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PROGRESS OF GEOLOGIC STUDIES, COLORADO PLATEAU PROJECT

By

F. W. Cater, L. C. Craig, and D. A. Phoenix

Colorado Plateau Project

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PROGRESS OF GEOLOGIC STUDIES

COLORADO PLATEAU PROJECT

By

F. W. Cater, L. C. Craig, and D. A. Phoenix

ABSTRACT

Carnotite deposits in the adjacent parts of Colorado, Utah, Arizona, and New Mexico have been the principal domestic sources of uranium. A program of exploration coordinated with comprehensive geologic studies is being undertaken by the Geological Survey on behalf of the U. S. Atomic Energy Commission.

The geologic studies are planned for long range results—to aid in determining the possible source of the metals in the carnotite deposits, the mode and route of transportation of these metals, and the conditions favorable for the localization of the ore deposits, as a guide to ore-finding and an aid in evaluating the resources of the region. The geologic studies consist of regional geologic mapping, stratigraphic studies, and ground-water studies.

Regional geologic mapping has been completed on the main carnotite-producing area of southwestern Colorado. The ore deposits of this area are largely confined to the upper part of the Salt Wash sandstone member of the Morrison formation. They show no apparent genetic relation to igneous activity, present-day topography, or geologic structures resulting from deformation during Tertiary time. However, localization of the deposits may have been influenced by structures originating far back in the geologic history of the region. These may have influenced the geologic environment during the time the ore-bearing beds accumulated and afterwards may have affected the ground-water conditions within these beds.

Stratigraphic studies are in progress in the region of carnotite deposits. On the basis of lithologic changes in the Salt Wash member, broad areas favorable for ore have been distinguished from those unfavorable for ore. Most of the ore deposits are in southwestern Colorado. In the area of the deposits the Morrison formation is relatively thick, the lithologic units of the Salt Wash member are moderately lenticular, and the Salt Wash contains a moderate amount of stream-deposited sandstone. These factors would govern the movement of mineral-bearing solutions through the Salt Wash and thus may have influenced the localization of ore deposition. Study of sedimentary structures within the Salt Wash suggests that drainage directions were persistent throughout the deposition of the Salt Wash. The regional plan of both the sedimentary structures and the ore structures show a tendency toward a systematic pattern. This suggests that sedimentary structures may have had a broad controlling influence on ore deposition. On the other hand, no relation between the location of ore in the sandstone and the grain-size and degree of sorting of the sandstone has been found.

The ground-water study, begun in September 1949, is using the results of the studies on stratigraphy and regional geology as a framework. Additional hydrologic data must be obtained and the geologic data analyzed, however, before any conclusions can be presented.

The continuing program of the geologic studies calls for regional geologic mapping of a part of southeastern Utah, extension of the stratigraphic studies to the limits of preservation of the Salt Wash, and studies of the present ground water in ore-producing areas, and of past ground-water conditions on a regional scale.

INTRODUCTION

The principal domestic source of uranium is found in southwestern Colorado, southeastern Utah, northeastern Arizona, and northwestern New Mexico. Since 1947 intensive geologic studies of, and exploration for these resources have been coordinated in the Colorado Plateau project of the U. S. Geological Survey, being undertaken on behalf of the U. S. Atomic Energy Commission.

The following report describes briefly the work done and plans for future work and presents preliminary conclusions reached midway in the program of geologic studies. Included in this report is a section entitled "Geologic Background," which briefly summarizes the geologic environment and occurrence of the uranium-vanadium ore deposits--a necessary preliminary to the sections on General Geology, Stratigraphy, and Ground-water Studies.

The conclusions reached by the men working on the general geology and those working on stratigraphy are subject to change, inasmuch as to date the chief concern of this work has been the gathering of basic field data. The interpretation and correlation of this data will continue during the winter months. Investigations of recent and paleo-ground-water conditions were begun in September 1949. Insufficient basic hydrologic and geologic data have been gathered in this short time to warrant even tentative conclusions, but plans presented for this study are correlated with the general geologic and stratigraphic studies.

PURPOSE AND SCOPE

The broad phases of the geologic studies are planned for long range results—to aid in determining the possible source of the metals in the carnotite deposits, the mode and route of transportation of these metals, and the conditions favorable for the localization of the ore deposits, as a guide to ore-finding and an aid in evaluating the resources of the region. As a direct service to the exploration work, however, the timing and emphasis of these studies and the daily activities of the geologists undertaking them are modified by the requirements of the geologists guiding exploration and the problems encountered in drilling. To serve effectively in such a consulting capacity, and because of overlap among these studies, the geologists work in close coordination for exchange of information and mutual gain.

The geologic studies in progress consist of the following:

1. General geologic mapping in southwestern Colorado and southeastern Utah.

2. Regional stratigraphic and sedimentary studies in Colorado, New Mexico, Utah, and Arizona.

3. Studies of past and present ground-water conditions in southwestern Colorado and southeastern Utah.

GEOLOGIC BACKGROUND

The rocks exposed in the Colorado Plateau Province are mainly horizontal sedimentary beds, ranging in age from Paleozoic to Tertiary, disturbed in places by broad folds, salt intrusions, and high-angle faults. Moderate-sized igneous bodies of Tertiary age have intruded these sediments in the La Sal, Abajo, El Late (Ute), Carrizo, and Henry Mountains (figure 1). The generalized description of the late Paleozoic to early Tertiary strata in southwestern Colorado and adjoining parts of Utah, Arizona, and New Mexico is given in table 1.

The uranium deposits of the Flateau Province, although of wide geographic distribution, have a narrow stratigraphic range. All known deposits of economic importance are restricted to the Salt Wash sandstone member of the Morrison formation, the Entrada sandstone, and the Shinarump conglomerate. The deposits in the Salt Wash member of the Morrison, by far the most numerous, occur in widely spaced clusters in an arc, west of the Uncompahgre Plateau, extending from Thompsons, Utah, southeast to Gateway and Uravan, Colorado, and from there southwest to the "four-corners" area. Large deposits in the Entrada lie to the east and northeast of this belt in two widely separated areas, Placerville and Rifle, Colorado; smaller outlying deposits in the Shinarump occur to the west and southwest in Utah and Arizona (fig. 1).

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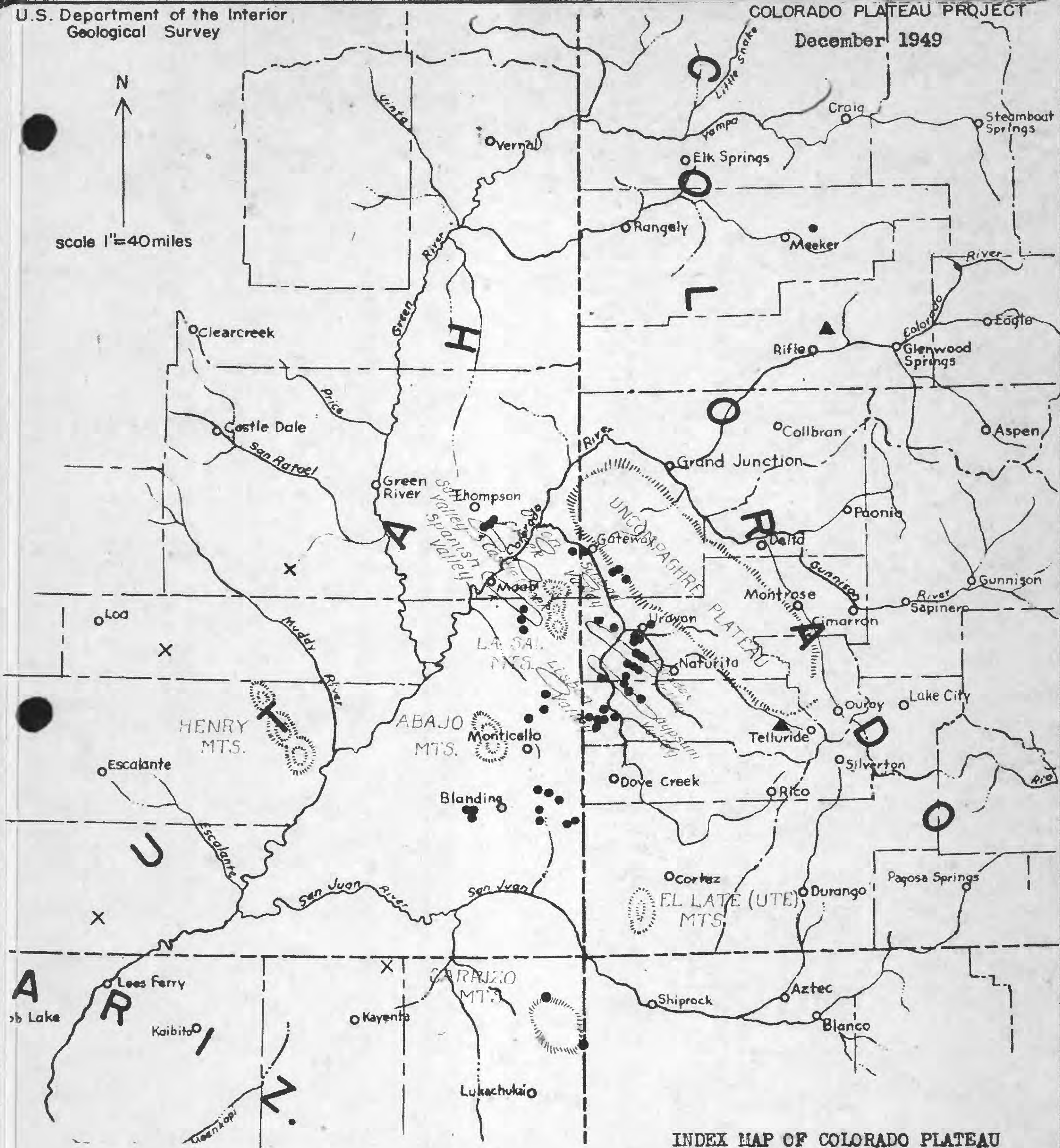
COLORADO PLATEAU PROJECT
December 1949



INDEX MAP OF COLORADO PLATEAU

EXPLANATION

- ● Deposits in the Morrison formation
- ▲ Deposits in the Entrada sandstone
- × Deposits in the Shinarump conglomerate
- ⬭ Principle structures due to salt flowage and intrusion

FIGURE I

Ore bodies in the Entrada sandstone have been the largest single producers of vanadium ore. Those in the Shinarump conglomerate have produced both uranium and vanadium, but their aggregate yield has been small. Ore bodies in the Salt Wash member of the Morrison have produced significant tonnages of vanadium, but in recent years have been most noteworthy for their uranium content.

Characteristically, the ore minerals impregnate sandstone, but shale pebbles and clay films along bedding planes in the ore-bearing sandstone are rich in vanadium. Fossil plants in and adjacent to ore bodies are in places also richly mineralized. The ore forms roughly lenticular or tabular layers whose long dimensions lie parallel to the bedding. In places, richly mineralized sandstone fades laterally to lean or barren rock. Elsewhere, the boundary of the ore is a well defined surface that is gently undulant to the bedding, or crosses it at a high angle in a smooth curve. In many places these curved or wavy structures, called "rolls" by the miners, are oriented in a common direction and may indicate the orientation of the ore body. Adjacent bodies are also likely to be aligned along this trend.

Many of the deposits are in or near the thicker, central parts of sandstone lenses. Beds of sandstone less than about 20 feet thick rarely contain sizeable ore deposits. In places the ore-bearing sandstone lenses are well defined, but most are broad and vaguely defined. Where observations can be made, trends of the lenses can be recognized by a study of bedding and the orientation of fossil logs.

The sandstone in the central parts of the lenses is dominantly medium-grained, medium-to thick-bedded or irregularly bedded, and moderately clean, though some mudstone in the form of grains, pebbles, and small lenses is common. In the vicinity of ore deposits the sandstone is predominantly pale to light brown and some of the mudstone associated with the sandstone has been altered from red to gray, whereas away from the deposits some of the sandstone has a reddish cast and the mudstone is unaltered.

No obvious genetic relationship exists between the ore bodies and regional structures, igneous intrusions, or hydrothermal activity. It is probable that the metals were transported by migrating ground water and perhaps localized by influences acting upon or within this solution before regional deformation disrupted the continuity of the beds.

On the other hand, evidences suggesting a sedimentary origin, hydrothermal origin, or an origin from later ground water are not altogether lacking. The relation of uranium minerals to primary sedimentary structures is so close that some students have felt that the minerals must have been deposited simultaneously with the containing sediments. Deposits in White Canyon, southeastern Utah, which contain uranium in close association with bornite and chalcopyrite have been described as hydrothermal. The presence of secondary uranium and vanadium minerals along fractures and in cavities in the rock and the lack of complete equilibrium relations among the disintegration products of uranium indicate activity of ground water after regional deformation. The several possible origins are not disregarded in the collection of geologic data. Regardless of the final determination of the origin of the uranium deposits, the data of the geologic studies will be essential to a thorough interpretation.

REGIONAL GEOLOGIC MAPPING

By F. W. Cater

Objectives

The principal objectives of the regional geologic mapping are to determine the geographic and geologic distribution of the carnotite deposits, the broad geologic controls, and the relations to regional stratigraphy and regional deformation, as well as to delimit areas favorable for detailed studies and exploration, to which special attention is given.

Progress

Regional mapping in southwestern Colorado began in 1941, when a small area between Uravan and the northeast rim of Paradox Valley was mapped. In 1945 the area between Egnar and Gypsum Valley was mapped; a preliminary geologic map of this area has been published. _/

_/ Stokes, W. L., and Phoenix, D. A., Geology of the Egnar-Gypsum Valley area, San Miguel and Montrose Counties, Colorado: U. S. Geol. Survey Oil and Gas Investigations Prelim. map 93, 1948.

Mapping was resumed in 1947, when the Geological Survey began working on the Colorado Plateau project for the Atomic Energy Commission, and it was continued through the field seasons of 1948 and 1949. Late in 1949, field work and some revision in details of earlier mapping were completed on the main carnotite-producing area of southwestern Colorado. This area, which extends from Gateway south to Egnar, includes eighteen $7\frac{1}{2}$-minute quadrangles (see fig. 2) for which topographic base maps are nearing completion. The final compilation of the geologic maps

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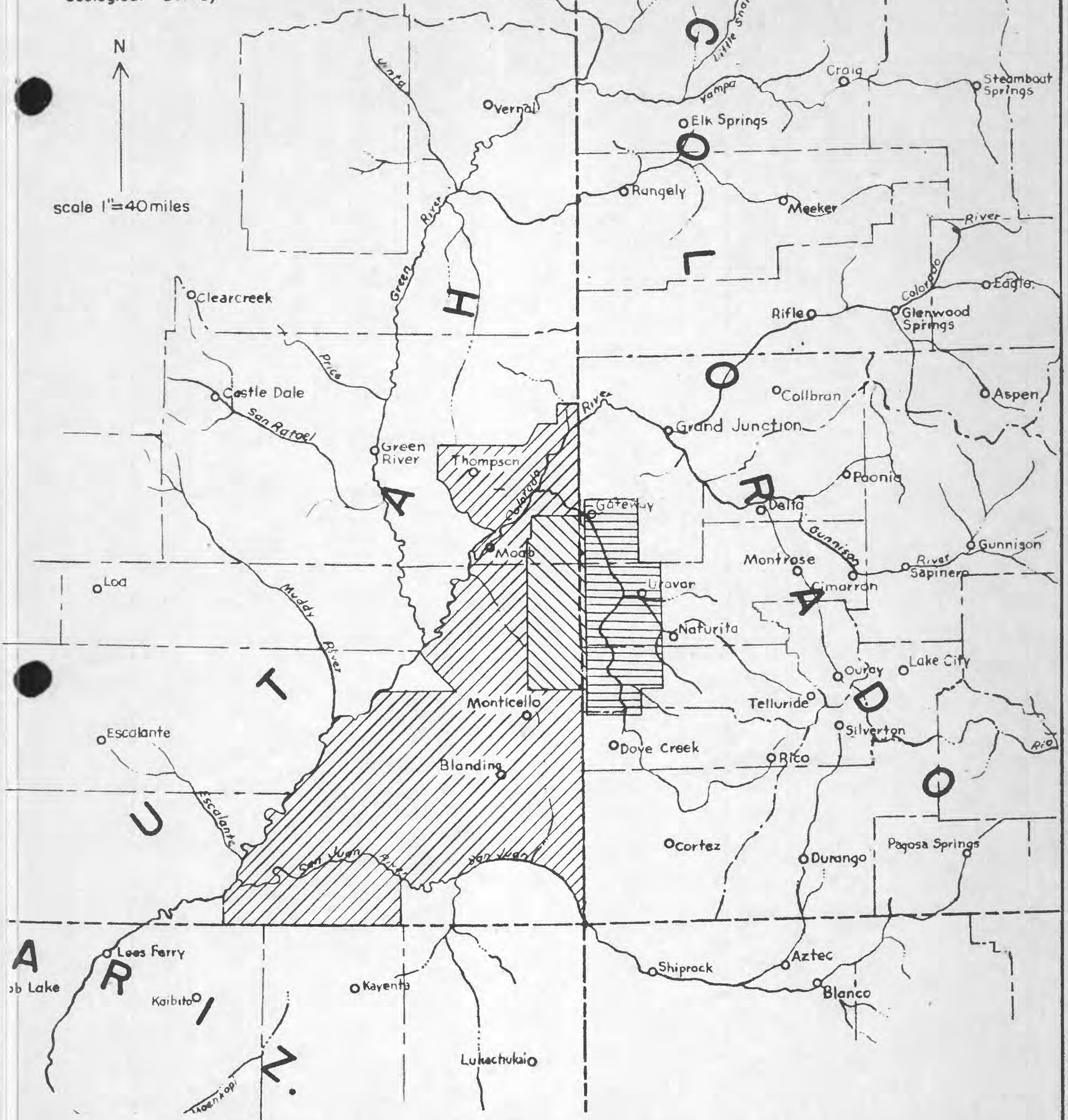

EXPLANATION

Area mapped from 1945 to 1949 (Colorado Plateau Project)

Areas described in former Geological Survey reports

Area planned for mapping in 1950

FIGURE 2

was begun during the early part of calendar year 1949; compilation work was recessed during the field season and resumed in November 1949. About 7 of the quadrangles had been completed by January 1, 1950.

Results

Results of regional geologic mapping obtained thus far are based on cursory analysis of field data and impressions gained during the progress of field work; they are, therefore, in no way to be considered final. Furthermore, some of the problems are closely inter-related to stratigraphic and ground-water problems, the solutions of which require the combined efforts of geologists working on these different specialties.

Bearing in mind the limitations set forth above, the results of regional mapping are set forth in several categories as follows:

1. The regional geologic setting of the carnotite-producing area.--The formations exposed in the carnotite-producing region of the Colorado Plateau consist largely of nearly horizontal sedimentary beds, ranging in age from late Paleozoic to Tertiary (see table 1). Exposures of the oldest formation, the Paradox of Pennsylvanian age, are confined to the intruded material along the eroded crests of collapsed anticlines and consist of black shale, limestone, gypsum, and salt. The next overlying formation, consisting of marine limestone, sandstone, and shale, is the Hermosa formation, also of Pennsylvanian age. It crops out in the same general areas where the Paradox formation is exposed. Above the Hermosa are interbedded marine and non-marine sediments of the Permian Rico formation. The Rico formation is transitional below into the Hermosa and above into the red beds of the Cutler formation. The Cutler formation consists of continental deposits of red shales, sandstones, arkoses, and conglomerates of Permian age.

Generalized section of late Paleozoic to early Tertiary strata in Southwestern Colorado and adjoining parts of Utah, Arizona, and New Mexico

System	Group	Group or formation	Character, distribution, and thickness (feet)	
Eocene		Green River formation	Light-gray shale, interbedded sandstone; oil shale. Thickness-	5,000
		Wasatch fm.	Variegated clay shale, sandstone and limestone. Widespread.	1,000
Cretaceous		Mesa Verde group	Light-gray sandstone and shale; coal-bearing. Cliff-forming. Widespread.	4,000
		Mancos shale	Gray, marine shale. Valley-forming. Widespread.	2,000-5,000
		Dakota sandstone	Gray & brown sandstone; carbonaceous shale, some coal. Mesa-capping. Widespread.	50-250
		Burro Canyon fm.	Light-brown conglomeratic sandstone and green shale. Mesa-capping.	50-250
Jurassic		Morrison fm.	Brushy Basin shale member: Variegated mudstone, claystone, some sandstone & conglomerate lenses. Forms slopes. Widespread.	300-500
			Salt Wash sandstone member: Light-gray sandstone ledges and red mudstone. URANIUM-VANADIUM-BEARING: Forms cliffs and benches. Widespread.	200-400
	San Rafael Grp.	Summerville fm.	Red shale, thin sandstone and limestone. Thickens westward. Forms slopes.	50-400
		Curtis fm.	Glauconitic sandstone, greenish shale, gypsum.	0-250
		Entrada sandstone	Light-orange, cross-bedded sandstone; thickens westward to red earthy sandstone. VANADIUM-BEARING. Cliff-forming in Colorado & Utah.	50-1,000
		Carmel fm.	Red, earthy sandstone in western Colorado & eastern Utah; thickens westward to gray & red shale, limestone and gypsum.	0-600
Jurassic (?)	Glen Canyon Grp.	Navajo sandstone	Light-buff, cross-bedded sandstone; thickens westward. Cliff-forming.	0-2,000
		Kayenta fm.	Maroon sandstone and shale, irregularly bedded, absent in eastern part of region. Bench-forming.	0-300
		Wingate sandstone	Red, massive, cross-bedded sandstone, absent in eastern part of region. Cliff-forming.	0-400
Triassic		Chinle fm.	Red mudstone, siltstone and shale; sandstone ledges. Forms slopes. Widespread.	100-800
		Shinarump conglomerate	Light-brown conglomeratic sandstone and shale. URANIUM-BEARING. Bench-forming.	0-100
		Moenkopi fm.	Red-brown shale and sandstone; absent in eastern part of region. Forms slopes.	0-1,000
Permian		Cutler and Rico fms.	Maroon arkosic sandstone and conglomerate, red and gray shale; thickest in Colorado though absent in places.	0-8,000
Pennsylvanian		Hermosa & Paradox fms.	Limestone, shale, gypsum, and salt.	Thick.?

TABLE 1

The Moenkopi, of Lower Triassic age, consists of red and chocolate brown shales, sandstones, and arkoses, and overlies the Cutler, in places, unconformably. Both the Cutler and Moenkopi formations thin eastward and pinch out entirely along the front of the Uncompahgre Plateau. Above the Moenkopi formation are red shales, sandstones and limestone conglomerates of the Upper Triassic Chinle formation, the oldest formation that extends northeastward across the summit of the Uncompahgre Plateau.

The Glen Canyon group of Jurassic age overlies the Triassic rocks and includes three sandstone formations--the reddish-brown Wingate sandstone at the base; the purplish-red Kayenta formation, containing some red shale and limestone conglomerates; and the light buff Navajo sandstone at the top. The Wingate and Navajo formations are largely of eolian origin, and the Kayenta is of fluviatile origin. The overlying San Rafael group is represented in Colorado by the Entrada and Summerville formations, but the basal part of the Entrada may be correlative to the Carmel formation of Utah. The Entrada consists of orange-buff, even- and cross-bedded sandstone; the Summerville of interbedded red shale and sandstone. The Morrison formation overlies the San Rafael group and comprises two units of approximately equal thickness--the Salt Wash sandstone member below, consisting of light-gray sandstone and red mudstone, and the Brushy Basin shale member above, consisting of shale or mudstone with some sandstone and conglomerate. Most of the carnotite deposits occur in the Salt Wash sandstone.

The basal formation of the Cretaceous series is the Burro Canyon, a cliff-forming unit of conglomerate, shale, and sandstone. Over it lies the Dakota sandstone, which grades upward into the gray marine Upper Cretaceous Mancos shale. The youngest formation remaining in the region of present mapping is the Mesa Verde. It consists of sandstone interbedded with gray shale. Undoubtedly, the Mesa Verde formation was overlain by early Tertiary sediments, but in the area now being mapped these have been entirely stripped away.

In addition to the sedimentary rocks, pre-Cambrian intrusive and metamorphic rocks are exposed along the front of and in the canyons cutting the Uncompahgre Plateau. Schist and gneiss are abundant in nearby areas on the Uncompahgre Plateau, but are rare within the area now being mapped. Gray, medium-grained quartz-diorite and pink, coarsely crystalline granite make up the bulk of the pre-Cambrian rocks exposed; the quartz-diorite is the older and is intruded by large irregular masses of the pink granite. Both are cut by numerous fine-to medium-grained dikes of various types, as well as granite pegmatite.

No igneous rocks younger than the pre-Cambrian are found within the area being mapped, but the laccolithic Tertiary intrusions of the nearby La Sal Mountains have produced structural disturbances that extend into the mapped area.

The various formations have been disturbed in places by moderately strong folds, intrusions of salt and gypsum, and high-angle faults. The Uncompahgre Plateau uplift and the Dolores anticline are the largest folds in the area being mapped, but strong anticlines caused by salt intrusion underlie Sinbad Valley, Paradox Valley, and Gypsum Valley. The most prominent synclines in the area are those of Dry Creek Basin and Pioneer Valley. The southwest front of the Uncompahgre Plateau is uplifted along faults that pass locally into monoclinal folds, and numerous faults displace the beds along the walls of Paradox, Gypsum, and Sinbad Valleys.

Probably the most immediate practical result of this regional mapping is the determination of the geographic distribution of the carnotite-bearing Salt Wash member of the Morrison formation. With this information an immediate separation between barren and potentially productive areas can be made. In addition, the depth to the favorable sandstones can be determined within relatively narrow limits where the sandstones are covered by younger formations.

2. <u>The relation of the deposits to stratigraphy</u>.—In general the uranium deposits of the Colorado Plateau are confined to three formations—the Shinarump, the Entrada, and the Salt Wash member of the Morrison. Correspondingly, the geographic distribution of the deposits in each of these formations is distinct; thus, the deposits in the Salt Wash member are mainly restricted to southwestern Colorado and the adjoining parts of Utah, Arizona, and New Mexico; those in the Entrada sandstone lie to the east near Rifle and near Placerville, Colorado; and those in the Shinarump conglomerate lie to the west in Utah. Only the main producing area in the zone of Salt Wash deposits is being mapped at the present time, and it is to this area that the following remarks are confined.

The deposits are mainly restricted to sandstone in the upper part of the Salt Wash member, but locally small deposits occur in sandstone lower in the Salt Wash, and even, in a few places, in the lower conglomerate layers of the overlying Brushy Basin member of the Morrison formation. Not everywhere is the upper part of the Salt Wash mineralized; The beds of this member are mineralized only in those areas where conditions, such as thickness of beds, lithology, and content of organic material were favorable.

3. <u>The relation of deposits to geologic structure</u>.—In contrast to the decided influence that favorable stratigraphic positions exercise in the localization of uranium deposits, the influence of large regional geologic structures appears to be either nonexistent or weak and ill-defined. A possible relation may exist in the close

parallelism between the belt of ore deposits in the Gateway-Uravan area and the front of the ancestral Uncompahgre highland, but this relation has more than structural significance and will be discussed under the section dealing with the influence of geologic history. Elsewhere the localization of deposits bears no apparent genetic relation to synclines, anticlines, or faults. Deposits are neither more nor less abundant nor large in the neighborhood of folds, faults, or other discernible structures than they are elsewhere. A few small occurrences of secondary mineralization resulting from the leaching of adjacent original deposits along faults and fractures, where the migration of ground water was favored, have little significance from either a structural or economic standpoint.

4. The relation of deposits to igneous activity.—The uranium-vanadium deposits of the Colorado Plateau have long been recognized as rather unique among metalliferous deposits because of the apparent lack of any connection between ore deposition and igneous activity. In this region a few small vein deposits mined for other metals have contained uranium and vanadium accessory minerals, but these could have been derived as well from contaminations of ground water mixing with the hydrothermal solutions as from primary igneous sources. The carnotite deposits are devoid of phenomena characteristic of deposits of igneous origin. The laccolithic masses forming the cores of the La Sal and Abajo Mountains are the only igneous masses near the mapped area later than the pre-Cambrian, and they appear to be younger

than the deposits and, consequently, have had little effect on them. The ground water or solutions from which the carnotite deposits were derived may have been influenced by contamination from remote hydrothermal sources, but evidence of such contamination has not yet been definitely recognized.

5. The relation of deposits to physiography.--Contrary to some theories existing in the past, there is no relation between the deposits and present day topography. Exploration and mining activities have demonstrated there is no relation between outcrop areas of ore-bearing sandstones and the location of deposits. Ore deposits are as numerous thousands of feet from outcrop areas as in them, nor does the depth of burial under younger formations affect distribution or size of deposits. Because of these factors there is every reason to believe that as many deposits will be found by drilling deeply buried ore-bearing sandstones where other conditions are favorable as in drilling ore-bearing sandstones at shallow depths.

6. The influence of geologic history on ore deposits.--Although in a sense the development of the uranium deposits is dependent upon the entire geologic history of the region, much of that history is lost to view, and some of the rest is as yet imperfectly understood. Therefore, the following summary of the features discussed is provisional in some respects, and definitely established in but few. The influence of geologic history is most strikingly demonstrated by

the relation of the La Sal Mountains to hydrothermal veins and the carnotite deposits, the relation of the deposits to the Uncompahgre Plateau, and the relation of the deposits to the salt intrusions of Gypsum Valley.

A glance at a map showing the location of deposits in the Salt Wash sandstone indicates that many of the deposits are localized in an arcuate belt partly encircling the La Sal Mountains. Likewise, around the periphery of the La Sals are a number of hydrothermal veins that have been mined at various times for silver and copper, and these veins probably are directly related to the La Sal intrusions. The carnotite deposits, on the other hand, are almost surely older than the La Sal Mountains, and thus are not directly related to the La Sal intrusions. Nonetheless, the localization of both the La Sals and the zone of carnotite deposits may be due to common or related causes that find their origins far back in geologic history. Such causes may have been buried structures that have influenced the flow of mineralizing solutions during the time of uranium deposition, and later controlled the emplacement of the La Sal laccoliths.

Of more significance, perhaps, than the relation of the La Sals to the carnotite deposits, is the parallelism between the deposits in the Gateway-Uravan part of the Uravan mineral belt/ and the edge of

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/ Fischer, R. P., The Uravan mineral belt: U. S. Geol. Survey, Colorado Plateau Project Topic Report No. 2, February 1950.

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the old Cutler basin of deposition along the front of the ancestral

Uncompahgre highland of pre-Cambrian crystalline rocks. Near or just before the beginning of Cutler deposition a great northwesterly trending fault, which closely follows the present day western edge of the Uncompahgre Plateau, lifted the land to the east and formed one of the principal source areas from which the sediments of the Cutler formation were derived. Very thick deposits of arkosic material accumulated against the steep fault escarpment throughout Cutler time. The overlying Moenkopi formation was deposited unconformably in part upon the Cutler, but pinches out between the Cutler and the Chinle before reaching the edge of the Cutler basin of deposition. The Chinle which overlies the Moenkopi throughout most of the Colorado Plateau area rests directly on pre-Cambrian crystalline rocks on the Uncompahgre Plateau, and is the lowest formation that continues northeastward across it. It is thought that continued greater settling of the thick sediments underlying the Salt Wash near the old Uncompahgre front, in contrast to the lesser settling possible in the thin sediments overlying the incompressible crystalline rocks of the nearby Uncompahgre area, may have exerted a controlling influence on the flow of ground water or solutions responsible for the deposition of carnotite.

To the southeast, the edge of the Cutler formation and the belt of ore deposits diverge and, correspondingly, the zone of carnotite deposits becomes less well defined and the deposits smaller and more scattered.

On the northeast rim of Gypsum Valley a number of carnotite

deposits have been found in the Hermosa formation, an apparently anomalous geologic position. Here the Salt Wash sandstone rests directly on the Hermosa formation because the intrusion of salt over a long period of time uplifted the Hermosa formation and was accompanied by either or both the removal and non-deposition of the formations normally lying between the Hermosa and the Salt Wash. The Hermosa formation is highly fractured and relatively permeable around the deposits and contains an appreciable quantity of organic matter. The ores have not yet been studied in any detail to determine whether or not they were leached from deposits in the overlying Salt Wash, but it is possible that ore deposition in the Hermosa formation occurred contemporaneously with ore deposition in the Salt Wash.

Plans and needs for future work

The final compilation of the geologic map of the area between Gateway and Egnar embraced by the eighteen $7\frac{1}{2}$-minute quadrangles for which maps are now available, will be undertaken, and probably completed, during the winter of 1949-50. During the summer of 1950, geologic mapping of the un-mapped part of southeastern Utah is planned (see fig. 2.). A topographic base is not requested for this work. Mapping will be done on air photographs and compiled on Soil Conservation Service planimetric maps. It is hoped that the field mapping in southeastern Utah, except possibly for that part of the area occupied by the La Sal Mountains, (and which is being done by another branch of the U. S. Geological Survey) will be completed in one summer (1950). This map

will be compiled in the winter of 1950-51, after which the geologic report on this area,and the area in Colorado as well, will be completed. No more regional geologic mapping is presently planned, but later more might be deemed advisable.

STRATIGRAPHIC STUDIES

By L. C. Craig

Objectives

The stratigraphic studies are planned to reconstruct the paleogeographic sequence of the ore-bearing rocks and adjacent strata in order to determine possible sources, routes of transportation, and localizing stratigraphic controls for the ore minerals. The stratigraphic studies also provide consultant service on problems of the exploration, ground water, and mapping geologists.

Methods of study

The character of the ore-bearing Salt Wash member of the Morrison formation permits convenient subdivision of the stratigraphic studies into four specialties, each of which will contribute information to certain aspects of the major objectives. The four studies are described below. These investigations are not entirely new to the Colorado Plateau, but they are being applied in more detail and promising new methods of study have been developed. The four studies are coordinated either by simultaneous operation in the same field areas or by field and office conferences.

1. Regional stratigraphic study.--The regional stratigraphic study will indicate the position and sequence of depositional environments of a considerable part of the Mesozoic strata of the Colorado Plateau and adjacent provinces by determining mass physical characteristic continuities, and relative ages. The study provides a consistent regional

framework for the operation of the other aspects of the Colorado Plateau project and will synthesize the data of all the stratigraphic studies. Detailed measurements of critical stratigraphic sections are the basic data of the regional study. The mass of available published and unpublished stratigraphic information is evaluated and utilized to the fullest possible extent.

2. Lithofacies study.--Lithofacies study will indicate the sequence and position of the major depositional environments of the Salt Wash sandstone member of the Morrison formation by determining the location of any persistent major drainage lines and the regional continuity of permeable beds. The ultimate objectives are to establish the routes of transportation of ore minerals and areas of favorable lithologic environment for ore localization. Measurements of a number of sections through the Salt Wash at selected localities, comparing the thickness of sediments deposited from flowing water (stream deposits) with the thickness of sediments deposited from slack water (floodplain deposits) provides the basic data of the study. Statistical treatment of these data permit analysis of Salt Wash lithologic variations.

3. Study of sedimentary structures.--Study of sedimentary structures will indicate the orientations and character of depositional environments of the Salt Wash by determining the current directions during Salt Wash deposition, the origin of the bedding, lamination, and channel structures, and the detailed relation of these structures to ore structures. The ultimate objectives of these studies are to establish the source direction of the sediments, direction of transportation of the

ore minerals, and possible detailed localizing controls for ore deposition. Measurements of orientations of bedding structures in selected areas provide the basic data of the study. Either individual or statistical treatment of the measurements permits determination of dominant current orientations.

4. Sedimentology.—Sedimentology will indicate the variations in detailed physical character of the ore-bearing formation and adjacent units by determining local and regional variations of grain-size, roundness, sorting, and heavy and light minerals. The objectives are to assist in determination of the sedimentary characteristics that may have influenced migration of metal-bearing solutions and localization of mineral deposition, to indicate the character of source rocks, to assist in the determination of depositional environments, and to assist correlations. Mechanical analysis and microscopic examinations of selected rock samples provide the basic data of the study. Statistical treatment of data permit reduction to significant terms that may be readily compared, either graphically or numerically.

Progress

Four major factors have influenced the progress of the stratigraphic study toward its objectives. Development of a stable and adequate staff has required that considerable time be spent in training and orientation. Consultant functions of the stratigraphic studies have been varied and only the major services are noted below. The separate field operation of geologists has required continuous effort to obtain standardization

in descriptions and techniques. The pioneering aspect of several phases of the program and the unique character of the ore deposits have required the development of new methods and standards.

1. Regional stratigraphic study.--The regional stratigraphic study was started in the summer of 1947. The first work concerned specific problems of the exploration and regional mapping programs. One critical section was measured and described. In the field season of 1948, 18 key sections were located, measured, described in detail, and sampled for laboratory use. This study was expanded in 1949 when an additional 37 key sections were measured. Ten partial sections were also measured to furnish information on specific stratigraphic problems. Location of the detailed measured sections is shown on figure 3. The areal extent of study completed to date and the area of reported Salt Wash occurrence are shown in figure 4.

2. Lithofacies study.--The lithofacies study began in the summer of 1948. First efforts were concerned with the development of appropriate methods and standards. The study was expanded in 1949 and measurements have been made at 24 localities as indicated in figure 3.

3. Study of sedimentary structures.--The study of sedimentary structures was started in 1948 by experimentation with methods and collection of data at the sites of two exploration projects, the Lower group and Calamity Mesa. During the field season of 1949, eighteen sedimentary structure studies were made at ten different

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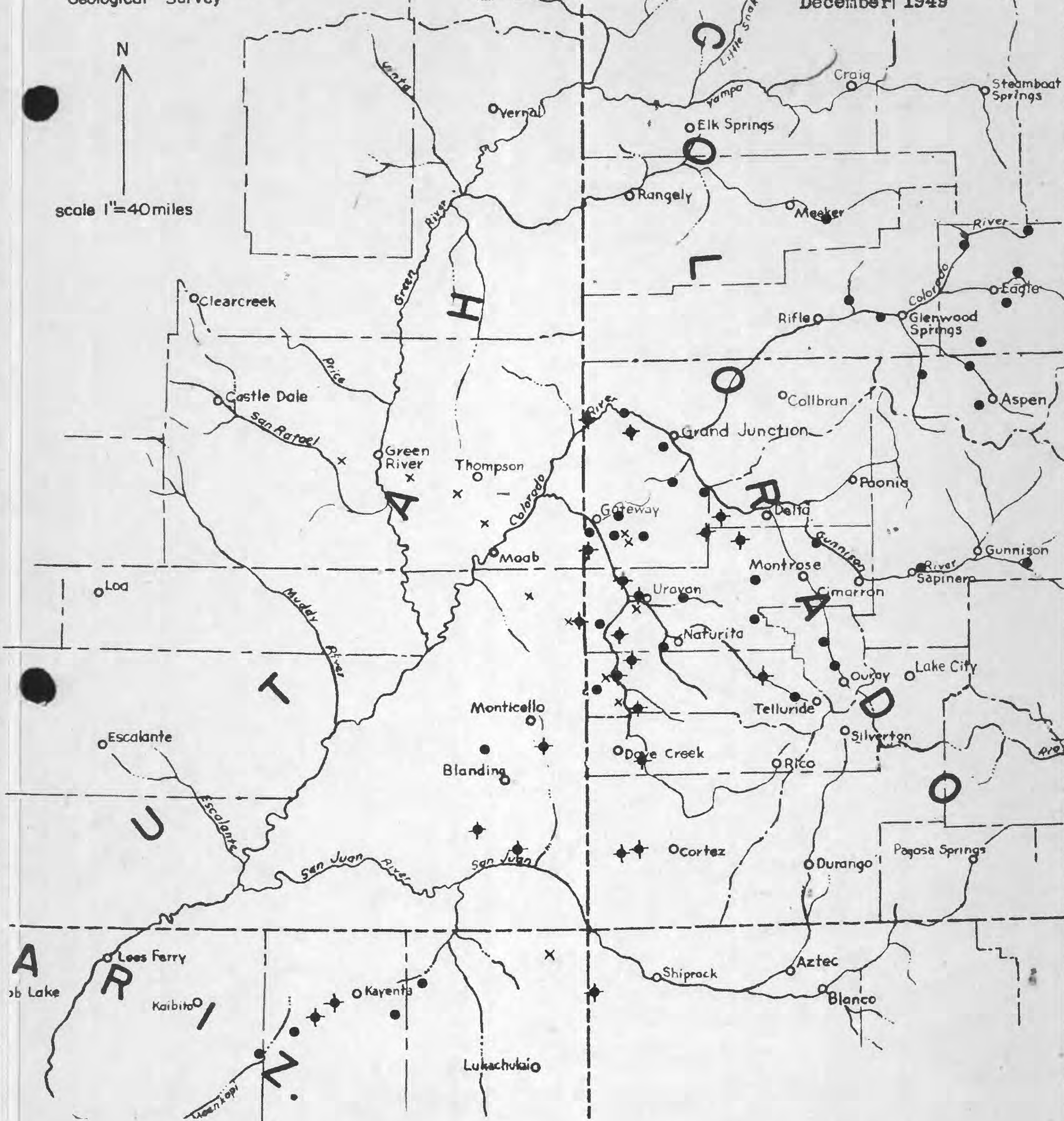
COLORADO PLATEAU PROJECT
December 1949



EXPLANATION

- ● Detailed measured section.
- ⌖ Lithofacies study.
- × Study of sedimentary structures.

INDEX MAP OF COLORADO PLATEAU

SHOWING LOCATIONS OF

STRATIGRAPHIC STUDIES

FIGURE 3

localities (fig. 3). Ten of these studies were made in cooperation with exploration geologists at the Spud Patch, Carrizo Mountains, Outlaw Mesa, and Club Mesa sub-projects. Considerable effort and time were spent in devising and testing techniques of study.

4. Sedimentology.--The sedimentology program was begun in the summer of 1948. Field study, and the planning, construction, and equipping of a laboratory occupied the rest of the year. The laboratory was put in operation in January 1949. Approximately 200 samples have been processed by the laboratory in twelve months of operation. At the present time, 30 to 40 analyses are completed each month.

Samples are collected to serve one of two objectives; to provide a background knowledge of the sediments, or to provide data on specific problems relating to regional stratigraphy or to ore deposits. The majority (approximately 150) of samples analysed to date provide original petrologic information. Of these, at least 50 are from the ore-bearing Salt Wash member of the Morrison formation. About 100 samples are from other sandstone units ranging from the Chinle formation of Triassic age to the Dakota formation of Upper Cretaceous age. The remaining 50 samples supply information concerning composition of the ore sands and information on rock structures that may have influenced ore deposition.

Results

1. Regional stratigraphic study.--The regional stratigraphic study has made advances toward its objectives, particularly in the problems of correlation and facies changes. Final interpretation of the paleogeography and paleogeology, source areas of the sediments, routes of transportation of metal-bearing waters, and details of sedimentary structures must await final compilation of data. However, several factors of economic importance may be noted from present compilations. The first factor is the change of lithologic characteristics of the Salt Wash sandstone along an irregular line in western Colorado (see fig. 4). To the west of this line the Salt Wash consists of interbedded medium-fine-grained sandstone and sandy shale, whereas to the east it consists of interbedded fine-grained sandstone and clay shale. It is believed that the western facies was more favorable for ore deposition because the sediments are more permeable. The regional favorable areas therefore can be roughly delimited from the unfavorable areas on a lithologic basis in western Colorado. This line of change will be extended by further study.

The sensitivity of ore-bearing solutions to a facies change is further indicated in the "four-corners" area. Here the Recapture shale member of the Morrison replaces the upper two-thirds of the Salt Wash and ore deposits are restricted to the underlying typical Salt Wash sandstone lenses. The major difference in lithologic characteristics between the Recapture and Salt Wash facies is thought

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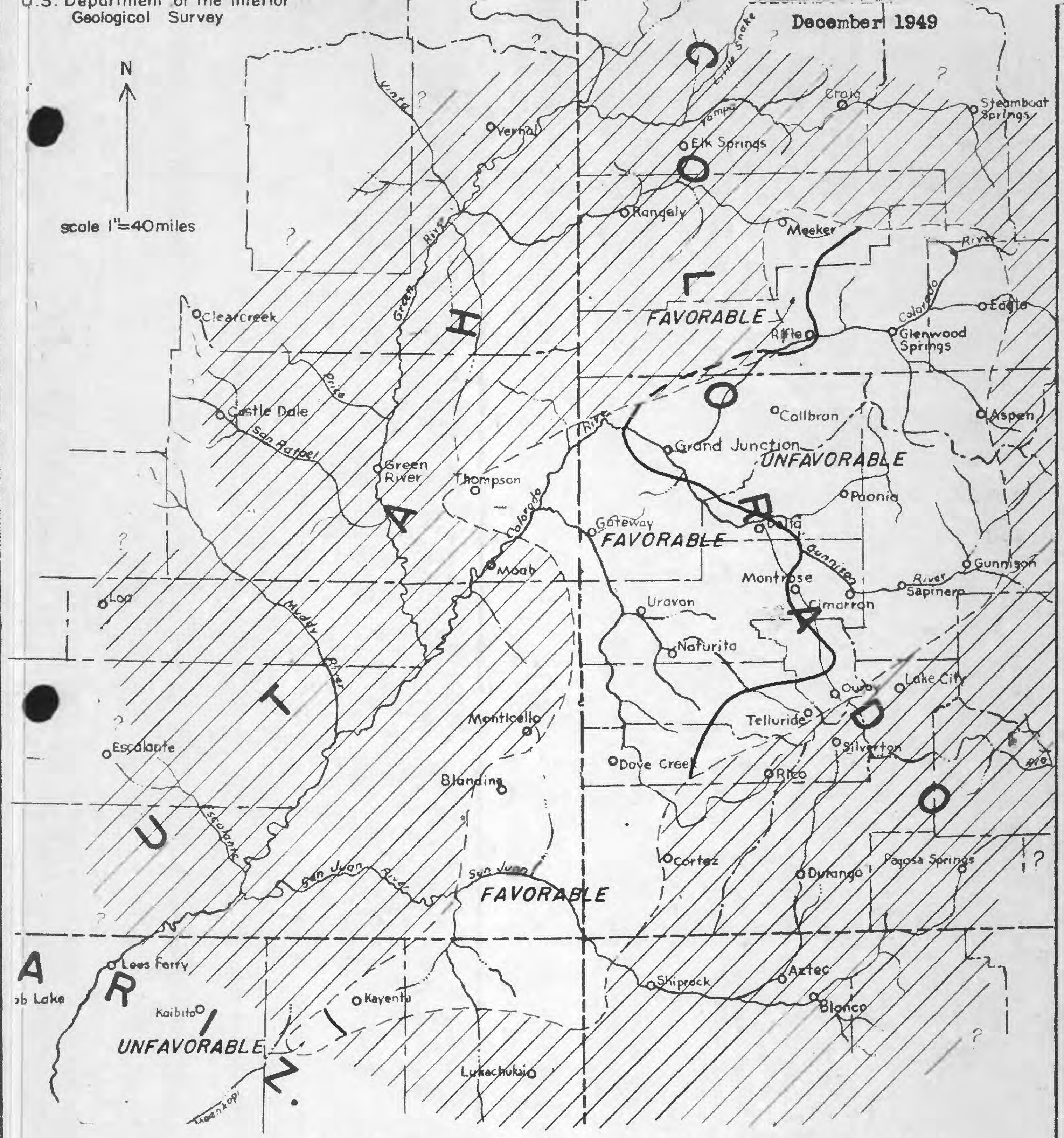


EXPLANATION

Area of completed regional stratigraphic study of Salt Wash.

Area of incompleted regional stratigraphic study of Salt Wash.

Boundary separating areas with typical Salt Wash facies favorable for ore from areas with facies unfavorable for ore.

MAP SHOWING LIMITS OF THE TYPICAL ORE-BEARING SALT WASH FACIES IN THE AREA OF COMPLETED REGIONAL STRATIGRAPHIC STUDY

FIGURE 4

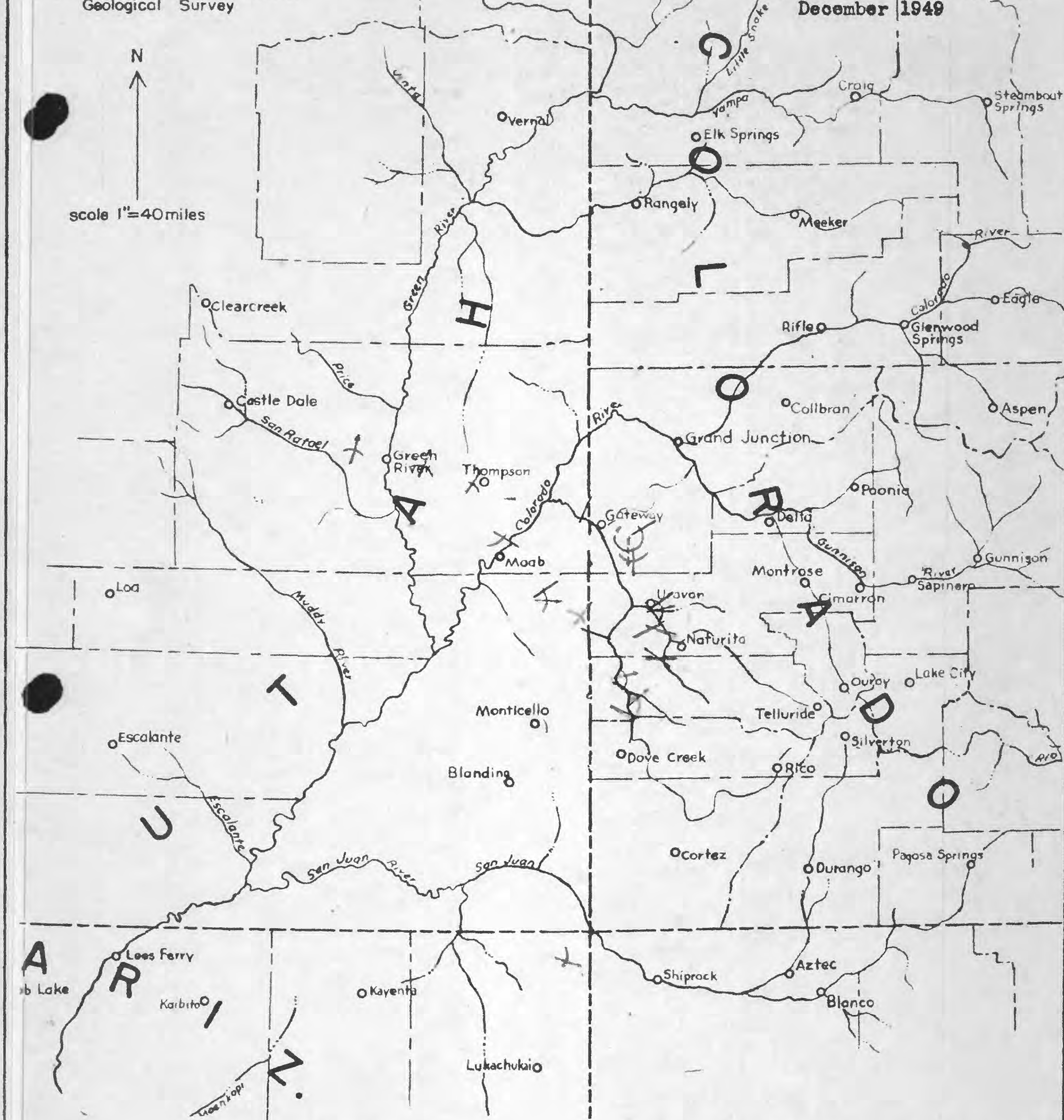
to be the greater amount of interstitial clay in the sandstones of the Recapture. This would produce lower permeability, and confine the migrating ore solutions to the underlying more permeable sandstones of Salt Wash type. A limit to the favorability for ore may be drawn southwest of Kayenta, Arizona (fig. 4), where the typical Salt Wash sandstone becomes less than 30 feet thick and farther southwest pinches out entirely.

A second regional factor in delimiting favorable areas for ore deposition is shown by isopach maps. The greatest concentrations of uranium deposits in Colorado coincide with broad depositional basins which may have produced conditions particularly favorable for the migration of ground water and the deposition of ore minerals. Thus, the combination of favorable lithologic characteristics within a basin environment can be used to guide exploration in Colorado.

2. Lithofacies study.—The methods developed for the lithofacies study permit the computation of a number of statistical quantities showing the variations of the Salt Wash lithologic characteristics. Caution must be exercised in interpreting these variations. The following preliminary example indicates the character of possible results and interpretations of the study.

A map showing the percent of stream deposited material in the Salt Wash indicates that for the area studied the ore deposits are most abundant in areas with a medial percentage range. A map showing the degree of lenticularity of the Salt Wash indicates that, to a lesser degree, ore deposits are most abundant in areas of moderate lenticularity. An optimum transmissibility within the Salt Wash sandstone beds in certain areas may have influenced the deposition of ore minerals. Transmissibility is controlled in large part by the percent of permeable stream deposits and by the lenticularity of these deposits. If extended study verifies these relations, the two factors could be used to outline broad areas that were favorable for ore deposition, even in regions where the Salt Wash is now covered by a considerable thickness of later sediments.

3. Study of sedimentary structures.—Some preliminary results of the study of sedimentary structures are expressed graphically on the map comparing probable drainage directions and ore deposit orientations (fig. 5). A red arrow indicates the resultant dip direction of cross-laminations at a particular place and is interpreted as the drainage direction. The red arc represents the probable range of the downstream directions of the braided channel system. A green line shows the average roll orientation in a particular group of ore deposits.



EXPLANATION

— Drainage direction as inferred from resultant dip direction of cross-laminations

) Range of directions of braided channels as inferred from range of dips of cross-laminations

— Average roll orientations of ore deposits of a particular group

MAP SHOWING RESULTANT DIP DIRECTIONS OF SALT WASH CROSS-LAMINATIONS AND AVERAGE ROLL ORIENTATIONS OF SALT WASH ORE DEPOSITS

FIGURE 5

The resultant dip directions correspond in a general way with the roll orientations, for a tendency toward a radial pattern is suggested in the regional plan of both the sedimentary structures and the roll trends. This probably indicates that sedimentary structures had a broad controlling influence on ore deposition. At Club Mesa and the Carrizo Mountains, drainage directions are nearly identical in several different ledges showing the persistence of drainage trends throughout the time of Salt Wash deposition. Such persistence may be directly influenced by the position and character of depositional basins outlined by the regional stratigraphic studies.

Few studies of the detailed relations of sedimentary structures to ore deposits have been made to date. However, one study shows that, although the ore is not confined to laminae of a particular orientation, laminae with certain orientations may be more favorable for deposition than those with other orientations. More data and observations are required, but this result may support the conclusions of an early interpretive study that suggested ore deposition was controlled by details of channel structures in sandstones of favorable thickness.

4. Sedimentology.--Properties of sediments which are being measured in the laboratory may be summarized as: individual characteristics of grain-size distribution, including statistical measures and detailed frequency and cumulative curves; ratios of different heavy minerals present; ratios of different light minerals present; and, percentage mineral composition of the sands. The

following examples of results of the sedimentary study demonstrate the application of these measurements to specific problems of the Colorado Plateau project.

Standardizing and analyzing the descriptive terminology used by the geologists of the Colorado Plateau project is an important and continuing problem. The sedimentology laboratory has been able to assist considerably. Grain-size descriptions have been standardized by providing sieved samples of the various grain-sizes to all geologists of the project. As a service to the exploration geologists, a series of selected samples of Salt Wash sandstone were analyzed for their silt and clay content. Although particle size of the fine material remains important in describing core from drill holes, the analyses showed that inspection could not adequately estimate the silt and clay content,and descriptive terms could not be assigned numerical values representing the relative abundance of silt and clay.

Problems of stratigraphic correlation are numerous and in many cases sedimentology can assist in their solution. A rock unit exposed in an isolated area of Jurassic outcrop was identified as either Entrada or Wingate. Field evidence was insufficient to permit exact correlation. A comparison of the detailed frequency curves of the unknown unit with those of known samples of Entrada and Wingate indicated with little doubt that the unknown unit must be assigned to the Entrada formation.

A detailed investigation of the textural relations within sandstone-filled channels in the Salt Wash was undertaken to determine the existence of postulated, regularly distributed grain-size and sorting influences on ore deposition. No systematic distribution of textural controls was found to exist in the sandstone units, and no relation of texture to the location of ore deposits was observed.

Plans and needs for future work

The program for stratigraphic studies calls for completion of the intensive study of the ore-bearing Salt Wash and adjacent beds in June 1951. Basing judgment on the past rate of progress and assuming that an adequate trained staff is maintained, the completion date seems reasonably attainable. The difficulty in solving future stratigraphic problems and the need for extended work on profitable lines of evidence that may emerge late in the course of the project are unknown quantities in estimating future progress and the desirability of terminating work at a particular future date.

During the office season of 1950, all methods, data, and preliminary interpretations, are to be summarized in a form that will be adequate to provide a reference of stratigraphic information for all geologists of the Colorado Plateau project.

During the field season of 1950, all the stratigraphic studies must extend the regional aspects of their work at least to the limits of preservation of the Salt Wash. The area of reported Salt Wash occurrence is compared in figure 4 with the area of study already completed. The regional stratigraphic study and the sedimentology study must extend beyond this limit to gain background regarding the possible source rocks of the Morrison and adjacent beds. In addition, all the stratigraphic studies will expand detailed work

that is in large part directed toward determining localizing controls for ore as an aid in guiding exploration work.

During the office season of 1950-51, final data compilations and interpretations will be made with the primary object of contributing stratigraphic information to a cooperative report dealing with the uranium-vanadium deposits of the Salt Wash member of the Morrison.

Plans beyond June 1951 suggest stratigraphic study of other ore-bearing formations of the Colorado Plateau, with one year estimated for completion of a study of the Entrada sandstone.

GROUND-WATER STUDIES

By D. A. Phoenix

Objectives

The objectives of this study will be, first, to interpret the ground-water conditions prior to and during the period of ore deposition, second, to correlate this interpretation with the geology of the ore deposits, and, third, if relationships can be established, to furnish information of a hydrologic and geologic nature which will assist in the total evaluation of an exploration for the uranium-vanadium resources of the Colorado Plateau.

Scope

The paleo-ground-water conditions will be determined by field and laboratory investigation of the recent ground waters, by analysis and interpretation of the geologic and stratigraphic studies, and by permeability and transmissibility studies of the ore-bearing sediments. The interpretation of paleo-ground-water conditions will be largely confined to the ore deposits of the Morrison formation inasmuch as those in the Entrada and Shinarump formations may not be correlative in age. It is expected, however, that the methods of study and results will be applicable, in part, to the other deposits.

Progress

Ground-water studies were initiated in September 1949. Since that time initial observations of the recent ground water have been made in the Outlaw and Calamity Mesa areas to establish relationships between ore bodies and the water table and springs. Water levels in drill holes have been measured and samples of the ground water from mines and springs have been submitted for analysis. Organization of field and laboratory work

and review of collected data have been necessary.

Results

Hydrologic conditions during Morrison time can be postulated to fit results obtained from the geologic and stratigraphic studies. Factual data are necessary, however, before these relationships can be firmly established and then utilized to determine the possible source and the mode and route of transportation of the uranium-vanadium bearing solution, and the conditions favorable for the localization of the ore deposits.

Plans and needs for future work

Much of the material included in this section was reported in Colorado Plateau Project Memorandum Report No. 10 entitled "Preliminary plans for ground-water studies" by D. A. Phoenix which was submitted in January 1950.

Recent ground water.--A study of the recent ground water will be carried on by field measurements to determine spring or well discharge, position and extent of ground-water bodies, areas of ground-water recharge or discharge, ground-water temperatures, and chemical characteristics of the ground water near or within the areas of known mineralization.

Field work will consist of periodic water level measurements in drill holes covering parts of Calamity and Outlaw Mesas. If water level fluctuations indicate the presence of a body of perched ground water, water table maps will be constructed, a geologic study of the area of recharge will be made, as well as geologic and phreatophyte _/ studies of the area of discharge.

_/ A plant that habitually obtains its water supply from the zone of saturation, either directly or through the capillary fringe.

Maximum ground-water temperatures will be taken in drill holes during the winter of 1949-50. These temperatures will be taken in the vicinity of ore bodies discovered by drilling, to observe if there are differences in ground-water temperature between barren and mineralized holes.

Samples of ground water have been collected for analysis from mineralized and non-mineralized areas, and additional samples will be collected. The analysis of these samples may indicate significant differences between the normal ground waters and those circulating past the ore bodies. If so, the results should materially assist the mineralogic studies and the paleo-ground-water interpretation. Initially, approximately 24 samples should be submitted for analysis of the normal constituents of water as well as for silica, boron, fluorine, uranium, vanadium, lead, copper, and for specific conductance. Perhaps mineralogic studies being undertaken by other geologists will suggest other constituents for which tests should be made. If this phase of the ground-water investigation proves to be important, and routine laboratory procedures can be established for the attainment of results, it may be expanded in 1950. If, however, it is found that ground water is limited in occurrence and is not conducive to study through the existing drill holes, then plans for an elaborate study will be abandoned and instead only occasional analyses will be necessary to help substantiate the data obtained from the initial samples. In this case, probably not more than 100 samples will be submitted for chemical analysis, and probably many of these will require only partial analyses.

Areas of transpiration adjacent to a ground-water body in the ore-bearing horizon will be mapped in the early spring or summer of 1950 at a time when plants are reaching maximum growth, and samples of the phreatophyte vegetation will be submitted for chemical analysis. Collection of this material will not be undertaken until it can be demonstrated that there are mappable areas of phreatophyte discharge from the ore-bearing sandstone.

Paleo-ground-water.--The past ground-water conditions will be determined by a study of the permeability relationships within the ore-bearing sandstone, by interpretation from the paleogeomorphic and paleogeographic conditions prevalent during or prior to the period of ore deposition, and by use of the data collected from a study of recent ground water.

The end results of the permeability study will be factual data supporting or disproving the theory that ground-water migration through the ore-bearing sandstone influenced the localization of the ore deposits. Selected samples from a sandstone lens will be chosen for permeability tests and possibly thin section study to determine special relationships of permeability. Specimens may also be selected from widely distributed lenses to determine regional relationships of permeability. Ultimately it may be necessary to determine the horizontal permeability of approximately 300 samples.

Sufficient laboratory permeability apparatus will be needed, the number of units depending upon the time required to determine the permeability of one sample. These determinations should be made by a lab technician so the ground-water geologist will be free to engage in field work and other research.

Office compilation and the interpretation and analysis of the results of general geologic mapping and stratigraphic and sedimentology studies will be made, to interpret the ground-water hydraulics during or after Salt Wash

time. Field work probably will be a minor phase of the paleo-ground-water studies, for the field collection of geologic data is being done by others. It will be necessary, however, to become thoroughly acquainted in the field with the various geologic features characteristic of the region as a whole, as well as with those features thought to have particular paleo-ground-water significance. This work will be a part of the field program for the fall and early winter of 1949 and the field season of 1950; the correlation of other geologic studies with the hydrology will occupy a large part of the winters of 1949-50 and 1950-51.

Basic data of scientific and practical value should result from the ground-water work. Progress reports, office memoranda, and technical reports will be submitted from time to time. Very little can be expected in the way of technical reports, however, until fiscal 1951. Assembly of preliminary basic data and general review and research are planned during the winter of 1950-51.