PB 197 099

REMOTE SENSOR APPLICATION STUDIES PROGRESS REPORT, JULY 1, 1968 TO JUNE 30, 1969: CONTROLLED FIELD EXPERIMENTS

L. C. Rowan, et al

Geological Survey
Washington, D. C.

1970

UNITED STATES

DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

REMOTE SENSOR APPLICATION STUDIES PROGRESS REPORT, JULY 1, 1968 to JUNE 30, 1969: CONTROLLED FIELD EXPERIMENTS

by

L. C. Rowan, T. W. Offield, R. D. Watson, P. J. Cannon,

M. J. Grolier, H. A. Pohn, and Kenneth Watson

Prepared by the U.S. Geological Survey for the

National Aeronautics and Space Administration (NASA)

(Work performed under NASA Task 160-75-01-43-10)

1970

This report is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards and nomenclature.

4¢

CONTENTS

ILLUSTRATIONS

TABLES

CONTROLLED FIELD EXPERIMENTS

by

L. C. Rowan, T. W. Offield, R. D. Watson, P. J. Cannon

M. J. Grolier, H. A. Pohn, and Kenneth Watson

U.S. Geological Survey

INTRODUCTION

Field sites (fig. 1) have been selected for controlled experimentation in order to determine the combined influences of the physical and chemical parameters found in the field upon the response of rocks to electromagnetic radiation. The main consideration in the selection of these sites is the availability of good exposure of nearly monomineralic rocks (sandstone, limestone, dolomite, and gypsum), level of geologic understanding, and ease of access.

A number of sites were chosen in which quartzose rocks are exposed: quartz sand dunes (Grand Sable dunes) near Lake Superior, quartzite outcrops in the Baraboo syncline, quartzite in the Beartooth Mountains, and quartz sandstone at Mill Creek, Oklahoma.

Carbonate rocks are exposed at several selected sites. Unconsolidated carbonate materials are well exposed on the shores of Florida at Whitewater Bay and Bahia Honda Key (pages 15 and 16). Marble, Colorado (pages 16-18), is a controlled site for experimentation on metamorphic carbonate rocks.

The White Sands sand dunes of New Mexico are described on page 19 as a potential site for remote sensing on gypsum rocks.

Excellent exposures of limestone and dolomite are found at the Mill Creek site in the Arbuckle Mountains of Oklahoma (Rowan and others, 1970), and Clarks Fork Canyon, Montana.

DESCRIPTION OF SELECTED SITES

Quartzose Rocks

The most common rock-forming mineral is quartz and, fortunately, it is relatively simple mineralogically. For these reasons, quartzose rocks in two of the three major rock classes--sedimentary and metamorphic--comprise the initial four field areas. The following sections briefly describe the geologic setting of these areas, and their locations are shown in figure 1.

Grand Sable Dunes, Michigan

The Grand Sable dunes are in Alger County, in the lowlands of the Upper Penisula of Michigan, about 100 miles west of Sault Saint Marie, and east of Marquette, Michigan. The Grand Sable dunes are active dunes of specific interest in that they constitute an example of unconsolidated quartz sand. They are on an old lacustrine terrace that stands from 250 to 300 feet above the present beach of Lake Superior at an altitude of 602 feet. The dunes form a band, about 5 miles long and 2.5 miles wide, in which quartz sand is excellently exposed, especially in dune ridges and large blowouts. They are easily accessible on foot or with a four-wheel drive vehicle.

The dune pattern consists of three dominant forms: (1) northwest-trending sand ridges, which are parallel or subparallel to one another and probably slightly oblique to the prevailing winds; (2) blowouts and depressions, which separate successive sand ridges; (3) a precipitation ridge, which is nearly continuous along the forest border in the western section of the dunes. This dune pattern is typical of coastal dunes in the humid temperate regions; the Grand Sable dunes resemble the coastal dunes in the Coos Bay region of Oregon (Cooper, 1958, p. 87-115).

An aspect of the dunes of particular interest for remote sensing is the yearly and seasonal variation in dune activity. Because of the midlatitude location, seasonal climatic variations are large, and sand motion and dune morphology are related to wind velocity, amount of rainfall, and presence or absence of snow cover and vegetative cover in a degree more striking than for dunes located in a warmer and more arid environment. The Grand Sable dunes are barren perhaps over 50 percent of their total area, the remaining half being sparsely vegetated with dune grass and small shrubs. There is a seasonal and yearly variation in the percentage of vegetative cover on the dunes: it is least in late winter and in the spring, and in dry years. Short-term climatic trends also appear to be reflected in the vegetative cover of the dunes.

The rocks exposed within a 5-mile radius from the dunes offer a nearly complete section of Upper Peninsula regional stratigraphy, from Cambrian sandstones to Recent beach sand. The stratigraphic section is as follows:

Age	Rock Unit	Lithology	Thickness (feet)
Recent	Beach Sand	Quartzose sand	10-20
Early Recent	Old lake terrace sand	Quartzose sand	20-100
Late Pleistocene	Glaciofluvial sand and gravel	Quartzose sand, some clay and gravel	200-300
Late Pleistocene	Boulder clay and sandy till	Sandy clay, with occasional boulders	100-150
Mid-Ordovician	Au Train Fm.	Dolomitic sandstone	50-70
Mid-Cambrian	Munising Fm.	Sandstone	200
Early Cambrian	Jacobsville Fm.	Sandstone	1,200 (only upper 40 feet exposed)

The stratigraphic section is of particular interest for remote sensing because almost all the rocks are sandstones of early Paleozoic age, or sands reworked from them during the late Pleistocene and Holocene cycles. These rocks will provide relatively pure samples for investigation of the spectral response of unconsolidated quartzose sands and the consolidated rocks from which they are derived. The Jacobsville formation, in particular, is exposed for long distances along the beach of Lake Superior, about 1 mile west of the dunes.

At least two populations of sand grains are present at the Grand Sable dunes: well-sorted, well-rounded grains probably derived from the Paleozoic sandstones forming the regional bedrock, and smaller angular grains derived from the glaciofluvial deposits that make up the substrate on which the dunes stand. Feldspar grains are abundant in the smaller size fractions, but represent a small fraction of the bulk sample.

The presence of a series of old lacustrine terraces, which mark · successive postglacial levels of Lake Superior, add geomorphological erest to remote sensing of quartz sand in this area. The terraces ıerally are underlain by podsols and podsolic soils, some of which are ıerlain by a hardpan of cemented sand that is 1-2 feet thick. Azonal ·ls do occur in poorly drained, swampy areas, and the forest on the ustrine terraces varies from dense to sparse.

It will be possible, in the Grand Sable dunes and in the area .hin 5 miles from them, to compare remote sensing data for loose sand nearly identical mineralogic composition, but in environments of fferent moisture content, different weathering stage and soil development, d in all transition stages from completely barren to heavily forested. ach sand along the shore of Lake Superior is coarser than the sand in dunes, and packing, sorting, roundness and sphericity do vary in the ne sand. Comparison of the spectral response of quartz sand of different t known grain sizes and moisture contents which is exposed in ripples and nes of different amplitude may lead to the application of remote sensing the analysis of grain size, moisture content, and surface roughness of nd.

A preliminary geologic report on the Grand Sable dunes is being epared by M. J. Grolier and will include a description of dune forms, a trographic analysis of the sand, and a section on representative physical operties of silica sand such as packing, porosity, color, shearing sistance, dielectric constant, specific heat, and relative heat nductivity.

Baraboo, Wisconsin

The Baraboo syncline is located in the "Driftless" region of south-central Wisconsin approximately 40 miles northwest of the city of Madison. The area is defined by the Baraboo ranges which represent the differentially eroded flanks of the syncline. The doubly plunging syncline, which is predominantly composed of Preçambrian quartzite, is approximately 25 miles long and 10 miles wide. Although the area has been extensively glaciated, only the eastern one-third of the syncline is overlain by deposits of glacial till. The ranges of the Baraboo syncline project as inliers into the surrounding Paleozoic formations which are primarily composed of Cambrian and Ordovician sandstone (table 1). The quartzite is of high purity (98 percent) as are the sandstones of three Cambrian formations (Dresbach, Franconia, and Trempealeau) and the Ordovician St. Peter sandstone in the area. The only other formation that crops out in the region of the syncline is the Oneota dolomite which unconformably underlies the St. Peter sandstone.

The main areas of outcrop of the Baraboo quartzite are in numerous quarries in the north and south limbs of the syncline as well as in two water gaps formed in the north limb by the Baraboo river. A third area of extensive outcrop of the Baraboo quartzite is in the cliffs surrounding Devils Lake in the south limb of the syncline.

Table 1

Paleozoic Sequence in the

Baraboo, Wisconsin, Field Area

Age	Formation	Thickness (feet)
Ordovician	St. Peter (sandstone)	40
	Oneota (dolomite)	80
Cambrian	Trempealeau (sandstone)	75
	Franconia (sandstone)	60
	Dresbach (sandstone)	75
Precambrian	Baraboo (quartzite)	4000

Where the Baraboo quartzite and Paleozoic sandstones exist in natural outcrops, the surface of the rock is frequently covered with lichen. Lichen give a blackbody response in the thermal infrared region, but where lichen are not dense, good spectral contrast has been recorded. The rocks in the quarry faces are relatively clean; however, the degree of cleanliness is largely dependent on the time elapsed since the last working of the quarry face.

In general, the region provides an excellent opportunity to examine pure orthoquartzites as well as to contrast them with weakly cemented sandstones.

Beartooth Mountains, Montana-Wyoming

The Beartooth Mountains comprise an 80- by 40-mile elevated block of Precambrian crystalline rocks which trend west-northwest along the Montana-Wyoming border. This range was uplifted 10,000 to 15,000 feet on the east and north sides, respectively, during Laramide time; Tertiary volcanic rocks of the Yellowstone-Absaroka Mountains cover most of the block on the south and southwest sides (Foose and others, 1961). The entire range has been glaciated leaving a broad plateau surface into which deep U-shaped valleys have been carved on the north and east sides. Precambrian granitic rocks, metasedimentary rocks, and metavolcanics are well exposed in the deep (2,000-3,000 feet) canyons; outcrops are sparse on the plateau but soil and grass cover is thin.

The area selected for remote sensing studies is located near the northeast corner of the range about 15 miles south of Red Lodge, Montana. It was selected because quartzite and many other high-grade (upper phibolite facies) metamorphic rock types are well exposed in the nyon walls, and this part of the range has been the subject of much tailed petrologic (James, 1946; Eckelmann and Poldervaart, 1957; rris, 1959; Casella, 1964) and structural analysis (Rowan, 1969).

The most widely distributed rocks are granitic gneisses and migmatites, it in some places layers of amphibolite, quartzite, and biotite schist id gneiss are persistent along strike for several miles; subordinate ick types are ultramafic rocks, iron-silicate rocks, and numerous isaltic to granitic dikes and sills.

In the current studies, the rock type of main interest is the iartzite. It is a white to bluish-gray recrystallized quartzite with ounded zircon grains suggesting a sedimentary origin. Individual beds inge in thickness from a few inches to several feet, but composite itcrops as much as 100 feet wide are present. In places, the quartzite ; very pure (95 percent silica) but by progressive addition of feldspar id some biotite the rock becomes, at least locally, a leucogranitic ieiss. In addition to excellent outcrops along canyon walls, isolated itcrops as much as 40-50 feet wide occur on the plateau surface.

The structural setting of the northeastern part of the Beartooth ountains Precambrian block is complicated by the superposition of two ild sets. The younger folds are open and symmetrical about SSW-plunging ies and in most places are 2-3 miles wide. The younger fold set, wever, is so dominant that the older set is generally detectable only : the outcrop scale. Faulting is minor.

The Beartooth Mountains quartzite provides the metamorphic end-member in the quartzose series and is therefore an important field area in the remote sensing program. As our understanding of the effects of the various parameters increases, we will be able to utilize this area and the accrued data for studying the other high-grade metamorphic rock units. In addition, remote sensing personnel will attempt preparation of an outcrop map of this area from the remote sensing data. Involved in this effort will be the analysis, using single line scans as well as images and photographs, of data from the appropriate parts of the e-m spectrum. The Beartooth Mountains area is well suited for this type of study because of the contrast between excellent outcrops on the canyon walls and the isolated outcrops on the plateau surrounded by thin soil and grass cover.

Mill Creek, Oklahoma

The Mill Creek, Oklahoma test site is located on the south flank of the Arbuckle Mountains in southcentral Oklahoma. Rocks of principal interest range in age from Precambrian to Pennsylvanian and include consolidated but weakly cemented sandstone, as well as abundant, relatively pure dolomite and limestone. This test site and remote sensing activities conducted there are described in some detail by Rowan and others (1970).

Summary

Each of these four field areas is important to the overall remote sensing program, because each represents a fundamental occurrence of quartzose material--unconsolidated (Grand Sable sands); consolidated, but weakly cemented (Mill Creek sandstone); tightly cemented (Baraboo orthoquartzite); and completely recrystallized (Beartooth Mountains quartzite.

Carbonate Rocks

Carbonate rocks constitute a significant proportion (20 percent) of the total sedimentary rock volume and are of considerable economic as well as scientific importance. Although relatively pure limestones and dolomites are not uncommon, many of them have had a complex history and contain small, but significant, fractions of other constituents such as silica, clays, iron. Relatively pure calcium carbonate and calcium magnesium carbonate occur in the three sites being considered for study and described below. Additional studies will be necessary to evaluate the many textural and chemical variations common in this series.

Clarks Fork Canyon, Montana

Tectonic uplift of the Beartooth Mountains block in Laramide time resulted in deformation of about 10,000 feet of rocks along the Beartooth front ranging in age from Precambrian to Cretaceous; approximately 10,000 feet of Paleocene and Eocene rocks were deposited subsequent to the uplift. The style of deformation ranges from monoclinal folding of the Paleozoic and Mesozoic rocks on the southeastern side of the block to overthrusting of the Precambrian onto the younger rocks on the north and northeast sides. The Clarks Fork of the Yellowstone River occupies a deep (3,000 feet) canyon along the eastern front. At this point, two major, nearly vertical faults, the frontal Beartooth fault and the Clarks Fork fault, intersect, forming a simple raised corner of the range (Foose and others, 1961). Outcrops of the entire stratigraphic section (see table 2) are excellent on this corner, and no structural complexities are apparent.

The wide variety of sedimentary rock types available in this small area makes it a highly attractive field area, but more important is the presence of both relatively pure limestone and dolomite in the Madison and Bighorn formations, respectively, and pure fine-grained sandstones in the Tensleep formation. Also of interest are the impure sandstone of the Flathead formation, the Amsden and Chugwater red beds, and many impure limestones, dolomites, and shales. Analyses of the electromagnetic spectra of these rocks will be attempted when careful study of the more pure rock types here and at other field areas has been completed.

Table 2

Sequence of rocks in the Clarks Fork Canyon area, Montana

	Formation	Lithology	Thickness (feet)
ernary		Terrace gravels, flood-plain deposits, glacial deposits	
ie	Willwood	Red to tan massive arkoses and conglomerates containing cobbles of sedimentary and Precambrian rocks.	2500+
ocene	Undivided	Gray to buff bentonitic siltstones and impure sandstones with local thin beds of pebble conglomerate.	2300-2700
	Cody	Black shale with thin calcareous concretion zones and thin platy sandstones scattered throughout.	1625
	Frontier	Gray massive to thin-bedded sandstones, dark-gray shale, volcanic-rich (west), thin beds of chert-pebble conglomerate.	300
aceous	Thermopolis and Mowry	Dark-gray shale with bentonites, thin gray platy sandstones.	1165
	Cloverly	Chert-pebble conglomerate (west), or pebbly crossbedded sandstone (east) at base, red claystone in middle, gray sandstone at top.	620
	Morrison	Pink and gray shales and claystones, light-gray sandstones.	160
ssic	Sundance	Pink and tan siltstone and limestone at base, tan siltstone and shale in middle, tan calcareous sandstone at top.	610
ssic	Chugwater	Bright-red sandstone, siltstone, and shale.	780
ian	Phosphoria	Gray vuggy limestone and dolomite, light-gray, very calcareous sandstone.	40
sylvanian	Tensleep	Light-gray to tan massive sandstone, locally crossbedded.	280
	Amsden	Red shale and siltstone, gray dolomite, gray cherty sandstone and limestone.	80
issippian	Madison	Thin-bedded to massive, light-gray to tan, coarsely crystalline to aphanitic limestone, locally dolomite, cherty in zones.	780

Table 2

(Continued)

Age	Formation	Lithology	Thickness (feet)
	Threeforks	Light-gray to yellow limestone and dolomite, thick calcareous sandstone at base.	125
Devonian	Jefferson	Gray to brown limestone and dolomite, breccias in zones, some fine-grained sandy beds.	240
	Beartooth Butte	Local lens of deep-red, medium-bedded, slightly calcareous sandstone.	0-55
Ordovician	Bighorn	Massive, tan, rough-weathering dolomite and dolomitic limestone, thin-bedded brittle dolomite at top.	310
	Grove Creek and Snowy Range	Limestone flat-pebble conglomerate, aphanitic gray limestone, dark-gray shale.	420
	Maurice	Gray to brown oolitic and coarsely crystalline limestone, some thin beds of limestone flat-pebble conglomerate.	90
Cambrian	Park	Interbedded dark-gray shale, tan platy sandstone and siltstone, platy aphanitic limestone, and local thin beds of limeflat-pebble conglomerate.	580
	Meagher	Light-gray, wavy-bedded limestone, some interbedded green shale.	55
	Wolsey	Dark-gray shale, some platy limestone and siltstone.	210
	Flathead	Light-tan to white, medium-grained sandstone, locally conglomeratic.	25-60
Precambrian		Granitic gneiss, amphibolite and mafic dikes.	

Because of their proximity, the Beartooth Mountain site and this site are being considered as one site for the purposes of the NASA-ERS remote sensing flights.

Whitewater Bay and Bahia Honda Key, Florida

Two areas, approximately 60 miles apart in southern Florida--Whitewater Bay and Bahia Honda Key--are being considered for remote sensing studies of unconsolidated carbonate materials.

The Whitewater Bay area, north of Flamingo, is in Monroe County, at the southwestern tip of peninsular Florida, and a few miles northeast of Cape Sable. It is easily accessible by road, from Coral Gables and Florida City, but a boat is required for beach, bayou, and lagoon exploration.

Whitewater Bay is about 20 miles long and 5 miles wide. It offers a series of environments of deposition, from the marine to the fresh-water swamp through the paralic swamp environment. The sedimentary rocks that are now being deposited in these shallow waters range from peat to calcitic mud and calcilutaceous silts, some of which are exposed on beaches and at low tide. Large bird rookeries are on islands nearby, and the percentage of calcium-rich apatite and fluorapatite increases in sediments toward the rookeries. Inland, calcitic mud secreted by algae is precipitated in tidal estuaries. Recent sedimentary rocks in Whitewater Bay overlie the Miami limestone, of late Pleistocene age. Beach rock likely is present in places.

The Bahia Honda Key area consists of the beaches and bayous of Bahia Honda Key, about 35 miles east of Key West in T. 66 S., R. 29 and 30 E. It is easily accessible by highway. There, carbonate sands of both aragonitic and calcitic types, and very probably some dolomite sand,

are being deposited and moved along beaches and in spillthroughs. The key itself consists mostly of carbonate sand and beach rock which rests on the upper oolitic member of the Miami limestone and probably on the Key Largo limestone. The oolitic member of the Miami limestone rests on the Key Largo limestone, but both units are late Pleistocene in age.

The two areas are only 60 miles apart, across Florida Bay, and together they represent several types of environments in which carbonates are being deposited today on and near mainland North America. Because more than one mineral phase of each mineral is being deposited, it may be possible, using remote sensing techniques, to detect textural and mineralogical gradations both in wet and dry environments.

Marble, Colorado

The Marble or Snowmass Mountain area is in northern Gunnison County, Colorado, at the western edge of the southern Rocky Mountains. The geologic area of specific interest is a dome, about 6 miles across, produced by the intrusion of a Tertiary granite stock (Vanderwilt, 1937). Elevations in the area reach 13,500 feet and exposures are excellent above the tree line; below tree line numerous large, clean, cliff exposures are available for most of the rock units. Quarries provide large smooth exposures and coarsely blocky rubble piles for the Yule marble, a rock unit made classic by detailed studies of its fabric and composition (Knopf, 1949; Turner, 1949; Griggs, 1936) and a prime target for the RSAS investigations.

Rocks exposed in the domal structure offer a nearly complete section of the region's stratigraphy, from Precambrian gneiss and Tertiary granite at the core to Cretaceous formations on the periphery. The section is as follows:

Formation	Thickness (feet)	Lithology
Mesa Verde		sandstone, shale
Mancos	2000-2800	shale
Dakota	200	sandstone
Morrison	400	shale, sandstone
Entrada	15-45	sandstone
Maroon	1000	sandstone, shale
Hermosa	1200-1300	limestone, sandstone shale
Leadville (Yule)	170-270	limestone
(Ordovician/ Devonian)	265-365	dolomite, limestone, quartzite
Sawatch	220-280	quartzite
(Precambrian)		biotite gneiss
(Tertiary)		granite, granodiorite

Of particular interest for remote sensing are the Sawatch quartzite, Leadville (Yule) limestone, and Dakota sandstone because they are conspicuous, well-exposed units that provide relatively pure samples for investigations of spectral response of fundamental, simple quartzose and carbonate rocks. In addition, the area offers an excellent opportunity to extend the investigations into other common rock types such as shale, dolomite, gneiss, and granite.

A further important aspect of the area is that the stratigraphic section below the Mancas shale around the dome has been thermally metamorphosed by the intrusive granite without significant changes in the rock compositions. The heating produced recrystallization, changing limestone to marble, sandstone to quartzite or hornfels, and shale to hornfels or slate. In the immediate vicinity, but away from the dome, the section from the Leadville upward through the Mesa Verde is exposed in unmetamorphosed condition. Thus, it will be possible to compare remote sensing data for all these formations in metamorphic and sedimentary states. Specifically, this will provide comparison of rocks identical in composition but different in texture, fracture characteristics, and, in some, mineral phases present. Comparison of responses from outcrop and blocky talus for the quartzose and carbonate units will also be practical and useful in defining effects of surface roughness.

Although our investigation is not specifically aimed at economic aspects of remote sensing, one result should be learning to recognize economically useful rock units such as marble and quartzite. Another aspect which may be of interest is remote recognition of faults and large quartz veins, which in this area are associated with lead-silver-zinc mineralization.

Gypsum Rocks

White Sands, New Mexico

The gypsum sand dunes of White Sands are in the south-central part of New Mexico. They cover an area of 131 square miles, within and outside the White Sands National Monument. The average thickness of the sand is about 20 feet. The White Sands are fourth-cycle deposits, whose primary source was the Permian gypsum beds in the San Andres, Oscura, and Sacramento Mountains. Their immediate source is the gypsum beds bordering Lake Lucerno and those around Alkali Flat.

The sand grains are cleavage flakes of selenite, subangular to rounded and frosted. The porosity is less than 25 percent.

The dunes of pure gypsum sand grade laterally into active and fixed dunes of gypsiferous sand, containing as much as 25 percent of other minerals. Secondary minerals are quartz, potash-feldspar, dolomite, and grains of metamorphic and igneous rocks, with suites of heavy minerals.

The interest in the gypsum sand for remote sensing lies in the possible comparison of its spectral response with that of quartz and carbonate sand. The porosity is smaller than in quartz sand, and it may be possible to weigh the influence of this parameter on remote sensing data return.

A large part of the pure gypsum dunes in the White Sands lies outside the National Monument, and constitutes an important national resource. The lateral gradation of the sand from pure to impure also provides a potential tool for the eventual interpretation of new gypsum deposits from remote sensing data collected elsewhere in the world.

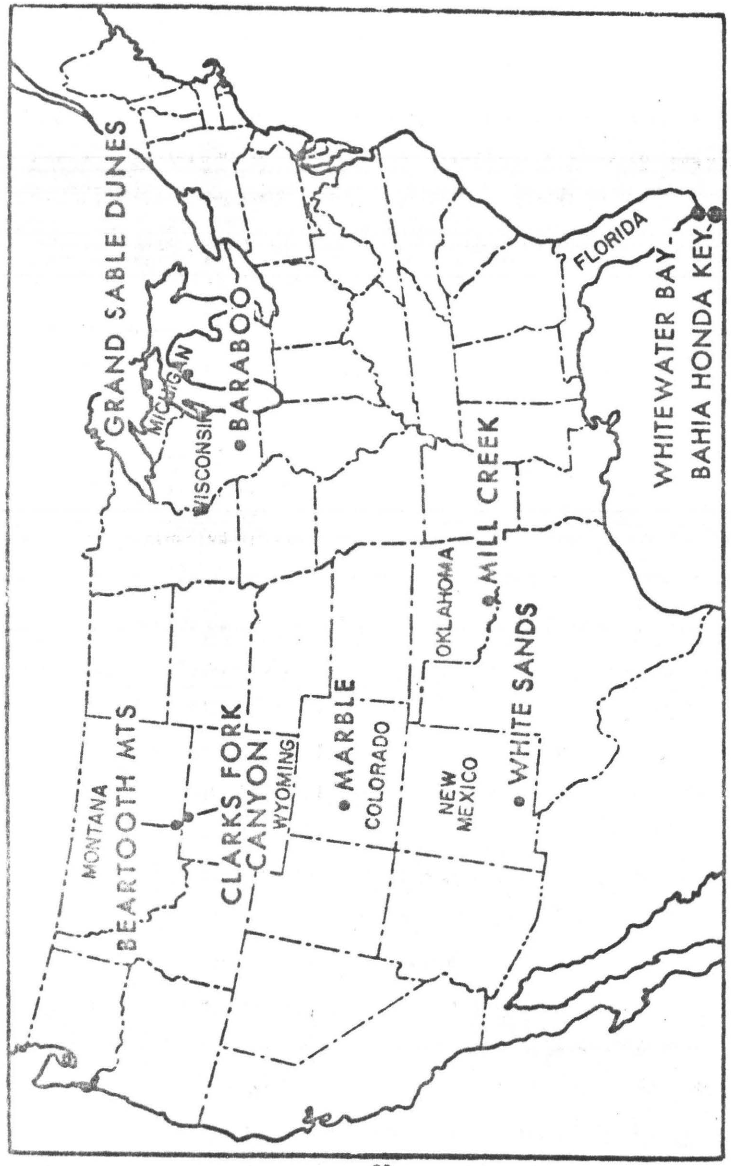
Other Rocks

Although all the above field areas are either sedimentary or metasedimentary, several sedimentary rock types have not been given consideration proportional to their importance. A case in point is that shales (including slates) comprise nearly 50 percent of the total sedimentary rock exposure, but have been given only secondary consideration in three of the above nine areas. However, shales are one of the most complex sedimentary rocks, and therefore, while of great importance, study of the spectral response characteristics of shales will be deferred until the response of quartzose and carbonate rocks is more completely understood.

Other important sedimentary rocks not yet considered are nonclastic siliceous sediments, evaporites, carbonaceous rocks, iron-bearing sediments, glauconite, and phosphatic sediments. Although these rocks are usually of restricted lateral and vertical extent, they are often key stratigraphic beds or economically important.

Beyond the pure (monomineralic) end members of the various sedimentary rock series, more complex aggregates of minerals (bimineralic, trimineralic, etc.) are encountered. In order to identify these aggregates through remote sensing techniques, it is necessary to be able to determine from the integrated spectra the individual constituents and something about the proportions of these materials, i.e., mixing problems, because the major igneous rock-forming minerals are more numerous and complex than in simple sedimentary rocks described here; moreover, the natural occurrences of a number of the igneous rock-forming minerals are usually too limited in areal extent to be useful remote sensing targets. Construction of mixing rules is best accomplished through laboratory and theoretical studies prior to application in the field.

Figure. 1. Location of controlled field areas in the United States.



FIELD MEASUREMENTS OF INFRARED EMISSION

For the remote identification of minerals and rocks, infrared spectroscopy is one of the most direct techniques in its application to space petrography. This is because many of the important rock-forming minerals demonstrate strong selective absorption in the infrared region of the electromagnetic spectrum. Associated with these absorption maxima are reflection maxima (emission minima) in infrared intensity. The spectra of different rock and mineral types are distinctive and are considered diagnostic "infrared spectral signatures." When infrared spectra are used in remote sensing investigations, it is important to note that the signatures can be modified by perturbing effects due to meteorological, biological, and geological processes. Understanding the perturbing processes is necessary both for a correct interpretation of infrared signatures and for a determination of the appropriate environmental conditions under which infrared measurements should be made. The field measurement program described in this section is designed to provide an understanding of the perturbing effects and to form a basis of comparison with laboratory and theoretical studies.

A vehicle-mounted spectrometer system, consisting of a Perkin-Elmer model 98 laboratory monochromator optically coupled to a 12-inch astronomical telescope, was used to obtain infrared emission spectra in the field. The telescope was converted from an F/15 Cassegrain to a F/4 Newtonian. This provided a more efficient coupling to the F/4.5 monochromator. The spectra were recorded on a model 7100 Mosely strip chart recorder.

Measurements were made during the summer of 1968 at several field sites containing excellent exposures of quartzose materials ranging from unconsolidated sediments to metamorphosed rocks, in order to evaluate the effects of grain size, surface contamination, and atmospheric conditions on the characteristic infrared emission. For these measurements, quartz was chosen as the basic mineral for reasons discussed by R. D. Watson and others (1970, p. 2). The field sites above were Mill Creek, Oklahoma; Baraboo, Wisconsin; Grand Sable dunes, Michigan; and the Beartooth Mountains, Montana. Measurements of the emission spectra were obtained in the atmospheric window from 8.0 to 14.0μ and over varying atmospheric pathlengths.

One of the major perturbing effects on the measured quartz spectra is that of surface contamination, caused by a variety of natural processes. The effects of vegetation and surface coatings are shown in figures 2, 3, and 4. Figure 2 demonstrates the loss of spectral contrast of the quartz emission features caused by complete lichen cover. Shown are the spectral emission features of the Dresbach quartz sandstone (Baraboo, Wisconsin) in clean exposure and covered with lichen. Figure 3 demonstrates the loss of spectral contrast of the quartz features in measurements made on a water-saturated quartz sand from Grand Sable dunes, Michigan. The experimental results agree with laboratory and theoretical studies discussed by R. D. Watson and others (1970, p. 19-21), where it is shown that a thin coat of water can effectively reduce or even eliminate the major spectral features of quartz. Figure 4 compares the emission spectrum of clear quartzite to that of pyrophyllite-coated quartzite and demonstrates the more complex spectrum that results from a partial coating of pyrophyllite. An analysis of this particular example by R. D. Watson and others (1970, p. 21-23) demonstrates that this complex spectrum is a product of

linear superposition of both the quartz and pyrophyllite spectra. Further studies are being directed toward gaining a more comprehensive understanding of the influence of coatings on both field and laboratory emission measurements.

The influence of atmospheric variation of infrared emission measurements (R. D. Watson and others, 1970, p. 29) was investigated in the field experiments. Changes in atmospheric emission characteristics at different field sites in Michigan and Illinois are illustrated in figure 5 for the period from July 1 to July 9, 1968. On July 9, a major cold front was located near the eastern tip of Lake Superior and extended from northeastern Canada to southwestern Kansas. The passage of the wedge of cold air produced atmospheric conditions which were quite unstable in the frontal zone. Measurements at Grand Marais, Michigan, on July 9 show the greatest short-term fluctuations and demonstrate the influence of meteorological conditions. Under stable conditions, with light winds, it was noted that over a variety of atmospheric pathlengths the spectral features of relatively uncontaminated quartz are evident. This is shown in figure 6, where the emission minima at 8.5, 9.0, and 12.5μ are identified even over pathlengths that exceed one air mass.

Another important atmospheric problem that needs to be carefully considered is the nature of emission from particulate matter in the atmosphere. This is a problem that can be quite important where atmospheric haze layers may have considerable influence on the results. It is related to the detection of volcanic debris ejected into the atmosphere, and particulate atmospheric pollutants from a variety of industrial sources. In an experiment at Mill Creek, Oklahoma, the infrared spectrometer was positioned downwind from a dolomite processing plant to measure the emission spectrum of moderate quantities of finely powdered dolomite injected into the atmosphere. Figure 7 shows the measured spectrum in which the 9.8 and 11.2μ absorption lines of dolomite appear as emission maxima. It seems clear that understanding of both scattering and emission from particulate matter will be important in future experiments from spacecraft altitudes.

In field measurements of the infrared emission of quartz sand at Grand Sable dunes, Michigan, some differences were noted in the ratio of emitted intensity of the 8.5 to 9.0μ lines when comparing the spectra of fine and coarse-grained quartz. This is tentatively interpreted as a grain-size effect, although, because of the long scan time of the field spectrometer, it was difficult to make a detailed analysis of grain-size effects. Current laboratory studies described by R. D. Watson and others (1970, p. 3) are promising in suggesting the application of infrared spectroscopy to both textural and grain-size problems. Further experiments are planned that will concentrate on sample control so that grain-size effects can be quantitatively determined.

Figure 2. Comparison of the emission features of the Dresbach quartz sandstone when relatively uncontaminated and when lichen covered.

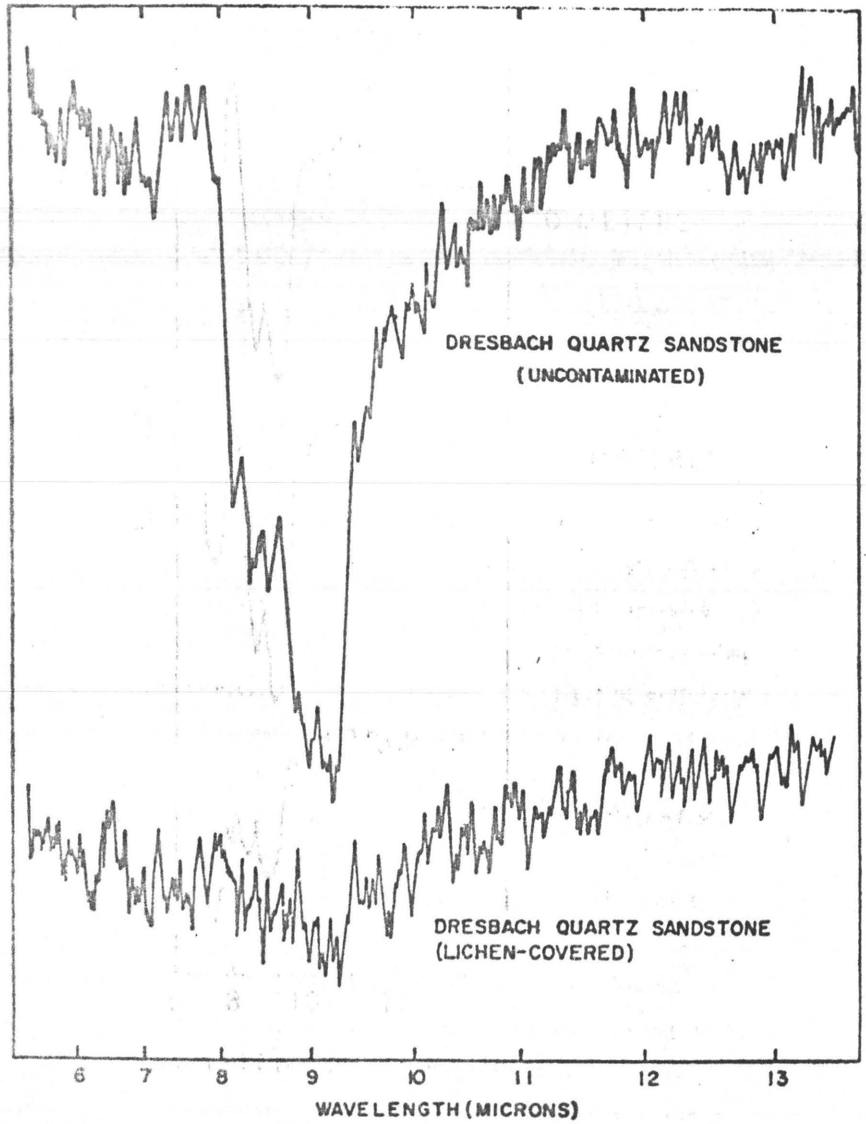
Figure 3. Comparison of the emission features of the Grand Sable quartz sand when dry and when water saturated.

Figure 4. Comparison of the emission features of Baraboo quartzite with varying degrees of pyrophyllite coating. Curves A, B, and C represent uncoated, partial coating, and nearly total coating, respectively.

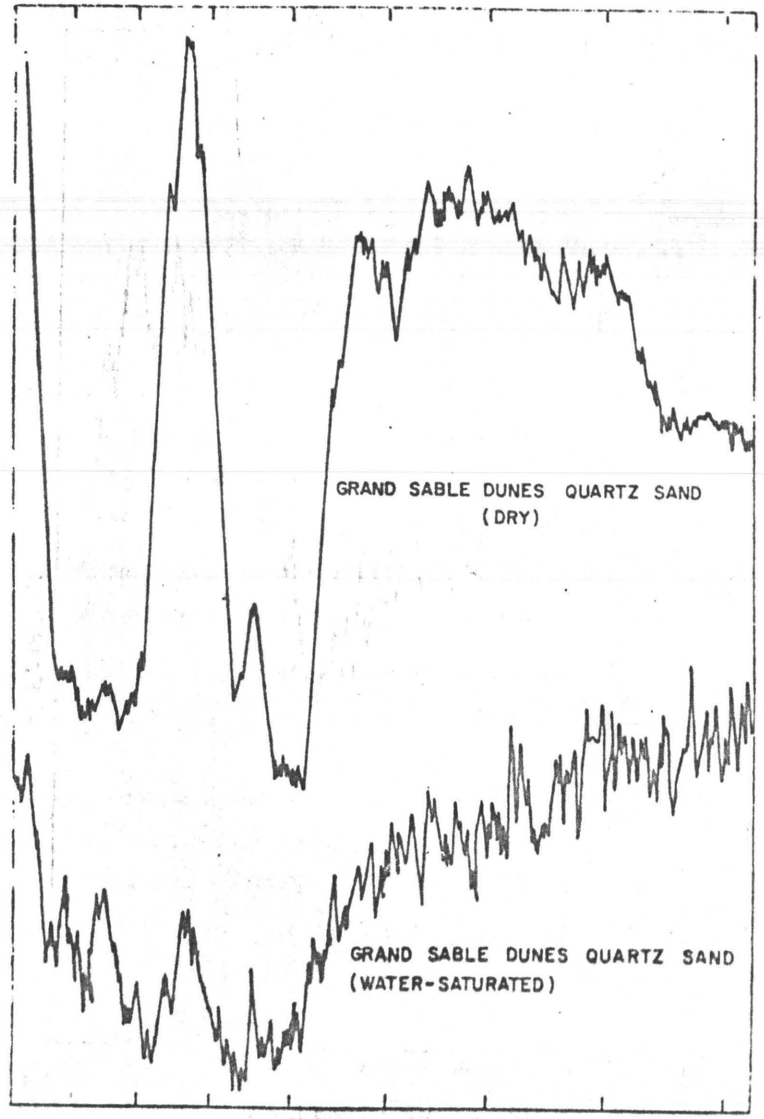
Figure 5. Comparison of the atmospheric emission features measured during the period of 7/1/68 to 7/9/68. The increase in noise on 7/9/68 is due to unstable atmospheric conditions.

Figure 6. Quartz emission spectrum versus wavelength, measured over a variable pathlength. Negaunee, Michigan; 7/9/68.

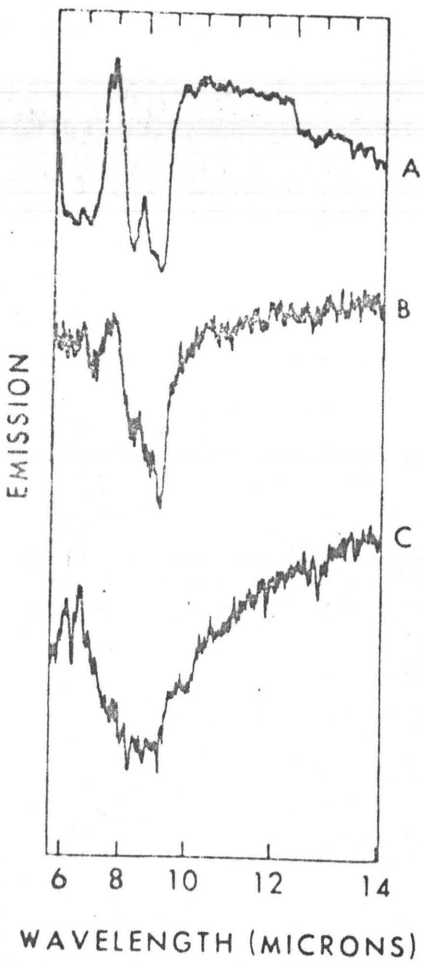
Figure 7. Emission spectrum of a dolomite dust cloud produced by a dolomite processing plant near Mill Creek, Oklahoma. The 9.8 and 11.2 absorption lines of dolomite appear in emission.



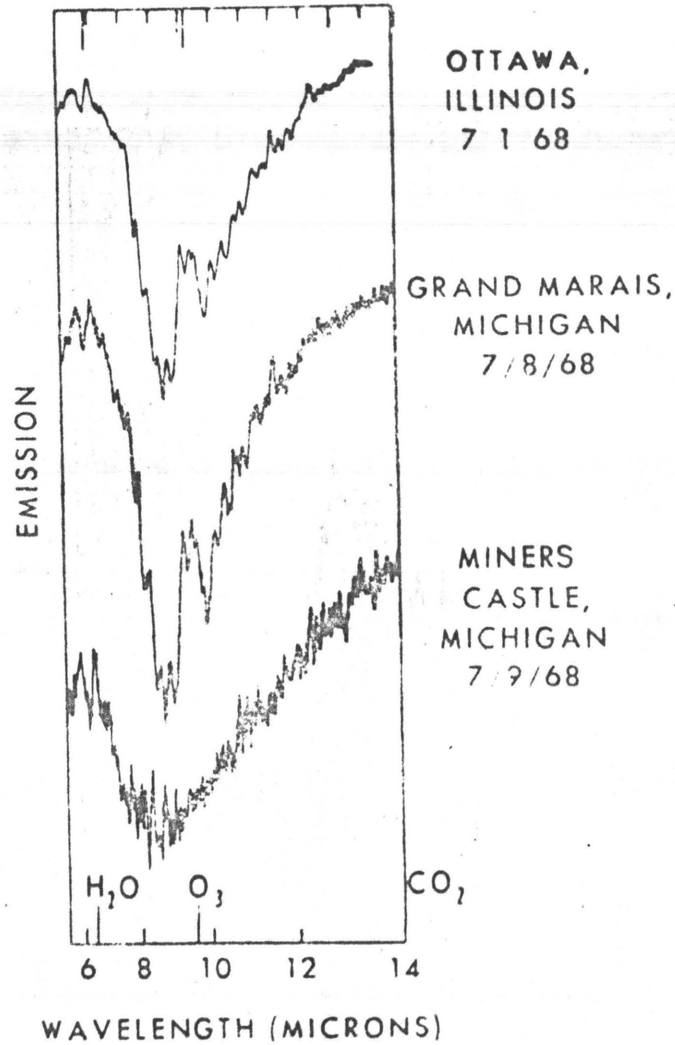
DRESBACH QUARTZ SANDSTONE
(UNCONTAMINATED)
DRESBACH QUARTZ SANDSTONE
(LICHEN-COVERED)
6
7
8
9
10
11
12
13
WAVELENGTH (MICRONS)



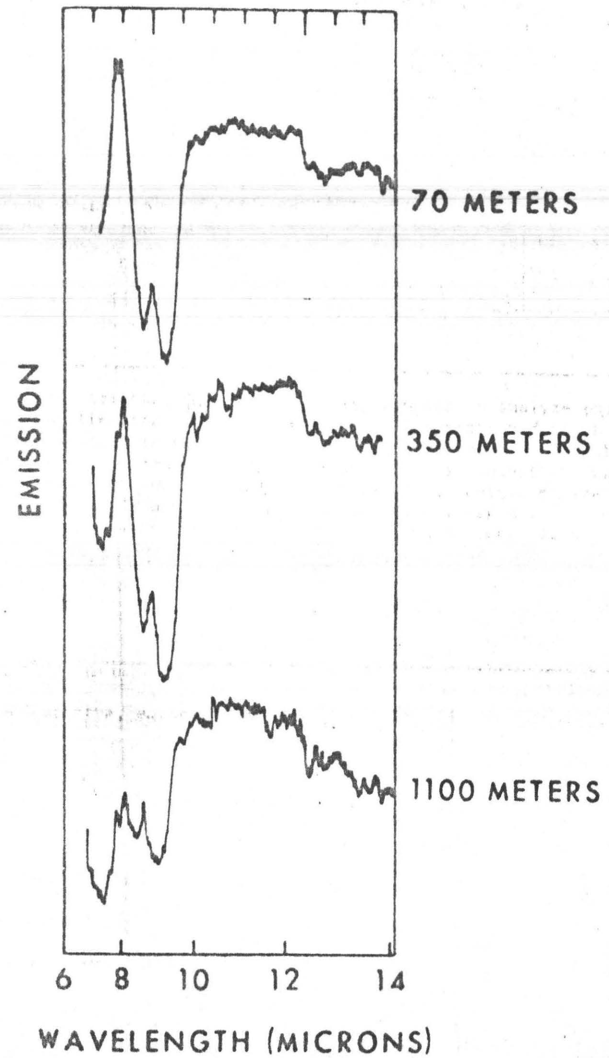
GRAND SABLE DUNES QUARTZ SAND
(DRY)
GRAND SABLE DUNES QUARTZ SAND
(WATER-SATURATED)



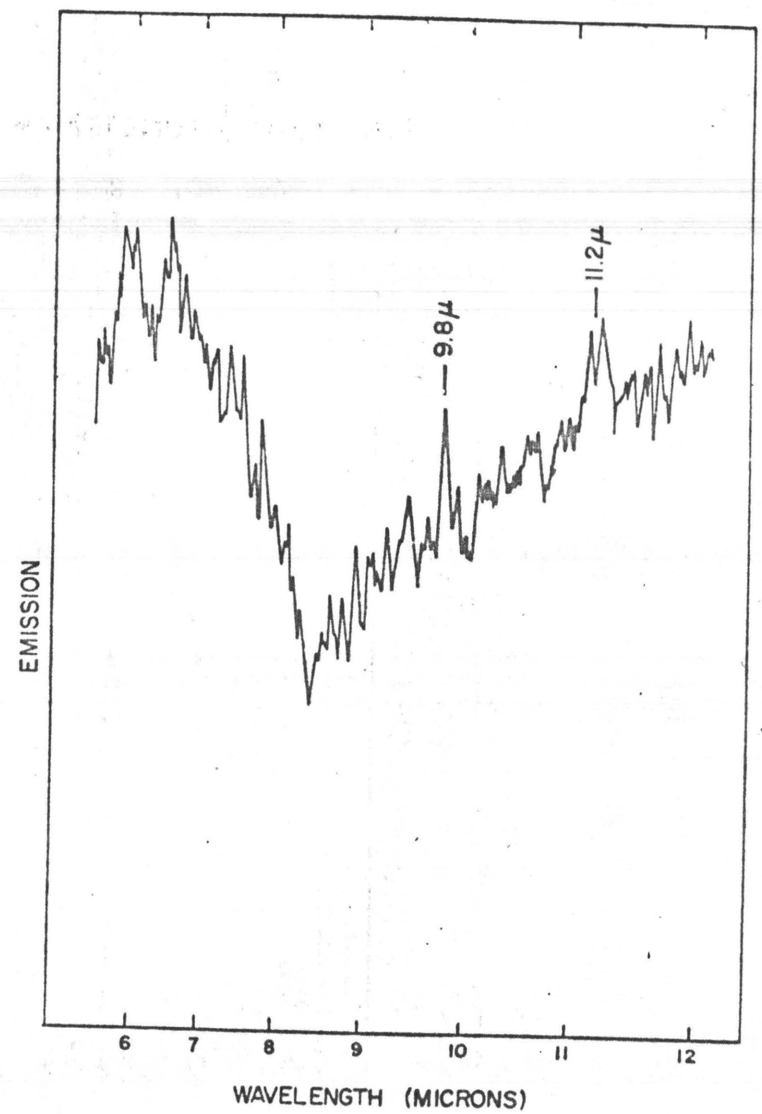
A
B
C
EMISSION
6
8
10
12
14
WAVELENGTH (MICRONS)



OTTAWA, ILLINOIS 7 1 68
GRAND MARAIS, MICHIGAN 7/8/68
MINERS CASTLE, MICHIGAN 7/9/68
EMISSION
H_2O
O_3
CO_2
6
8
10
12
14
WAVELENGTH (MICRONS)



70 METERS
350 METERS
1100 METERS
EMISSION
6 8 10 12 14
WAVELENGTH (MICRONS)



9.8μ
11.2μ
EMISSION
6 7 8 9 10 11 12
WAVELENGTH (MICRONS)

REFERENCES

Casella, C. J., 1964, Relationship between Precambrian and Laramide structures in the Line Creek area, Pt. 4 of Geologic evolution of the Beartooth Mountains, Montana and Wyoming: Geol. Soc. America Bull., v. 75, no. 10, p. 969-986.

Cooper, W. S., 1958, Coastal sand dunes of Oregon and Washington: Geol. Soc. America Mem. 72, 169 p.

Eckelmann, F. D., and Poldervaart, Arie, 1957, Archean history of the Quad Creek area, Pt. 1 of Geologic evolution of the Beartooth Mountains, Montana and Wyoming: Geol. Soc. America Bull., v. 68, no. 10, p. 1224-1261.

Foose, R. M., Wise, D. U., and Garbarini, G. S., 1961, Structural geology of the Beartooth Mountains, Montana and Wyoming: Geol. Soc. America Bull., v. 72, no. 8, p. 1143-1172.

Griggs, D. T., 1936, Deformation of rocks under high confining pressures: 1, Experiments at room temperature: Jour., Geology, v. 44, no. 5, p. 541-577.

Harris, R. L., Jr., 1959, Gardner Lake area, Wyoming, Pt. 3 of Geologic evolution of the Beartooth Mountains, Montana and Wyoming: Geol. Soc. America Bull., v. 70, no. 9, p. 1185-1216.

James, H. L., 1946, Chromite deposits near Red Lodge, Carbon County, Montana: U. S. Geol. Survey Bull. 945-F, p. 151-189 [1947].

Knopf, E. F., 1949, Fabric changes in Yule marble after deformation in compression: Am. Jour. Sci., v. 247; Pt. 1, no. 7, p. 433-461; Pt. 2, no. 8, p. 537-569.

Rowan, L. C., 1969, Structural geology of the Quad-Wyoming-Line Creek area, Beartooth Mountains, Montana: Geol. Soc. America Mem. 115, p. 1-18.

Rowan, L. C., Offield, T. W., Watson, Kenneth, Cannon, P. J., and Watson, R. D., 1970, Remote sensor application studies progress report, July 1, 1968 to June 30, 1969: Remote sensing reconnaissance Mill Creek Area, Arbuckle Mountains, Oklahoma; U.S. Dept. Commerce Natl. Tech. Inf. Service

Turner, F. J., 1949, Preferred orientation of calcite in Yule marble: Am. Jour. Sci., v. 247, no. 9, p. 593-621.

Vanderwilt, J. W., 1937, Geology and mineral deposits of the Snowmass Mountain area, Gunnison County, Colorado: U.S. Geol. Survey Bull. 884, 184 p.

Watson, R. D., Watson, Kenneth, Offield, T. W., and Rowan, L. C., 1970, Remote sensor application studies progress report, July 1, 1968 to June 30, 1969: Laboratory and theoretical investigations; U.S. Dept. Commerce Natl. Tech. Inf. Service.

...PAGE ...ORTS	1. Report No. USGS-GD-71-007		3. Recipient's Catalog No.
Title: ...mote sensor application studies progress report, July 1, 1968 ... June 30, 1969: Controlled field experiments			5. Report Date 1970
			6. Performing Organization Code
...thor(s) L. C. Rowan, T. W. Offield, R. D. Watson, P. J. Cannon ... J. Grolier, H. A. Pohn, and Kenneth Watson			8. Performing Organization Rept. No.
...rforming Organization Name and Address ...S. Geological Survey ...shington, D. C. 20242			10. Project/Task Work Unit No.
			11. Contract/Grant No.
...onsoring Agency Name and Address ...tional Aeronautics and Space Administration ...shington, D. C. 20546			13. Type of Report & Period Covered Progress FY 1969
			14. Sponsoring Agency Code

...pplementary Notes

...bstracts

...eld sites have been selected for controlled experiments to analyze physical and ...emical parameters affecting the response of electromagnetic radiation to geological ...terials. Considerations in the selection of the sites are the availability of good ...posures of nearly monomineralic rocks, level of geologic understanding, and ease of ...cess. Seven sites, where work is underway or planned, contain extensive outcrops of ...e following rocks: sandstone, limestone, dolomite, and gypsum. Field measurement ... infrared emission of quartz sand have been conducted at four sites.

...y Words and Document Analysis. (a). Descriptors

...ology, infrared spectra, emission spectra

Identifiers/Open-Ended Terms

...nomineralic rocks, remote sensing

COSATI Field/Group 08 G 20 K

...istribution Statement	19. Security Class (This Report)	21. No. of Pages
...eleasable to the public, available from ...TIS, Springfield, Va. 22151	UNCLASSIFIED	41
	20. Security Class. (This Page) UNCLASSIFIED	22. Price

...M NBS-667(1-70)