APPLICATION OF REMOTE SENSOR DATA

TO

GEOLOGIC ANALYSIS OF THE BONANZA TEST SITE

COLORADO

SEMIANNUAL PROGRESS REPORT

1 April 1973 - 30 September 1973

Remote Sensing Report 73-4

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Compiled and Edited

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APPLICATION OF REMOTE SENSOR DATA

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Semiannual Report, 1 April 1973 - 30 September 1973

INTRODUCTION

This report summarizes the research activities of the Colorado School of Mines faculty and students and the Martin Marietta Corp. scientists for the period 1 April 1973 to 30 September 1973. During this period, Professors Keenan Lee and D. H. Knepper, Research Associate D. L. Sawatzky, and graduate students R. W. Butler, J. C. Fisher, and D. Huntley of CSM, and research scientists R. C. Hulstrom, J. R. Muhm, K. E. Worman and D. C. Wychgram of MMC carried out research under the project.

ACQUISITION OF REMOTE SENSOR DATA

A NASA aircraft support mission was requested for June 1973, using the NP3A aircraft. Data requested included color and color IR photography, black and white infrared low sun-angle photography, predawn thermal infrared imagery, predawn PMIS microwave imagery, and ARSS infrared spectrometry.

The requested mission was flown as Flights 25, 26 and 27 of Mission 235, on 18, 20 and 22 June 1973, respectively. Most of the requested data were acquired, including the color and color IR photography, and predawn IR and microwave imagery. The low sun-angle photography (LSAP) was not taken because of detrimental snow cover. The infrared spectrometry was not acquired due to the non-availability of the ARSS system.

On 6 September 1973, a flight request was submitted to NASA/AMES Applications Aircraft Support Program, via J. A. Vitale, for an NP3A mission in June 1974. Data requested include the LSAP and IR spectrometry not obtained in 1973, plus additional photography and IR scanner imagery.

PROGRESS REPORT ON GEOLOGIC REMOTE SENSING APPLICATIONS

Regional Geologic Mapping

Bonanza Test Site Geologic Compilation Map

The compilation of the geologic map of the Bonanza Test Site is progressing, with anticipated completion during the next reporting period. Using published large-scale geologic maps from various sources, the geology of the area is being compiled on a base scaled at 1:250,000. This compilation map will be used to evaluate ERTS, Skylab and remote sensing underflight data.

Regional Geology Test Site

The geologic map and report on the RGTS are nearing completion, with publication anticipated during the next reporting period.

Detailed Geologic Mapping

Research carried out during this period concerned the final analysis and evaluation of remote sensor data. Evaluation of the capabilities and limitations of the remote sensor data has been based on comparison with geologic field data collected during three summers' work. At present, the final report is still in the process of being completed.

Surficial and Engineering Geology

Research activities consisted of the compilation of field and laboratory data to produce geologic, engineering geologic, hydrologic, and slope maps of the test site. Evaluation of the imagery over the test site obtained by Mission 205 was performed with respect to usefulness and potential applications to surficial mapping. The final report on this research is expected during the next reporting period.

Fracture Studies

During part of the reporting period, investigation was involved with the detection and identification of the regional fracture system and faults in the southern Front Range. Much of this time was spent making operational several computer programs that determine and statistically evaluate trends in fracture or linear data. The remainder of this time was spent interpreting high altitude color photography (Mission 205, flight lines 4-9). Inputs into this effort were previous knowledge of the geology of the Front Range and Canon City embayment and ground measurements of joint sets.

Analysis of joint sets measured in the Canon City embayment (Phantom Canyon) revealed three statistically significant joint sets in Precambrian metamorphic and igneous rocks. The sets are near vertical and trend N.6W., N75E., and N.58W. The first set is most prominent and is 2.5 times more abundant than the last one. On the high altitude color photography (scale 1:100,000), several large outcrops are discernable that have two well-developed joint sets, the N.6W. trend and the N.75E. trend.

Numerous extensive linear features are also discernable. On Cooper Mountain west of Phantom Canyon, two parallel linears follow the N.75E. trend and extend eastward across Phantom Canyon. They are in Precambrian rocks and pass into Laramide or younger structures on the eastern mountain flank and are interpreted as faults. Another single linear follows Milsap Creek and extends from the western mountain flank near Sheep Mountain northeastward many miles across Phantom Canyon and the Beaver Creek drainage area into the Pikes Peak batholith northeast of Victor. This linear is near a large outcrop dissected by two joint sets, one of which it parallels (N.75E.). Its involvement with Laramide or younger mountain flank structures indicates the linear is a major fault related to a regional joint trend in the Precambrian metamorphic rocks. Also on Cooper Mountain, several linears of lesser length parallel the prominent N.6W. joint trend in nearby outcrops.

Little use has been made yet of the color IR photography, but good results are anticipated. Nevertheless, the relationship of major geologic structures and smaller structures measured on the outcrop has been easily demonstrated by use of high altitude color photography.

Mineral Deposits (Uranium) Exploration

Introduction

Various types of remote sensing data have been evaluated as to the utility of their application to uranium exploration.

An area of vein-type uranium mineralization in the Front Range of Colorado was chosen as a test site (Fig. 1). The area is composed mainly of Precambrian metasediments. Faulting and rock types seem to control the ore localization, and the identification and mapping of these features is fundamental to the location of possible mineralized areas.

Ore Controls

The main features that seem to control the localization of uranium ore of the Front Range, vein-type deposits are:

1. Occurrence of metasedimentary rocks in nearby association to the Front Range mineral belt of metamorphic and intrusive rocks.

2. The existence of major NNW-trending fault zones within the metasedimentary rocks (areas of intense fault bifurcation are especially prospective as exploration targets).

3. Competent metamorphic rocks and associated brecciation due to faulting.

4. Faulting at an angle to metamorphic foliation, rather than along it, as the former causes fault dilation and greater brecciation.

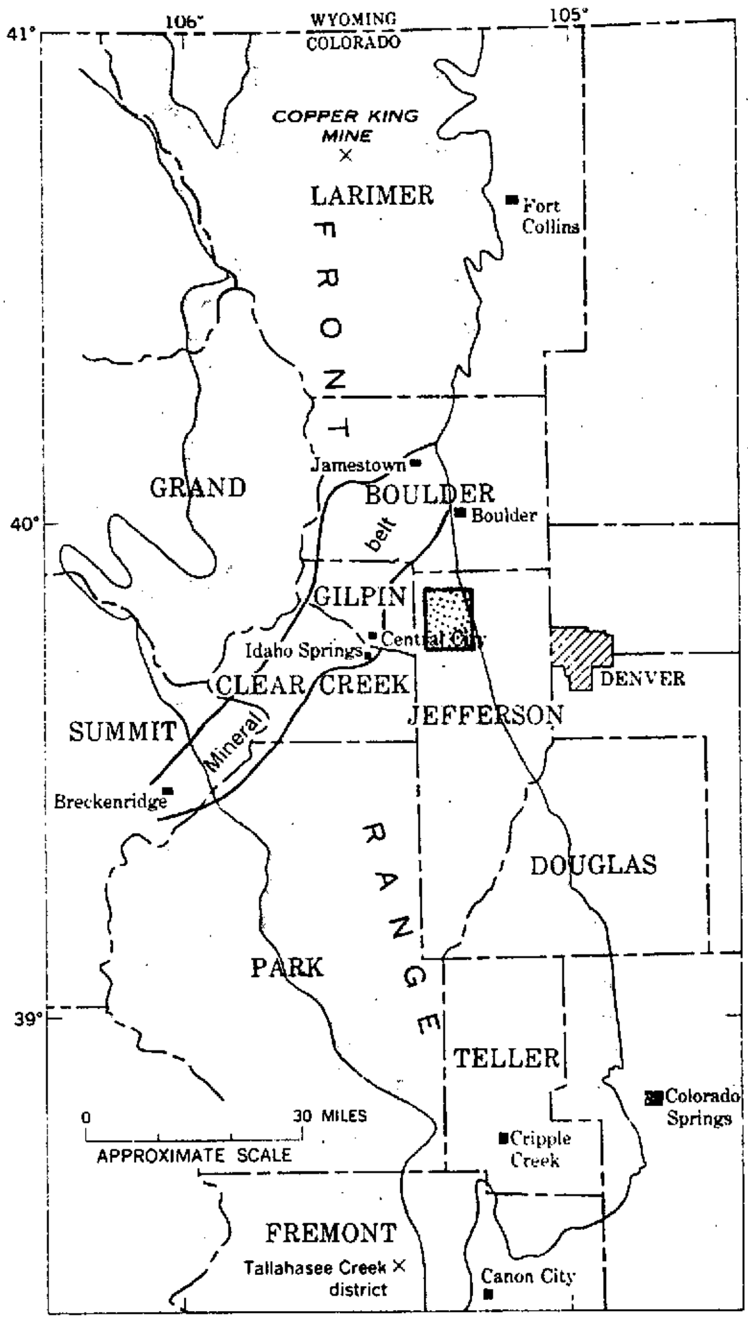


Figure 1. Uranium exploration test site.

5. Iron staining or alteration, because of the possible association of uranium deposition with zones of pyrite, which oxidize to hematite.

Remote Sensing Evaluation

1. ERTS Imagery - Faults, joints, or relict structure lineations easily seen and mapped. The nearly-constant illumination azimuth limited data to the mapping of only a couple of lineation sets. No contacts of schistosity foliation were discerned.

2. U-2 high-altitude black and white Photography (approximately 1:120,000) - Snow cover obscured much of the photography. The same faults were seen on this imagery as seen on ERTS imagery.

3. Medium-altitude black and white photography (1:64,000) - Large pegmatites were seen and mapped, as well as some of the more obvious schistosity lineations. No lithologic discrimination possible. Large through-going fault systems not as obvious as on ERTS or U-2 photography.

4. Low-altitude black and white photography (1:22,000) - Excellent for schistosity lineation plotting, poor for contact mapping. Large fault systems in map area were not recognized except in short sub-parallel segments that could often be connected to form the larger faults. No tonal anomalies recognized.

5. Low Sun-Angle Photography (1:40,000) - Since the

photography is of only one sun angle and azimuth, only two regimes of lineations are displayed. Other sun azimuths might reveal other regimes.

6. High-Altitude Color and Color Infrared Photography (1:106,000) - Faults and metamorphic schistosity easily mapped. Granitic gneiss-amphibolitic gneiss contacts seen and mapped in areas of good exposure. No color anomalies easily seen.

7. Medium-altitude Color Infrared Photography (1:53,000) - Obvious contacts between granitic gneiss and biotite-amphibolite-hornblende gneiss easily seen and traced. Faults not as obvious as on high altitude photography except in short, seemingly unconnected segments. Possible color anomaly seen.

8. Low-altitude Color and Color Infrared Photography (1:12,000) - Best for contact mapping, even in areas of poor outcrop or extensive tree cover. Small pegmatites (3-10 feet wide) easily seen and mapped. Very short segments of faults mapped, but in some cases segments connect to form the through-going larger faults. Fault brecciation displayed on surface only by swarms of intersecting faults. Color anomalies very obvious and easily subdivided as to color.

Preliminary Conclusions

In planning an exploration program in areas of possible Front Range, vein-type uranium deposits, it is recommended that two types of photography be obtained: a high-altitude, small-scale black and white photography mission for structural features (faults and schistosity), and in conjunction, large-scale, low-altitude color and color infrared photography for the mapping of lithologic contacts and color anomalies due to alteration and iron staining.

Further Study and Research

Other techniques of remote sensing applied to uranium exploration that may be evaluated (depending upon data availability*) are:

1. Infrared spectrometry*
2. Side-looking airborne radar
3. Airborne scintillometer spectrometry
4. Skylab imagery and photography
5. Multiband photography
6. Thermal infrared imagery
7. Color additive viewing of ERTS imagery
8. Ground scintillometer surveying
9. Soil radon emanometry
10. Sulfur gas sampling
11. Biogeochemical and geobotanical sampling
12. Soil and stream sediment sampling; and
13. General ground-reconnaissance geology

* These data have been requested in the past, but were not obtained due to non-availability of the ARSS on Mission 235. A similar request for IR spectrometry data forms part of our flight request for a mission in June 1974 (see p. 2).

Plans

The data collection phase of the above surveys should be completed by the end of summer 1974. Interpretation of the data and writing a report of the results will follow.

Hydrogeology - Mosquito Range

Introduction

Field work was conducted in the summer of 1973 in support of NASA Mission 235, for the purpose of studying the hydrogeology of a test site in the Mosquito Range of Colorado and evaluating selected remote sensors for hydrogeologic studies. Photography and imagery were also collected over a second test site in South Park. Field checks will be conducted in the summer of 1974 after image interpretation.

Test Sites

The test sites are in the western part of Park County, Colorado (Fig. 2). Test Site #1 is a 50 square mile area on the east slope of the Mosquito Range, coinciding with the drainage basin of the headwaters of the Middle Fork, South Platte River. Test Site #2 is a 20 mile long strip from Antero Reservoir to Fairplay.

As explained in the previous Remote Sensing Report (73-2, p. 39-40), the purpose of Test Site #1 is to evaluate the usefulness of high- and low-altitude color and color infrared photography for hydrogeologic studies. Test Site #2 was chosen to evaluate night-time thermal infrared and passive microwave imaging systems for detecting ground water and soil moisture.

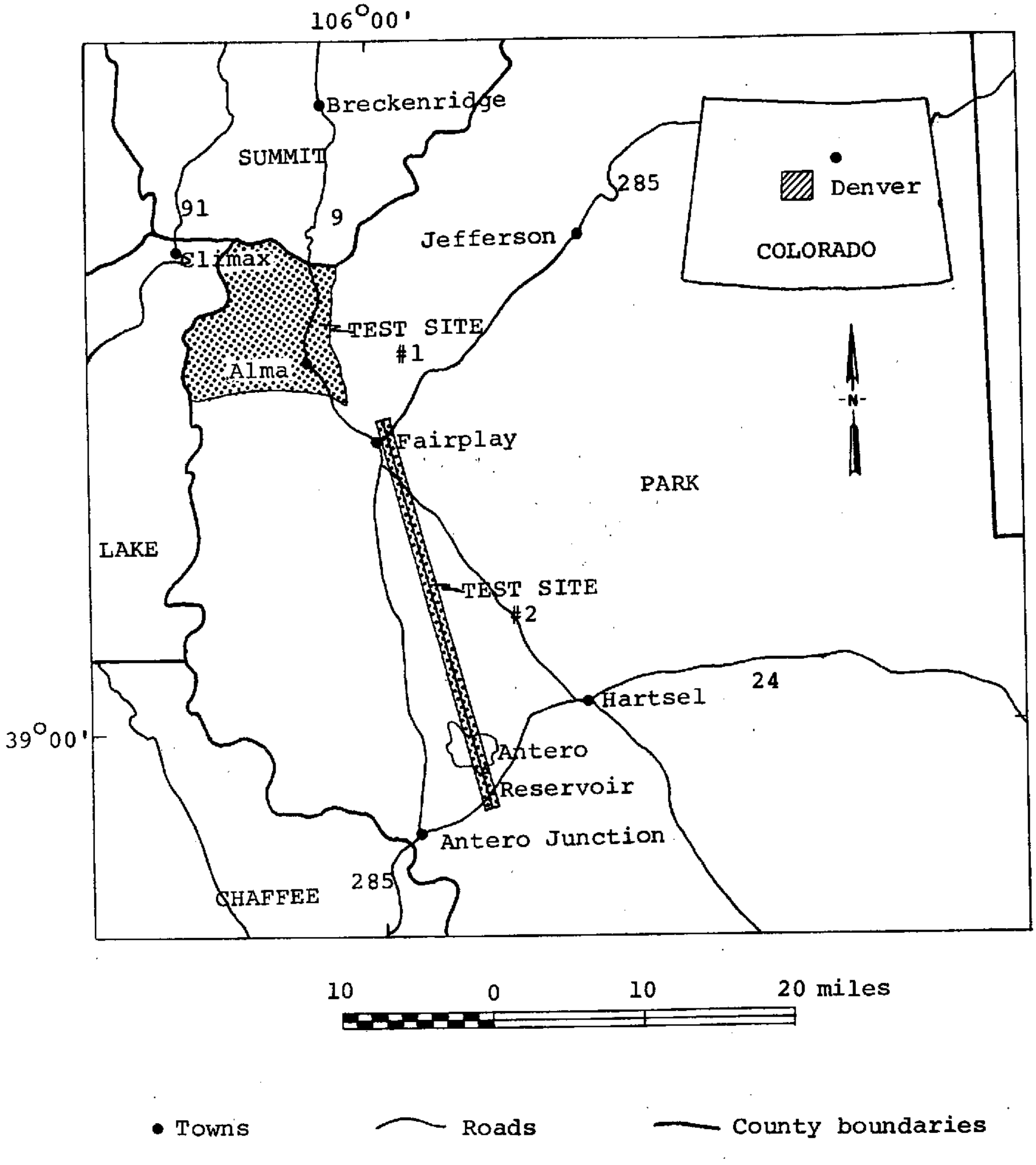


Figure 2. Index map of the remote sensing test areas for hydrogeology.

Remote Sensing Data Acquisition and Quality

The NASA P3A aircraft flew ten remote sensing lines over the test sites in June (Mx 235). Color and color IR large-scale, low-altitude RC-8 photography was flown on 20 June 1973 over the two test sites. Night-time thermal infrared imagery (RS-14) and passive microwave imagery (PMIS) were flown on 22 June 1973 over Test Site #2.

The RC-8 low-altitude photography is of variable quality. It will be of limited usefulness in Test Site #1 because of the 30-40% snow cover above 11,500 feet. Below this altitude, snow cover is less than 5%. Cloud coverage is minimal in this test site, but obscures 15% of the photography of Test Site #2. There is no snow cover at this site. The quality of the color photography is good, with the best color balance in the Antero Reservoir-Fairplay test site. The color IR photography is generally of fair quality; color balance is poor, resulting in a blue cast over the photographs. Good color discrimination between different lithologies, obvious in color photography, is hard to see in the color IR photography.

The thermal IR (RS-14) night-time imagery is of good quality. Preliminary observations indicate good thermal discrimination between several geologic features in the test site. The passive microwave (PMIS) night-time imagery, flown simultaneously with the RS-14, has been received in three formats: on-board 35mm photography of the cathode ray tube; color-digitized, 16-step, vertical and horizontal polarizations in different antenna temperature ranges; and a computer printout listing antenna temperature versus beam position. The on-board 35mm photography is of little value, because of the very small format (less than half-frame) and the difficulty of geographically locating the imaged area. The 16-step color-digitized image greatly enhanced large features in the test site. For instance, Antero Reservoir and dredge tailings just south of Fairplay are obvious. Further correlations with geologic features are tentative at this point. Three separate microwave images have been color-digitized, each with 16 color steps. One strip is vertically polarized (130-300°K antenna temperature range), and the other two are both horizontally polarized (50-300°K and 180-300°K antenna temperature range). The color-digitized image is considerably easier to interpret compared with the on-board 35mm photography; however, the general absence of cultural features and the non-photolike image is going to hinder correlation between ground and image features. At the present time, most of the evaluation of the computer data has been directed towards understanding the system and the information on the printout itself.

Field Work

Field work during the summer of 1973 was almost totally limited to the mountain test site, #1. Only a preliminary examination of Test site #2 was made, during preparation for the night-time flight. Two soil samples were taken near Antero Reservoir, and their soil moisture was measured for correlation with the thermal IR and PMIS imagery. Radiometric temperatures were also measured at one of the soil sampling sites and at Antero Reservoir.

The geology of the area has been divided into five basic hydrogeologic units:

1) Precambrian
   - Metasediments; gneisses and schists.
   - Granite gneiss.
   - Granite.
   - Pegmatite dikes.

2) Pre-Pennsylvanian
   - Cambrian Sawatch Quartzite.
   - Cambrian Peerless Formation consisting of sandy dolomite and interbedded dark shales.
   - Ordovician Manitou Dolomite.
   - Devonian Chaffee Formation consisting of the Parting Quartzite and Dyer Dolomite members.
   - Mississippian Leadville Dolomite.

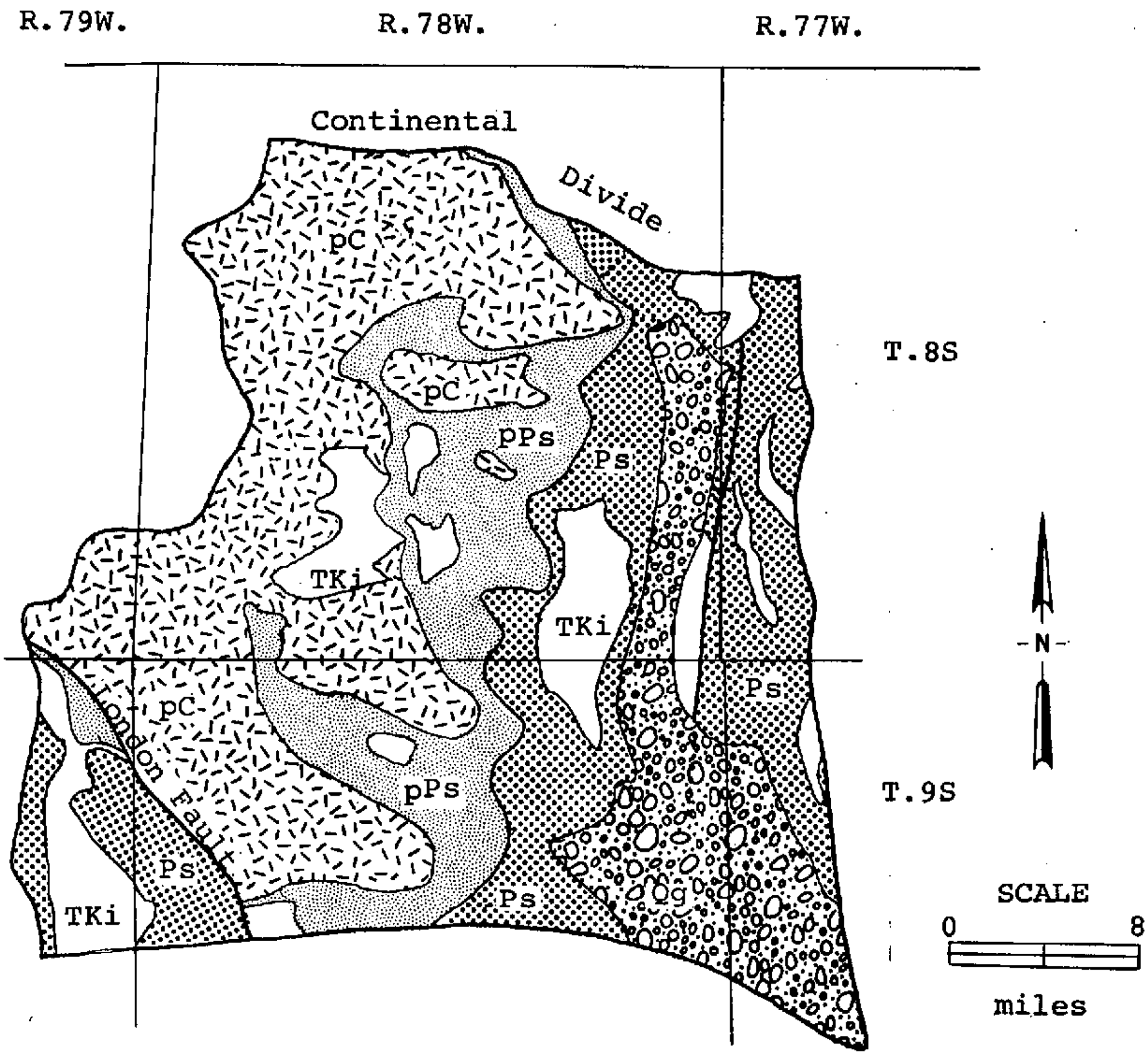
3) Pennsylvanian
   - Belden Formation (formerly the Weber); predominantly clastic, consisting of shale, siltstone, sandstone and conglomerate, with minor calcareous beds; beds are conspicuously micaceous, arkosic and cemented with silica.

4) Upper Cretaceous and Tertiary intrusive rocks
   - Diorite to granite in composition, forming dikes, sills, and stocks.

5) Quaternary unconsolidated material
   - Glacial till.

Figure 3 is a generalized map of the five major hydrogeologic units within Test Site #1.

Test Site #1 is part of the east flank of the Sawatch arch. The Paleozoic sedimentary beds form an eastward-dipping homoclinal sequence. A major reverse fault, the London Fault,



Qg Quaternary glacial deposits

TKi Upper Cretaceous and Tertiary intrusive rocks

Ps Pennsylvanian sedimentary rocks

pPs Pre-Pennsylvanian sedimentary rocks

pC Precambrian metasedimentary and granitic rocks

Figure 3 Generalized geologic map of Test Site #1.

dipping steeply eastward, is responsible for a shear zone up to 100 feet wide and may have several thousand feet of displacement (Singewald and Butler, 1941, p. 24-26). Another reverse fault, the Cooper Gulch Fault, is less steeply dipping and has considerably less displacement than the London Fault.

Field work, in addition to geologic mapping, included chemical analysis of wells, streams and mine water; infiltration tests in the glacial till for permeability and porosity studies; stream gaging; well pump tests; and vegetation studies. Laboratory work in conjunction with some of the field studies is currently being conducted.

Ground Water Occurrence

Ground water occurs in at least four of the hydrogeologic units. The Upper Cretaceous and Tertiary rocks were the hardest to evaluate because of their limited spatial occurrence. There are about 40 domestic wells in the area, varying in depth from 4 to 230 feet. Well logs and field observations indicate that almost all of the wells penetrate the Pennsylvanian Belden Formation or the Quaternary glacial till. A few wells may penetrate the pre-Pennsylvanian sedimentary units, and possibly the Precambrian metasediments and granite, but this is not certain.

The wells in the glacial till are generally shallow (less than 25 feet deep), often dug rather than drilled, and of large diameter. Yields are generally low, about 5 gpm or less, although some owners claim up to 25 gpm. Preliminary observations indicate that much of the ground water is tributary to the streams, but there may be limited recharge of the ground water by the streams during certain times of the year.

The wells in the Pennsylvanian sandstones may be deriving their water from either fracture or intergranular permeability, or a combination of the two. Outcrops are well-silicified and in some cases iron oxide and calcium carbonate deposits are found coating fractures, indicating water flow through fractures. However, some wells, confined by clay layers, are artesian and occasionally flow, indicating possible intergranular permeability as well.

Preliminary Remote Sensing Evaluation

The remote sensing evaluation is in progress and will continue for a period of several months. The photography of Test Site #1 on Mx 235 will be of limited usefulness because of the high snow cover. Also, because of the time lag between the Mx 235 flight and the time the data were received, color photography from Mx 184 was used principally in the field. The Mx 184 color photography was of much better quality than the recently acquired Mx 235 color and color IR photography. Because there was not complete coverage of the test sites by Mx 184, Mx 235 color photography and Mx 205 high-altitude color photography are being used to fill in those incomplete areas.

The color photography was used in the field mostly for geologic mapping, in this case surficial mapping. Surficial units mapped were talus, frost-wedged bedrock, till, different types of moraines, alluvium, mine dumps, tailings ponds, dredge tailings, bedrock and residuum. Bedrock geologic mapping proved to be difficult due to poor exposure. This resulted from the fact that most of the bedrock exposures are along near-vertical valley sides, providing a narrow outcrop width. The widespread occurrence of thick surficial material also obscured the bedrock. However, the Precambrian-Paleozoic contact was generally obvious.

The occurrence of phreatophytic vegetation - that is, plants that take water directly from the water table or overlying capillary fringe, is one clue of finding near-surface ground water. Two types of vegetation, willow (Salix) and quaking aspen (Populus tremuloides), were investigated for possible connection with ground water occurrence. Both plants are easily observed and mapped on the low-altitude color photography. Robinson (1958, p. 64) states that "most species of willows are believed to be phreatophytes, for they are nearly always associated with moist situations". However, aspen, although they prefer moist localities, do not necessarily depend upon water from the zone of saturation (Meinzer, 1923, p. 58). For example, Meinzer states that although frequently found on mountain summits and slopes, they are not generally found in mountain canyons that contain ground water.

Preliminary observations of willow indicate that, as well as growing in valley bottoms next to streams, they often grow on older, stabilized talus and glacial till, and utilize water that is being recharged through these units from the mountain bedrock units to the stream below. Aspen often were found growing in areas where water from mines was flowing on, or just beneath, a slope. Aspens, in general, also seemed to grow preferentially on unconsolidated material, particularly glacial till. A possible explanation for this might be a differential permeability between the unconsolidated till and the bedrock material underneath, resulting in an interface along which ground water might be accumulating.

In the Precambrian rocks, fractures, faults, and pegmatite dikes are quite obvious in the color photography. Since fracture permeability is fundamentally important in crystalline rocks for ground water movement and accumulation, the presence of fractures would indicate that ground water occurrence is entirely possible in such an area. Pegmatite dikes and faults are also good places to look for ground water, and they are considered by some to be a more predictable source than merely the presence of fractures (Florquist, 1973).

Other general observations are:

- Large-scale photography is preferred over small-scale.
- Stereo viewing greatly improves the ability to do photo-geology.

- Positive transparencies are superior to prints for extracting information.
- Sun angle is important; information is enhanced by a slight amount of shadow, whereas direct sunlight on the opposing slope often obscures information.

Plans

Laboratory work and compilation of field data will continue during the coming months. Remote sensing data will be further evaluated in the same time period, concentrating on Test Site #1, where most of the field work was conducted. Preliminary mapping from color and color IR photography, plus existing published data, will be done in Test Site #2. Field checking of this test site will be done in early summer, 1974.

Hydrogeology - San Luis Valley

Introduction

Research was begun in June 1973 on an evaluation of the applicability of remote sensing techniques to hydrogeologic studies in the San Luis Valley. This study has two underlying principles: 1) the flow of ground water is largely controlled by the geology of an area, and remote sensing has been used successfully to interpret geology, and 2) many phenomena used in remote sensing to indirectly interpret geology, such as the occurrence of vegetation anomalies along fault zones, relate directly to ground water conditions.

The study is being conducted in two stages. The first stage is a detailed study of a small area in order to determine the hydrogeologic properties of the various rock units and the general hydrologic conditions that exist in the San Luis Valley. This part of the research is due to be completed in the near future. The second stage involves extrapolating information gained in the preliminary stage to a regional study with extensive use of remote sensing techniques.

The area chosen for the initial study encompasses approximately 90 square miles of the San Luis Valley and Sangre de Cristo Mountains near Crestone, Colorado (Fig. 4). Rocks encountered in this area are Precambrian igneous and metamorphic rocks and Paleozoic rocks of the Sangre de Cristo

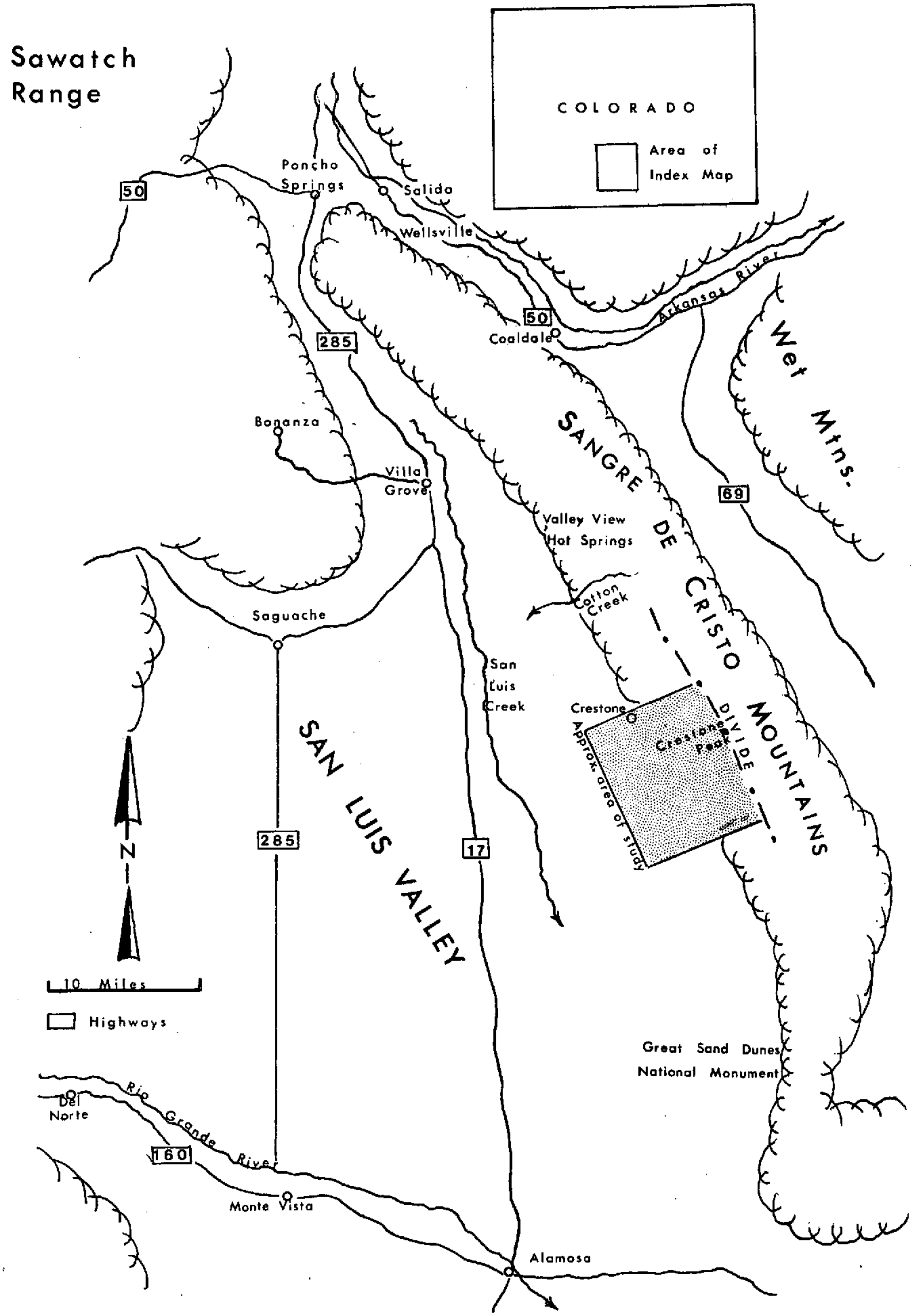


Figure 4. Location of San Luis Valley hydrogeology test site

Mountains, as well as extensive Quaternary alluvial deposits lying on a thick section of Tertiary sediments in the San Luis Valley. Extensive field work was conducted during the period of this report to establish the essential surface and subsurface control required for this type of study.

Hydrogeology

Fractured Precambrian igneous and metamorphic rocks crop out extensively in the Sangre de Cristo Mountains, along with Paleozoic quartzites, dolomites, sandstones, and conglomerates (Fig. 5). Intergranular permeability was interpreted as being negligable compared to fracture permeability in all the above lithologies. An attempt will be made to verify this interpretation by permeability tests on cores. Fractures in the competent quartzites, dolomites, and Precambrian igneous and metamorphic rocks tend to remain relatively "tight", whereas fractures in the less competent sandstones and conglomerates of the Sangre de Cristo Formation are generally more likely to be water-bearing. Springs and seeps from major faults, minor fractures, joints, and along bedding planes are common in the Sangre de Cristo Formation. Rock-falls and debris-slides are often found in association with major fractures and are a seasonal source of springs.

Quaternary alluvial material has been divided into six units based on depositional processes, relative age, and hydrologic characteristics. Most extensive are the alluvial

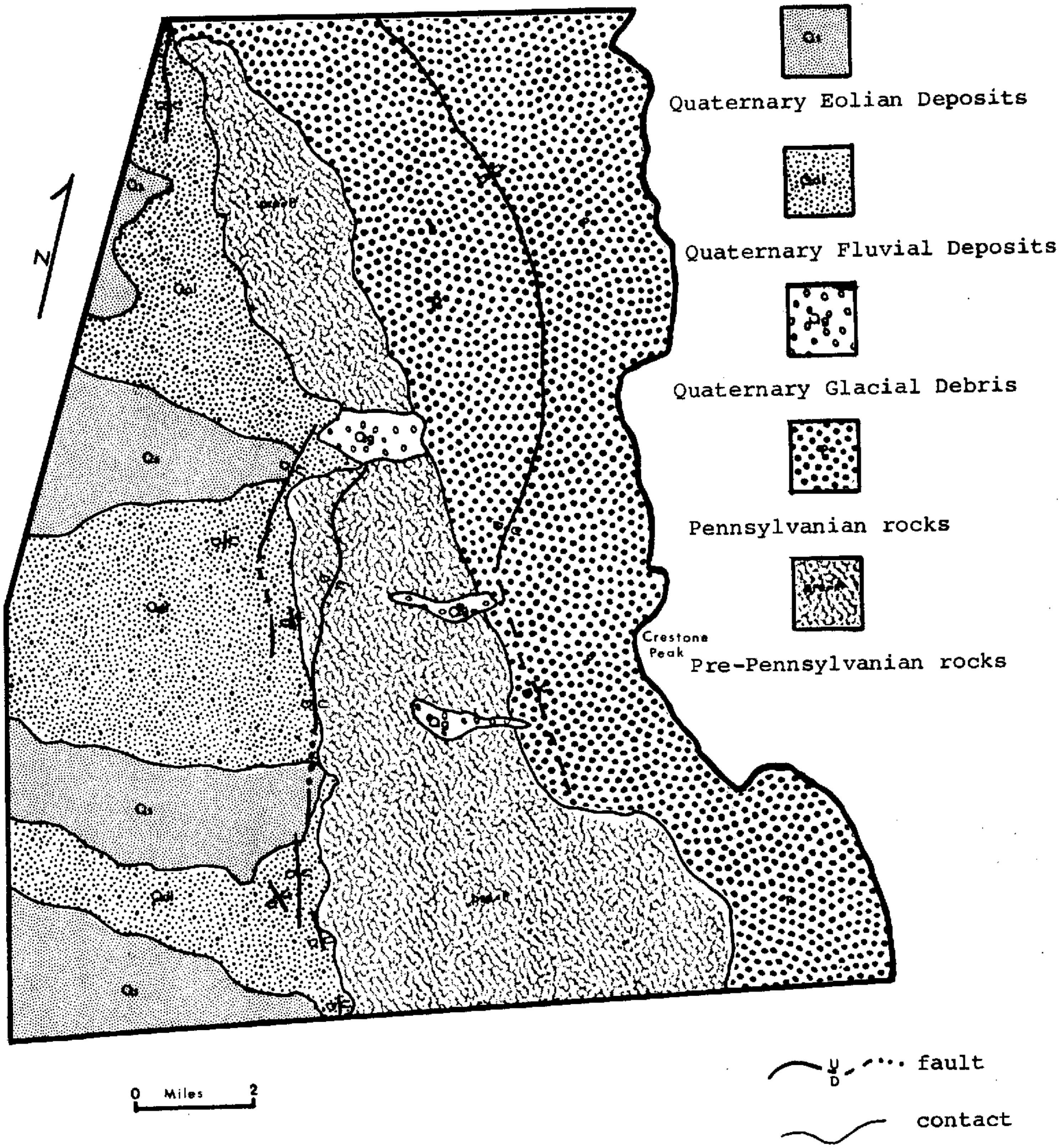


Figure 5. Geologic map of San Luis Valley hydrogeology test site.

fans, designated Qaf I, Qaf III, and Qaf IV, with Qaf I being the oldest fan and Qaf IV the youngest fan. Much of the fan area is covered by a mantle of wind-blown sand and silt, varying in thickness from several inches to 30 feet, called Qs. Qaf I has relatively steep slopes, is highly dissected, and is composed of very large (up to 3 feet) angular boulders and coarse-grained angular matrix. Permeability computed from grain-size analysis is the highest of all the alluvial units, averaging 55 darcys, but a caliche layer at the top of the unit, 2-5 feet thick, restricts infiltration of precipitation and stream flow into the aquifer. Qaf III is a gently sloping, relatively large, undissected fan that is presently being deposited. Its large size indicates that it is Pleistocene in age. The material composing Qaf III is finer-grained and better sorted than Qaf I, with a maximum cobble size of 8 inches. All of the shallow wells in the area are in Qaf III. Permeabilities computed from grain-size analysis of Qaf III samples range from 1 to 39 darcys, averaging 14 darcys. Permeabilities derived from three pump tests of wells in Qaf III range from 12 to 55 darcys, with a value of approximately 20 darcys being representative. The youngest alluvial fan unit, Qaf IV, consists of small, steeply sloping fans occurring at the base of the mountains and fed by very small streams. These are Holocene in age. Their limited areal extent reduces their importance to the region's hydrology.

The mantle of wind-blown sand and silt is believed to be thin, and therefore it is important only in its effect on infiltration of water into the underlying units. Permeabilities computed from grain-size analysis range from 1 to 11 darcys and average 5 darcys. Bimodal grain-size distributions of the sands suggest a local source for the coarser material, with the fines being derived from sand dunes at Great Sand Dunes National Monument to the south.

Presently-active stream channels are designated as Qal. The lithology of this unit is controlled by the alluvial unit within which the stream flows, being sandy and cobbly material within Qaf III and Qaf IV, and sandy in Qs. Stream gaging was used to judge stream infiltration rates. Infiltration rates depend primarily upon stream depth, wetted perimeter of the stream, permeability of the stream bed, and the subsurface hydraulic gradient. Where the ground water table is shallow, the gradient is very low (<0.2) and infiltration rates are relatively low. Where the ground water table is deep, the gradient is 1 and infiltration is relatively rapid. The greatest rate of infiltration recorded was 24 cfs in a one-mile reach of a stream with a water depth of 1.5 ft and a wetted perimeter of 13 ft.

Quaternary glacial debris is present in many of the mountain canyons of the study area. Where present, this debris serves as an aquifer. Grain-size analysis of a sample of lateral moraine reveals a size distribution remarkably similar to that of Qaf I, suggesting an interrelationship in either source or depositional process between the two units.

Quaternary faulting affects all three of the alluvial fan units. This faulting is most easily distinguished in Qaf I because the coarse, angular material allows a relatively steep fault scarp to be maintained. Faulting of Qaf IV indicates that fault activity has continued well into Holocene time. Ground water seeps and springs have been noted on the scarp-slopes of several of these eroded fault-scarps. This may be attributed to either ground water ponding behind an impermeable fault or to seepage because of an abrupt change in topography, or both.

Several species of phreatophytes have shown themselves to be valuable in determining depth-to-ground-water in the study area. Where mountain streams enter the San Luis Valley, an aspen (Populus tremuloides) - narrowleaf cottonwood (Populus angustifolia) - willow (Salix spp.) assemblage exists where ground water is less than 10 ft below the surface and in most cases less than 6 ft below the surface. At lower elevations, the aspen dissappear. Dense growths of rabbitbrush (Chrysothamnus nauseosus) generally indicate a depth to ground water of 20 ft or less, but shallow ground water may exist without a dense growth of rabbitbrush. Areas of shallow ground water, where the water contains a relatively high amount of dissolved solids, are generally marked by a growth of wiregrass

(*Juncus balticus*). This species occurs primarily where the water table is less than 4 ft deep and periodically reaches the surface.

Remote Sensing Evaluation

Field work was conducted using USGS black and white photographs at a scale of 1:20,000. Unfortunately, the photographs were of poor quality, having low resolution and being out of focus in places. Rock discrimination, except between basement rock and alluvial material, was minimal. Discrimination of the deciduous vegetation, which includes the aspen, narrowleaf cottonwood, and willow, from the coniferous vegetation, essential for ground water studies, is possible only in places. Most Quaternary faults are not detectable on the black and white photography.

On 18 and 20 June 1973, 9 lines of low altitude (1:20,000) color and color infrared (IR) photography and 6 lines of predawn thermal infrared (θ IR) imagery were obtained during NASA Mission 235. Preliminary evaluation of this photography and imagery and high-altitude (1:100,000) color and color IR photography of NASA Mission 211 reveals the importance of a planned package of remote sensor data. High-altitude photography is very useful in giving the interpreter a synoptic view of the entire area of study, showing general relations between the mountainous area and the alluvial fans, and between the alluvial fans and the areas of relatively shallow ground water farther out into the valley. Regional faults and fractures that cut across the strike of beds or the foliation of the Precambrian metamorphics can easily be detected on the high-altitude photography, and the basement rock-alluvium contact generally can be mapped. The major alluvial faults can be tentatively identified on this photography. Color IR is preferable to color because of the contrast between deciduous vegetation, much of which is phreatophytic, and coniferous vegetation.

Low-altitude (1:20,000) color and color IR photography is essential for rock discrimination, both in the Precambrian-Paleozoic terrain and in the area of Quaternary alluvium. Many faults and fractures not seen on the high-altitude photography can easily be mapped on the low-altitude photography. The Precambrian-Paleozoic rock contact with the Quaternary alluvium can be easily and accurately mapped. Discrimination between alluvial units can be made, based on surface texture and morphology. Major Quaternary faulting can be quickly identified, and less-evident faulting can be identified by alignment of phreatophytes along fault scarps or fault traces. Estimation of the hydrologic significance of the faulting can be made using the low-altitude color IR photography. In general, color IR is again preferable over color because of the contrast between deciduous and coniferous vegetation, although rock discrimination is easier using color photography.

The predawn θ IR imagery shows great promise for use in this study, particularly in the alluvium. Discrimination between Qs and the other units is very accurate, because the wind-blown sands and silts are very loose and porous, and consistently appear very cool relative to the surrounding rocks. Discrimination between Qaf I, appearing relatively warm, and Qaf III may also be possible, though it appears that the distinctive morphology of Qaf I may make its identification easier on photography. Where vegetation is not abundant, Quaternary faulting is easily identified on θ IR imagery as a warm lineament, representing a vegetation alignment along a fault. Where vegetation is relatively dense, color IR photography is better than θ IR imagery, because the photography is able to discriminate between deciduous and coniferous vegetation.

Preliminary Conclusions

The most desirable sources of ground water in the study area, based on grain-size analysis, pump tests, stream infiltration studies, and observation are, in order of decreasing desirability:

1) Qaf III
2) Qaf IV
3) Qs
4) Qaf I
5) Quaternary glacial debris

6) Fractures in the Sangre de Cristo Formation

7) Fractures in other Precambrian-Paleozoic rocks

8) Talus piles in mountains

9) Thick soils developed near streams in mountains.

Remote sensing is a valuable tool in hydrogeologic studies. In general, the geologic factors affecting ground water movement can be better mapped on photography and imagery than in the field, with considerable addition of accuracy and savings in time. Most valuable of all the data appears to be low altitude (1:20,000) color IR photography. The most desirable package of data appears to be high-altitude (1:100,000) color IR photography, low-altitude (1:20,000) color and color IR photography, and θ IR imagery.

Plans

Plans for the next reporting period include petrologic analysis of sediment samples, completion of water budgets on several representative watersheds, contouring of depth-to-groundwater within the initial study area, and expansion of the remote sensing interpretation from the initial study area to a regional area including the watersheds of all streams entering the northern closed basin of the San Luis Valley. This will be in preparation for the 1974 field season.

Data Reduction and Enhancement

Introduction

Much of the research on data reduction and enhancement has been conducted by scientists at Martin Marietta Corp. A summary report covering these efforts has been submitted to CSM by MMC, and will be incorporated, in detail, in the Final Report. Abstracted below is a summary of the conclusions.

Image Processing - General

Image processing in general was found to be unfruitful for geologic interpretation when applied to film imagery. We must state emphatically at this point that this conclusion does not apply to all classes of geologic imagery data, especially those data which have been received from the sensor platform via telemetry, as opposed to physical film return.

Successful digital manipulation and enhancement by JPL of Mariner images of the Martian surface amply demonstrate this valuable application of image processing.

But the Bonanza program did not deal with telemetry data. Our job was to investigate the benefit to geologic interpretation derived from various film imagery enhancement techniques. Film products consisted of natural and false color photography exposed in a nine-in.-format aerial camera, multispectral photography in either four-in. or 70mm format, black-and-white imagery produced by electronic scanners in various wavelengths, and side-looking airborne radar (SLAR). We investigated four enhancement techniques using these film products.

Our self-grading method involved experiments with enhancement techniques followed by comparison of the results with conventional stereointerpretation of the nine-in.-format color and false color photography. Since conventional stereo interpretation is a widely-practiced and economically-proven method of using aerial photography, we compared all of our experimental enhancement results with this baseline.

Optical Processing

Optical processing was applied to several different images with uniform unfavorable results. Enhancement of structural geologic features was not superior to conventional photointerpretation. Lithologic discrimination was non-existent. In addition, and as stated earlier, the set-up time, individual tailoring of the apparatus to the case at hand, and the necessity for a nearly foregone idea of what image information will be enhanced, combine to render the process unattractive for the type of application attempted in this series of experiments.

We recommend that no further effort be expended in the type of optical enhancement we attempted unless a much different approach is employed.

Digital Processing

Digital enhancement of film imagery was also tried on Bonanza data. The results, generally, were no more encouraging than optical enhancement. Here, a qualifier needs to be interjected; our experiments were conducted in 1970, the second year of the program, and many improvements in both hardware and computer processing routines have been made since then. To avoid any misunderstanding, we repeat that our experiments did not deal with telemetry data; we digitized images which were initially recorded on film and the film, itself, was physically returned. The pertinent question then becomes; can we dissect a film image, process it, and then reconstruct it in such a way that it becomes more useful to the geologic interpreter than it was in its original form? The answer is no. Because of the image degradation inherent in the digitizing and playback processes, digital processing has not proven useful for the applications tested. We recommend film dissection and digital processing not be employed on aerial photography.

Video Processing

Video enhancement of film imagery is theoretically sound and some encouraging results have been achieved. The human eye is unresponsive to small differences in shades of gray (density on a black and white film image), while being particularly sensitive to differing colors. The video processor has the capability to detect small differences in density, expand these differences and display them as contrasting colors. The theory surpasses the practice. Only one or two cases can be thoroughly substantiated where video processing succeeded in portraying structural geologic information better than can be detected through conventional photogeologic interpretation. The experiment described in Chapter II.C involving lithologic discrimination of sedimentary rocks near Canon City, is one such example. Nevertheless, enough success has been seen to encourage further experimentation.

Newer density-slicing systems employing video presentation are now available on the commercial market. These systems appear to be easier to operate and provide better control. Since they allow the geologist to become directly involved in the enhancement procedure, without the previous requirement of a technician to actually operate the controls, greater success is expected. We recommend continued investigation.

Multispectral Projection

Multispectral photography is another area where practical application is hard-pressed to validate the theory. In general, the spectral character of rock outcrops is not as important in geologic mapping as is geomrophic expression, stratigraphic position, weathering characteristics, and vegetational characteristics. Although examples may be found where certain rock or soil units are differentially depicted on certain narrow-band black-and-white photography, these same units are usually just as easily mapped on good quality color photography. In addition, multispectral photography suffers by comparison with nine-in.-format aerial photography in a number of ways:

1) Multispectral photography is seldom flown in a stereo mode, thus sacrificing a good measure of its interpretability at the outset;
2) It is usually presented in a reduced format and small scale, again making for more difficult interpretation;
3) There has been less experience in the acquisition of multispectral photography, thereby reducing the dependability of receiving optimum exposures. The exposure of successive frames of multispectral photography is characteristically variable and poor. Additionally, each band of a multispectral set should receive a different exposure, which complicates operational procedure.
4) Additional, and sometimes costly interpretation equipment is required for multispectral photography. By contrast, any person or office can afford a simple stereoscope for genuinely-useful interpretation of conventional stereo color photography;

5) There is very good spectral information in both natural and false-color photography which requires practically no special training and very little special equipment to use;

6) Multispectral photography requires previous ground measurements to use at maximum advantage, a consideration not required for color and false-color photography. This requirement practically insures a high project cost in that previously-flown data is not optimally useful. This aspect, however, leads into an area where multispectral photography might be beneficially applied.

It should be possible to carefully establish the spectral character of a targeted rock or soil unit in advance of an aerial photographic mission and then select a combination of film and filter to maximize the density contrast between the desired outcrop and other rock types. This specific application of multispectral theory is recommended for further study.

Electronic Analog Enhancement

A system to allow for inexpensive, near-real-time manipulation of scanner data has obvious applications. Various filtering and spatial enhancement routines can be electronically applied to magnetic tape-recorded data and the beneficial algorithms identified for digital operation in a large computer system. Continuation of this research is recommended.

PERSONNEL CHANGES

Faculty

No Change

Research Associate

Don L. Sawatzky	Until 31 May 1973

Research Assistants

Rodney J. Eichler	Until 31 July 1973
David Huntley	From 1 June 1973
Lee H. Jefferis	Until 31 May 1973

Secretarial

No Change

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