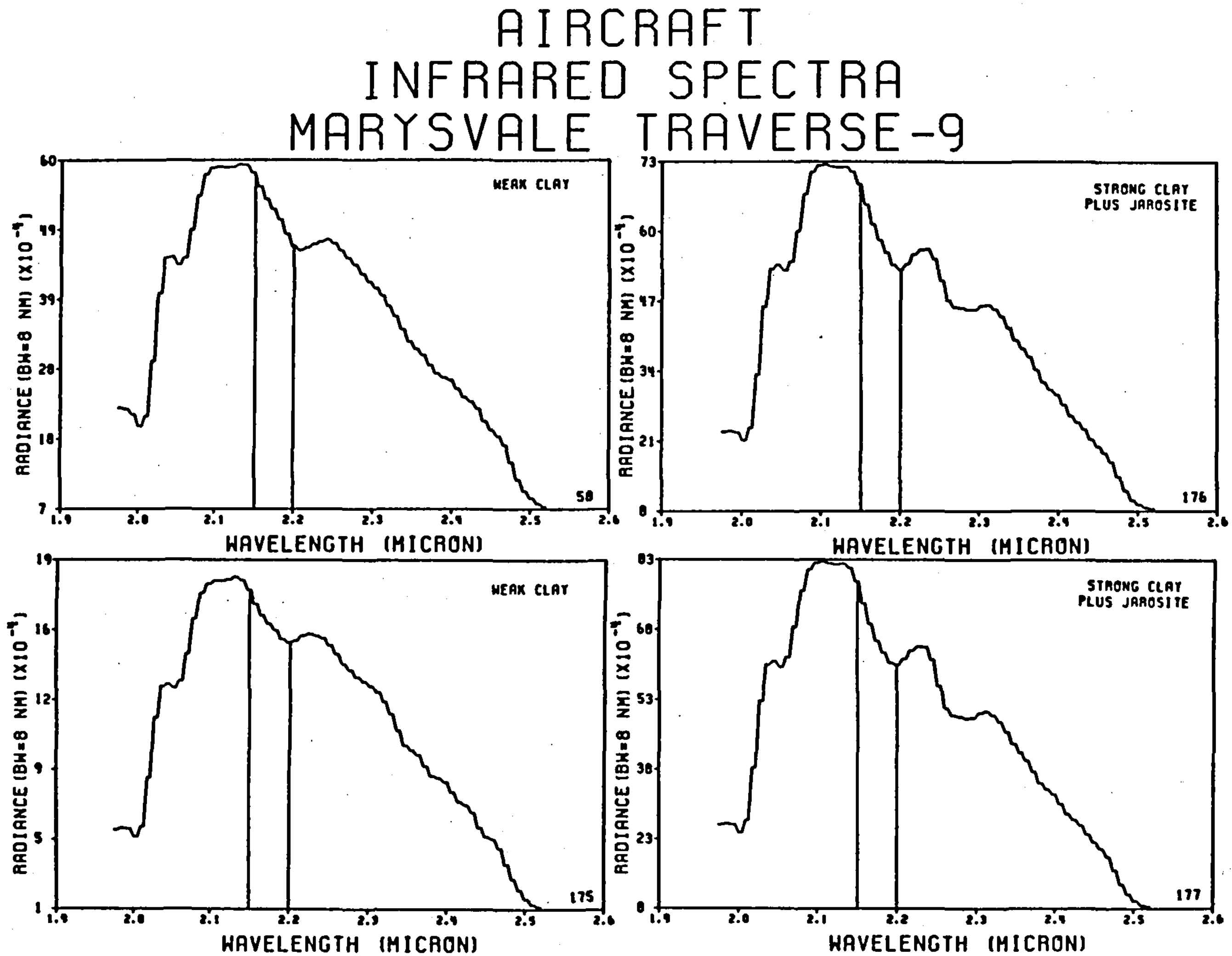


Figure 10. Spectra from traverse 9 where it crosses the smaller western alteration cell. Spectra 176 and 177 are from the area where this traverse crosses traverse 11. The spectra are similar to spectra 14 and 15 in Figure 9.

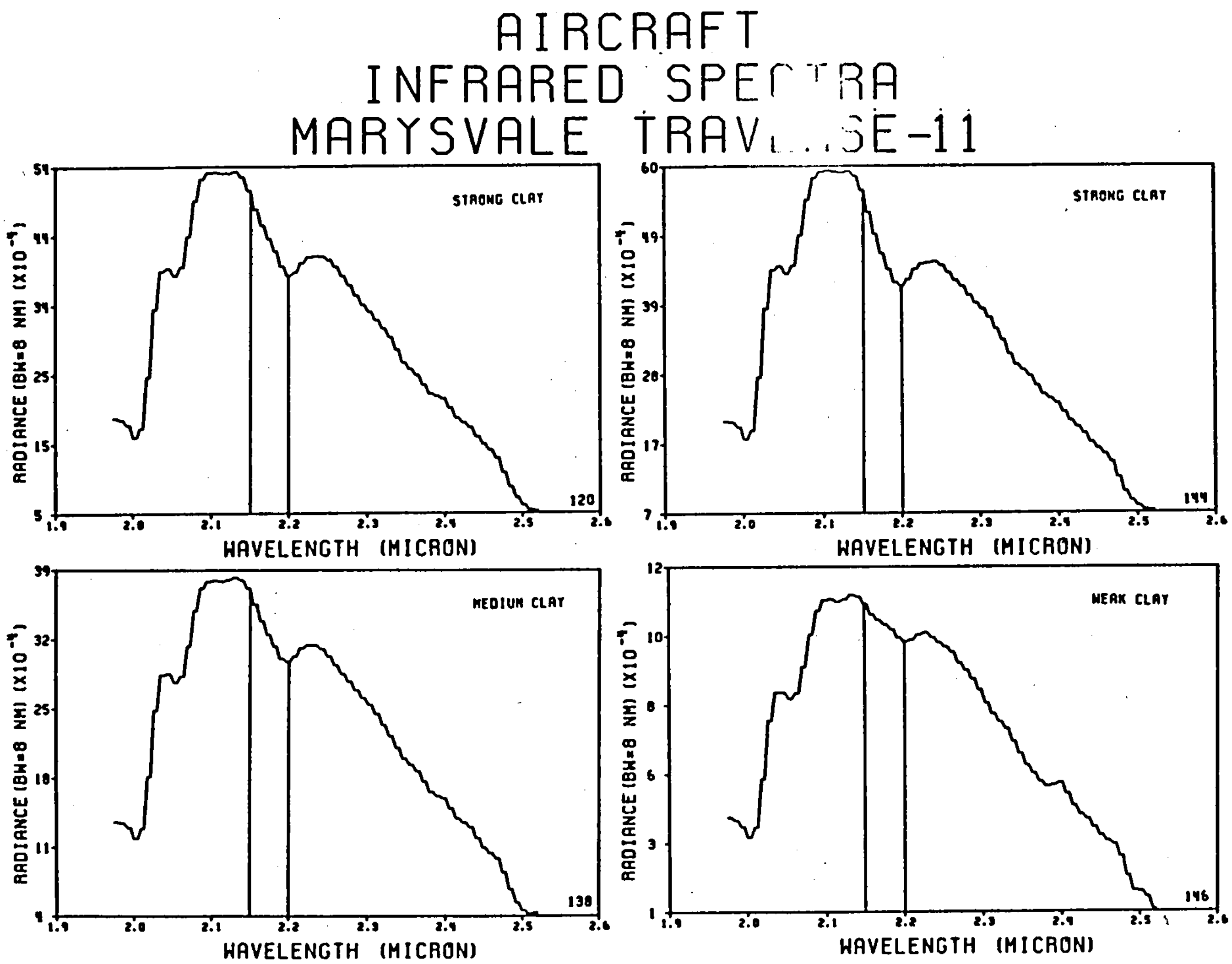


Figure 11. Spectra from the western section of traverse 11 where it crosses the western most alteration cell. The mineralogy appears to be uniformly montmorillonite clay.

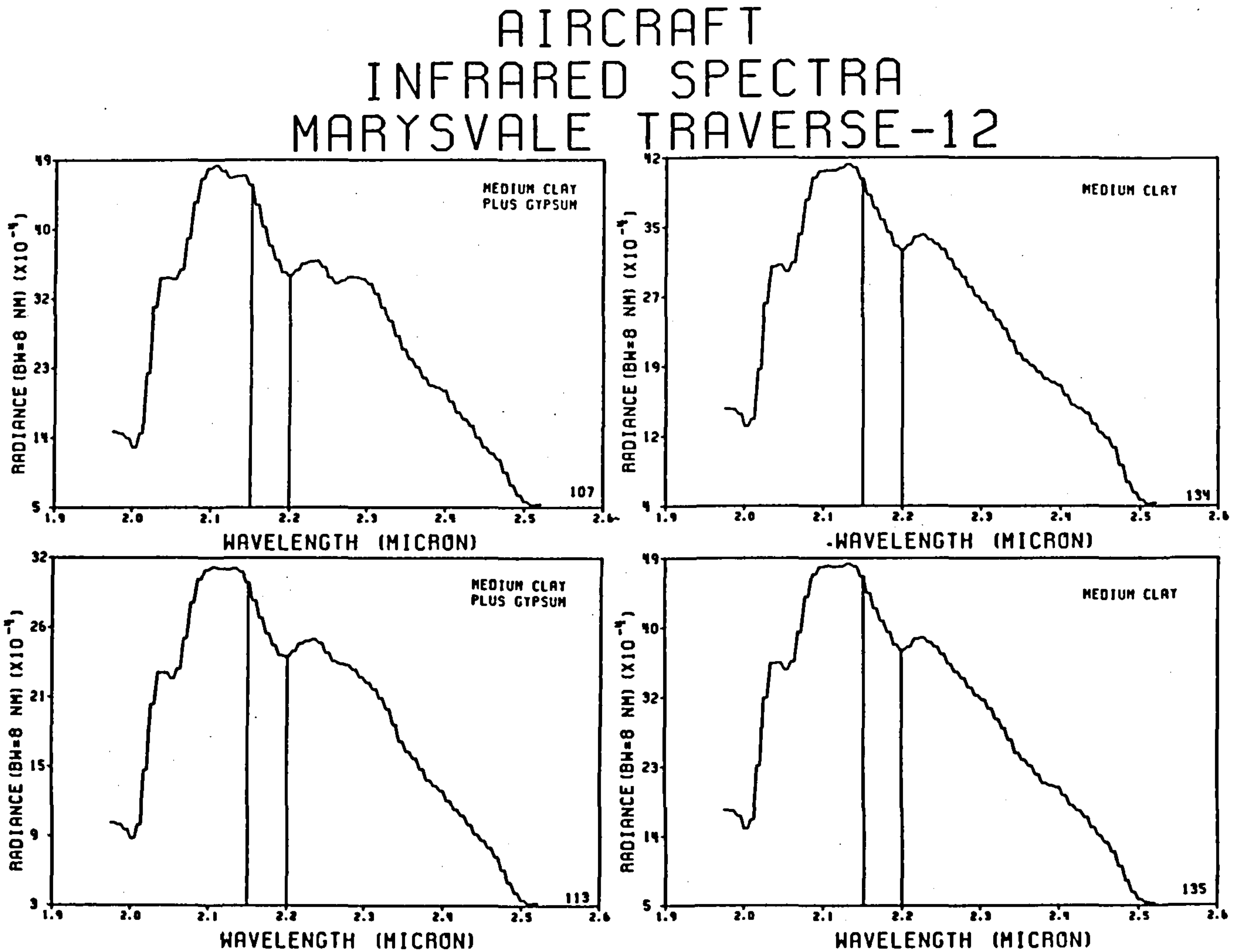


Figure 12. Spectra from the western section of traverse 11 where it crosses the western most alteration cell at the northern end. The mineralization appears to be uniformly montmorillonite clay with a mixture of gypsum.

montmorillonite. The smaller cell is characterized by a very mixed mineralogy including the montmorillonite clay and the "jarosite" mineral with the strong 2.25 to 2.30 micron bands.

Traverse 11 continues to the west where it crosses the center part of the western most alteration cell in the area of Big Rock Candy Mountain. This section is mapped as solid cherry red in Figure 4. Typical spectra from this section of traverse 11 are shown in Figure 11. The spectra show medium to strong 2.21 micron montmorillonite bands. The alteration intensity in this section is mapped as alternating medium to strong intensity in Figure 1. Spectrum 146 in Figure 11 shows the typical background signal where the traverse crosses out of the alteration zone.

Traverse 12 crosses the northern edge of the western most alteration cell. The spectra in Figure 12 show again quite uniform montmorillonite with some mixed gypsum. The northern half of this alteration cell is distinctive in showing uniformly medium to strong montmorillonite alteration.

The spectra in Figures 13 and 14 are from traverse 10(B) across the southern section of the western most alteration cell.

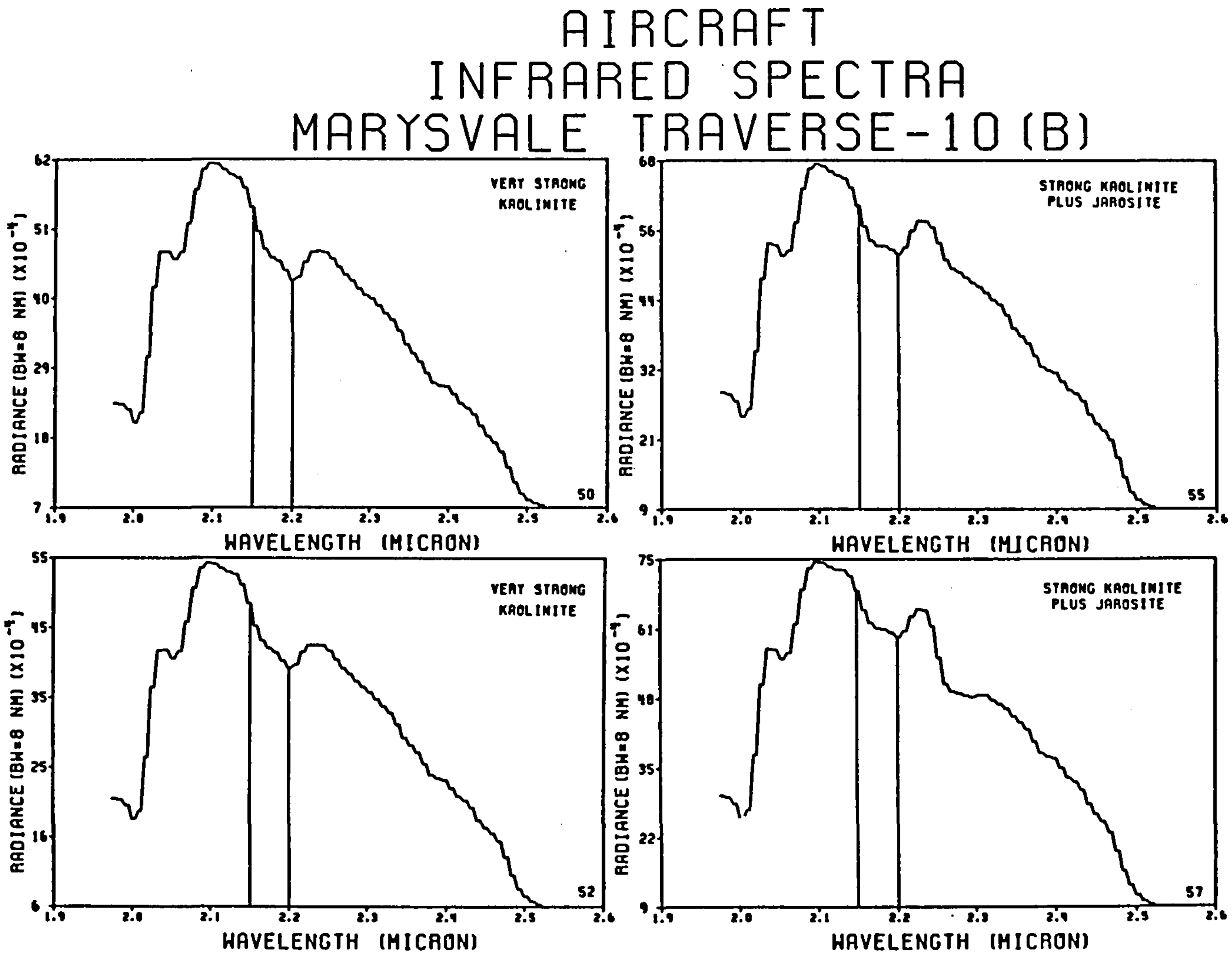


Figure 13. Spectra from the southern section of the western most alteration cell. The mineralogy in this zone is distinctly kaolinite with a mixture of the "jarosite like" mineral.

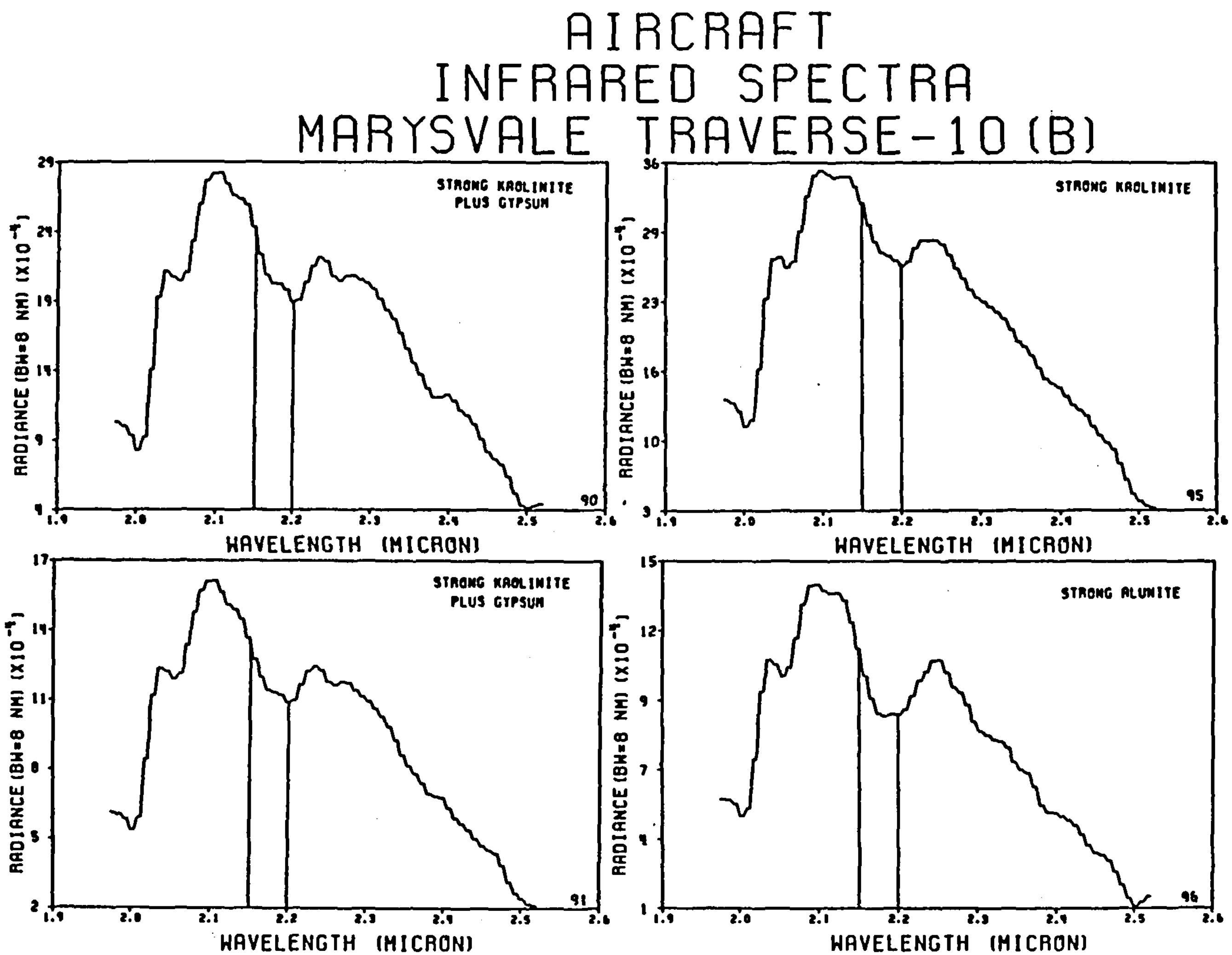


Figure 14. Spectra from the southern section of the western most alteration cell. The mineralogy is distinctly kaolinite with some alunite. A mixture of gypsum is present in some of the kaolinite areas.

This zone of the cell is distinctly different from the northern zone. There is no montmorillonite mineralization. The mineralization is predominantly very strong kaolinite with some very strong alunite. The gypsum and "jarosite like" spectral features are superimposed on some of the kaolinite spectra. The southern part of the cell, then, is a zone of kaolinite/alunite mineralization similar to the two eastern zones with the exception of gypsum and the "jarosite like" mineral mixture.

CONCLUSION

The airborne infrared spectroradiometer, at 8nm spectral bandwidth, functions very effectively in mapping the intensity and species of minerals with bands in the 2.0 to 2.5 micron region. The 8nm bandwidth is a critical factor in this application because it is near the lower limit of the natural bandwidths of the mineral features. With less spectral resolution, the capacity to identify specific minerals would rapidly disappear. Survey tests at 16nm bandwidth show that much of the resolution is already lost. At 8nm bandwidth, however, we achieve an optimum spectral resolution of the infrared mineral bands with still wide enough bandwidths to also achieve very good signal to noise ratio.

The survey over Marysvale shows that detailed airborne mineral mapping can be achieved repidly over large areas. This type of mapping has been very difficult in the past using ground techniques. The airborne technique can substantially improve exploration effectiveness and reduce the costs and time involved in initial site evaluation and development.