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RECONNAISSANCE OF THE CAMERON AREA, COCONINO COUNTY, ARIZONA

By
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June 1955

Exploration Division
Grand Junction Operations Office
Grand Junction, Colorado

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RECONNAISSANCE OF THE CAMERON AREA,

COCONINO COUNTY, ARIZONA

ABSTRACT

In the Cameron area, in north-central Arizona, a belt of Triassic sedimentary rocks dips northeast toward Black Mesa Basin. Uranium is found in the Chinle formation and the Shinarump conglomerate.

Geologic criteria useful in locating uranium are stratigraphic position, sandy lenses, carbonaceous material, color and traces of molybdenum.

Chemical analysis of 5 elements from samples taken from mineralized and barren lenses indicates that molybdenum has a significant relation to uranium distribution. A determination by field tests of the vanadium content in samples revealed no usable criteria.

No relationship appears to exist between ore deposits and fracture patterns detectable on aerial photographs.

At the Huskon No. 1 mine, ore is distributed in the lower 60 feet of the "C" member of the Chinle formation in a sandy mudstone lens about 40 feet thick, which contains abundant carbon trash.

INTRODUCTION

The discovery of several radioactive outcrops, early in 1952, placed the Cameron area among potential uranium-producing localities. Subsequent airborne radiometric reconnaissance by the Atomic Energy Commission located numerous anomalies and provided a stimulus to prospecting. The objectives of this reconnaissance program were threefold:

1. To develop criteria of ore deposition which would serve as guides in physical exploration and in reconnaissance prospecting.

2. To evaluate the anomalies discovered by airborne radiometric survey.

3. To recommend a plan for work in those portions of the area where exploration is warranted.

The Cameron area consists of about 750 square miles underlain by Triassic sedimentary rocks trending northwest, in a belt, approximately 10 miles wide and 75 miles long between Leupp and Cedar Ridge, Arizona (fig. 1).

The Cameron area lies principally within the Navajo Indian Reservation in Coconino County, Arizona (fig. 1). The most important uranium production comes from an area near the trading post of Cameron, Arizona, on U. S. Highway 89, about 50 miles north of Flagstaff, Arizona. The deposits here are accessible by automobile, but the more remote deposits can be reached only by vehicles with four-wheel drive. Many wagon trails cross the area, and serve as points of departure to the more remote localities, but during winter months or in wet weather these often are impassable. Mineral rights of lands on the Reservation are the property of the tribe, and mining companies operate by contract with the Navajo Tribal Council.

The Arrowhead Uranium Company began the initial production in the Cameron area in the spring of 1953. In 1954 there were five operators in the area.

Reconnaissance in the area is given impetus by Indian prospectors who receive a royalty from any ore produced from their claims.

GEOMORPHOLOGY AND CLIMATE

The Cameron area is about 4,000 feet above sea level. Ward Terrace (fig. 2), a broad, east-dipping cuesta rising about 400 feet above the Little Colorado River, borders the area on the east and north. The area lies principally along the valley of the Little Colorado River, which had cut through the soft clays of the lower part of the Chinle formation in most places and is flowing on the more resistant underlying Shinarump conglomerate. The valley is composed of large areas of mud flats broken by hummocks and knolls forming typical badland topography.

Annual rainfall is about 4 inches, hence vegetation is very sparse. Temperatures during the summer months may reach 120 degrees Fahrenheit, an extreme which hampers field work. During the remaining months, however, temperatures seldom go down as low as zero.

GENERAL GEOLOGY

The Cameron area lies along the southwest flank of the Black Mesa Basin; Triassic and Jurassic sedimentary rocks dip from one to three degrees to the northeast. The volcanic fields of the San Francisco Mountains lie near the southwest margin of the area. The Kaibab monocline and its branches generally parallel the area on the west. The southern end of the Echo Cliffs monocline lies north and east of the northern part of the area and merges southward into a large, low cuesta, Ward Terrace, which flanks the remainder of the area on the east (fig. 2).

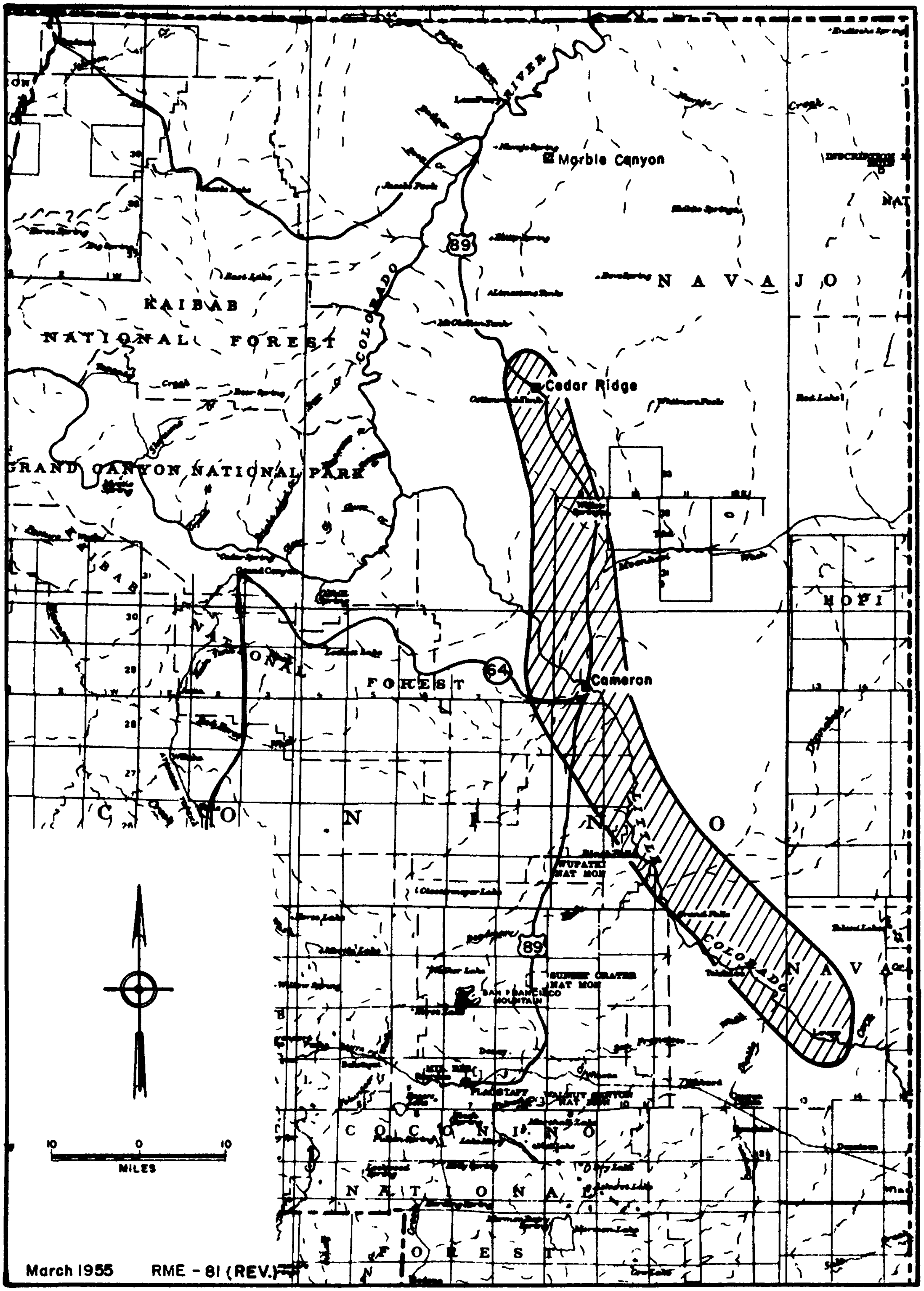

Figure 1. Location of Cameron area Coconino County, Arizona

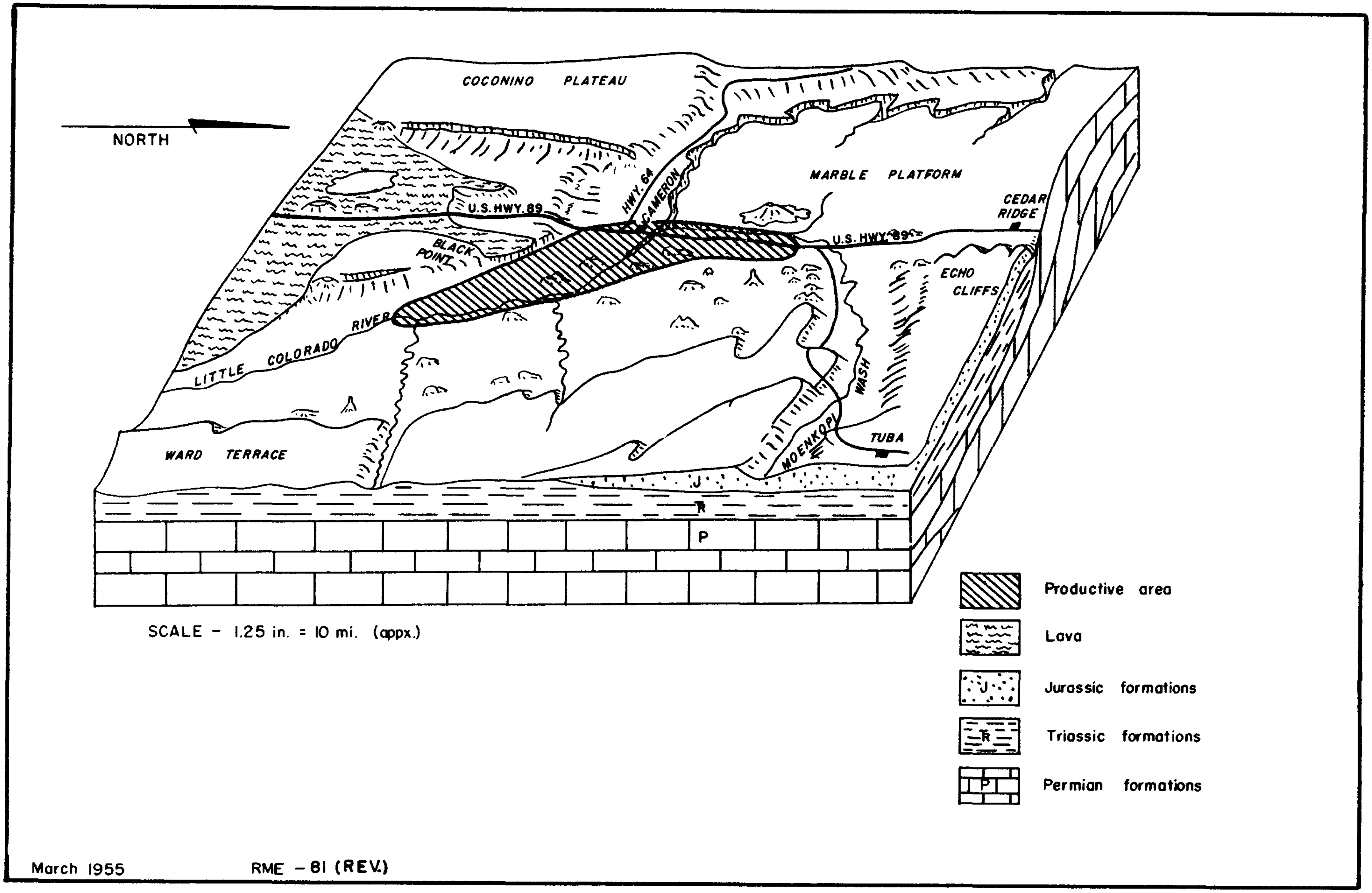

Figure 2. Block diagram of the area near Cameron Coconino County, Arizona

The greater part of the investigation was concentrated within a 15-mile radius of Cameron, Arizona, as commercial production of uranium ores was limited to this area.

Sedimentary Rocks

Near Cameron the Triassic Chinle and Moenkopi formations and intervening Shinarump conglomerate, and the Permian Kaibab limestone crop out. These formations are described briefly in figure 3.

The Triassic rocks in this area thin abruptly to the north, reaching a minimum thickness near the Cedar Ridge Trading Post. The Chinle formation thins from about 800 feet near Cameron to about 400 feet near Cedar Ridge and the Shinarump member pinches out entirely in the same area. This thinning of the Triassic rocks may reflect the effects of uplifting of the area during Triassic time. The greatest productivity is from the south flank of this postulated Triassic uplift.

The source of the Upper Triassic sediments is believed to have been to the south or southeast, with the paleodrainage flowing toward the Late Triassic Sea of Nevada (5). Studies of cross-bedding in several deposits indicated a general northward flow of the paleostreams which deposited sediments of the lower part of the Chinle.

Most uranium ore in this area is mined from medium- to fine-grained clastic rocks at and near the contact of the Chinle formation and Shinarump conglomerate. In the absence of more complete information and for the purpose of this paper, an arbitrary contact was chosen at the top of a bed of mottled clays and sands, purple through yellow in color, from 5 to 12 feet thick and occurring at the base of the "C" member (6) of the Chinle formation. This layer is generally capped by a quartzitic sandstone, usually less than one-foot thick, which serves as an excellent marker bed - separating the clay beds of the Chinle above from the predominantly sandy beds below. The clays and sands immediately below the marker bed may be the "D" member of the Chinle formation, but in the absence of proof, strata below the quartzitic sandstone, the marker bed, and above the Moenkopi are herein termed Shinarump.

Igneous Rocks

The Quaternary period was marked by igneous activity in the Cameron region. The Tappan lava flow, which forms Black Point promontory (fig. 2), and the Shadow Mountain cinder cone and basalt flow are the nearest volcanics.

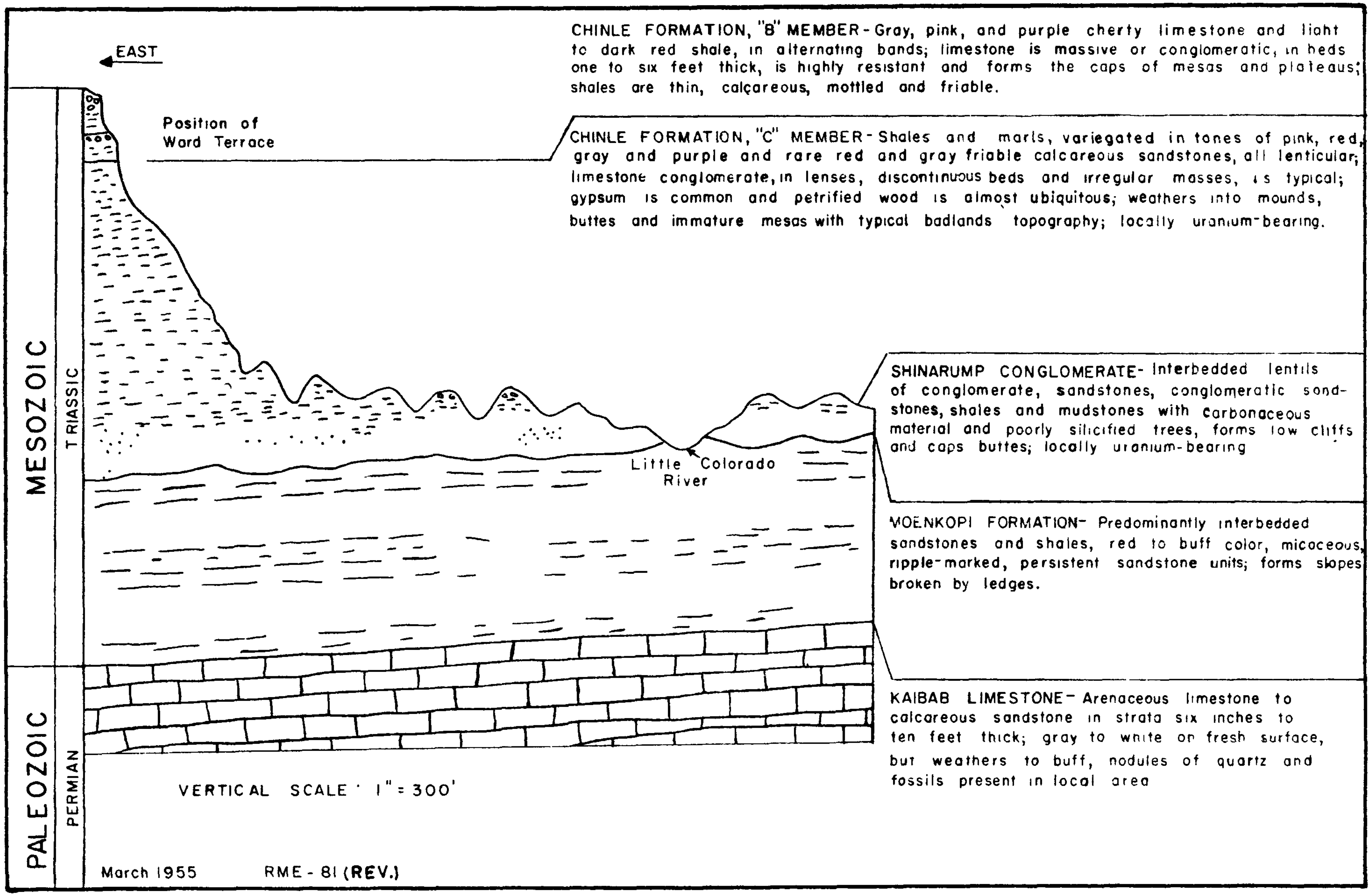

Figure 3. Geologic column, Cameron area, Coconino County, Arizona

In addition the "C" member of the Chinle formation is composed largely of montmorillonite clay derived from volcanic ash. This material is the result of Triassic volcanism to the south, in Central Arizona. The clays have more than the normal uranium content of sedimentary rocks, and may be the source of the deposits.

Tectonic Structures

A short distance west of Cameron, the East Kaibab monocline divides - one part, the Black Point branch, which forms the south and west boundary of the productive area, swings sharply to the east (fig. 2). Erosion has exposed the Triassic formations in the form of flatirons and cuestas on and around this steeply dipping monocline. North of the Black Point branch and productive area is disturbed by several small undulations in the gently eastward-dipping strata. These flexures appear to have no relationship to the occurrence of ore.

Faulting, of minor extent and magnitude, occurs just west of the productive area, near the junction of Moenkopi Wash and Little Colorado River. No major faults were observed in close association with the uranium deposits. North of the productive area the sharp fold of Echo Cliffs monocline flattens toward the Cameron region.

The plotting, on a Schmidt equal-area net, of the strike of fractures visible on aerial photograph indicates a prominent northeast trend with a less distinct set trending northwest. No relationship between ore deposits and fracture patterns or fracture concentration was observed.

Geologic History

During late Triassic time lower Chinle clays and sands were deposited by aggrading streams as lenses on valley flats. The aggrading streams flowed from the south toward the late Triassic Sea of Nevada to the northwest. Streams approaching the present site of Cameron, Arizona, were diverted to a more westerly course by an uplifted area near the present site of Cedar Ridge. Volcanic debris from the south mixed with products of erosion was thus deposited as the part of the Chinle formation in the Cameron region. Deposition of post-Chinle "C" sediments was accompanied by both silicification and coalification of woody debris in the Chinle "C".

It is postulated that uranium-bearing solutions were expelled by compaction from the volcanic debris and forced into the more pervious older sandy layers. These solutions would have moved slowly through the sandy lenses allowing for precipitation of the uranium, probably by organic substances.

Deposition of sediments probably continued until the Laramide orogeny. Crustal disturbance at the close of the Cretaceous period formed the Kaibab monocline and its associated structures, the Black Mesa Basin and the Echo Cliffs monocline. The same orogeny lifted the area to near its present altitude. With uplift came erosion which continued until the present state of denudation was reached. Quaternary volcanism raised the San Francisco Mountains and poured forth sheets of lava which blanket areas to the south and west of Cameron. From time to time, until about 1100 AD, sporadic volcanic activity occurred, accompanied by local flexing and faulting. Erosion now reveals uranium-bearing sandy lenses and mineralized trees in the midst of the clays of the lower Chinle.

ECONOMIC GEOLOGY

Mineralization

In the vicinity of the Cameron Trading Post uranium production is largely from the Chinle formation; ore is also produced from the Shinarump member.

Although uranium may be found throughout the Shinarump, in this area it is most common in the upper part of a buff-colored, thin-bedded, cross-laminated sandstone and commonly is associated with carbonaceous material. In other areas of the Plateau, ore in the Shinarump is commonly confined to the lower part, in clastic sediments filling paleostream channels incised into the Moenkopi formation.

Uranium deposits in the Chinle formation of the Cameron area may be grouped into these types:

Bedded or lens deposits - The greatest production in the area has been from deposits in which the ore occurs within an elongate lens (fig. 5) which possesses distinct lithologic characteristics. These productive lenses appear to represent scour fillings, and are within the lower sixty feet of the "C" member of the Chinle formation. They are underlain by mudstone, similar in texture and hardness to the country rock, but altered from the usual drab grey color to a light buff or yellowish grey. This altered mudstone varies from a few inches to several feet in thickness.

The ore-bearing lens is composed of muddy sandstone or sandy mudstone and sandy-mudstone-flake layers which contain varying amounts of carbon in the form of fine flakes and trash. These carbon-bearing layers attain a thickness of several feet and may be steeply cross-bedded, but more often intersect each other at low angles or are parallel. The sand grains within these layers are well rounded, but are poorly sorted. The mudstones contain the montmorillonite and kaolinite type clays.

Within the lens, color ranges from black through yellow, the darker colors reflecting the amount of carbon present. From a distance the lens has a light brown appearance. Limonite, jarosite and gypsum are abundant throughout; calcite is noticeably absent.

Ore may be found throughout this lens, but is most abundant in the lower parts, particularly in the more sandy and carbonaceous layers.

Mineralized fossil trees - A poorly silicified, uranium-bearing fossil log often forms a cap to a mound of clay. A halo, sometimes several feet in diameter, of altered (oxidized) country rock marked by a yellow limonite color, commonly surrounds the tree. Distributed through the halo is an abundance of limonite, jarosite, and gypsum. Such mineralized logs, invariably the central point of an area of alteration, are scattered throughout the "C" member of the Chinle formation and very often occur in clusters. Most radiometric anomalies discovered by airborne reconnaissance proved on ground examination to be of this type, but total production from them has been less than 40 tons.

Mineralogy

Uraninite, meta-autunite, carnotite, zippeite, uranophane, and metatorbernite have been identified as the ore minerals in the Cameron deposits. Gangue minerals commonly associated with them are: quartz, kaolin (from feldspar), gypsum, calcite, limonite, jarosite, and montmorillonite clays.

Ore Deposits

Ore has been produced from 18 deposits in the Cameron area.

The Huskon No. 1 mine is one mile east of Cameron, Arizona, on the north bank of the Little Colorado River (fig. 4). Stratigraphically, the deposit is about 60 feet above the base of the "C" member of the Chinle. In this locality beds dip northeast at 1-1/2 degrees. The lithology, predominantly mudstones of various colors composed mainly of montmorillonite clays, is typical of the part of the Chinle formation that overlies the Shinarump member. The ore occurs within an elongate lens of sandy material, described above, which attains a thickness of about 40 feet.

Numerous fractures cut the ore-bearing lens, but appear to have no effect on either location or amount of mineralization. Small gypsum-filled faults offset mineralized horizons as depicted by the isorad map (fig. 6). A plot of fractures, mapped in detail, shows that the predominant set trends northeast, parallel to the long axis of the lens, and dips both southeast and northwest. A secondary set trends southeast and dips to the southwest.

A radioactivity (i.e., isorad) overlay map showed that the abundance of fractures, an index to the openness of ground, has no relationship to the surface intensity of radioactivity.

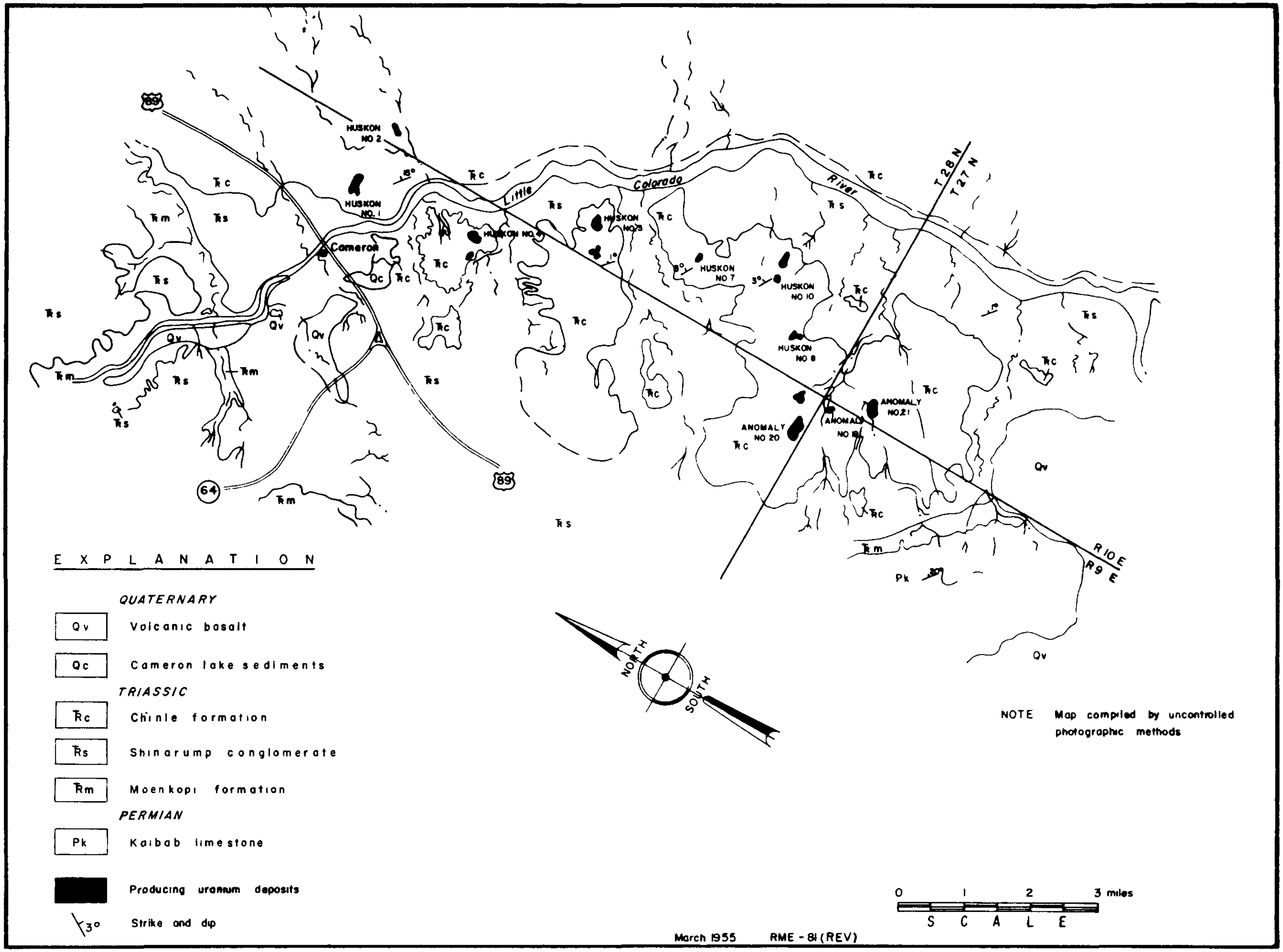

Figure 4. Geology of area near Cameron, Coconino County, Arizona

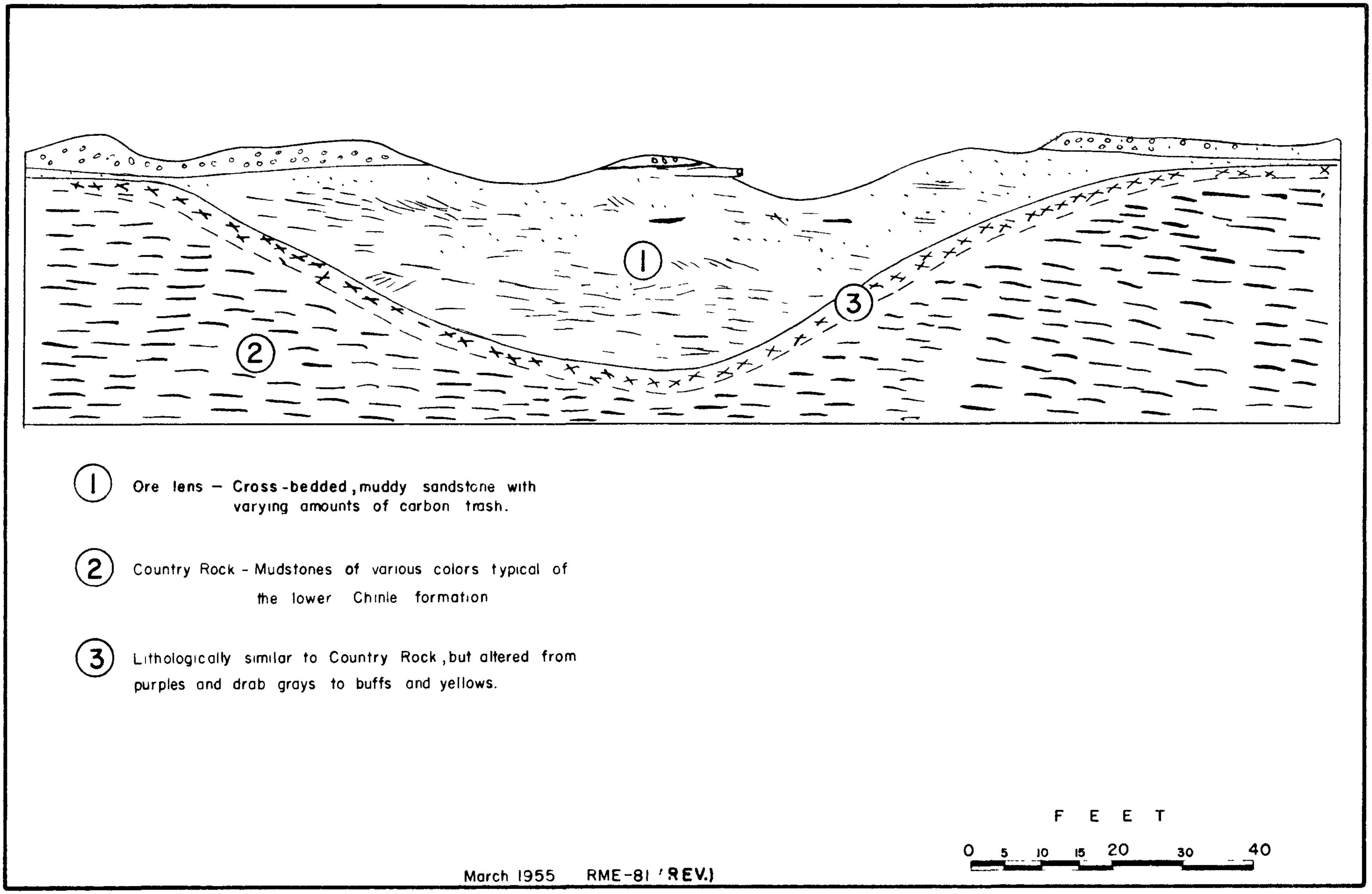

Figure 5. Generalized cross section of typical ore-bearing lens in Chinle formation Cameron area, Coconino County, Arizona

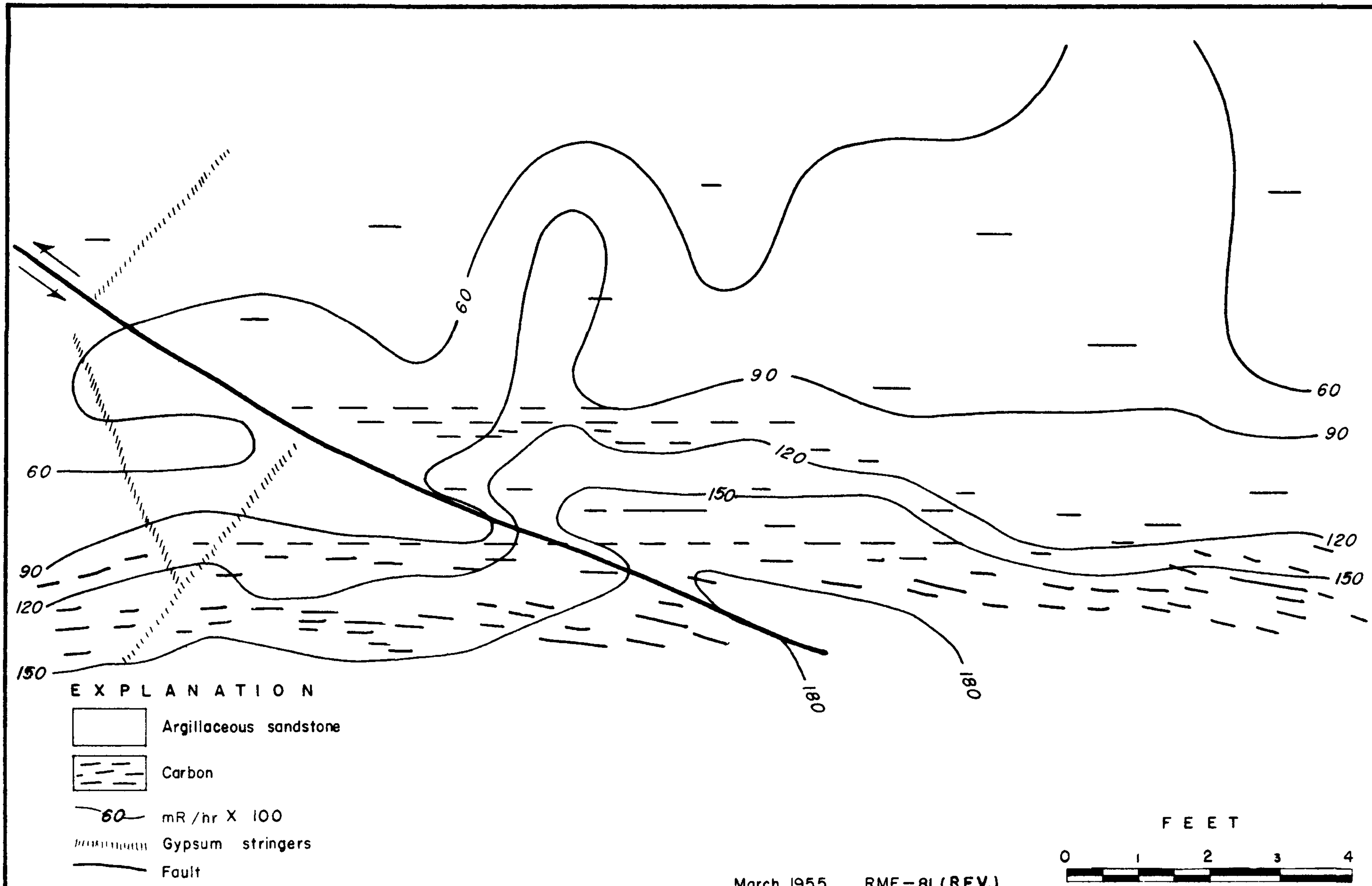

Figure 6. Isorad map of mine face showing reverse fault displacing ore layer Huskon no.1 mine, Cameron, Coconino County, Arizona

No regularity in the grade distribution of sand within the lens is apparent; however, some layers appeared to have slightly better sorting than others. Uranium ores appear to favor the coarser layers as indicated by the following table:

Table 1 - Association of ore with coarser clastics

Size	Ore Aggregate (percent)	Barren Aggregate (percent)
Greater than 1 mm.	21	8
Between .044 and 1 mm.	48	33
Less than .044 mm.	31	59
	100	100

Ore Controls

There are several features associated with the occurrence of ore in the Chinle formation of the Cameron area which, if they are not controls of ore, have a consistency which allows them to serve as a guide to it. These are:

1. Stratigraphic position: Most ore bodies of consequence have been found in the lower 60 feet of the "C" member of the Chinle formation, although mineralized trees may be found throughout this member.

2. Sandy lenses: Sandy lenses in the favorable stratigraphic interval generally possess anomalous radioactivity.

3. Grain size: Within ore-producing lenses, uranium is more abundant in the medium-grained sandstones than in the fine-grained sandstone and mudstone lentils.

4. Carbonaceous material: Anomalous radioactivity is almost always found where carbonaceous debris is encountered in the favorable stratigraphic position.

5. Color: Light yellow, buff, and rust color, due to jarosite, limonite, and other oxidation products, are always associated with ore. These hues are particularly noticeable from the air, from which vantage point they contrast with the duller colors of the lower Chinle.

6. Molybdenum: Molybdenum is more abundant in and around ore-bearing lenses than in barren lenses, although present only in trace quantities in both.

EXPLORATION TECHNIQUES

Formation contacts, mines, and fractures were marked on aerial photographs of the uranium-producing area near Cameron, Arizona, and transferred to a photo assemblage (fig. 4). Geologic structures were later plotted on the mosaic as they were observed in the field.

Surface radiation maps were prepared for several anomalous localities, two of which, subsequent to mapping, have become ore producing. Uranium mineralization in both cases is close to the surface.

Rim Stripping

Portions of fifteen uranium outcrops were stripped by a bulldozer between December 19, 1953, and February 3, 1954. The objectives of this work were: (1) to locate the boundaries of ore deposits, and (2) to search for information regarding the occurrence of uranium.

A feasible method of testing a deposit was, on flat terrain, to dig trenches radially outward from the center of mineralization or to cut trenches down the slopes of the low hills on which there were radioactive outcrops. By this means a small portion of talus and overburden was removed; the bounds of mineralization and the margins of the favorable host rock were exposed in fresh outcrop.

A total of about 45,000 lineal feet of trenching by a D-7 caterpillar bulldozer uncovered approximately 1,500 tons of ore of shipping grade, much of which was found beyond the expected limits of the deposits.

Geochemical Studies

In the vicinity of Cameron there are, in the "C" member of the Chinle, barren sandy lenses which have the same megascopic features as the productive lenses. Geochemical studies were undertaken to determine whether other significant differences could be detected between barren and mineralized lenses.

A semi-quantitative spectrographic analysis was made for 35 elements in 25 samples collected from two deposits. Table 2 shows the relative trends among the elements for which tests were run.

Table 2 - Elements associated with mineralized lenses

Element becomes more abundant toward mineralization		Element becomes more abundant outward from mineralization
	Si	
	Al	- - -
	Fe	
	Ti	- - -
- - -	Mn	
	P	
- - - - - - - - - -	Ca	
	Sc	
	Sn	
	Sr	
	U	
	V	
- - -	Y	
- - -	Yb	
-	Ge	
	La	
- - - - -	Mo	
	Nb	
	Nd	
- - - - -	Ni	
- - - - - - - - - -	Pb	
	Mg	-
	Na	
	K	
	Ag	
	As	
	B	
	Ba	
	Be	
- - - - -	Cd	
- - -	Ce	
- - - - - - - - - -	Co	
	Cr	
	Cu	
	Ga	

Of these 35 elements, manganese, molybdenum, lead, copper, and vanadium are most likely to be related to the occurence of uranium or to an ore environment. These were subsequently analyzed by quantitative chemical methods. Tests were run on 26 samples representing four general environments: (a) the interior of a sandy, altered (oxidized) mudstone lens; (b) the halo of altered country rock around the core; (c) unaltered country rock adjacent to the halo and (d) country rock not associated with alteration. Suites of samples were taken from both ore-producing localities and altered areas which do not contain ore. This study indicated that the distribution of molybdenum is the best index of an environment favorable to the occurrence of uranium (Table 3).

Table 3 - Average molybdenum content

	Parts per million
Barren lens material	1.0
Productive lens material (non-ore samples)	9.4
Productive lens material (ore samples).	45.0

Although the difference in content between productive lenses and non-productive lenses is not great, the consistent low values from the non-productive lenses (mean deviation 0.09) indicate the molybdenum ratio may be valuable in geochemical prospecting, and warrants further attention.

In comparison with other localities of production from the Chinle on the Colorado Plateau, the Cameron area contains an unusually small amount of vanadium or vanadium-bearing minerals.

A study was undertaken to determine whether a significant difference exists in the quantity of vanadium within the three zones of a deposit and also between the productive lenses and the non-productive lenses. The field testing techniques outlined by Ward and Marranzino (1) were applied to 102 samples taken from the four environments, described above, in both barren and productive lenses.

Three generalizations can be drawn from this work:

1. In 92 percent of the samples, vanadium present in any environment was less than 0.03 percent.

2. Outward from the center of the lens into the barren surrounding country rock, less vanadium is found than in productive lenses. However, the difference noted in vanadium content is too small to be useful as a definite guide to uranium ore.

Vanadium-uranium ratios appear to have no systematic arrangement in the Cameron area. In ores from the producing mines the $V_2O_5:U_3O_8$ = 0.09:0.63. This variation, a factor of 7, is abnormally high compared with the Colorado Plateau average. According to Riley and Shoemaker, "V_2O_5/U_3O_8 ratio within a small district generally varies by not more than a factor of 3." (3)

It was observed that there is considerable variation in vanadium-uranium ratios between non-ore samples taken from productive lenses and non-ore samples taken from non-productive lenses. The ratio was 2.2 from the productive lens against 11.8 for the non-productive lens. The average vanadium content varied but slightly, however, with 0.04 percent from the productive lens and 0.03 percent from the non-productive lens. The variation in the ratios was, therefore, caused primarily by changes in the uranium content.

Airborne Reconnaissance

Aerial reconnaissance greatly expedited the location and study of the numerous anomalies in the Cameron area.

Following location of the anomaly from the air and determination, by the same method, of a suitable ground route, the locality was examined in detail.

Surface Isorad Mapping

The changes in radioactivity at the site of Anomaly No. 27, (fig. 4) on a butte capped by Shinarump, were plotted and contoured and a "favorable" area delineated before exploration was begun. Subsequently, the site produced 50 tons of ore from shallow depth, all from within the "favorable" area shown by the isorad map.

Anomaly No. 19 (fig. 4) is on the flat terrain underlain by the lower part of the "C" member of the Chinle where, with the aid of a surface isorad map showing "favorable" areas, a stripping plan was prepared. Stripping revealed considerable ore of shipping grade within the areas delineated as "favorable."

From this experience it was concluded that, in the Cameron area, near-surface deposits can be outlined accurately by surface isorad work before physical exploration begins.

CONCLUSIONS

In the Cameron area the greatest uranium production comes from the Chinle formation in the lower parts of the "C" member; the Shinarump member affords only minor production. Orebodies in the Chinle are moderate in size, discontinuous, and show no obvious structural control. The following features are the best indicators of favorable ground:

1. Stratigraphic position: No orebodies of consequence have been found higher than 60 feet above the base of the "C" member of the Chinle formation.

2. Sandy lenses: Within this stratigraphic interval sandy lenses were generally found to possess anomalous radioactivity.

3. Carbonaceous material in any form.

4. Color: the light yellow, buff, and moderate rust color.

5. Geochemical traces of molybdenum: preliminary tests suggest that this element is more abundant in the ore-bearing lenses than in barren lenses.

Thick alluvium locally covers the outcrop of the lower 60 feet of the "C" member of the Chinle formation. If this belt were flown at low altitude, deposits concealed under alluvium might be detected with airborne scintillation equipment.

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