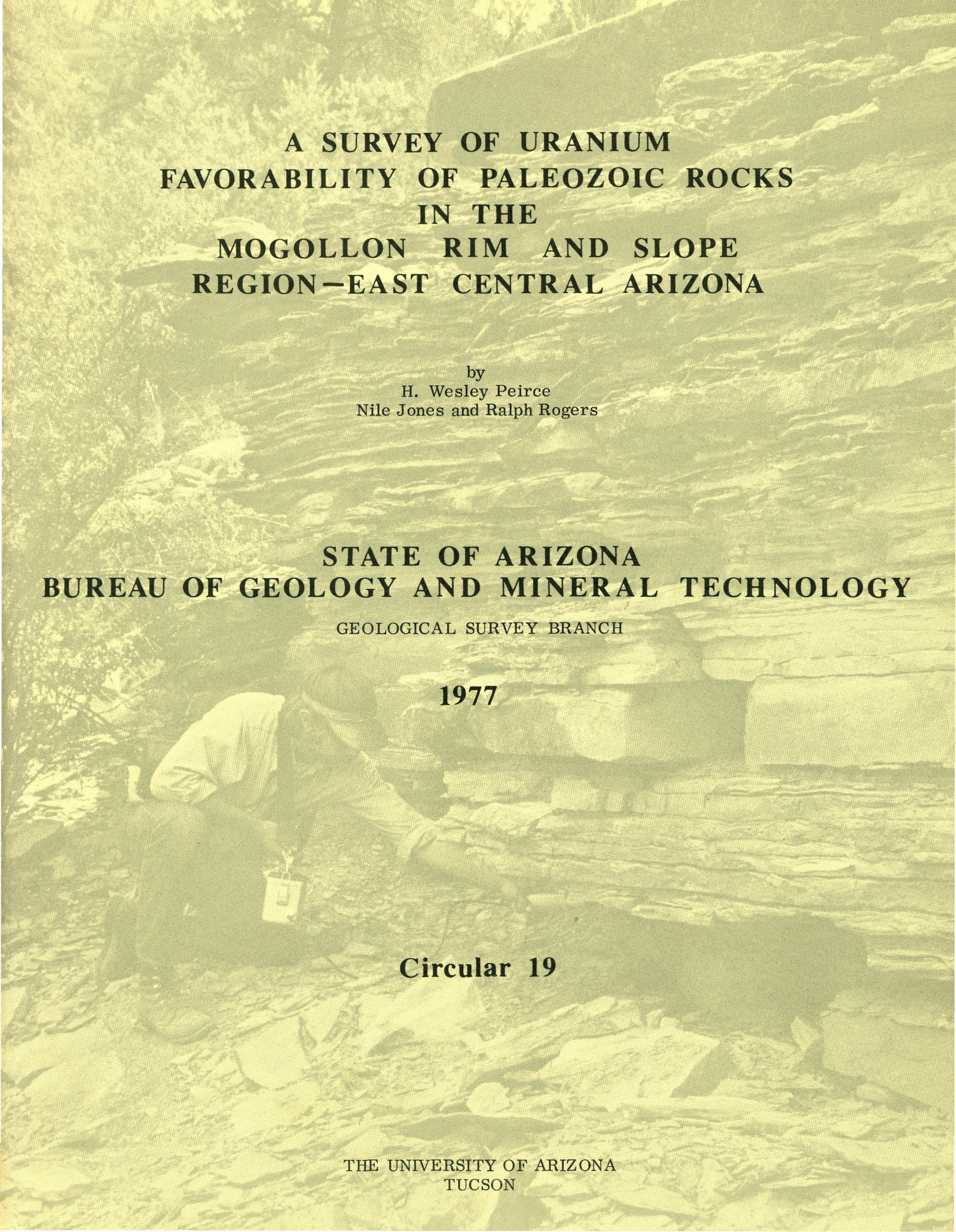

A SURVEY OF URANIUM FAVORABILITY OF PALEOZOIC ROCKS IN THE MOGOLLON RIM AND SLOPE REGION—EAST CENTRAL ARIZONA

by
H. Wesley Peirce
Nile Jones and Ralph Rogers

STATE OF ARIZONA
BUREAU OF GEOLOGY AND MINERAL TECHNOLOGY

GEOLOGICAL SURVEY BRANCH

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Circular 19

THE UNIVERSITY OF ARIZONA
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FOREWORD

This report by Dr. H. Wesley Peirce, Nile Jones, and Ralph Rogers, summarizes the results of a study made for the U. S. Geological Survey by the Arizona Bureau of Mines, University of Arizona under Grant No. 14-08-0001-G-147.

The purpose of the investigation was to fill an information gap relating to the regional geologic implications of certain uranium occurrences in Arizona Paleozoic rocks.

It is considered that the final report, herein presented as Circular 19 of the Bureau of Geology and Mineral Technology, adequately fulfills the agreement objectives.

Richard T. Moore, Principal Geologist
Geological Survey Branch
Bureau of Geology and Mineral Technology
University of Arizona, Tucson
June 1, 1977

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS

ABSTRACT

Paleozoic strata of Pennsylvanian and/or Permian age contain laterally persistent zones that are favorable hosts for the occurrence of uranium, both in outcrop and in the subsurface.

A survey of over 80 miles of Paleozoic outcrop along the escarpment at the southern edge of the Colorado Plateau, and of 30 subsurface control points over about 10,000 square miles of plateau surface, reveals that anomalous uranium in outcrop and anomalous radioactivity in the subsurface is widespread.

Outcrop study indicates that portions of certain stratigraphic units were fluvially deposited and contain channel-fill conglomerates and associated sandstones, siltstones, and mudstones. Fossil vegetable matter, in the form of either imprints, carbonaceous films or coalified material, though in variable amounts, also is widespread. Examination of well cuttings establishes the extension of carbonaceous materials into the subsurface and helps to explain radiometric peaks within stratigraphic units believed correlative with surface exposures.

Although no commercial mining has taken place, exploration efforts have been expended in the past and recently have been renewed. The largest prospect, one that has received thousands of feet of exploration drilling, is beneath Promontory Butte near Christopher Creek in Gila County. This occurrence is of the peneconcordant tabular variety with a reduced zone mineralogy developed in various lithologies associated with what is believed to have been a point-bar fluvial depositional environment. Limestone pebble conglomerate and associated finer-grained clastics contain coalified plant debris. The uranium is believed to be present in coalified material as uraninite. Associated sulfides in small entities include chalcopyrite, bornite, chalcocite, covellite, galena, sphalerite, pyrite, and marcasite. Mineralization is believed to be related to diagenetic processes and associated ground waters, and to be Paleozoic in age. Lithification, combined with lack of severe post-mineral fracturing, has served to protect the occurrence from subsequent destruction by near-surface oxidizing environments. Associated flora and fauna are fresh water forms that are either latest Pennsylvanian or earliest Permian in age.

Regionally, anomalous uranium and anomalous radioactivity (subsurface) is within strata assigned to either the Naco Formation or the base of the Supai Formation. To the east, conglomerates are within a sequence that contains thin marine units while to the west the conglomerates are associated with rocks having an increasingly less obvious marine aspect. Even so, the conglomerates are thought to be laterally related and of significance in regional correlations. Past workers have drawn stratigraphic boundaries that, westward, pass downward through the zone of conglomerates.

Because of the absence of a workable regional nomenclatural system, it was thought necessary, for the purposes of this study, to devise an informal functional system. The letter "C" is used in place of the Naco Formation and the Packard Ranch Member of the Supai Formation to the west; "B" is the unit to the west known by some as the Oak Creek Member of the Supai Formation, or, by others, as unit B of the Supai Formation in Oak Creek Canyon. To the east the marine limestones entering the conglomerate interval create a subdivision here referred to as unit B-2. Elsewhere, it is the Gamma Member of the Naco Formation, the Lower Member of the Supai Formation, etc. Unit B-1 overlies the highest fossiliferous limestone and extends upward to a lighter colored sequence of siltstones and sandstones, here called "A". "A" overlies "B" to the west, B-2 having pinched out or otherwise disappeared laterally. The principal conglomerates are contained in unit "B" to the west and unit B-2 to the east.

In outcrop, B-1 contains a thin horizon of plant fossils that locally contains anomalous uranium in the Cibecue area. Analogous horizons might extend into the subsurface and account for radiometric peaking there in B-1.

Together, units "C", B-2, and B-1, or, "C" and "B" to the west, constitute a maximum stratigraphic interval of about 1,400 feet in outcrop near Carrizo Creek in the central portion of the region. To the west this interval thins to about 650 feet at Oak Creek Canyon and, to the north and east, it pinches out against largely granitic rocks of the Defiance Positive Area. The northwestward thinning is attributed to activity on the Kaibab Positive Area.

These positive regions surround the shoaling northern end of the Pedregosa Basin, which extends into the southern edge of the plateau from far to the south. Plants and fluvial phenomena were associated with these features. Drainage was from the west, north, and east.

The geologic history along the Defiance front is an important subsurface problem that remains poorly understood. Overall uranium favorability could be enhanced in this region providing that environments prevailed that allowed a bordering clastic build-up to develop. This trend also appears to have a significant oil and gas potential which should provide additional incentive to investigate the region more closely.

The existing known parameters surrounding anomalous uranium occurrences do not suggest the likely existence of large targets. However, the geologic favorability for smaller targets seems high, especially in shallow drilling areas such as the extensive benchlands of the Ft. Apache Indian Reservation where favorable rocks potentially underlie, within 300 feet of the surface, hundreds of square miles.

Any deep drilling that is done from the plateau surface should provide an opportunity to gather information regarding the occurrence of uranium in Paleozoic strata, especially in units B-2 and the upper half of "C".

INTRODUCTION

General Statement

This report summarizes the highlights of a general uranium favorability study of Paleozoic rocks of the Mogollon Rim and Slope region of east-central Arizona. The project began on October 1, 1974 and ended on December 16, 1975. The study was carried out under the Office of Energy Resources. United States Geological Survey, Bldg. 25, DFC, Denver, Colorado 80225.

The English system of measurement is used throughout this report.

Purpose and Scope

The purpose of this project was to assemble and evaluate both surface and subsurface geologic data needed to support a preliminary assessment of the geologic favorability of Paleozoic rocks as possible hosts for uranium mineralization in the subsurface of the Mogollon Slope region. Favorability was narrowed and emphasis placed on a reconnaissance field study of particular portions of a "zone of interest" that occurs within Paleozoic rocks of Pennsylvanian-Permian age. Subsequently, some of the field data were utilized in attempting to effect correlations into the subsurface of the Mogollon Slope. These correlations support the construction of a preliminary regional stratigraphic model essential to clarification of a sedimentary framework that is believed to closely control actual and potential occurrences of uraniferous minerals.

It should be emphasized that the ratio between the number of subsurface well control points (30) and area considered (10,000 square miles) is so small as to necessarily limit the scope of this report to that of a preliminary survey.

Acknowledgments

We wish to express our deep appreciation to Mr. Ronnie Lupe, Chairman of the White Mountain Apache Tribe, for his complete cooperation in regard to studies conducted on lands of the Ft. Apache Indian Reservation. Too, we thank Warren I. Finch and John C. Campbell of the United States Geological Survey for valuable time shared in the field. Drs. Dietmar Schumacher, Joseph Schreiber, and Spencer Titley of the University of Arizona Department of Geosciences generously discussed many problems with us.

Location and Physiographic Setting

The area of principal interest, herein described as the Mogollon Slope region, covers in excess of 10,000 square miles along the southeastern edge of the Colorado Plateau geologic province in east-central Arizona (Figure 1). The edge of the physiographic Plateau is a variously dissected scarp generally known as the Mogollon Rim (Figs. 19, 26, 43). Because of a slight northeast structural dip (Figure 2) of the otherwise relatively undeformed rocks of the Mogollon Slope region, the Mogollon Rim is both structurally and topographically high, which makes the Rim a regional drainage divide. Waters to the north of the Rim eventually traverse the Grand Canyon of the Colorado River and waters to the south flow through the Gila system to enter the Colorado River near Yuma in extreme southwestern Arizona. Elevations at the Rim approximate 7,500 feet and northward the Mogollon structural-topographic slope descends to 5,000 feet at Holbrook.

The report embraces the southern parts of Coconino, Navajo, and Apache counties and the northern part of Gila county. The western limit is Oak Creek Canyon near Flagstaff and the eastern limit is the New Mexico-Arizona border. The outcrop of Paleozoic rocks along the Rim is partly on lands in the Tonto National Forest and partly on the Ft. Apache Indian Reservation. Much of the Mogollon Slope surface consists of State and Federal lands.

Almost the entire stratigraphic section of Paleozoic sedimentary rocks is exposed along the forested Mogollon Rim and preserved beneath the Mogollon Slope. This is to say that wells drilled to the Precambrian basement from the surface of the Mogollon Slope penetrate a full section of Paleozoic rocks (Figure 2).

Approach

The initial interest in this project stemmed from poorly understood outcrop occurrences of locally radioactive Paleozoic strata exposed along the Mogollon escarpment and the consideration that significant anomalous radioactivity might extend into the subsurface beneath the Plateau. Previous geologic investigations had been both general and provincial and, though invaluable, were insufficient to provide the base data needed to assess the region-wide significance of these and other occurrences of radioactive substances. Too, there was a deficiency of subsurface studies designed to integrate the surface and subsurface stratigraphy into a regional whole. To the best of our knowledge there are no published data that discuss uranium occurrence and/or potential in Paleozoic rocks of this region--it is "frontier" territory.

Field effort was expended over the summer season of 1975 (May through September) and was designed

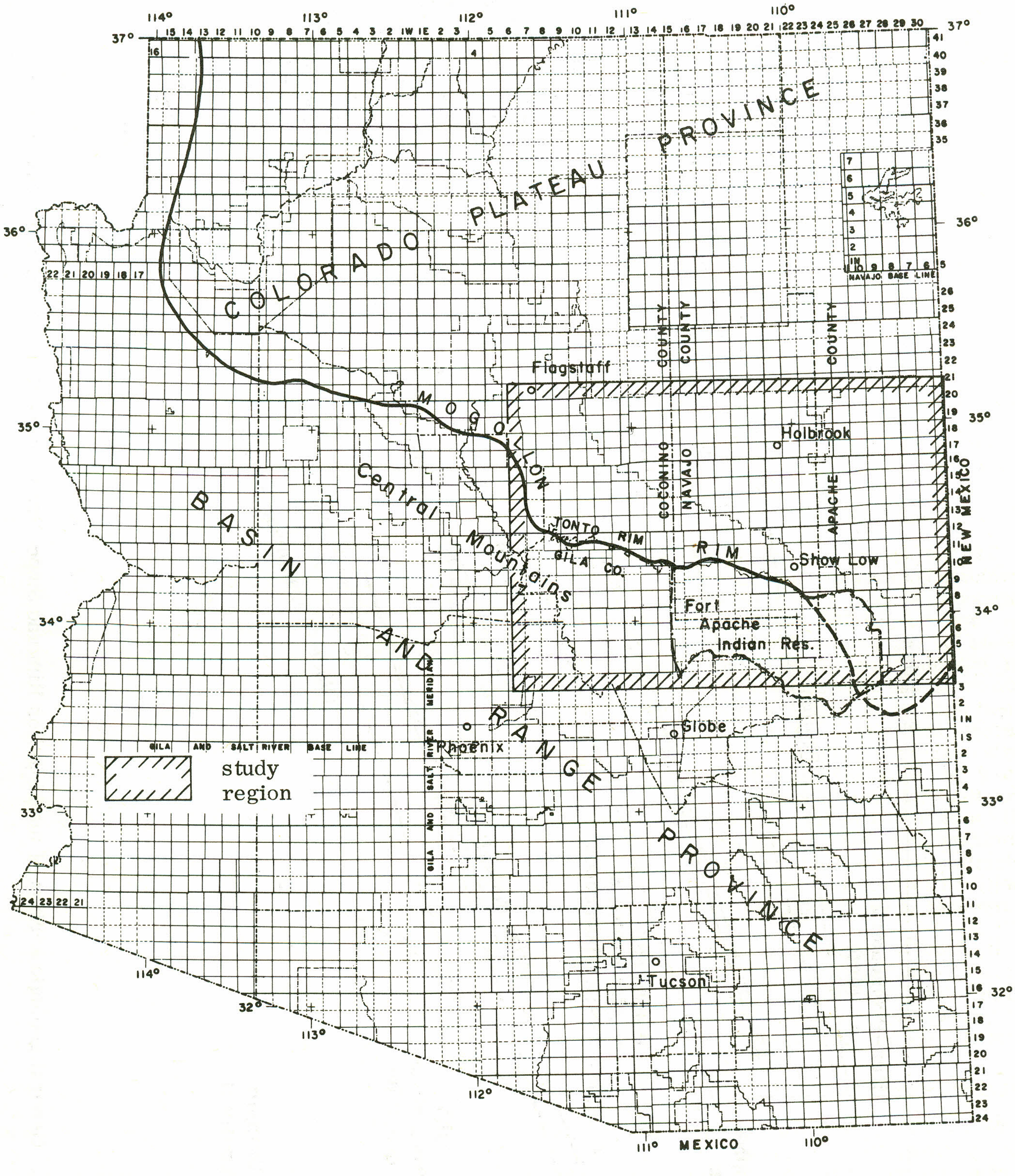

Figure 1. Index map of Arizona showing physiographic subdivisions and study region.

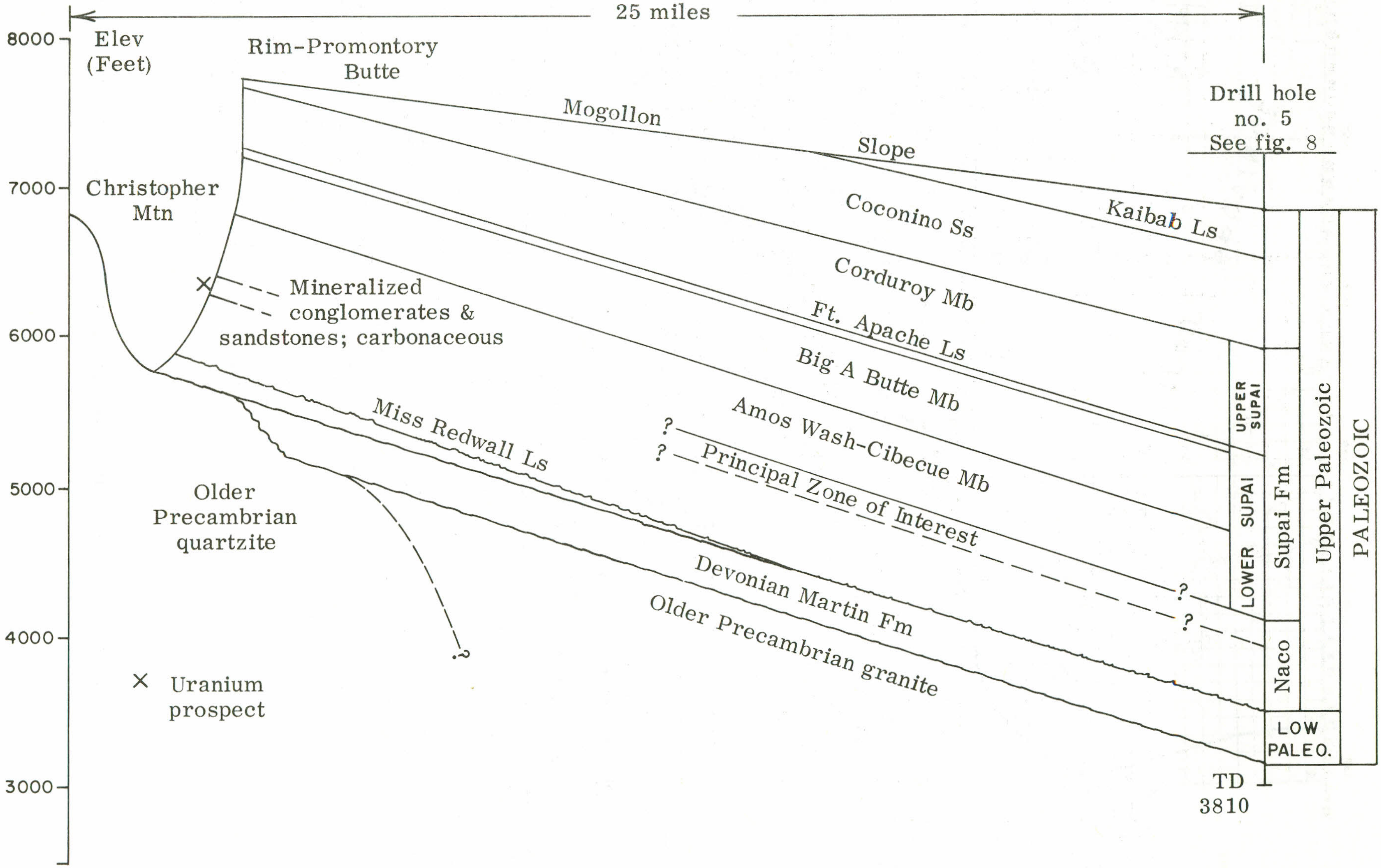

Figure 2. General geologic section of the Mogollon Rim and Slope-Promontory Butte uranium prospect area

to fill in some of the fundamental gaps that existed in basic geologic understanding: (1) stratigraphic positions of anomalous radioactivity, (2) lateral relationships of separate and widely spread occurrences, and (3) local geologic and mineralogic relationships. Office and Laboratory research included: (1) literature survey, (2) subsurface studies, (3) preliminary microscopic study of thin sections and polished surfaces, (4) integrating surface and subsurface data, and (5) evaluation of information as it pertains to a preliminary assessment of uranium favorability. Selected samples were submitted for quantitative determinations of certain constituents including uranium, vanadium, and copper.

The highlights of the results of these various efforts are summarized in this report.

GEOLOGIC FRAMEWORK

General Statement

The study region is the southern margin of the Colorado Plateau geologic province in east-central Arizona. The southern boundary of the topographic Plateau is well defined in certain places, as along the Tonto Rim segment (Figure 1) of the more general Mogollon Rim, and not so well defined where there is an extensive volcanic terrain such as the White Mountain volcanic field to the southeast (Figure 3). The Paleozoic rocks are preserved in the Plateau subsurface and are exposed along the escarpment at the Plateau edge. Holes drilled on the Plateau surface in search of petroleum products frequently penetrate the entire Paleozoic section and thus complement surface exposures.

The Paleozoic rocks consist entirely of sedimentary rocks that range in approximate thickness between 2,000 and 4,000 feet. It is convenient to subdivide the Paleozoic rocks into lower (Cambrian-Mississippian) and upper (Pennsylvanian-Permian) Paleozoic sequences. The lower Paleozoic sequence ranges in thickness between zero and 500 feet whereas the upper Paleozoic sequence ranges between about 1,500 and just over 4,000 feet (Figures 4 and 5). Figure 6 depicts some of the general regional stratigraphic, structural, and nomenclatural relationships and depicts the position of the "zone of interest".

Because we are not aware of any significant occurrences of anomalous radioactivity associated with lower Paleozoic strata, they are excluded from detailed dicsussion. However, certain general thickness patterns and lithologic characteristics are of tectonic significance and will be reviewed when appropriate.

In the remainder of this report all comments apply to the study area unless otherwise noted.

The contrasts between the geologic histories of the lower and upper portions of the Paleozoic Era can be presented in numerous ways, all of which add up to contrasts in tectonic aspects. The lower Paleozoic, as used here, spans a time interval of about 250 million years for which there is a maximum known preserved rock record of only 700 feet, the ratio between thickness and time span being 2.8. However, the upper Paleozoic, representing a time span of only 95 million years and a preserved maximum rock record of 4,000 feet, has a ratio of 42. This is to emphasize that almost all of the preserved Paleozoic strata were deposited during the latest 25% of Paleozoic time. It was during a portion of this latter interval that sedimentary materials favorable to the accumulation of anomalous radioactivity were deposited within the study region. Emphasis is placed on a "zone of interest" that is closely associated with Pennsylvanian and Permian strata (Figures 2, 6, and 7).

The following paragraphs summarize some of the general stratigraphic, structural, and economic highlights of the study region and surrounding country.

The Pre-Pennsylvanian

Pre-Pennsylvanian rocks of the region consist of Older Precambrian crystallines and sedimentary rocks, Younger Precambrian sedimentary and igneous rocks, probable Cambrian sandstones, and Devonian and Mississippian sedimentary rocks.

Precambrian rocks are exposed to view along the southern margin of the Colorado Plateau south of the Mogollon Rim where, in the central mountains (Figure 1), they stand structurally higher than the Mogollon Rim. Christopher Mountain, in Gila County, just south of Promontory Butte, is at the northeast end of an outcropping Older Precambrian N. 40° E. trend that marks the northwest edge of exposures of Younger Precambrian rocks that consist of relatively flat-lying Apache Group strata and overlying Troy Quartzite (Wilson et. al, 1959). This northeast trend consists of deformed Older Precambrian crystallines along with the Mazatzal Quartzite that makes up much of Christopher Mountain (Figure 20). The latter was a resistant mass that was exposed at least into Pennsylvanian and perhaps even younger time (the Promontory Butte uranium prospect is located near Christopher Mountain. Figure 2). To the northwest of this trend, basal Paleozoic rocks were deposited on Older Precambrian crystallines whereas to the southeast they were deposited on Younger Precambrian rocks (Figure 3). These relationships establish the existence of a pre-Paleozoic structurally higher area to the northwest which might in some way be related to later Paleozoic "less negative" tendencies in the same region. Too, it appears as though reactivation along this zone of Younger Precambrian stratal onlap influenced, at least locally, Pennsylvanian lithofacies development.

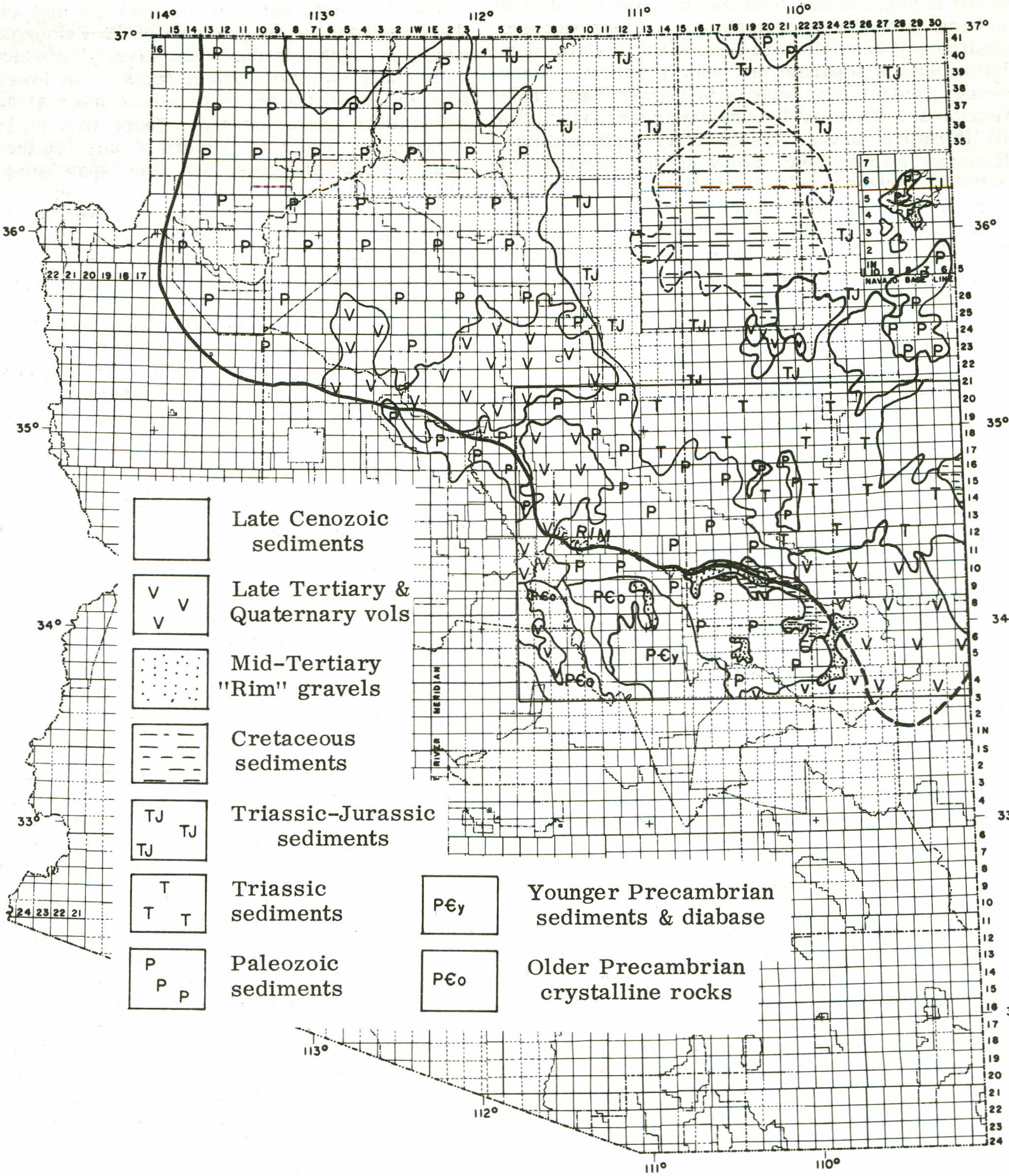

Figure 3. Generalized geologic map of the plateau and an adjacent portion of the central mountains

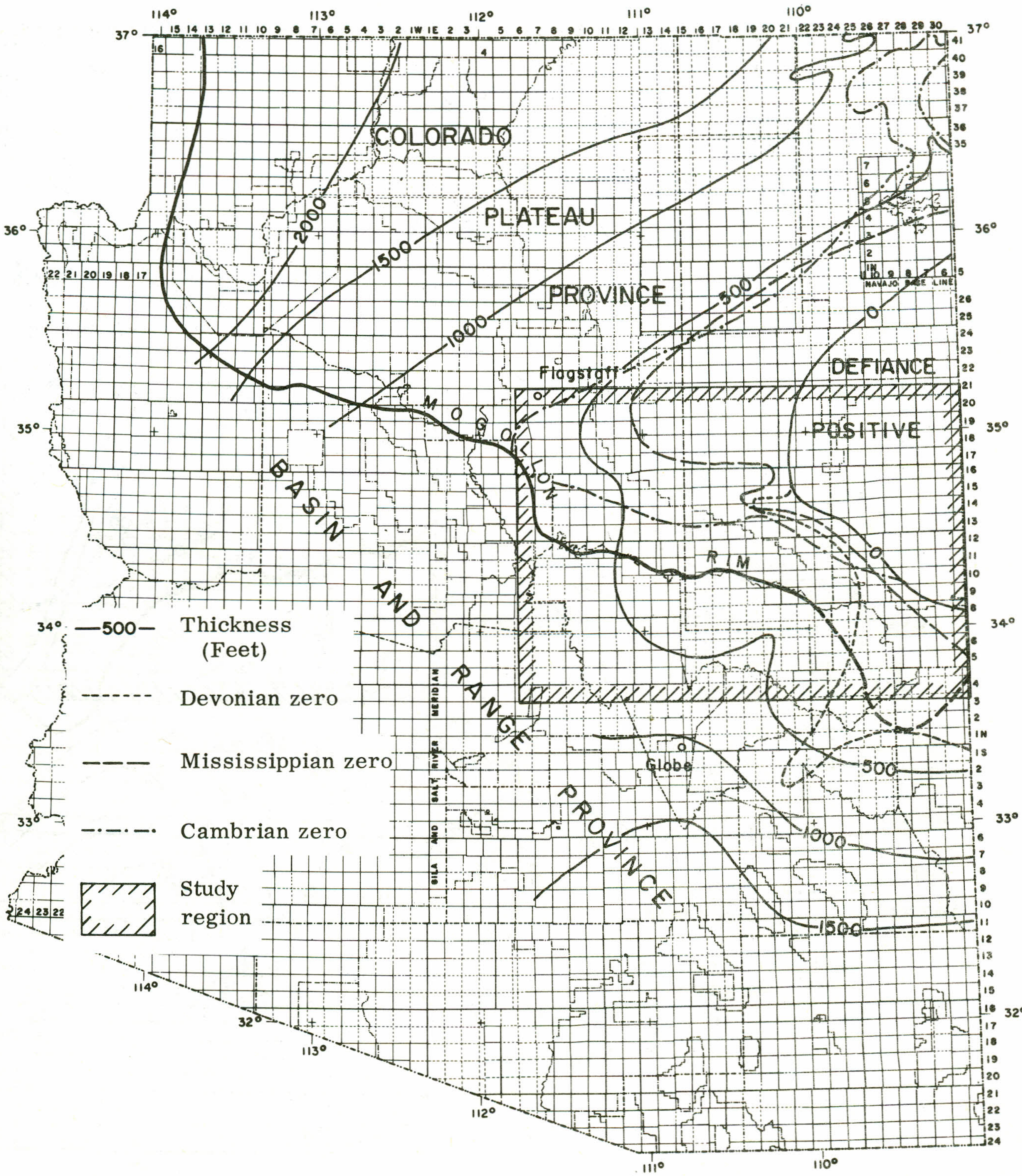

Figure 4. Isopachous map of lower Paleozoic interval (Camb-Dev-Miss) with zero lines for each system

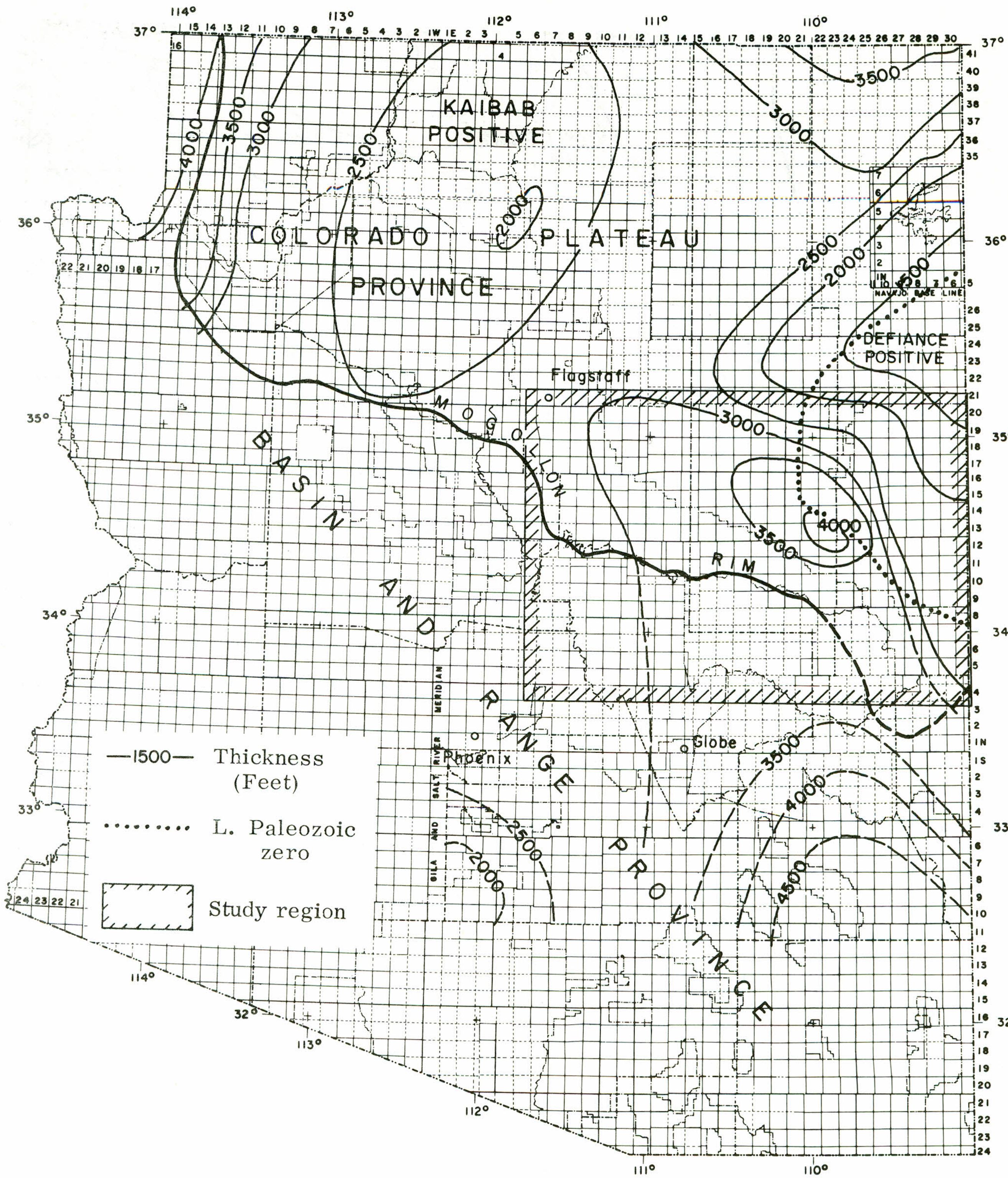

Figure 5. Isopachous map of upper Paleozoic interval (Penn-Perm) with lower Paleozoic zero line

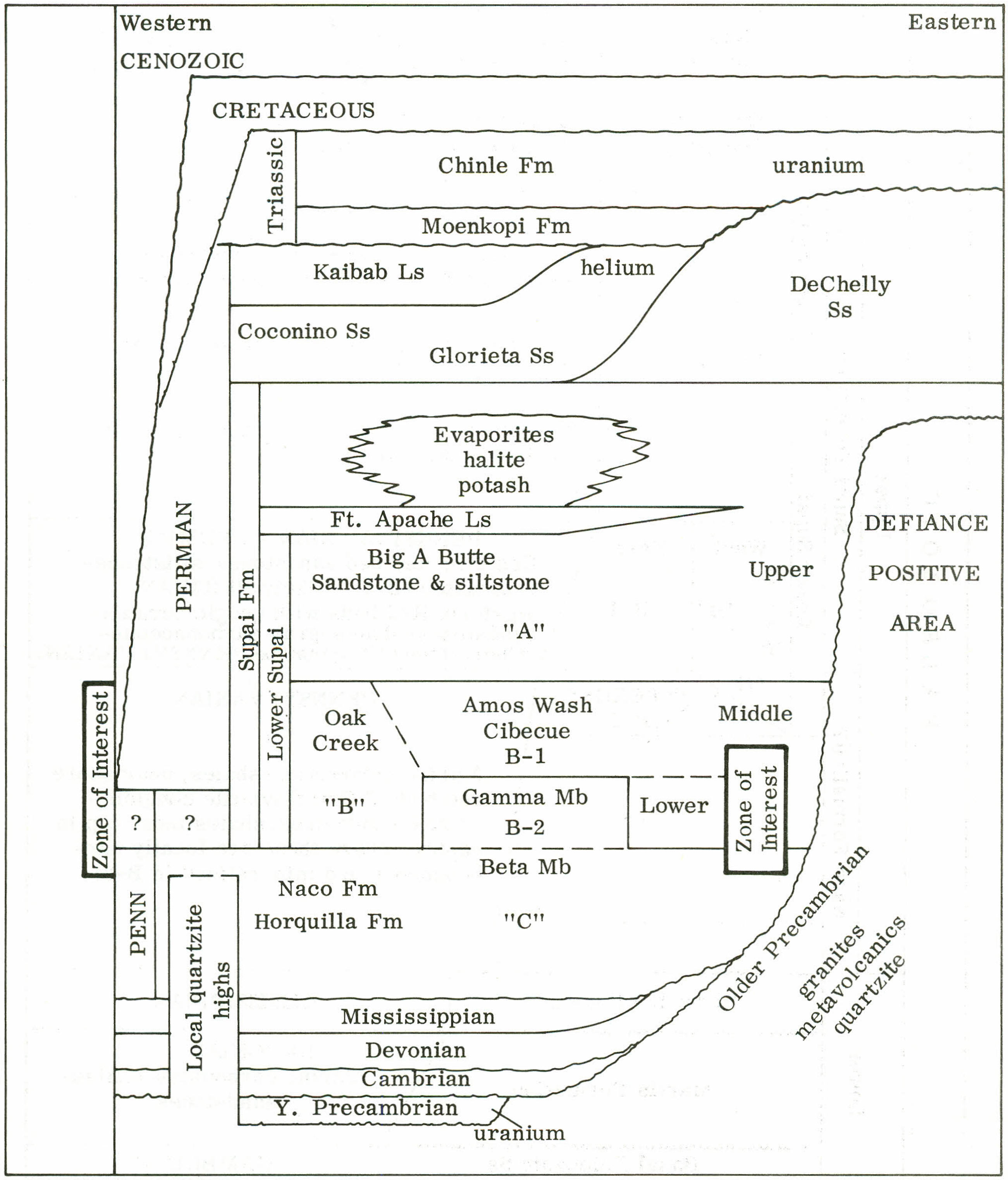

Figure 6. Diagrammatic representation of the regional general geologic setting showing some nomenclatural variations

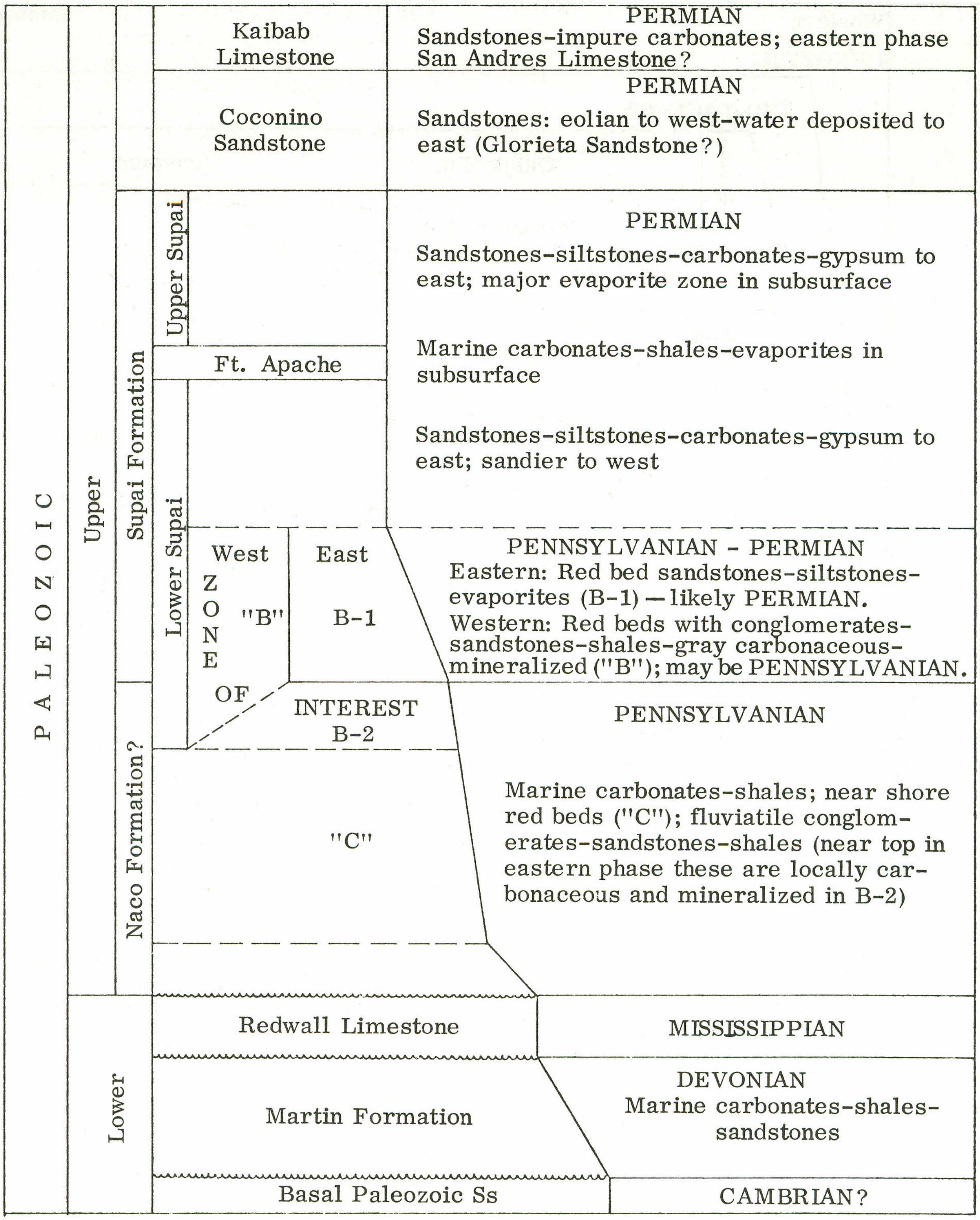

Figure 7. Highlights of Paleozoic stratigraphy.

On the Defiance Plateau, in east-central Apache County, there are two areas of exposure of probable Older Precambrian rocks beneath the Permian Supai Formation: (l) Bonito Quartzite near Ft. Defiance (Figure 21) and (2) granitic, metamorphic, and sedimentary-volcanic rocks south of Hunters Point (Figure 22-Wilson et. al, 1960; Lance, 1958, p. 69-70). The quartzite has none of the ear marks of the Younger Precambrian quartzites of central Arizona. In fact, none of the Apache Group and/or Troy Quartzite is known to occur beneath the Mogollon Slope. Apparently, the southern part of the Plateau was positive relative to Younger Precambrian rocks now exposed adjacent to and south of the Rim. The more resistant portions of this old topography remained as islands during part of the Paleozoic Era and it is probable that some of these remain buried and unknown.

There was complex structural development during Precambrian time as evidenced in faulting, folding, metamorphism, plutonism, and mineralization. Northeast directional attributes frequently are emphasized but it seems significant to recognize east-west, north-south, and northwest trends as well (Wilson, 1962, p. 10-19). It has become commonplace to take note of possible relationships between post-Precambrian structural elements and the previously established Precambrian structural habit.

There were mineralization events during Older and probably Younger Precambrian time. The famous Verde District (Jerome) near the present Plateau edge is noted for its Older Precambrian copper-gold-silver deposits long protected beneath Paleozoic strata. There are numerous base metal mines and occurrences in the central mountains believed to be of this age. Too, there are nonmetallic-metallic minerals in certain pegmatites believed also to be Older Precambrian in age.

The Apache Group in central Arizona, especially the Dripping Spring Quartzite, contains over 120 known uranium occurrences which some believe to be associated with the intrusion of Younger Precambrian diabase (Keith, 1970, p. 136). Cambrian and/or Devonian strata rest on truncated Apache Group, Troy Quartzite, and diabase south of the Rim.

Pre-Pennsylvanian Paleozoic rocks constitute a relatively thin sequence of strata consisting of thin to absent Cambrian sandstones (Tapeats Sandstone), thin to absent Devonian strata (Martin Formation), and thin to absent Mississippian carbonates (Redwall Limestone). This lower Paleozoic grouping ranges in thickness from zero to about 700 feet in the study region. These systemic pinchouts are depicted in Figure 4.

Cambrian rocks thin beneath Devonian strata to the southeast from northwest Arizona and to the north from southern Arizona. The Ordovician-Silurian-lower Devonian hiatus (Figure 6) represents a time gap in excess of 100 m.y. (million years). Whatever tectonism there was during this interval seems to have been epeirogenic in style. The overall distribution of Upper Devonian strata is considerably more varied and intricate than for the Cambrian. There is hiatus between Devonian and Mississippian rocks during which some erosion took place. The distribution of Mississippian rocks, strikingly, reverts to the Cambrian pattern. Both appear to be strongly influenced by a similar zone of tectonic activity usually attributed to the Defiance Positive Area (McKee, 1951, p. 484) which is believed to have influenced the entire Paleozoic Erathem (Figure 6). The details of this influence are a matter of continuing interest. It wasn't until later Paleozoic that tectonic instability resulted in a much thicker and more varied sequence of sedimentary rocks that includes pervasive anomalous radioactivity.

Pennsylvanian and Permian Rocks

The so-called "zone of interest" that contains the principal uraniferous anomalies occurs within a stratigraphic interval that likely includes the Pennslyvanian-Permian systemic boundary.

In the subsurface of the Mogollon Slope the combined Pennsylvanian-Permian stratal sequence attains thicknesses in excess of 4,000 feet and, in places, constitutes the total Paleozoic representation. The Permian System alone makes up about 3,000 feet and thins above Older Precambrian crystalline rocks to about 1,500 feet in outcrop on the present-day Defiance Plateau.

The principal Pennsylvanian and Permian units, from bottom to top, are the Pennsylvanian Naco Formation, the Pennsylvanian and Permian Supai Formation, the Coconino Sandstone, and the Kaibab Limestone. Because there are no known uraniferous occurrences in the Coconino and Kaibab units within the study area, they will not be discussed in detail.

Table I summarizes the nomenclatural and correlational aspects of the stratigraphic units most important to this study. The stratigraphic arrangement used in this report will be discussed in a later section.

Naco Formation

The name "Naco" customarily is extended into central Arizona from southern Arizona through discontinuous outcrop and regional considerations. Other Pennsylvanian stratal provinces such as the Four Corners and western Grand Canyon regions represent different basins and therefore have contrasting nomenclatures.

The Naco Formation is characterized by a diversity of lithologies that acumulated, in part, in

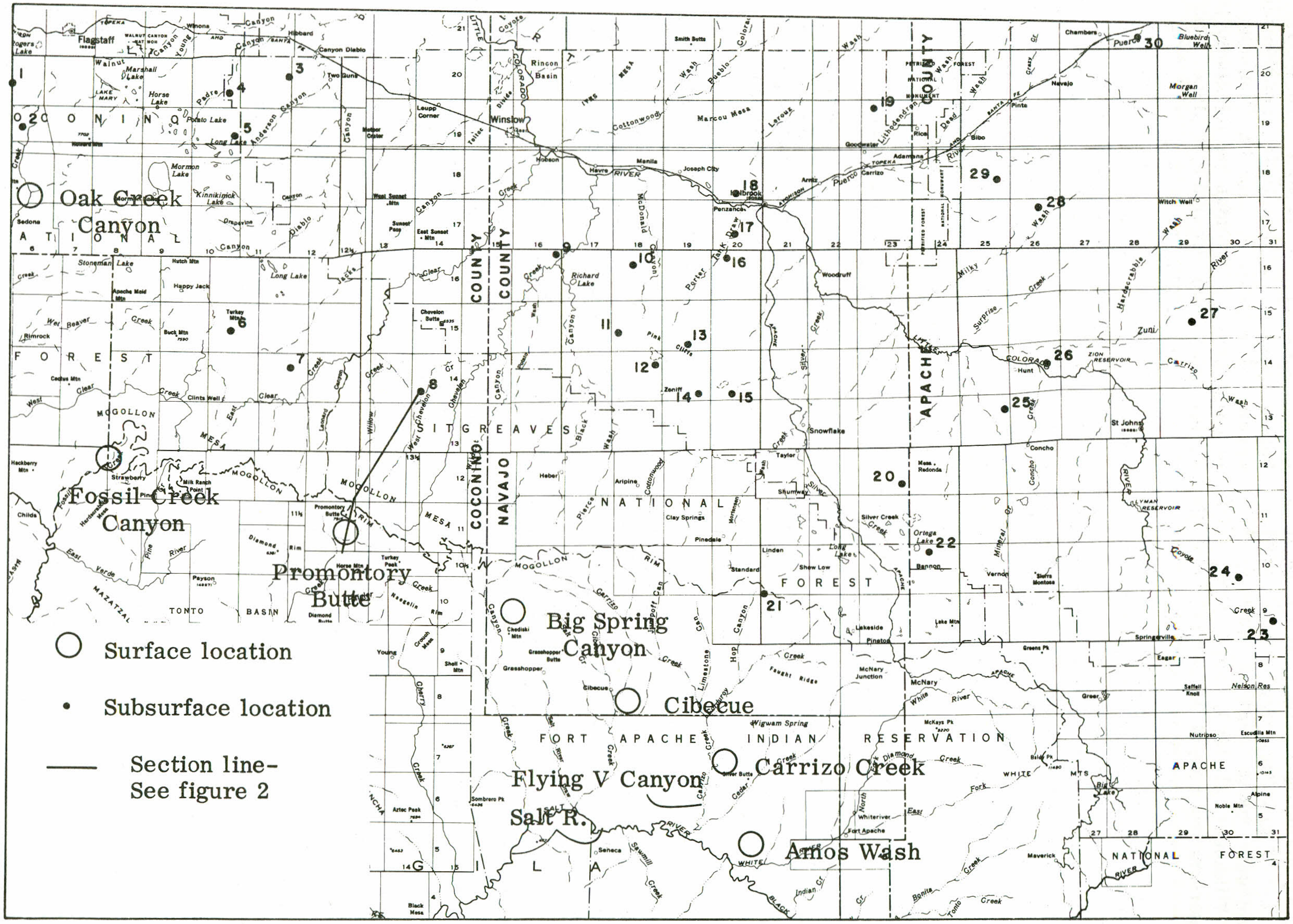

Figure 8. Index of surface and subsurface control points

marine environments as indicated directly by fossiliferous content. Various types of ledge-making, gray weathering carbonate units alternate with a variety of slope-making gray shales. Upward, the Naco Formation loses light-colored fossiliferous marine rocks as the section is taken over by a variety of relatively nonfossiliferous red beds. The change is the sort of seemingly gradational sequence that results in boundary decisions that are matters of personal choice. Some workers have assigned boundaries on the basis of the highest fossiliferous marine unit of Naco type regardless of interbedded red beds while others have tended to assign the first red bed to the Supai Formation regardless of still higher interbedded fossiliferous marine units of Naco type.

The thickness and character of the more clear-cut portions of the Naco Formation marine rocks change to the west, north, and east from the Salt River-Flying V Canyon area, which is about longitudinally centered between Oak Creek Canyon on the west and the New Mexico-Arizona border on the east (Figure 8). In these directions the typical Naco either thins or disappears altogether. Broadly speaking this defines the north end of a basin (Pedregosa) that plunged to the south and continued into both New Mexico and Mexico. Part of the northern end of the basin is preserved beneath the southern edge of the Plateau. Ross (1973), in delineating Pennsylvanian-lower Permian sedimentary facies, refers the region of interest to the Mogollon Inner Shelf and restricts the Pedregosa basin to an area of basin facies far to the south.

The manner of change of the Naco Formation is of considerable interest because it bears heavily upon paleogeographic interpretations and the geologic significance of closely associated occurrences of anomalous uranium mineralization.

Although there are boundary problems, the gross aspects of the Naco Formation seem definable. As already stated the typical fossiliferous marine strata disappear beneath the Plateau in all directions. The traditional general explanation for this has been lateral gradation into red bed environments assigned to the Supai Formation, especially to the north and west. However, to the east, both outcrop and drill data demonstrate that a thinned Supai Formation depositionally overlies Older Precambrian units that include quartzite, granitic, sedimentary, and metamorphic rocks. Thus, to the east, there is a major unconformity beneath the Permian Supai Formation. Not only is there no Naco Formation recognized in this direction but also no Pennsylvanian-aged strata (Figure 6).

Subsurface data suggest that the Naco Formation onlaps Older Precambrian crystalline rocks eastward and that it thins relatively abruptly to pinch out. This establishes the fact that these Precambrian rocks, apparently largely granitic, were exposed to weathering and erosion during much of Naco and part of Supai time. The larger paleogeographic feature is the Defiance Positive Area (McKee, 1951). Indications are that there was significant differential tectonic activity, perhaps including faulting, between the end of deposition of the Mississippian Redwall Limestone and the onset of deposition of the Naco Formation. It was in Pennsylvanian and possibly earliest Permian time that coarse grained materials derived form the Defiance Positive Area clearly are evidenced in the outcropping sedimentary record. From Carrizo Creek south to Amos Wash (Figure 8), arkosic conglomerates contain coarse grained first cycle grits of quartz and feldspar believed derived from granitic rocks (Figs, 23, 24). Apparently, temporary marine regression permitted machanical transport along a stream system with headwaters in a terrain of Older Precambrian rocks to the east and north of the sites of conglomerate deposition. Further to the west, conglomerates, though persistently present, do not contain such conspicuous evidence of the influence of a crystalline source area. This, coupled with the persistence of conglomerates westward while marine fosiliferous units notably decrease, raises questions as to the precise lateral relationships between conglomerates and associated sediments as regards time, origin, source areas, and general tectonic-paleogeographic implications. Indeed, it is of fundamental importance to determine, if possible, if there is regional tectonic significance to the conglomerates in contrast to local, so-called intraformational effects. This importance is emphasized by the fact that some of the more anomalous occurrences of uraniferous materials in the "zone of interest" are associated with conglomerates that should not casually be disposed of simply as being "intraformational" (Figs. 25, 40, 48).

In contrast to the relatively rapid and dramatic subsurface loss of the Naco Formation eastward, the causes of northward and westward gradual thinning and facies trends are more subtle and problematical. It is in these directions that the classic Naco-Supai-Pennsylvanian-Permian problems are manifested. The northward aspects largely are a subsurface problem whereas the westward aspects have been and can be partially studied in outcrop along the Mogollon Rim.

Little subsurface detail has been published. However, Lokke (1962, p. 84) has made significant observations derived by comparing the Salt River-Flying V Canyon area surface section of the Naco Formation with certain exploration holes drilled on the Mogollon Slope. He reiterates that fossiliferous surface rocks tend to change to an unfossiliferous red bed sequence northward which complicates dating and correlation of strata northward. He emphasizes this point by noting that whereas thirty-two fusulinid-bearing intervals were recognized in the surface section, only one interval was observed in the subsurface. Fortunately, this one interval afforded a time horizon that enabled Lokke to conclude that, northward:

". . . significant thinning of Pennsylvanian sediments must be recognized in addition to the previously described (by other workers) interfingering of redbed clastics with Naco subsurface equivalents."

His diagrams emphasize an onlap relationship over Mississippian strata. Another conclusion is that the older parts of the Naco (Desmoinesian) likely extend further to the west and north than to the northeast. This is important because it suggests that the style of change to the west (offlap) likely is different than that which occurs to the east (onlap). The regional tectonic element implied to exist to the northwest will be referred to as the Kaibab Positive Area.

Neither the top of the Naco Formation (base of the Supai Formation) nor its lateral extent are agreed upon, either in outcrop or in the subsurface. The maximum thickness possible in the vicinity of the study area seems to be about 1,000-1,200 feet in the eastern Ft. Apache Reservation from the Salt River-Flying V Canyon section to the Black River-White River area at the southeastern edge of the region of outcrop. Seventy miles to the northeast, in well section no. 24 (Figure 8), the Naco Formation is absent because of the depositional limits imposed by the largely granitic Defiance Positive Area. This pinch out is buried beneath Cenozoic Volcanics and older rocks of east-central Arizona. Therefore, its precise position is not known (Figure 3).

In the subsurface of the Mogollon Slope an upper boundary of the Naco Formation has been difficult to pick. On the edge of the Rim, near Show Low, a well (well Section no. 21) drilled to Precambrian rocks appears to have cut about 1,000 feet of strata assignable to the Naco Formation. Sixty miles to the north, 18 miles northeast of Holbrook, there is no Naco Formation (well section no. 19) because unequivocal Supai Formation overlies granite in the subsurface. Between these two localities about 1,700 feet of Paleozoic section disappears. Of this amount about 500 feet of overall Paleozoic section is lost between the Rim and Holbrook (well section no. 18) whereas the remaining 1,200 feet is lost between Holbrook and well section no. 19. Between the Rim, where there is about 1,000 feet of strata placed in the Naco Formation, and the Creager State hole where, because of onlap there is no Naco, the amount of fossiliferous limestone decreases, making it difficult to trace key beds so as to effect accurate surface to subsurface correlations and therefore difficult to determine the reason or reasons for lateral stratal changes.

In the western portion it is generally recognized that the Naco Formation is thinner than it is in the Salt River Canyon-Carrizo Creek locality. Most workers recognize some Naco Formation at Fossil Creek (Figure 8) whereas there is a difference of opinion as to its presence in the vicinity of Oak Creek Canyon. A fusulinid zone near the base of the Naco Formation at Fossil Creek, where the typical Naco is thinned, is thought to be Desmoinesian in age whereas, to the east, the youngest Naco fossiliferous strata are thought to be either Virgilian or, according to one worker (Brew, 1965) even "post-Virgilian" in age. The persistence of clear-cut marine units to the east, as contrasted with unfossiliferous stratal types and red beds above older portions of the Naco to the west, has led to the idea that the Naco Formation interfingers with or grades laterally westward and northward into probable Pennsylvanian components assignable to the Supai Formation. Because the actual position of the systemic boundary is not known, it has not been possible to demonstrate conclusively what portion of the so-called Supai Formation actually is Pennsylvanian in age and, therefore, a possible lateral correlative of the Naco Formation. Also, it has been difficult to assess the amount of time represented in possible but as yet undelineated unconformities. It seems likely that the conglomerates observed during this investigation offer a possible route to enlightenment in this regard.

Supai Formation

The Supai Formation overlies the Naco Formation where the latter is recognized. It has been subdivided in several different ways. The name is derived from the Grand Canyon region and has been extended through Oak Creek Canyon to the Mogollon Rim. It is dominated by clastic rocks generally classed as "red beds". However, depending upon location, the formation contains both important evaporite and marine limestone occurrences in its upper part. As now defined it represents a complex group of sedimentary rock types and is the thickest of all of the Paleozoic formations. In the study region it ranges from about 1,600 feet on the Defiance Positive Area to about 2,500 feet in the subsurface of the Mogollon Slope. The zone of interest, especially to the west, is within units assignable to lower parts of the Supai Formation.

The three-fold subdivision of the Supai Formation at Grand Canyon (Noble, 1923) was extended to Oak Creek Canyon by McKee. Members, from top down, were designated A, B, and C. Although different names have been applied, this three-fold subdivision at Oak Creek Canyon persists and is indicative of the naturalness of division into three basic units. Huddle and Dobrovolny (1945), in a generally fine piece of work, studied the paleozoics of the Rim region and the Mogollon Slope subsurface. In so doing they divided the Supai Formation into three parts: Lower, Middle, and Upper members. However, included within the Upper Member, was a relatively prominent cliff-forming marine unit called the Ft. Apache Member. They correlated this unit with a thin marine limestone in their Upper Member at Oak Creek Canyon. The Ft. Apache unit now is recognized throughout all of the outcrop and much of the subsurface

OAK CREEK--FOSSIL CREEK--TONTO RIM

<table>
<tr><td rowspan="8">Redwall Limestone</td><td colspan="3" rowspan="2">NACO</td><td colspan="3">SUPAI</td><td rowspan="8">Fort Apache</td><td rowspan="2">Jackson</td></tr>
<tr><td>Packard Ranch</td><td>Oak Creek</td><td>Big A</td></tr>
<tr><td colspan="3">NACO</td><td colspan="3" rowspan="2">Supai Undiff.</td><td rowspan="2">Brew</td></tr>
<tr><td>Alpha</td><td>Beta</td><td>Gamma</td></tr>
<tr><td colspan="3" rowspan="2">NACO</td><td colspan="3">SUPAI</td><td rowspan="2">Huddle & Dobrovolny</td></tr>
<tr><td>Lower</td><td>Middle</td><td>Upper</td></tr>
<tr><td colspan="3">HORQUILLA</td><td>Earp Eq.</td><td colspan="2">Supai Undiff.</td><td>Ross</td></tr>
<tr><td colspan="4">C</td><td>B</td><td>A</td><td>This Paper</td></tr>
</table>

WESTERN FT. APACHE REGION

<table>
<tr><td rowspan="7">Redwall Limestone</td><td colspan="2" rowspan="2">NACO</td><td colspan="3">SUPAI</td><td rowspan="7">Fort Apache</td><td rowspan="2">Finnell</td></tr>
<tr><td>Limestone sandstone</td><td>Cibecue</td><td>Sandstone siltstone</td></tr>
<tr><td colspan="3">NACO</td><td colspan="2" rowspan="2">Supai Undiff.</td><td rowspan="2">Brew</td></tr>
<tr><td>Alpha</td><td>Beta</td><td>Gamma</td></tr>
<tr><td colspan="2" rowspan="2">NACO</td><td colspan="3">SUPAI</td><td rowspan="2">Huddle & Dobrovolny</td></tr>
<tr><td>Lower</td><td>Middle</td><td>Upper</td></tr>
<tr><td colspan="2">C</td><td>B-2</td><td>B-1</td><td>A</td><td>This Paper</td></tr>
</table>

EASTERN FT. APACHE REGION

<table>
<tr><td rowspan="8">Redwall Limestone</td><td colspan="2" rowspan="2">NACO</td><td colspan="3">SUPAI</td><td rowspan="8">Fort Apache</td><td rowspan="2">Huddle & Dobrovolny</td></tr>
<tr><td>Lower</td><td>Middle</td><td>Upper</td></tr>
<tr><td colspan="3" rowspan="2">NACO</td><td colspan="2">SUPAI</td><td rowspan="2">Winters</td></tr>
<tr><td>Amos Wash</td><td>Big A Butte</td></tr>
<tr><td colspan="3">NACO</td><td colspan="2" rowspan="2">Supai Undiff.</td><td rowspan="2">Brew</td></tr>
<tr><td>Alpha</td><td>Beta</td><td>Gamma</td></tr>
<tr><td colspan="2">HORQUILLA</td><td>Earp Eq.</td><td colspan="2">Supai Undiff.</td><td>Ross</td></tr>
<tr><td colspan="2">C</td><td>B-2</td><td>B-1</td><td>A</td><td>This Paper</td></tr>
</table>

MOGOLLON SLOPE SUBSURFACE

Redwall; Martin; Precamb.	C	B-2	B-1	A	F.A.	

Table I. Nomenclature and correlation aspects of the Naco Formation-lower Supai Fm interval, Mogollon Rim surface and Mogollon Slope subsurface.

region herein being considered (Figs. 26, 43). This is important because the unit, when properly identified in the subsurface, provides essential stratigraphic orientation. Certain gross stratigraphic errors in some pertinent literature are the result of subsurface miscorrelation of this important marker unit (Baars, 1962; McKee, 1967).

Because the Ft. Apache Member is thickest (over 100 feet) towards the southeast, in that area it has there long been given member status by many workers (Gerrard, 1969, p. 176. A consequence of this is the subdivision of the Upper Member of Huddle and Dobrovolny into three formal members, at least in the eastern part of the Ft. Apache Reservation. In this subarea Winters' (1963) subdivision is in general use. From the base up the section is: (1) Amos Wash Member, (2) Big A Butte Member, (3) Ft. Apache Limestone Member, and the (4) Corduroy Member. The Supai Formation is overlain by light-colored sandstones that, at least for now, are assigned to the Coconino Sandstone.

The Amos Wash Member, characterized by red beds, sharply overlies a conspicuous ledge-making, fossiliferous, marine, red to orange chert-bearing, limestone assigned by Winters to the topmost unit of the Naco Formation (Figs. 27, 53). Too, he designates this contact as the Pennsylvanian-Permian boundary largely because of the occurrence of a youngest Pennsylvanian fusulinid fauna in the higher parts of the Naco Formation of this region. However, representatives of an oldest Permian fauna are not known in the generally unfossiliferous Amos Wash strata, therefore, the designation is imprecise. Brew (1965) suggests that the highest Naco, as defined by Winters and accepted by Brew, is "post-Virgilian", which supports Winters' concept of it being at least youngest Pennsylvanian. Brew's designation seems to permit a possibility that Winters' highest Naco Formation might even be Permian in age. This is all the more possible when it is realized that the critical fauna is about 200 feet below the highest limestone ledge assigned to the Naco Formation. This upper 200 feet of Naco is included within Brew's Gamma Member and contains a significant part of the "zone of interest" on the Ft. Apache Indian Reservation (Figure 6; Table 1).

To reemphasize, the Ft. Apache Member is a key unit that is more persistent and recognizable than less competent stratigraphic zones both above and below it. It also serves as a convenient basis for dividing the Supai Formation, informally, into upper Supai and lower Supai (figure 7). Much of the later discussion involving the Supai Formation relates to the lower Supai, or, that part below the Ft. Apache Member and above the Naco Formation (Table 1).

In Oak Creek Canyon the thin (10-12 feet) unit believed to be the Ft. Apache Member equivalent has not been recognized as a separate member of the Supai Formation. However, if the Tonto Rim, the subsurface, and the Oak Creek areas are to be stratigraphically and nomenclaturally linked, it seems advisable to subdivide the "A" or Upper Member at Oak Creek, accordingly. Because the Ft. Apache is not recognized in Grand Canyon, and the Supai section differs in other ways, it seems natural to link the Oak Creek section with the Rim area and consider as casual, attempts to extend Grand Canyon Supai Formation nomenclature into Oak Creek Canyon.

In the western Ft. Apache Reservation, from the vicinity of Cibecue west to Canyon Creek, Finnell (1966) has mapped the Paleozoic strata. He developed a five-fold subdivision of the Supai Formation in which the units, though designated differently, are similar to those of Winters' not far to the east. Finnell calls Brew's Gamma Member of the Naco Formation, Limestone and sandstone member of the Supai Formation. Here, then, according to the classification of Finnell, the "zone of interest" is partially within the lowermost member of the Supai Formation. Finnell's units of the Supai Formation, above the Limestone and sandstone member, are: (1) Cibecue Member, (2) Sandstone and siltstone member, (3) Ft. Apache Member, and (4) Limestone and siltstone member.

West of Canyon Creek there is a notable decrease in the amount of limestone in the Naco Formation and lower portions of the Supai Formation as defined by Finnell to the east. It appears as though the west to northwest lateral stratal changes of the outcropping Naco Formation, as reflected in loss of fossiliferous limestones and shales, and the gain of red beds, takes place relatively rapidly between Canyon Creek and Promontory Butte within a distance of less than 20 miles. This seems to be an important and fundamental zone of change previously recognized by Ross (1973, p. 903). However, Ross emphasizes onlap and unconformity whereas we would emphasize facies change. Although clastic rocks, many of them red bed types, appear to laterally replace limestones, it is not at all clear that they necessarily should be designated components of the Supai Formation. A "zone of interest" exists on both sides of this zone of change in such a way as to strongly suggest lateral continuity to the "zone of interest". Because many of the stratal changes take place beneath a "zone of interest" they are confined upward by it in such a way as to call into question any previous correlations that cross it.

The Tonto Rim portion of the Mogollon Rim remains unmapped in detail, therefore the system of Supai subdivision is based upon measured sections. At Fossil Creek (Figure 38), at the west end of the Tonto Rim, the Supai has been correlated with the Oak Creek Canyon section by Huddle and Dobrovolny (1945), Jackson (1951), and others (Table 1). Above the Naco Formation at Fossil Creek Jackson recognizes Supai members designated: (1) Packard Ranch

Member, (2) Oak Creek Member, (3) Big "A" Sand facies", (4) Ft. Apache Limestone, and (5) Corduroy "Sand facies". The last three are judged correlatives of Winters' section 75 miles to the east in which Jackson recognizes a coarsening westward along the Rim.

Based upon regional considerations Jackson considers the Oak Creek Member of the west to be Pennsylvanian in age and thus correlative with the upper portion of the Naco Formation of Winters to the east. At Fossil Creek the "zone of interest" is within Jackson's Oak Creek Member whereas to the east at Carrizo Creek it is within the Naco Formation of Winters. This strengthens the previous regional correlations but precise ages remain in doubt.

In general summary, a "zone of interest" is present over a lateral outcrop distance of 100 miles and is contained within parts of a number of juxtaposed stratigraphic units that include: (1) Huddle and Dobrovolny's Lower and Middle members of the Supai Formation, (2) Jackson's Oak Creek Member of the Supai Formation, (3) Finnell's Naco Formation, Limestone and sandstone, and Cibecue members of the Supai Formation, (4) Winters' Naco Formation, and (5) Brew's Gamma and Beta members of the Naco Formation. From Fossil Creek to Canyon Creek the zone apparently is above conspicuous fossiliferous marine strata. East of Canyon Creek the zone occurs within a sequence of strata that includes conspicuous fossiliferous marine strata.

Because of the inherent difficulties of separating the Naco and Supai formations from place to place it is useful to bracket the problem by recognizing a stratigraphic interval between the top of pre-Pennsylvanian rocks and the base of the Ft. Apache Member of the Supai Formation. In essence this is the Naco-lower Supai interval and is recognizable throughout the region both in outcrop and in the subsurface (Figures 2, 6, and 7; Table 1).

Coconino Sandstone-Kaibab Limestone

Neither of these formations is known to contain pervasive anomalous radioactivity in the study region, therefore they are not discussed in detail. Of interest, however, are the general data that pertain to tectonism.

Both of these names are derived from the Grand Canyon region to the northwest. To the east in the Zuni Mountains of western New Mexico, roughly equivalent or analogous strata are the Glorieta Sandstone and the San Andres Limestone. However, the linkage between these Arizona and New Mexico units is not as straightforward as might first appear. Relationships present in the study region suggest that there might be significant geologic distinctions to be made.

In the western part of the region (Oak Creek-Fossil Creek) typical eolian Coconino Sandstone is 600-700 feet thick. Eastward the sandstone thins and becomes increasingly water deposited from the base upward until most of the 300 feet of sandstone along the Rim near Show Low is waterlain. This is not typical Coconino Sandstone and might bear a close relationship to the Glorieta Sandstone.

The Kaibab Limestone contains interbedded sandstones and various calcareous strata that in the study region range in thickness between zero and about 400 feet. It regionally pinches in the subsurface eastward from Grand Canyon and in outcrop in the vicinity of Holbrook on the Mogollon Slope. Here, the wedgeout below Triassic rocks is towards the northeast. In the eastern half of the study area this stratigraphic position is occupied by a marine unit that contrasts in lithology and fauna (therefore environment of deposition) and pinches to the northwest. These two wedgeout zones together define what might be interpreted as the nose of a south plunging arch. However correlations are made, it seems essential to recognize a continuing local tectonic influence on these youngest Paleozoic rocks.

Structurally, the late Paleozoic sedimentary record evidences relative tectonic instability. Except for rapid pinching against the Defiance Positive Area the Naco Formation reflects the existence of fluvial, shelf, and shallow basin environments. Plant fossils and carbonaceous material suggest the influence of "uplands". The setting was such that numerous slight regional vertical adjustments, or changes in sea level, caused environmental changes over large areas. The Supai Formation reflects local differential tectonism as well as broad, but slight, regional adjustments. It contains both marine, nonmarine, and red bed sediments of unclear origin. Land areas, existent during the earlier phases of deposition, were encroached upon and generally buried at the close of Supai time. Plant fossils and associated carbonaceous materials locally contain anomalous radioactivity and are a part of the "zone of interest".

The Coconino Sandstone and Kaibab Formation both reflect continuing tectonic influence. The Coconino Sandstone changes in both thickness and facies details towards the southeast in the study area where it thins and is water deposited, not wind deposited. The Kaibab Formation, which contains much sandstone, wedges out towards the northeast in outcrop on the Mogollon Slope. Some of this thinning is the result of post-Kaibab pre-Moenkopi (Triassic) erosion (McKee, 1938).

The Mesozoic

Mesozoic representation is limited to Triassic and Cretaceous sedimentary rocks.

In the western half of the region the modern erosion surface is cut upon the Kaibab Formation with remnants of overlying Triassic Moenkopi Formation and even fewer remnants of the basal portions of the

Triassic Chinle Formation. However, in the eastern half, these Triassic formations blanket the Paleozoic rocks (Figure 3) except in rare cases along structural highs cut by shallow canyons.

Portions of the Chinle Formation, especially in the vicinity of the Petrified Forest, serve as hosts to numerous, scattered, and small uranium occurrences (Keith, 1970, p. 120).

Along the Rim, from Canyon Creek east to about McNary, a remnant of strata of Upper Cretaceous age truncates slightly northeast dipping Paleozoic rocks. Within the span of outcrop the Cretaceous marine rocks unconformably overlie the Kaibab, Coconino, and Supai units southward. Near Deer Creek, southeast of Globe, strata correlated with the Upper Cretaceous Pinkard Formation (Miller, 1962, p. 92) overlie the Naco Formation and may represent a subsequently disrupted continuation of this erosional surface.

It is clear that Paleozoic strata were tilted to the northeast prior to Upper Cretaceous time. The estimated slope at that time was no less than 30 feet per mile or about 2.5 degrees. The present Mogollon Slope represents, for the most part, this exhumed structural slope. The tilting event might be considerably older than Upper Cretaceous. Regardless, there was a Mesozoic surface that truncated older rocks to the southwest and likely exposed crystalline Older Precambrian rocks in central Arizona that served as source rocks for Cretaceous and possibly older sediments that are coarse grained and arkosic. This surface truncated the "zone of interest" somewhere not far south of the Mogollon Rim and should be considered in regard to influence on mineralization. Much of the structure reflected at the Plateau surface today is traced to manifestations of the Laramide Orogeny of late Cretaceous-early Tertiary time, especially folds. However, where Cretaceous rocks are not present, such an age cannot be established with certainty-there may be unrecognized older Mesozoic structure in addition to the tilting already mentioned.

Although the Laramide interval was a time of major mineralization in southern Arizona, especially copper (Figure 28), mineralization of this vintage is not yet known to exist in the southern part of the relatively undisturbed Plateau region. A major copper district in the vicinity of Globe is only 60 miles south of the Mogollon Rim.

The Cenozoic

The Cenozoic Era is represented by continental sedimentary rocks and volcanic rocks. The oldest of the sedimentary materials is the so-called "Rim gravel" which occurs as remnants at high elevations along the southern edge of the Plateau (Figure 3). These have long been noted for their content of recognizable clasts of Precambrian units that ultimately could have been derived only from once relatively higher positions in southerly to southwesterly directions from the Rim. These gravels are somewhat analogous to the Cretaceous rocks in that they too appear to lie on a surface of erosion that truncates older rocks to the south. At the Rim they overlie the Cretaceous strata and southward, near Whiteriver, they overlie the Supai Formation. This surface, whatever its precise form, most likely truncated the "zone of interest" not far to the south of the Rim. This event, too, should be evaluated as to relationship to mineralization. There are younger continental sediments on the Mogollon Slope but they will not be discussed here.

Cenozoic volcanic rocks cluster around centers such as the White Mountain Volcanic Field in the eastern half of the region. Away from such centers occasional dikes, sills, or thin flows are seen.

Cenozoic tectonic activity is evidenced primarily by volcanism and faulting along the Plateau edge. Much of the present Mogollon Rim escarpment is fault-related but apparently not in the way that has been implied in relatively recent literature (McKee and McKee, 1972, p. 1923). The expression "Plateau uplift" has become relatively commonplace and is often used to suggest that the Plateau, as we see it today, has been uplifted several thousands of feet relative to the central mountains. The vision seems to be that there is a large fault beneath the Mogollon Rim along which such uplift was effected. Although there is faulting, nowhere is there documented evidence of throws in excess of 1,500 feet. Although this is sufficient to create the eroded scarps and canyons represented along the Rim, it does not explain the elevation of Cretaceous marine strata above 7,000 feet in elevation. It would appear as though one should search elsewhere for explanations. It is suggested that the answer might be in epeirogeny of a much larger region than that represented by the present Plateau outlines.

The Tonto Rim segment of the larger Mogollon Rim is structurally higher than is the Rim segment east of Canyon Creek. This is evidenced by structurally higher Permian formations to the west as well as the preservation of the relatively lower block of Mesozoic and Cenozoic strata. This is interesting because: (1) this local structural aspect also appears to have manifestations in both Precambrian and late Paleozoic rocks, and (2) the outcropping better mineralized areas within the "zone of interest" occur in this structural segment.

The present escarpment, along which Paleozoic strata crop out, is an eroded fault scarp that in the Tonto Rim area has retreated at an estimated minimum rate of one mile per 1.8 million years, or, 3.5 in. per century.

THE ZONE OF INTEREST

General Statement

Information assembled during the course of this study suggests that there is, within the Paleozoic rocks of the Mogollon Rim and Slope region, a widespread, generally definable zone of particular interest within which the more anomalous radioactivity tends to occur. The "Zone", although intended to convey the idea of occurrence independent of stratigraphic preconceptions, generally can be outlined in terms of outcropping units defined by previous workers. However, as stated previously, numerous stratigraphic names have been applied, not only to laterally correlative units in adjacent localities but also to the same unit in single localities. Because of our regional requirements, we have chosen the simplest informal system of nomenclature available to us that recognizes units described by others in outcrop and that can be extended into the subsurface.

Stratigraphic Definitions and Characteristics

Table I summarizes the stratigraphic interval and nomenclature that is of primary concern. To the west only unit "B", in outcrop, is known to contain anomalous uranium. Eastward, unit "B" is subdivided into two parts, B-1 at the top and B-2 below. Although B-1 contains local examples of anomalous uranium it is B-2 that is most significant in both outcrop and the subsurface. Unit "C", especially the upper half, appears to be of some interest in the subsurface. Examples of outcropping anomalous radioactivity in unit "C" are not known although they could exist. Figure 9 is useful in depicting an example of gamma ray characteristics of units B-1, B-2, and "C" in the subsurface.

Eastward, "B" picks up thin fossiliferous marine units in its lower half and these constitute the basis for subdividing "B" into B-2, and B-1. Together, in outcrop, "B" and B-2 constitute a zone of major interest that we judge to be laterally continuous over the outcrop length of about 100 miles. The relationships between B-1 to the east and "B" to the west are not clear but it is our interpretation that B-1 is a phase that pinches westward. To reiterate, emphasis is placed on the laterally related "B" and B-2 stratigraphic intervals.

Translated into terms previously used by others, "B" to the west and B-2 to the east approximate the (1) Middle Member of the Supai Formation of Huddle and Dobrovolny (1945) to the west and the Lower Member of the Supai Formation to the east, (2) Oak Creek Member of Jackson (1951) to the west ("B"), (3) Gamma Member of the Naco Formation of Brew (1965) to the east (B-2) and the Supai Formation undifferentiated to the west ("B"), (4) Limestone and sandstone member of the Supai Formation of Finnell (1966) (B-2), and (5) Earp equivalent of Ross (1973) to the east (B-2) and the Supai Formation undifferentiated to the west ("B") (Table I). This is why we are using A, B, and C, even though it, too, is confusing to those familiar with other designations.

In the discussion to follow a distinction should be made between "B" and B. B will be used to express combined B-2 and B-1.

"B" is of interest because it is, in places, a locus of mineralization characterized by combinations of various metallic sulfides, copper oxides, and some uranium. Mineralization, in turn, is closely associated with features that are common to many of the peneconcordant type of uranium deposits, principally fluvial clastic sedimentary rocks that are gray to gray-green in color, and, concentrations of carbonized and/or coalified plant debris.

In outcrop, along the densely forested Tonto Rim segment of the Mogollon escarpment, the principal zone (unit "B") is best reflected in ledge-making conglomerates that may or may not be mineralized (Figures 39, 40). Float derived from conglomerates is readily recognizable when present in modern water courses (Figure 29). Conglomerates seem to be the most ubiquitous and easily detected of the outcrop indicators of the zone along this western part. However, in the subsurface, in the absence of core, the best indicator seems to be the presence, in well cuttings, of gray to gray-green shale pieces with distinct remains of carbonized plant fragments. If a radioactivity log is available these shales, or related rocks (possibly more coarsely clastic types) generally produce radiometric peaks that either are above background or sufficiently pronounced to be labeled "anomalously radioactive" when compared to the total Paleozoic rock column penetrated by the bit.

Unit B-2 to the east acquires carbonate ledge makers which tend to render conglomerates more obscure.

Outcropping conglomerates occur at the extremes of the study area as well as at numerous localities in between. Absolute tracing for any distance is impossible on the forested and talus strewn slopes of the Tonto Rim segment where exposures tend to occur on fresh surfaces in canyons and gullies. Conglomerates are present in Oak Creek Canyon (unit "B") to the northwest and at Amos Wash (unit B-2) near its junction with White River to the southeast, a separation distance of about 120 miles. Regarding gray carbonaceous shales, they are present in outcrop in Fossil Creek Canyon (Figure 38) on the southwest and occur in the subsurface about 115 miles to the northeast. These dimensions are not cited to establish lateral continuity, but rather occurrence ranges. Implied, however, is that these occurrences are believed to be organized within closely related and generally definable stratigraphic units.

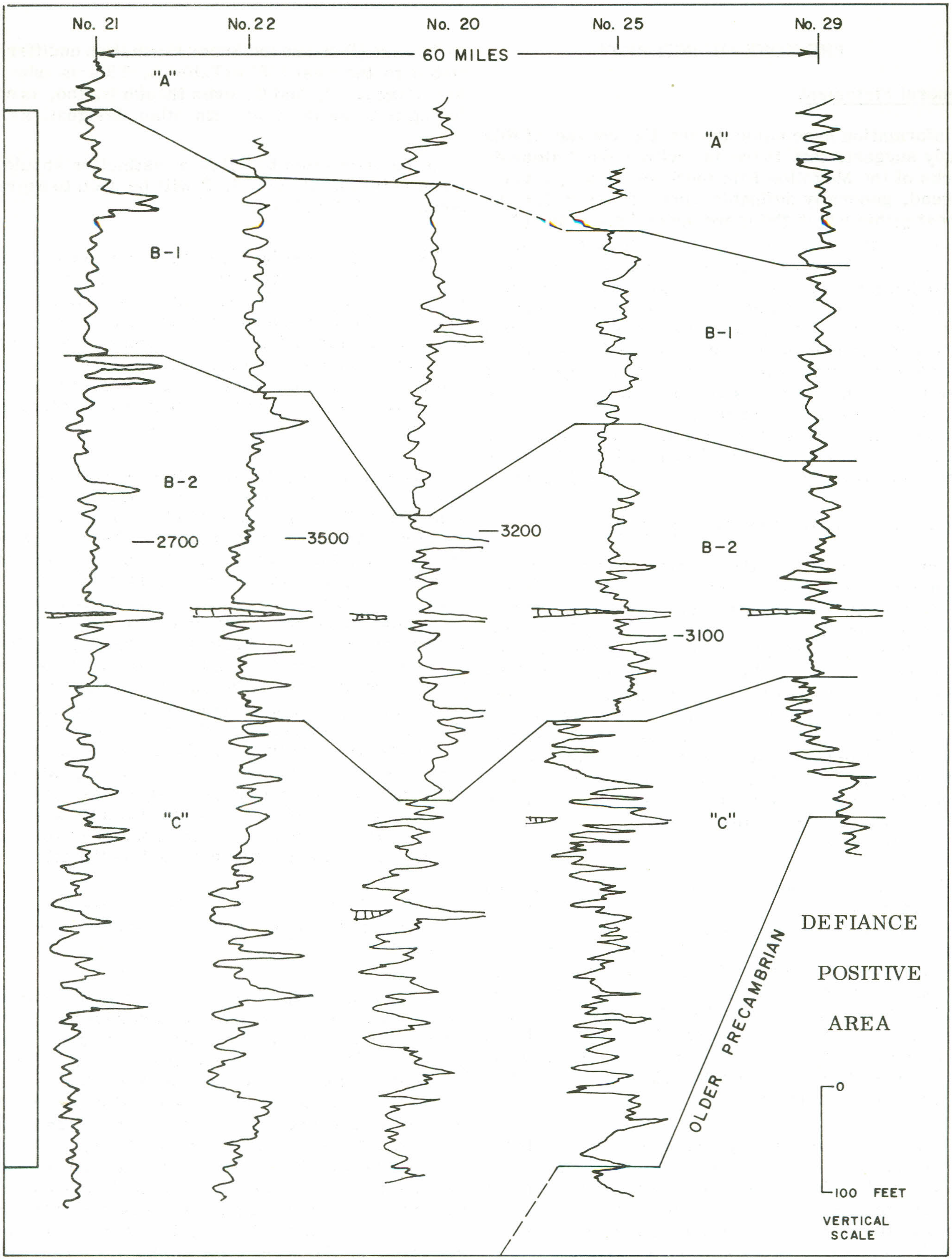

Figure 9. Gamma ray curves, correlations, and the Zone of Interest over a distance of 60 miles

Stratigraphically, all horizons (zones) discussed here are confined between the base of "C" ("C" is the Pennsylvanian Naco Formation of most workers) and the base of the Permian Ft. Apache Member of the Supai Formation. Table II (see Appendix) provides basic subsurface stratigraphic data and attempts to point out the positions of both above background, and anomalous radioactivity. Some of these data also are depicted, along with outcrop highlights, in Figures 9 and 15-18.

Sedimentation Framework

As stated and depicted elsewhere (Figure 6) the base of "C" overlies a regional unconformity. This unconformity represents a late Mississippian and lower Pennsylvanian time interval. Pennsylvanian-Permian deposition was initiated in Desmoines time by marine transgression from the south. Although time lines are not well understood it seems clear that shoaling tendencies were encountered in all directions around the northern end of an embayment (Figure 12). To the northwest the Kaibab Positive Area was sufficiently active to influence thinning and lithofacies development (Figure 16) whereas to the east and north the Defiance Positive Area likely was an exposed land area that was not finally covered until the time of unit "A" (Figures 10, 16, and 18). That land supportive of vegetation was, at times, close by, is evidenced by silicified or carbonized plant fossils locally present in units "C", B-2, B-1, and "B". Although not relocated during this study, Finnell (1966a) reported the following occurrence in the Naco Formation (unit "C"):

> ". . . a bed of ripple-marked tan sandstone on the west side of Sam Canyon contains coalified and silicified plant fragments."

Sam Canyon is near Canyon Creek on the western edge of the Ft. Apache Indian Reservation. Shales with carbonized chips were noted in well cuttings from unit "C" and two wells (nos. 11 and 13, Table II) have core descriptions that note "carbonized wood" in what we believe is the upper part of unit "C".

Coaly units (Figure 30) were studied in Fossil Creek Canyon by McGoon (1962, p. 89) and reported earlier by Ransome (1916, p. 160) who wrote:

> "About 800 feet below this bed [Ft. Apache of today] is a layer of gray limestone conglomerate, about 1 1/2 feet thick, with pebbles of limestone as much as 2 inches in diameter. A seam of very impure lignite, reported to be in places 20 inches thick, lies just under this conglomerate and is said by prospectors to be accompanied by some native copper."

This occurrence is in unit "B". McGoon wondered about the possible correlation of this occurrence with the carbonized wood just noted in wells to the east. We now are satisfied that they do not correlate.

Finch (1967, p. 6) reported, in a table, a "Promontory uranium claim "in Supai sandstone ? in "carbonaceous zones 1-4 feet thick." This occurrence also is in unit "B". Many of the well samples contain shales with carbonized chips or flakes from laterally related unit B-2.

Darton (1925, p. 89) writes:

> "A few impressions of coniferous twigs and leaves found in the medial beds of the Supai... about 5 miles west of Cibecue were examined by David White. He informs me that they are 'almost certainly Walchia gracilis, a tree characteristic of the Permian.' The horizon was about 60 feet above the 'lower limestone member.'"

This occurrence is in unit B-1 (Figures 31, 32, 33). In the subsurface there are a couple of unusual above background radiometric peaks in unit B-1 that might be analogous to the surface occurrence (Figure 9, well nos. 20-21).

Finnell (1966a), in describing his Limestone and sandstone member of the Supai Formation (unit B-2) writes:

> "A thin-bedded silty facies of the uppermost limestone along Spring Creek contains coalified plant fragments, and a shale in the upper part of the lower unit contains silicified logs as much as 2 feet in diameter about a mile south of Lonely Mountain."

An American Stratigraphic Company well log (D-2777) notes an occurrence of dark gray shale with carbon flakes in unit B-2 (well no. 21). However, it seems significant to relate that numerous carbonized phenomena were observed during our study of well cuttings that apparently were not previously recorded. This merely is to suggest that "old" stored well samples might yet contain relevant new information--it all depends on what one is looking for.

The idea that the study area includes the northern shoaling end of a basin that extended from the south seems to be reflected through unit B (combined B-2 and B-1) (Figures 11, 12, and 13). Unit "A" expresses a changing tectonic pattern in which differential subsidence took place parallel to but generally north of the Mogollon Rim. This trend is well developed in the Ft. Apache Limestone (Gerrard, 1969, p. 176) and in the overlying post-Ft. Apache evaporite basin (Peirce et al., 1970, p. 67). This later trend cuts

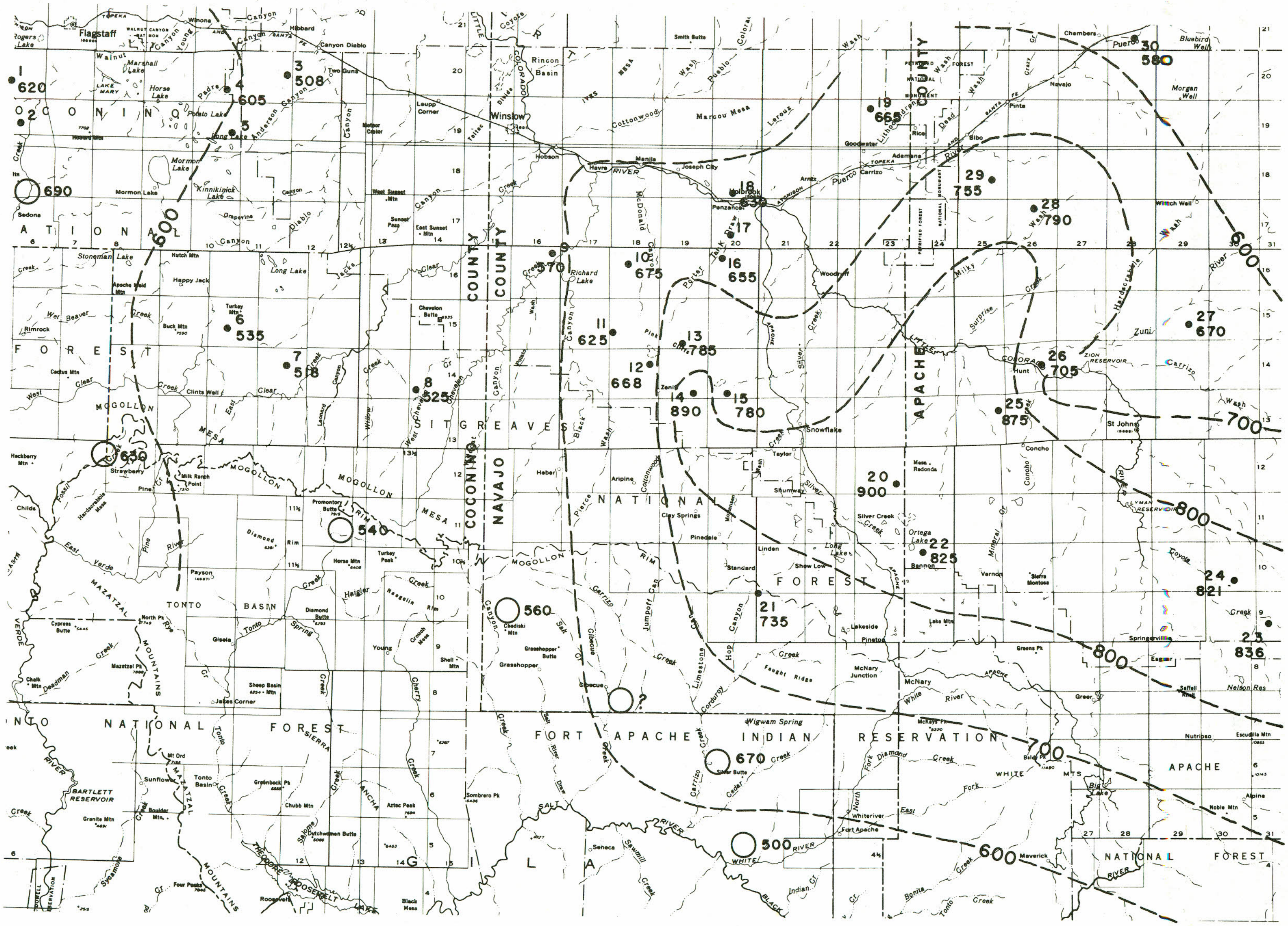

Figure 10. Isopachous map of unit "A" showing basining north of Rim

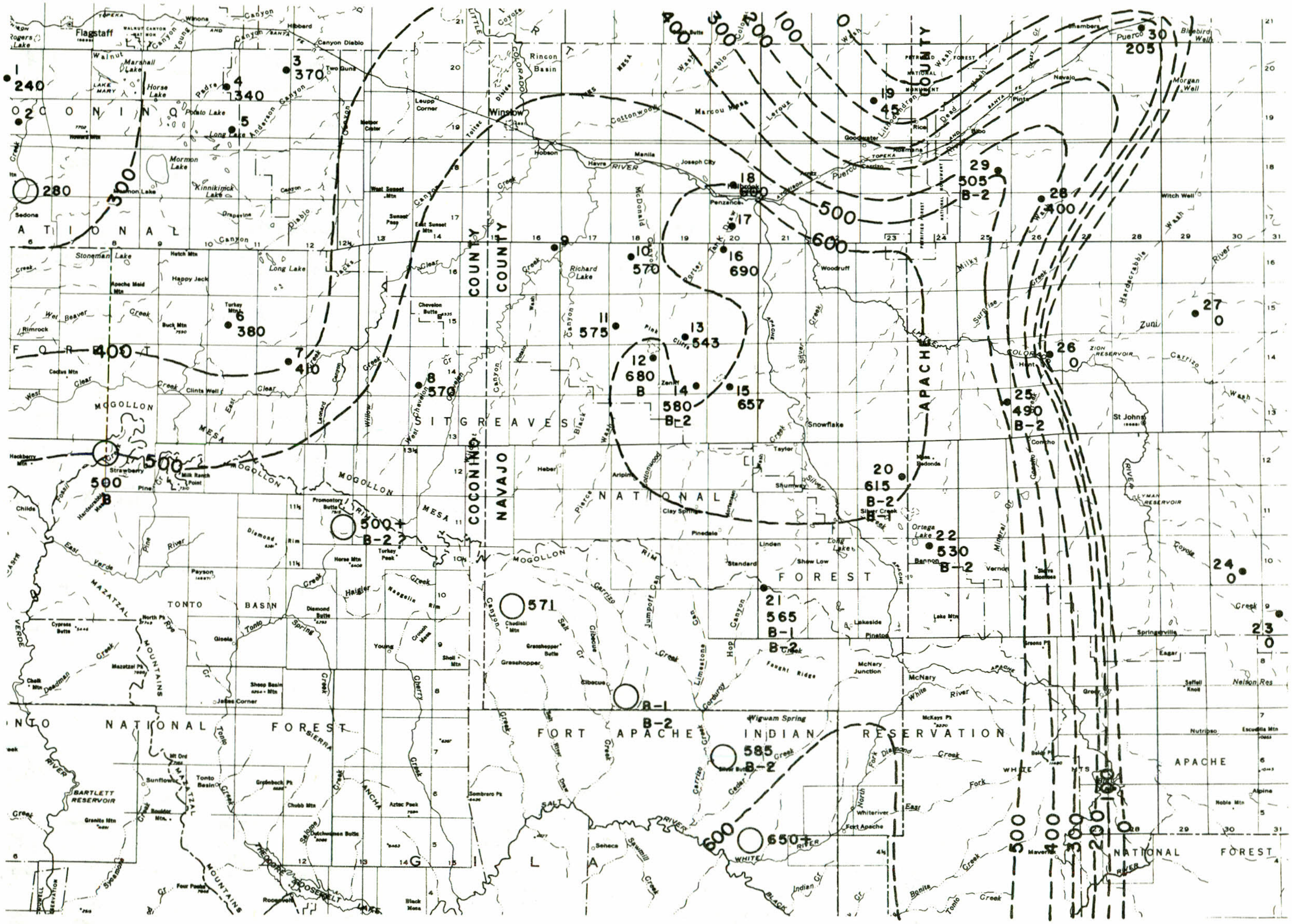

Figure 11. Isopachous map of total "B" and B-2 plus B-1-showing locations and units containing anomalous uranium (surface) or anomalous radioactivity (subsurface)

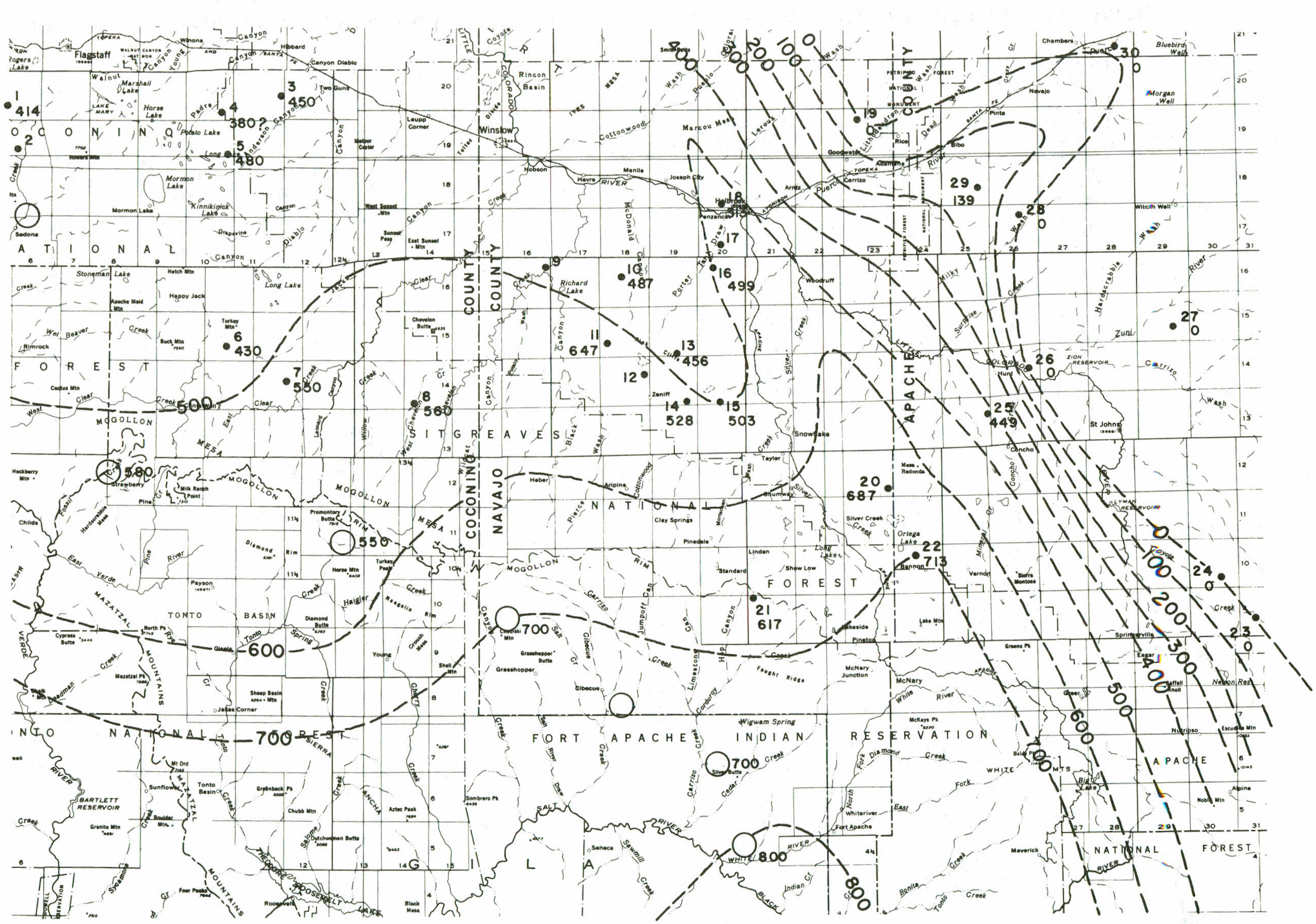

Figure 12. Isopachous map of unit "C"

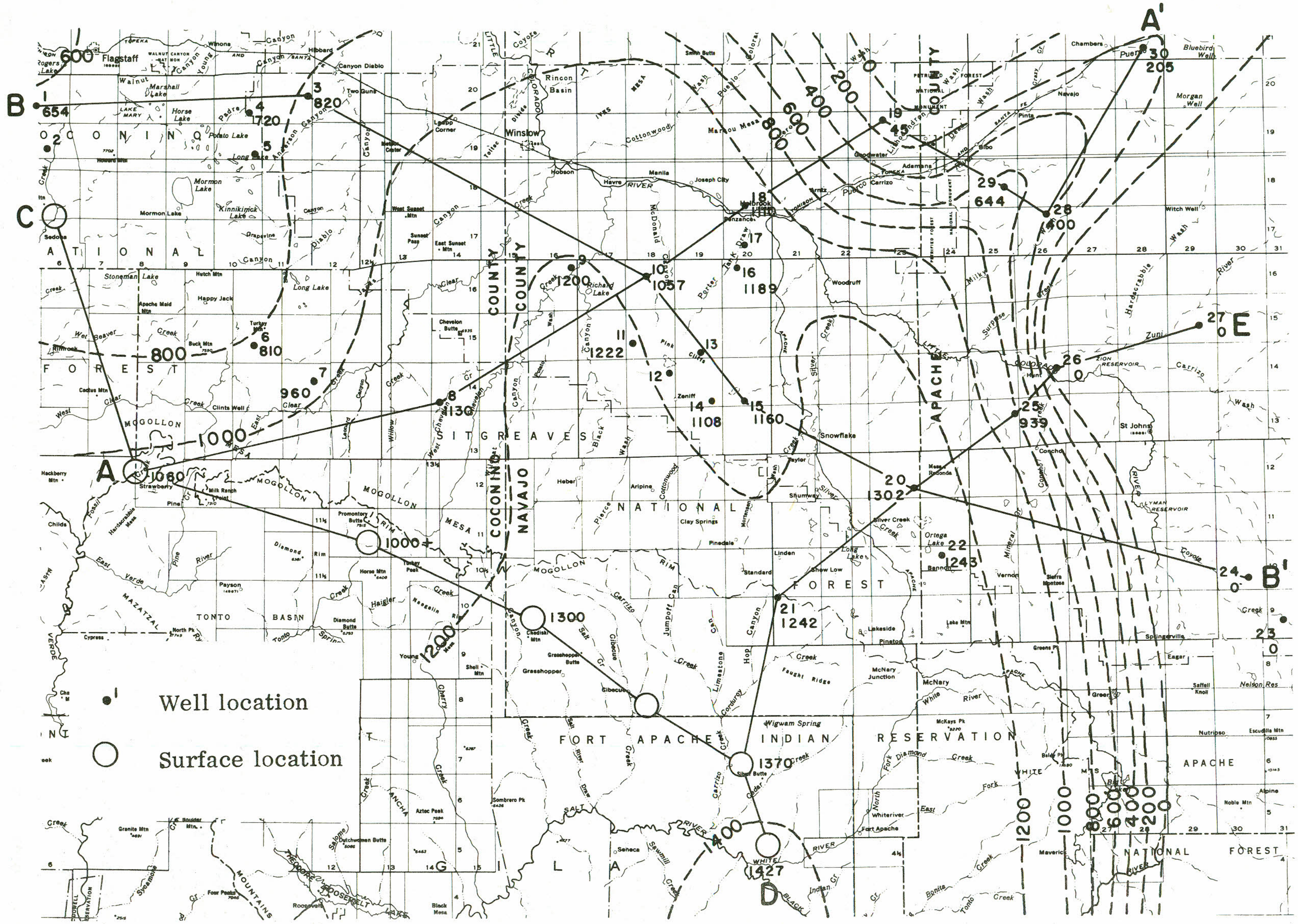

Figure 13. Thickness of total B's combined with "C" with index to sections

across the northerly trend of the units "C" and B strand zone formed along the western edge of the Defiance Positive Area.

An overall assessment of the depositional environments represented by units "C" and B-2 includes shallow water environments ranging from clear water marine to fluvial-lacustrine. The precise depositional environments of the many red beds have long been topics of discussion. Concepts vary according to ideas as to their spatial relationships to marine environments, whether shallow marine, intertidal, coastal plain, lagoonal, deltaic, floodplain etc. It seems likely that all of these are possible and that, basically, the problem demands additional detailed study by students of depositional environments.

Relationships to the Kaibab Positive Area to the north and west can be partially inferred from outcrop study whereas relationships to the Defiance Positive Area are buried from view. It seems clear that the latter was decidedly active during the depositional history of units "C" and B-2 but, just how is not clear. Kottlowski and Havenor (1962, p. 77) have reviewed the Pennsylvanian rocks of the Mogollon Rim area and from drilling data conclude that although

> ". . . Pennsylvanian and lower Permian rocks lap onto the Zuni-Defiance arch from the southwest, the positive area had a relatively small relief as most of the shoreline clastic rocks are shales, calcareous siltstones, and silty limestones."

It is our opinion that this evidence for low relief is inconclusive. One need only recall the case of very fine-grained playa muds or evaporites surrounded by high relief mountains in order to appreciate the role of process in determining grain size relative to distance from a positive feature. In Arizona, we see lake beds depositionally against the lower elevations of high relief mountains.

That the Defiance Positive was active in B-2 time is demonstrated, as mentioned previously, by products derived therefrom in conglomerates in the Amos Wash and Carrizo Creek sections. In the latter, in addition to the limestone pebbles commonly seen in the conglomerates of "B" or B-2, there is a large percentage of coarse quartz grits (Figure 23) and pink feldspars that obviously were derived from a granitic terrain. The conglomerate occupies a channel (Figure 34) and is about 30 feet in maximum thickness. Available but meager data suggest a northerly-southerly channel alignment and a surmised southerly flow direction.

The closest point known to the north where B-2 rocks abut granite is between well nos. 18 and 19, about 70 miles distant. The closest known point to the northeast is about 60 miles between well nos. 25 and 26. To the east, well control is lacking but projection suggests a distance of from 30 to 60 miles.

The Carrizo Creek conglomerate is about 50 feet above a horizon of Virgilian fusulinids and about 190 feet below the highest undated fossiliferous marine limestone that is the top of B-2 (Figure 35). The contact of this limestone with the overlying red beds of B-1 is the contact arbitrarily designated as the Pennsylvanian-Permian boundary by Winters (1963, p. 15) and generally accepted by subsequent workers (Brew, 1965; Ross, 1973).

The experience at Carrizo Creek is characteristic of the Ft. Apache outcrop region in that fluvial conglomerates are within a section of rocks that include fossiliferous marine components. Apparently, the transition from dominantly marine rocks to poorly understood red beds represents periodic base level changes that might be related to local tectonic effects or world-wide climatic changes (eustasy), or both.

There is a northeasterly trending embayment in the western edge of the Defiance Positive Area that is strongly reflected in unit B rocks (Figures 11 and 15). Well no. 29 contains anomalous radioactivity that occurs in or between coarse clastic rocks. This horizon is interpreted to pinch by nondeposition before reaching well no. 28 about 6 miles to the southeast. As an aside, hole 29 was the one in which potash was first detected in the evaporites above the Ft. Apache unit. Pinta Dome, an important helium field, also occurs in this embayment area although it produces from the "Coconino" Sandstone above the evaporite sequence. The origin of the helium has always been an interesting question. Peirce et al. (1970, p. 69) briefly discuss two principal hypotheses involving decay of radioactive substances in: (1) the overlying Triassic Chinle Formation and (2) Precambrian crystalline rocks. They favored the latter. This helium occurrence might constitute an indication that Precambrian rocks of the region contain radioactive substances. This embayment, and other phenomena, are believed to represent a fundamental northeast directed zone of repetitious tectonic activity that has not been well studied and discussed. Certainly, it influenced sedimentation patterns of units "C", B-2 and B-1 and could be indicative that the western edge of the Defiance Positive Area is not as simple as might at first be indicated by sparse well control. Conceivably, this embayment position might have been a locus of southwesterly directed drainage. Perhaps it is coincidence that the southwesterly-flowing Puerco River occupies that position today?

A B-2 conglomerate at the Amos Wash-White River locality also contains arkosic debris. Here, distinct but unidentified bone fragments and segments were found (Figure 36), as was the single pebble of "good-honest" quartzite (Figure 24). A distinct channel form is indicated and orientation is westerly where observed. Flow direction, again surmised, is believed to be towards the west. This conglomerate is about eight feet thick where examined (Figure 37) and is unit no. 26 of Winters (1963, p. 81) who placed it 225 feet below the base of his Amos Wash Member (B-1) of the Supai Formation. It is bracketed by fusulines identified as Triticites. Brew (1965, p. 184) describes a conglomerate in unit "C" in the same region, about 590 feet below the Amos Wash, thus:

> ". . . calcirudite, grayish orange 10 YR 7/4, with clasts up to 4 cm long, from 34 to 35 feet (laterally, this ledge increases in thickness, clasts are up to 12 cm long, and the conglomerate becomes extraformational with quartz grains and quartzite in the matrix and as pebbles)."

He says (p. 102) that the quartzite pebbles likely were derived from the Defiance Positive Area and that the conglomerate is Missourian in age. However, Brew places the thicker conglomerate of Winters in Brew's post-Virgil Gamma Member (B-2) of the Naco Formation.

This interbedding of relatively thin units of marine and probable nonmarine sediments might be explained by an idea attributed to Havenor (Kottlowski and Havenor, p. 79):

> "Havenor suggests that deltaic beds are only a minor part of the Supai sequence, believing that the lower Supai red beds and carbonate rocks are predominantly shallow water marine deposits, laid down in a shallow ephemeral sea--where a lowering of sea level by only a few feet may have exposed several hundred square miles of the sea bottom."

As mentioned before, to the west the sedimentary section, though it changes, does not abruptly pinch out as it does to the east and north. To the west workers envision activity by a Kaibab Positive Area that is invoked largely to explain the thinning and/or loss of Pennsylvanian marine sections from the Cordilleran, Paradox, and Sonoran regions.

For the purposes of this present discussion the western region is from Cibecue west. Although the general section is similar to that to the east there is one difference that might be of significance. Whereas the conglomerate at Carrizo Creek contains evidence of derivation, in part, from the Defiance Positive Area, those in a similar stratigraphic position in Cibecue and the localities further west do not contain such evidence, being, as they are, limestone pebble conglomerates without the obvious arkosic constituents. However, some of them contain more organic matter and anomalous radioactivity than any known to the east. Although caution must be exercised in regard to the vagaries introduced by random esposures, considering that there are many conglomerate exposures further to the west, and that none is coarsely arkosic, suggests a fundamental difference in source region--the Kaibab Positive Area. The idea envisioned would be a drainage system convergent from the west, north, and east that flowed to an axial low that drained southerly toward the Pedregosa basin. It is intriguing to note that the modern drainage network in the Ft. Apache region mimics this basic idea.

West of the Big Spring section there is a notable decrease in the amount of fossiliferous marine limestone and shale. From here west the top of B-2, marine limestone, is not present although the conglomerates and related rocks continue and, in our opinion, the entire complex thickens upward to displace B-1 before reaching Fossil Creek. Limestone also disappears from unit "C" although, in our opinion, correlative rocks continue beneath "B" at least as far as Oak Creek Canyon.

It seems clear that there was a tectonic element between Big Spring Canyon and Promontory Butte that controlled limestone development in much of "C" and B-2 time. Although, because of heavy forests, discontinuous exposure, and possible unobserved faulting, thickness data in the Promontory Butte area are sketchy, there appears to be a loss of section of about 200 feet (Figures 13 and 17). However, at Oak Creek Canyon to the northwest the section is halved by thinning of "C" at the base and the thinning of "B", here interpreted to be the loss of B-1.

The concept of a Supai delta prograding in a southerly direction restricting and displacing normal marine environments has been reiterated by many workers. Havenor, as previously mentioned, considers many of the red beds to be shallow marine and not deltaic. This question continues to be of fundamental concern. Deltaic environmental complexes are complicated systems and to evaluate them requires both large and small scale detail. Much more work needs to be done in central Arizona before some of these questions will give way to authoritative answers. Certainly, the "C" and B-2 portions of the stratigraphy become less marine to the west and north and "C" and "B"-B also thin in these directions. It seems likely that fluvial and shallow marine processes interfaced but it is not clear that water depths were sufficient to permit anything other than relatively thin and local delta-related environments to persist. Finer-grained constituents may have been widely redistributed which would help to explain a lack of recognized mud units of notable thickness.

The distribution of vegetative debris and thin coaly units is common to some deltaic environments where swamps, marshes, and marginal uplands permit growth to take place. However, it seems likely that such environments could just as well occur in a

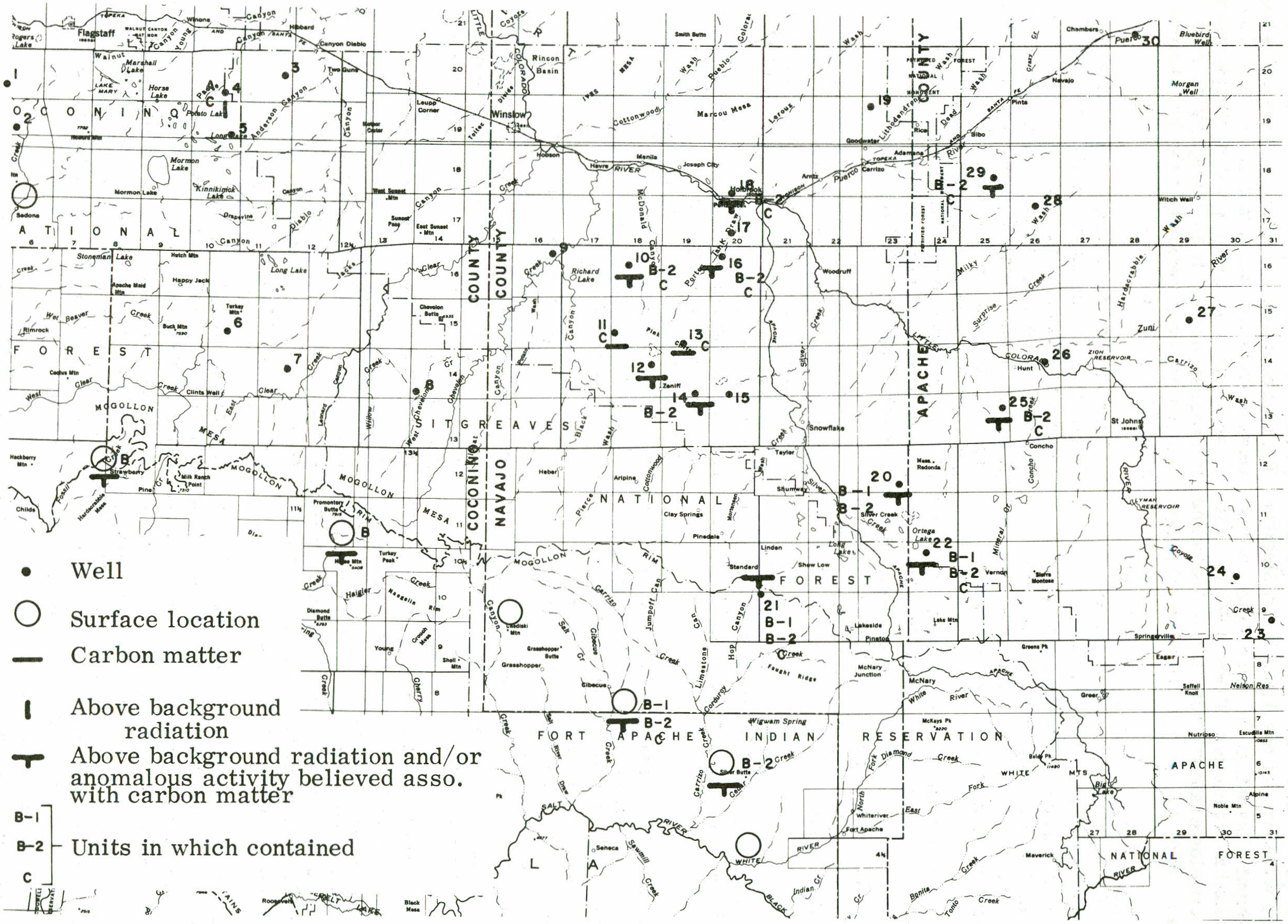

Figure 14. Distribution of carbon matter and abnormal radiation

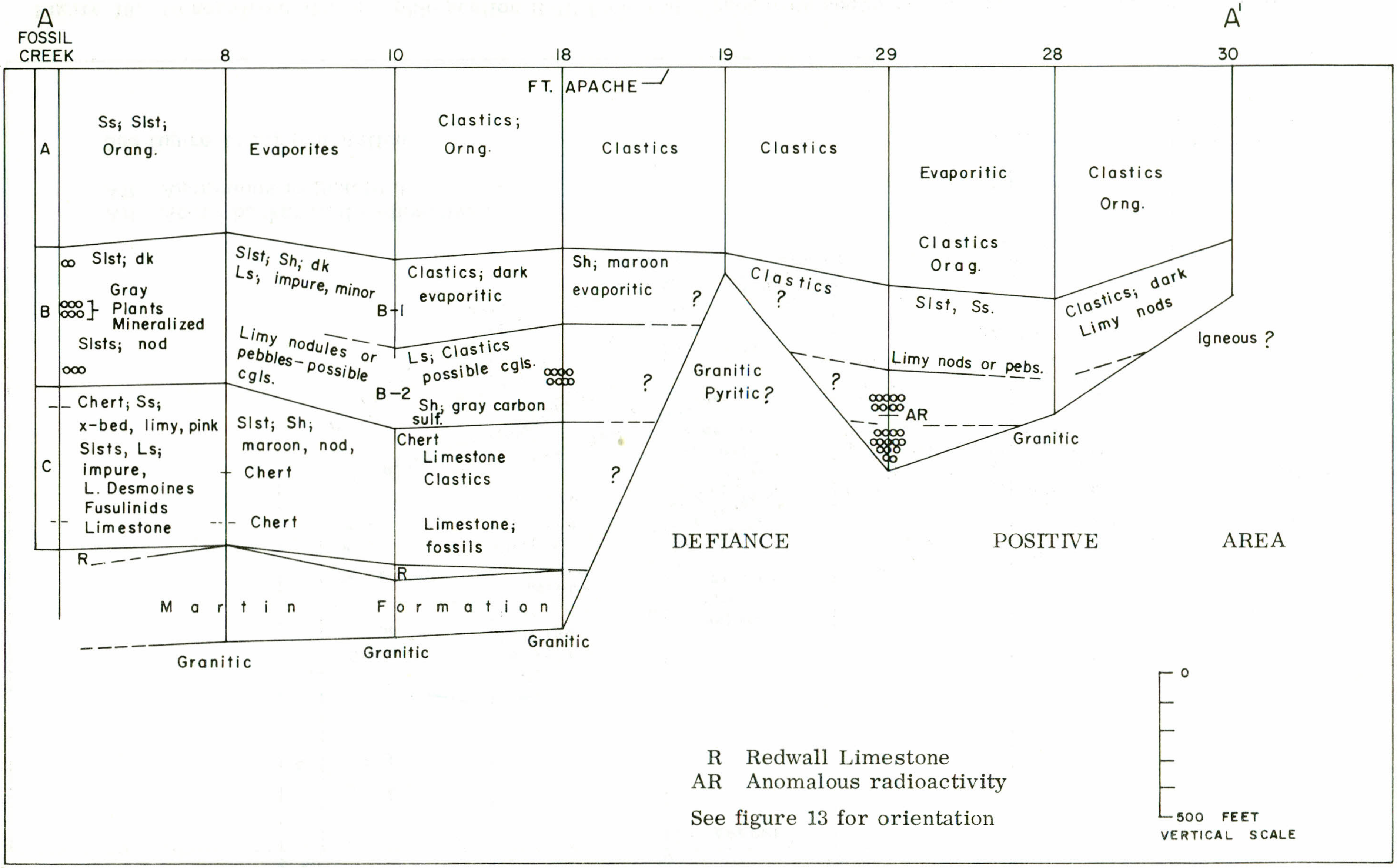

Figure 15. Generalized stratigraphic section A-A' from Rim to northeast showing onlap against the Defiance Positive Area

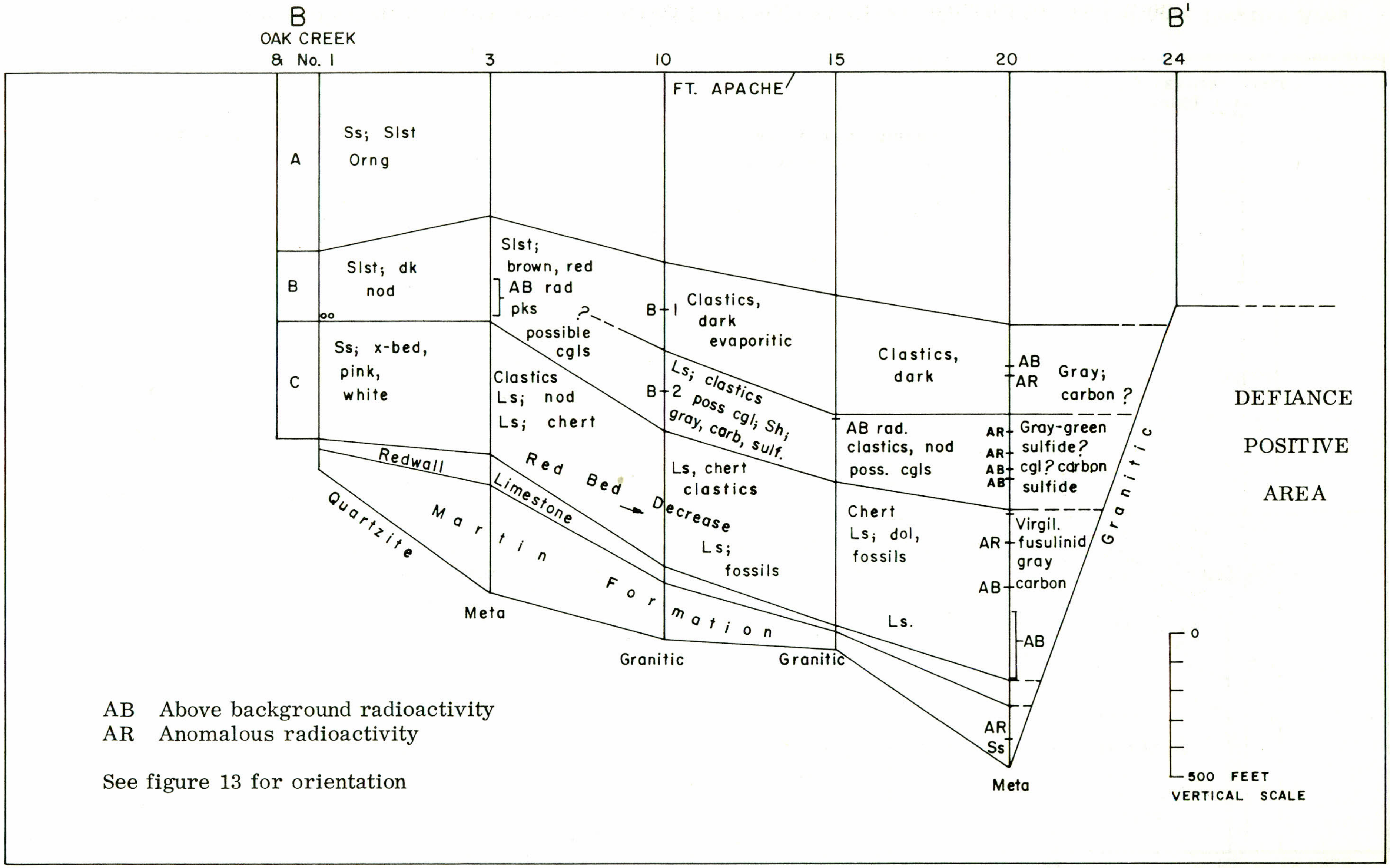

Figure 16. Generalized stratigraphic section B-B' from Oak Creek area southeast showing onlap, basining, and positions of radioactivity

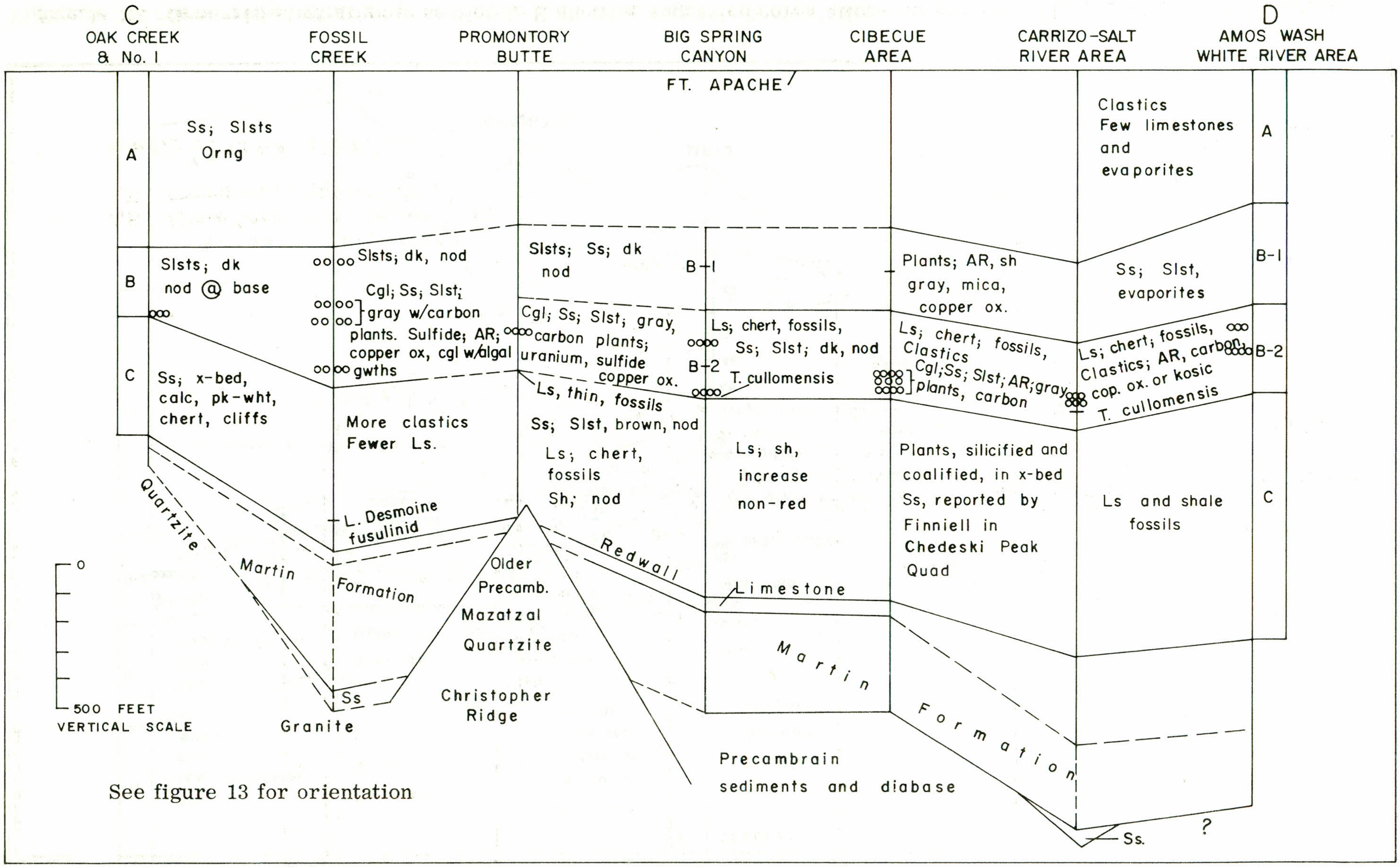

Figure 17. Generalized stratigraphic outcrop section C-D from Oak Creek southeast to Amos Wash

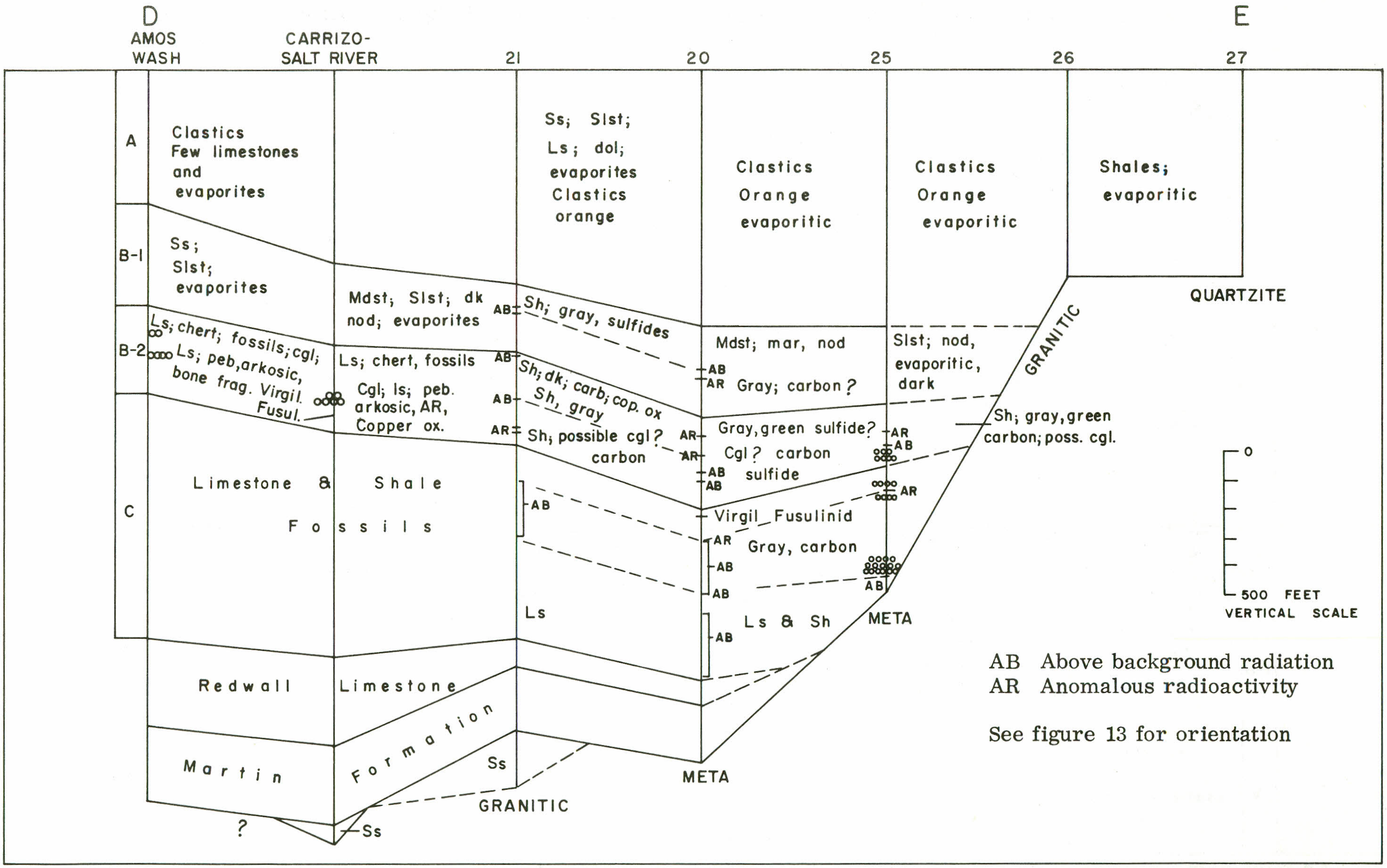

Figure 18. Generalized stratigraphic section D-E showing suggested correlations and onlap relationships

number of low gradient, marginal situations not conducive to the construction and preservation of easily recognized delta systems of the more classic types (Fisher, et al., 1969).

On the larger scale, Bissell (1969, p. 140) refers the central-northern Arizona Supai red beds to a deltaic environment fed by sediments being transported south from southern Utah between a northwestern Arizona partly marine facies and an east-central Arizona predominantly marine facies.

In summary, the shoaling northern end of the Pedregosa Basin is flanked on the east and north by the Defiance Positive Area, and on the northwest by the Kaibab Positive Area (Western Arizona Platform of McKee, 1967, p. 72). The former contributed arkosic and minor quartzitic debris to late Pennsylvanian fluvial sediments before being buried in Permian time. To the northwest Pennsylvanian sediments thin and lose clear-cut marine components. Fluvial sediments include conglomerates and related rock types.

Both regions are believed to have supported plant growth that was redistributed in certain fluvial and possibly shallow marine environments associated with a common basin, the Pedregosa.

Mineralization and Distribution of Radioactivity

Distribution of radioactivity in outcrop was determined by a hand-carried portable scintillometer and from gamma ray-neutron logs of holes drilled from the surface of the Mogollon Slope. In outcropping areas having known anomalous radioactivity, grab samples were taken of representative lithologies and submitted for quantitative determinations for uranium, vanadium, and copper. A few selected samples were analyzed for gold, silver, copper, lead, zinc, molybdenum, nickel, uranium, carbonate, calcium, and magnesium. The results of some of these analyses are shown in Tables II and III. For purposes of this report anomalous uranium is 10 ppm or more. No data are available to confirm the presence or absence of uranium in the subsurface. Gamma ray curves were subjectively judged as to whether or not peaks represented background for the hole, above background. or were anomalous. In this case "anomalous" carries no quantitative importance and is intended only to determine whether or not there is persistence suggestive of a subsurface zone of possible interest that might be correlative with the outcropping zone of interest.

Surface

Anomalous uranium is known in units "B", B-2, and B-1 in outcrop. We are not aware of any occurrences north of Fossil Creek Canyon at the west end of the Tonto Rim. Apparently, unconfirmed plant fossils reported from Oak Creek Canyon are impressions in oxidized red beds in unit "B" that is less than 300 feet thick (Figure 11). At Fossil Creek, 35 miles to the south, unit "B" is about 500 feet thick where it includes at least four channel-fill conglomerate horizons over a vertical interval of about 400 feet. A mineralized zone occurs within a 65-foot interval between the second and third conglomerates from below, the third conglomerate also being mineralized (Figure 38). The center of this gray mineralized zone is about half way (800 feet) between the base of "C" (Redwall Limestone) and the base of the Ft. Apache Limestone at the top of unit "A" (Figure 15). The zone has been exposed in several bulldozer cuts made in the process of exploring for copper and coal deposits (Figure 39). The coaly units, as mentioned, have been discussed by McGoon and are associated with gray to gray-green shales. Overlying the soft zone is a cliff-making complex of fluvial cross-stratified sandstones and limestone pebble conglomerates that contain plant impressions --the coalified materials largely having been destroyed (Figures 40, 41). Anomalous radioactivity is preserved only within some of the coaly zones within shales (Figure 30--Table II, nos. 1-2).

Mineralization other than uranium at Fossil Creek is found in a variety of lithologies and modes of occurrence. The capping conglomerate contains some hematite, pyrite, malachite, chalcopyrite, bornite, chalcocite, and covellite. These minerals occur as blebs in pebbles and matrix. Some sandstones contain azurite, malachite, pyrite, chalcocite, and covellite, which occur as nodules and as cavity fillings. A thin black limestone contains hematite, pyrite, marcasite, chalcocite, covellite, bornite, and chalcopyrite which occur as blebs and local fracture fillings. Azurite and malachite occur as thin laminae and spots within some of the coaly units. Gypsum veinlets also transect coaly units. Mineralization, though widespread, is spotty and not concentrated.

Orientation of the conglomerate units, though clearly channel fill deposits, are not readily established. The overall impression is southerly directed axes with surmised southerly flow directions. Fossil Creek flows southwest and is incised into unit "C". Unit "B" mineralization occurs on each side of the canyon a little over a mile apart. On both sides of the canyon the gray shale-carbonaceous zone pinches northeastward within one quarter of a mile while "red bed" conglomerate ledges continue laterally upstream. The southwestern limit is the present outcrop as it is near the edge of the ancestral Mogollon Rim and has been cut out (Twenter, 1962, p. 107) to the west and the space re-filled with Cenozoic volcanics (Figure 39).

In this locality all of the conglomerates, which range up to about 25-30 feet in maximum thickness, consist of clasts usually termed "limestone pebbles" (Figure 42). Relatively close inspection does not reveal large clasts derived from any units lower than "C" and most likely represent lag deposits composed of limestone nodules and other carbonate growth phenomena reworked by denudation of unit "B" rocks. Some of the growth forms are believed to represent individual algal growth features. The lowest conglomerate, on the north side of Fossil Creek, along one wall of a filled channel, contains what we believe to be an algal stromatolite. Separate and distinct, however, are individual rod shaped clast units that often are fetid and of complex internal structure. It is of interest to note that these rod shaped clasts are ubiquitous in all outcropping "B" and B-2 conglomerates, including those further east that are arkosic.

Although these conglomerates have been called "intraformational" it seems necessary to recognize that a fluvial system can transport only that which is available within the drainage basin. It is one thing to suggest "locally derived" but quite another to isolate that clast that has traveled the greatest distance. Even though the conglomerates seen in Oak Creek Canyon are within oxidized red beds, they still contain the conspicuous, rod shaped clasts, which often are five to six times longer than they are wide.

The nearest datable marine fossils are Desmoinesian fusulinids that are about 700 feet below the coaly units. Several years ago Peirce received a personal communication from Norman O. Frederiksen of the Socony Mobil Oil Company after the latter had been sent a sample of Fossil Creek coaly material for spore-pollen study. Mr. Frederiksen reported that he would consider the materials probably to be Lower Wolfcamp in age but could be as old as Upper Cisco (late Pennsylvanian-Virgilian). Huddle and Dobrovolny thought that the upper limit of Pennsylvanian representation likely was in rocks of our unit "B"; Jackson thought them probably all Pennsylvanian; and Brew judged them to be above rocks of Missourian age while defining a lower unit as Desmoinesian Gamma Member of the Naco Formation beneath all of the "B" unit conglomerates. However, at Big Springs Canyon to the east, his Gamma (our B-2) contains conglomerates that we believe are related to conglomerates at Fossil Creek. As a consequence we think his subdivision forces the Gamma downward across time lines in unnatural fashion. The conglomerates, from east to west, seem closely related and our correlations therefore reflect this likely possibility. Actually, Brew probably was influenced by Huddle and Dobrovolny who did about the same thing prior to his work. At Carrizo Creek their boundary between their Lower and Middle members of the Supai Formation is above the conglomerates whereas, at Fossil Creek, it largely is below them. This is why our boundary between "B" and "C" at Fossil Creek (Table I) differs from these other worker's--it considers the conglomerates and associated phenomena to be laterally related. This is to say that our eastern B-2 correlates within the western "B".

The next occurrence of known anomalous radioactivity is about 25 miles east in the forests beneath Promontory Butte. Probes up drainages between these localities, usually without the scintillation counter, revealed almost universal evidence of conglomerate, either in outcrop or as float. Often they were in red beds and not accompanied by reduced, or gray zones. Some malachite was observed in conglomerate near Milk Ranch Point southeast of Pine, Arizona.

The Promontory Butte uranium property has received much attention because it is the largest of the known outcropping occurrences of anomalous uranium. It is partially exposed by a large open-cut and has been drilled by numerous interests (Figure 43). Because we are interested primarily in the regional implications of this property, we provide only the highlights as we believe them to be.

Stratigraphic measurement in this region is rendered imprecise because of discontinuous exposure in the forest. We estimate that the mineralized horizon is about 700 feet above the Redwall Limestone and 900 feet below the Ft. Apache marker unit (Figure 43). There seems to be but one prominent zone of conglomerates and related cross-stratified sandstones and shales all laced with carbonized and coalified plant debris. The mineralized zone occurs within a maximum exposed vertical interval of about 10 feet and is erratic, as is the fluvial complex in general (Figure 44).

Although the uranium mineral occurs in coaly material and was not isolated, it is believed to be uraninite. Coaly material occurs in scraps along various planes in thinly-bedded sandstones and in larger entities over one foot in length and width in conglomeratic sediments (Figures 45, 46). Many plant impressions are present, the carbonized material not having been preserved. Carbonized materials are not equally mineralized and there is no ready explanation for the variance.

Sulfides, in small amounts, are well represented and occur as small blebs in pebbles and matrix, around pebbles, and in minute veinlets associated with calcite. Sulfides identified include pyrite, chalcopyrite, bornite, chalcocite, covellite, sphalerite, galena, and marcasite. Malachite and azurite occur locally and iron oxides occur along fractures. Some chemical analyses are listed in Table III, no's. 3-30 and Table IV, nos. 9-11.

The fluvial complex displays a progressive northward shift of channel deposits with pebbles grading to inclined siltstones-claystones on the south sides of channels, which we believe represent the inside of meanders. It is our opinion that the current was flowing in an easterly direction and that these are point-bar deposits (Figure 47). The channel complex is blanketed by a gray-green shale bed that contains abundant thin carbonized films of plant remains. This horizon is several feet thick, contains a thin coaly unit, but is not notably radioactive. A preliminary analysis of the claystone suggests that it consists of illite, chlorite, calcite, and quartz. This cap is believed to have had a significant influence as a confining layer above the underlying zone of once higher transmissivity.

Unoxidized sulfides and uraniferous materials remain in spite of the extensive erosional history that formed the escarpment and exposed a portion of this occurrence. This seems to be explained by the relative impermeability of the rocks that are involved, an impermeability likely inherited from Paleozoic time (Figure 48).

Blazey (1971) studied the macro and micro flora of this locality. He designated 21 species in 18 genera and 9 unassigned species of macrofossils, and, 41 species in 29 genera of spores and pollen. He suggests that the sediments are uppermost Pennsylvanian or lower Permian in age, an age similar to that suggested by Frederiksen for the coaly materials at Fossil Creek, and, an age indicated by Brew for the section containing conglomerates (unit B-2) at Carrizo Creek to the east, as determined by fauna.

Blazey identifies both wet and better drained upland species and notes a freshwater annelid, Spirorbis, attached to fossil foliage. A small pelecypod, also fresh water, is identified by Schumacher (personal communication) as a Pennsylvanian form, Carbonicula, widely associated with coal measures. However, he would not say that it could not be lower Permian in age.

Although the Promontory site is in unit "B" it seems likely that it is closely related to B-2 conglomerates to the east. Although there are differences from Fossil Creek, notably intensity of mineralization, it seems likely that both localities should be linked as representing a related fluvial history even though the important, smaller scale internal environments, differ in detail. These details, however, seem to be critical in localizing mineralization.

A few miles to the east, on the north side of Colcord Road, there is a prospect pit in conglomerate and sandstone that contains conspicuous copper oxides (Figure 49). Analytical work indicates anomalous uranium content (Table IV, nos. 1-2). The sulfide minerals pyrite, chalcocite, and covellite were identified. Again, plant debris is evident, especially as imprints.

Barren conglomerates were observed at Turkey Mountain and just north of the intersection of Chamberlain Trail with Colcord Road.

Eastward, Canyon Creek marks the approximate zone of transition from "B" to B-2 and B-1, and where "C" thickens and contains a larger proportion of normal marine beds. In spite of the introduction of marine units, conglomerates are present and are believed to be closely related to those present in "B" just to the west.

At Big Springs Canyon, B-2 overlies "C" with a sharp contact that likely represents a disconformity. B-2 is about 300 feet thick and contains multiple conglomerates and few shales although the details are obscured by forest and structure. The conglomerates encountered, though representative of only a small region, were judged to be barren of anomalous radioactivity.

The Cibecue area is characterized by a group of areally expansive benches cut on beds in B-2, principally the limestone at the upper contact with B-1 (Figure 50). Channel-fill conglomerates underlie these benches and at least one horizon 10 feet thick, and about 250 feet below a bench, is known to carry anomalous uranium (Figure 25-Table III, nos. 31-49; Table IV, no. 7). This channel complex consists of small interbedded lenses of sand, silt, and conglomerate and the complex interfingers laterally with siltstone. Although plant imprints and carbonaceous films locally are plentiful, chunky coalified material was not seen in outcrop. Other nearby conglomerates range up to 15-20 feet in thickness and frequently pinch rapidly in one direction and more slowly in the other (Figures 51-52). Drainage directions are not clear but the "feel" is easterly to southerly. The conglomerate horizons should be exposed in many places along the edges of the intricately eroded benches, therefore can be subjected to more extensive and intensive investigation.

In the Cibecue region, the type area of Finnell's Cibecue Member of the Supai Formation (B-1), there are anomalous occurrences of uranium in the B-1 unit (Table III, nos. 50, 51). The horizon is about 145-160 feet above the base and is a 6-inch zone rich in plant debris in gray, micaceous shales (Figures 31, 32, 33). Some copper oxide is closely associated.

Continuing towards the east, conglomerates again crop out in the vicinity of Carrizo Creek near where State Highway 77 crosses the bridge (Figure 34). Conveniently, a highway road-cut a short distance south of the bridge exposes the anatomy of the upper part of a channel-fill zone and a nearby modern channel exposes the remainder. The maximum thickness measured is about 30 feet. This is one of the arkosic conglomerates and in addition to the usual "limestone pebbles" there are carbonate clasts that might represent parts of "C", or even Redwall Limestone. There is some red chert which undoubtedly was derived from "C". Plant impressions are present, but rare. Here, the conglomerate is about 200 feet below the highest bench making marine limestone of B-2 (Figure 53).

That anomalous uranium is present is indicated in Table III, nos. 52-55. Some copper oxide was observed in the road-cut.

From Carrizo Creek to the Amos Wash-White River locality (Figures 37, 54) the terrain is bench-like, again largely because of the contrasting competence between limestones and clastics, especially the B-2 and B-1 contact. There are many miles of possible conglomerate exposures and very few were visited in the time available to us. Those few encountered were judged to be barren of anomalous radioactivity.

Subsurface

The subsurface control used is listed in Table II. There are 30 localities on the Mogollon Slope, and adjacent areas, where drill holes penetrate the zone or zones of interest. For the most part there is little core data and reliance for information must be placed on well cuttings and radioactivity logs. These logs, where available, were used as guides to stratigraphic horizons of possible interest and appropriate well samples were washed and examined under a binocular microscope. The Arizona Bureau of Mines maintains an active well sample repository. Although largely unreported in the past, recognizable carbonaceous material is widespread and stratigraphically confined to units believed directly correlative with surface exposures just discussed. Unit B-2 appears to contain the most examples of anomalous subsurface radioactivity over a large area. The upper part of "C" contains above background and anomalous activity that apparently is closely related to carbonaceous materials. This part of the surface stratigraphy was not examined closely. The only known reference to fossil vegetative materials in outcrop in unit "C" already has been cited (Finnell). However, its radioactivity level is not known.

There does not appear to be a systematic occurrence of anomalous radioactivity northwest of well no. 8 even though "B" conglomerates are believed to be present in wells no. 4 and 5, and might be present in nos. 6, 7, and 8 (Figure 14). Carbonate well cuttings from unit "B" attributed to limestones on some logs might represent nodules and/or actual conglomerates composed of reworked carbonate growths, therefore, the presence or absence of conglomerates often seems problematical.

Most of the wells southeast of a line through 8-9, with the exception of those in which unit "A" rests on Precambrian rocks, contain some evidence of carbonaceous material, especially in shales. As suggested above, conglomerates generally are difficult to isolate with certainty in well cuttings.

Core descriptions for wells 11 and 13, over 8 miles apart, contain similar descriptions of abundant "carbonized wood" with pyrite. These horizons are believed to be in unit "C". In the absence of radioactivity surveys, we do not know the radiation levels of these particular occurrences.

Perhaps the most interesting pattern is that shown in Figure 9 in unit B-2. These wells stretch over a lateral distance of about 60 miles. There is an interesting hint of lateral or stratigraphic continuity of anomalous radioactivity in B-2.

The kick in well no. 20 at about 3,280-3,285 was inadvertently left out of Table II. It likely is a conglomerate, and, some sulfide is suspected. All of the kicks along this line, except the one in no. 21, are possible conglomerates. The one in no. 21 is believed to be a carbonaceous shale.

Well nos. 25 and 29 seem to contain more conglomerate in B-2 and both are relatively close to Precambrian rocks that stand at levels higher than B-2. Carbonaceous materials this close to the Defiance Positive Area should suggest that the Defiance region was supportive of a vegetative cover. It would be very interesting to learn more about the depositional environments that prevailed along its edges. That there was fluvial activity seems established.

ORIGIN OF MINERALIZATION

Much has been written about the origin of uranium deposits and occurrences and it is beyond the scope of this report to again summarize the literature on this subject. Finch (1967) and Fischer (1974) were particularly useful. To quote form Fischer, p. 363:

> "Finch (1967) recorded the distribution and characteristics of nearly 4,600 peneconcordant uranium deposits in the United States. Most deposits are in sandstone lenses of stream origin, in beds of late Paleozoic age or younger, probably coincident with the evolutionary development of land plants. Although many formations are host to these deposits, in any mining district most deposits are in only one or a few favored stratigraphic units."

The peneconcordant deposits are of two basic types, tabular and roll. Most of the sandstone type deposits of the Colorado Plateau region belong to the tabular type. Again, from Fischer (p. 364):

> "Below the zone of recent near-surface oxidation, the tabular bodies of the Colorado Plateau region are enveloped in rocks of reduced geochemical characteristics—the sandstone is pale gray to

white and contains coalified plant fossils and finely disseminated pyrite; the associated mudstone is gray or green and also contains disseminated pyrite."

And (p. 373):

"Virtually all known deposits are in sandstone lenses interbedded with mudstone; these beds formed in intermontane basins, on broad alluvial plains or fans, or on coastal plains. The host sandstone ranges from fine- to coarse-grained, and in places it is conglomeratic; it is dominantly quartzose but commonly arkosic.

"The major uranium deposits formed in beds that seem to have had a gentle dip, which had resulted from either stream gradient or slight tectonic tilting. And these deposits probably formed at shallow to moderate depths—the major uranium districts and belts were localized in zones ranging in distance from a few miles to a few tens of miles from the depositional or erosional edges of the host beds....

"The time of ore formation has not been determined with assurance, but...the tabular deposits formed relatively soon after the host beds accumulated, perhaps during a general period of sedimentation of the overlying beds."

Uranium ores in Pennsylvanian-Permian rocks have not been economically mined within the region nor do published studies of any of the occurrences exist. Too, our laboratory work is yet minimal. Even so, we have a few general ideas.

The occurrences noted are of the peneconcordant type, associated with plant debris, are light-colored, contain pyrite in most cases, and one, (the largest) Promontory Butte, is intimately related to shale (mudstone). All are clastic rocks believed to have been deposited in fluvial and closely associated environments. Anomalous uranium is widespread and seems clearly to be stratigraphically controlled.

The Promontory Butte deposits, in spite of its position within a zone of relatively intense erosion and a rainfall sufficient to support a pine forest, has been able to maintain its reduced zone mineralogy. There are no known cross-cutting mineralizing relationships suggestive of post lithification fracture filling. We are led to a tentative conclusion, that mineralization is diagenetic and related to the migration of ground waters, that is, the Promontory Butte prospect represents mineralization of late Paleozoic rocks in late Paleozoic time.

Recognizing the mobility of uranium, it is not possible, in the cases of anomalous but low uraniferous content, to speculate as to the emplacement timing. At the Carrizo Creek locality anomalous uranium is associated with a blackened modern root zone that occurs at the contact between conglomerate and underlying gray siltstone (Table III, no. 55). Roots usually grow where there is water, so the evidence suggests that, where possible, some uranium is still in transit.

The sources of uranium in late Paleozoic ground water are limited to any of the preexisting rocks or sediments with which water came into contact. On the Defiance side it is clear that there was a variety of Older Precambrian rocks exposed, including granites, quartzites, meta-volcanics, and weakly metamorphosed sediments. However, it is likely that a granitic terrain was dominant. On the west side of the basin, where the most anomalous known uranium occurs, information is more speculative.

In the vicinity of the Promontory Butte prospect, unit "C" is in depositional contact with Older Precambrian Mazatzal Quartzite that is at the northeast end of the paleogeographic Christopher Ridge. Further to the southwest the ridge contains a variety of rock types including rhyolites. None of these rock types is evident in the conglomerates but this does not mean that these older rock types had no effect, regional or local, on the composition of waters. The nature of the terrain to the south and west in late Paleozoic time is not known because Paleozoic rocks, if ever present, have been removed from these regions.

To the northwest, unless there is unknown buried topography, the only rocks exposed on the Kaibab Positive Area were previously deposited Paleozoic strata.

We suspect that the Precambrian rocks were sources of uranium even though reconstruction of the paleogeography is difficult. The Younger Precambrian Apache Group uranium deposits are to the south but their former extent and topographic-structural position relative to late Paleozoic sedimentation is not clear. Perhaps, should these Precambrian uranium deposits also require a source in preexisting Older Precambrian rocks, they and the late Paleozoic occurrences could have a common ancestor.

URANIUM FAVORABILITY OF PALEOZOIC ROCKS

It is clear that certain Pennsylvanian and/or Permian strata contain rock arrangements favorable for uranium mineralization. This favorability is contained within unit B-2 in particular and "C" in general. These units are widespread and are believed to underlie at least 2,500 square miles in the deep subsurface of southern Navajo and Apache counties, and hundreds of square miles in the shallow subsurface of the Ft. Apache Indian Reservation.

It should be emphasized that the occurrence of anomalous uranium has not been established anywhere in the subsurface of the Mogollon Slope. Microanalytical techniques have not been applied to any of the well cuttings. It is assumed that radiometric peaks closely associated with carbonaceous matter likely represent slight, local increases in uranium content. The consequent rationale is that uranium sources probably are not the limiting factor. The proper host conditions, including sedimentary and chemical environments, are believed to be more important controls on the degree of uranium favorability.

The mere size of the generally favorable region, coupled with limited detailed data pertaining to the distribution of depositional environments, leaves much room for speculation and individual judgment. In the absence of absolute knowledge, favorability level, based upon perception of geological possibilities, is a subjective matter.

The fact that there are no known uranium deposits of economic size and grade, over a lateral distance of 80 miles in outcrop, could be construed as a negative factor against the existence of potentially economic deposits. On the other hand, this is but one slice through a region that demonstrates a known variability ranging from barren rock to concentrations of anomalous uranium sufficient to justify considerable past and present industry exploration effort. What some other slice through the region would reveal is a matter for speculation.

Although fluvial activity was widespread in "B" and B-2 time, its results seem to be manifested largely in limestone pebble conglomerates and associated finer-grained clastics, and not widespread accumulations of interbedded sandstones and mudstones. This could have a constraining influence on size of deposit potential, especially west of central Navajo County. Along the Defiance front, however, there is evidence that at least locally, a coarsening takes place that includes siliceous components. Depending upon relief-process relationships, there could have been bordering relatively narrow alluvial plains, fans, or small deltas, or a narrow strand zone receiving relatively coarse fluvial components. Base level and other changes could've led to favorability enhancing interbedding of coarse and finer-grained clastics. Too, plant debris is believed to have been introduced from the Defiance region. In well no. 22 (Figures 8, 9), at a depth of about 3,600 feet, well cutting fragments contain very small rod-like coalified plant remains (stems?) that appear identical to forms observed from the Promontory Butte outcrop locality 70 miles to the west.

Carbonaceous phenomena, in the form of carbonized vegetable materials, appear to be more widespread, both in outcrop and subsurface, than heretofore was known. It is possible that many of the light-colored carbonaceous shales, especially in "C", accumulated in shallow marine waters and are disassociated from fluvially deposited shales. On the other hand, those around or near suspected conglomerates, especially in B-2, might be fluvial-lacustrine deposits. The presence of carbonaceous matter in shallow marine "C" implies that this material had a not too distant land source and that, landward, "trash collections" may exist in rocks of "C" time.

If, as previously mentioned, the most significant episode of constructive mineralization is Paleozoic in age, then there is an important preservational requirement. Promontory Butte offers the only experience in which some of what is believed to be original (primary) mineralization remains "frozen in". Examples of macroscopic secondary uranium minerals are not known. The preliminary geochemical data suggest that the occurrences recorded here are of the copper-uranium type and not uranium-vanadium. With low vanadium content, stable uranium-vanadium minerals, such as carnotite, might not have formed. If this be so, the targets might tend to be the original reduction type primary deposits.

Although brief mention was made of regional angular unconformities beneath rocks of Upper Cretaceous and Middle Tertiary age, there is no evidence that the geologic histories represented had any influence, constructively or destructively, on Paleozoic host rock mineralization. Both unconformities include beveling of Paleozoic strata that were slightly tilted towards the northeast. The earliest of the unconformities is intimately related to the Grants uranium district in New Mexico, the largest such district known in the United States. In the latter case the beveled rocks are Jurassic in age.

Whether or not these post-Paleozoic regional events significantly influenced the down-dip portions of these older rocks is difficult to determine. In the case of Promontory Butte the only criteria involve judgments as to the timing of the permeability reduction that seems essential to protect the primary mineralization. Mineralization is closely related to coalified plant material therefore a prime requisite for mineralization was preservation of wood so that it could become coalified. Subsequently, it was necessary to preserve both carbonized substances and mineralization. These preservational requirements seem best served by early diagenetic processes that terminated in a protecting lithification. Subsequent breaching of this protection, by fracturing and ground water percolation, could prove destructive. The widespread occurrence of carbonaceous materials in the subsurface suggests that preservational aspects might be positive.

Strata of similar age in New Mexico are known to contain uranium deposits in the red bed Permian Abo Formation and the Pennsylvanian-Permian Sangre de Cristo Formation, which also contains some thin marine limestones (Finch, 1967, p. 56).

The favorability of certain late Paleozoic strata as hosts for uranium mineralization is a fact. From what is now known the degree of favorability varies depending upon depths of exploration. Everything else being equal the favorability level is higher for shallow drilling areas, such as the Ft. Apache Indian Reservation, than it is for the deep drilling required on the Mogollon Slope. This is to say that there is no direct evidence of the likely occurrence of deposits of sufficient size and grade to justify deep drilling. However, geological considerations lead to the possibility of enhanced favorability along the western edge of the Defiance Positive Area, including the region beneath portions of the White Mountain volcanic field. Only subsequent drilling will provide answers to the important questions.

It should be emphasized that a case can be made for the possible occurrence of oil and/or natural gas along this trend. As this aspect remains largely untested, it may be that this will give added incentive for the drilling needed to learn more about uranium favorability along this geologically significant but unevaluated trend.

SUMMARY AND CONCLUSIONS

This report summarizes the general geologic history of a 12,000 square mile region along the southern edge of the Colorado Plateau geologic province, in Arizona. Emphasis is placed on uranium favorability of both outcropping and subsurface Paleozoic rocks. The Paleozoic section crops out along the escarpment at the plateau edge, the Mogollon Rim, and about 30 oil and gas tests provide subsurface control beneath the plateau surface. This work is preliminary in that the region is large, subsurface control is deficient, and there is little previous literature on uranium favorability of Paleozoic host rocks in this region.

Pre-Pennsylvanian Paleozoic rocks are thin to absent and consist largely of marine rocks where present. Pennsylvanian and Permian strata, in contrast, constitute a thick sequence consisting of marine and near marine rocks at the base, red beds in the middle, and sandstones and marine strata at the top. Rocks considered favorable hosts for uranium occur close to an ill-defined Pennsylvanian-Permian systemic boundary. Regional stratigraphic terms place the zone within the upper half of the Naco Formation and in overlying rocks classified as Naco Formation by some and Lower Member of the Supai Formation by others. The latter is the zone of prime interest and often is considered a transition between the Naco and Supai formations.

For regional stratigraphic purposes it is useful to consider a stratigraphic interval between the base of the Pennsylvanian Naco Formation, which is a regional unconformity, and the base of the Permian Ft. Apache Limestone Member of the Supai Formation. The latter is present throughout the study region and is an important stratigraphic reference horizon in the subsurface. Numerous stratigraphic names have been used to describe units within this interval and, as yet, there is no regional system of nomenclature that is functional. For the purposes of this study we have used an informal system that recognizes three basic units to the west: "C", "B", and "A" from the base up, and four units to the east: "C", B-2, B-1, and "A". These units also are recognized in the subsurface. "C" is the Naco Formation and equivalents, B-2 is the transition zone, B-1 represents the basal unit of the Supai Formation of most recent workers, "B" occupies the position to the west that B-2-B-1 do to the east, and, "A" is the remainder up to the base of the Ft. Apache Member.

"C" becomes less marine to the north and northeast and pinches out sharply against the largely granitic rocks of the southwestern side of the Defiance Positive Area. To the northwest it thins and changes facies by loss of clear-cut marine units. Some workers think of this as lateral gradation with the Supai Formation but we prefer to think of the changed facies also as "C", or Naco Formation. The paleogeographic element to the northwest is the Kaibab Positive Area that acted differently than the Defiance Positive Area, where Older Precambrian rocks were exposed.

That there were nearby land areas in "C" time is demonstrated by subsurface geologic relationships and by plant fossil debris reported in outcrop and present in subsurface rocks.

Marine conditions persisted longer southeast of Canyon Creek than in the area to the northwest. Whereas "B" to the northwest contains limestone pebble conglomerates associated with plant debris and red beds, B-2 to the southeast contains similar conglomerates and plant debris associated with red beds, but also, thin marine carbonate rocks and shales. These conglomerates, in many cases, are clearly fluvial in origin and it seems likely that, somewhere, fluvial products were contributed to a shallow marine basin. Such conditions might not have permitted the construction of large scale deltas.

In outcrop, both "B" and B-2 contain anomalous uranium (10 ppm or more). Together, anomalous uranium was detected, by chemical analysis, from outcrops distributed over a lateral distance of 75 miles. From the northwest these occurrences are at Fossil Creek Canyon, Promontory Butte, Colcord Road-Turkey Mountain, Cibecue, and Carrizo Creek (see Table V for specific locations). More extensive study would undoubtedly reveal additional anomalous areas.

In the subsurface, B-2 and "C" are anomalously radioactive on gamma ray logs. Carbonaceous debris, as reflected in shales, is widespread in the subsurface, occurring 115 miles to the northeast of the Fossil Creek outcrop locality.

That the Defiance Positive Area contributed clastics to parts of B-2 is reflected by coarse quartz and feldspar grits as far west and south as the Carrizo Creek bridge locality where these constituents are present in channel deposits along with limestone pebbles and some red chert. That they are not seen anywhere to the west is interpreted to mean that the western conglomerates were sampling a different terrain associated with the Kaibab Positive Area. Coalified plant parts from B-2 in one of the eastern well sites is believed to indicate derivation of plants from the Defiance Positive Area.

Unit B-1, in outcrop, contains some anomalous uranium near Cibecue and a couple of radiometric peaks in the subsurface B-1 may be analogous. The outcrop is characterized by a thin plant fossil zone that is carbonized and associated with malachite, a copper oxide. Unit B-1 is interpreted to either pinch against or grade laterally westward into "B".

Uranium is closely associated with copper, and not vanadium. Primary mineralization, characterized by metallic sulfides and uranium, probably as uraninite in coalified material, is viewed as having formed in Paleozoic time by diagenetic processes that include a final sealing that has allowed some of these deposits to endure in their reduced state.

Units "C", and B(B-2 and B-1) define the north closing end of a shoaling basin that opened towards the south. This is believed to be the north end of the Pedregosa Basin that was a marine basin in southeastern Arizona and adjacent regions, in Pennsylvanian and Permian time. This north end was surrounded by paleogeographic features that supported plant growth and fluvial processes. Precambrian rocks are believed to have provided sources of uranium in both surface and ground waters.

That some of these rocks are favorable hosts for uranium is clear. From what is known thus far, the targets might be relatively small. Smaller targets should warrant immediate exploration effort in those areas where the potential target is shallow, perhaps less than 500 feet. There are hundreds of square miles of favorable exploration ground on the Ft. Apache Indian Reservation benchlands that are closely underlain by unit B-2 (Figure 50).

In the deeper drilling country of the plateau surface, targets would be difficult to determine. The Defiance Positive Area trend is relatively untested and may provide geologic conditions that would enhance favorability. Future exploration for oil and gas might provide additional information useful in the assessment of deeper uranium potential.

Whatever the reason for drilling, explorationists should be encouraged to gather as much data as possible regarding horizons of potential uranium occurrence, especially those in B-2 and the shoreward phases of "C".

Figure 19 Forested slopes along Mogollon Rim escarpment—Little Diamond Rim in center distance. Looking easterly.

Figure 20 Christopher Mountain, a paleogeographic feature composed of Older Precambrian quartzite, rises to the south of Promontory Butte uranium prospect that occurs within Pennsylvanian—Permian strata. Looking southerly.

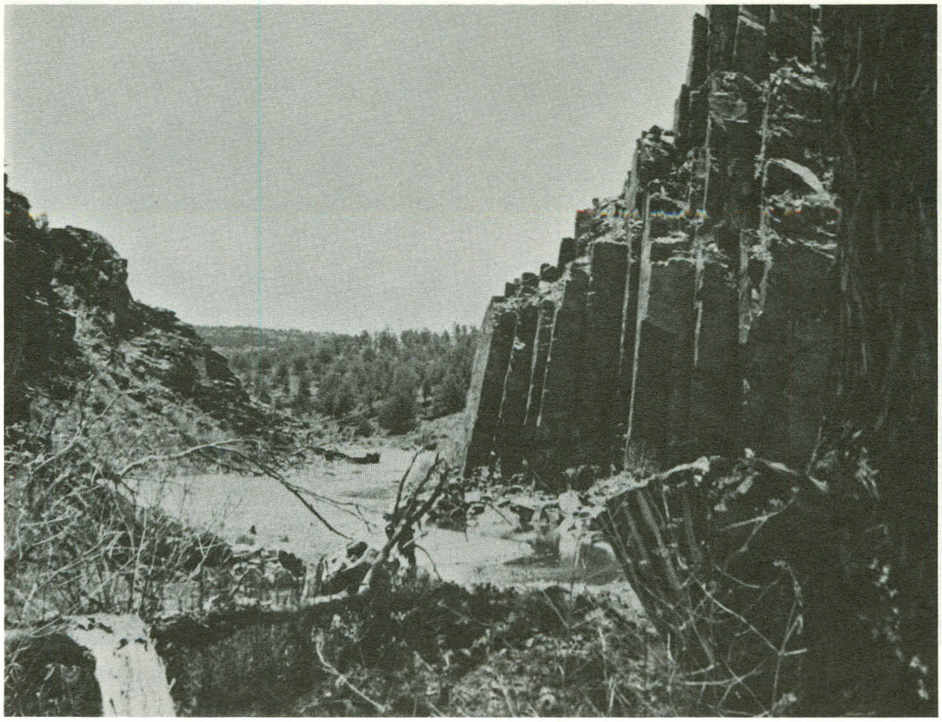

Figure 21 Jointed Bonito Quartzite of probable Older Precambrian age. Defiance Plateau looking northerly.

Figure 22 Quarry in Older Precambrian granitic rock overlain by the Permian Supai Formation. Southern Defiance Plateau looking northwesterly.

Figure 23 Conglomerate in unit B-2 at Carrizo Creek. Arkosic grit is quartz believed derived from Older Precambrian granitic rocks of the Defiance Positive Area.

Figure 24 Conglomerate in unit B-2 at Amos Wash. In addition to coarse quartz and feldspar grains, pencil points to a quartzite clast.

Figure 25 Conglomerate near Cibecue deposited within a fluvial system. Contains plant impressions, some carbon, and some anomalous uranium and copper. Looking northerly.

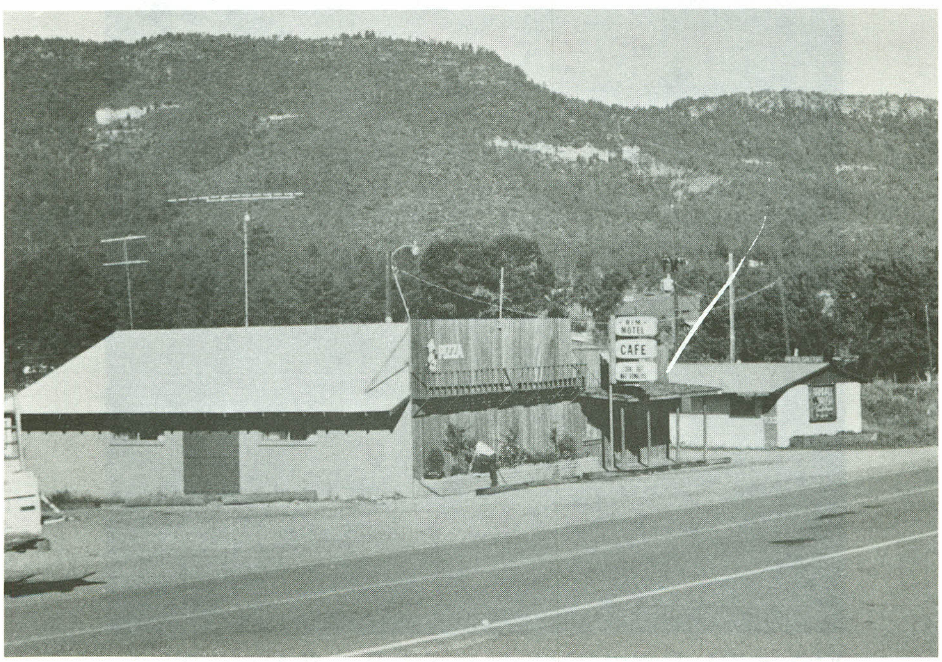

Figure 26 Light-colored band is Ft. Apache marker unit near Pine, Arizona. Cliffs are Coconino Sandstone along Mogollon Rim. Looking northwesterly.

Figure 27 Central bench is Pennsylvanian-Permian (Naco-Supai formations) contact of Winters. It is the contact between units B-2 and B-1 of this report. East Cedar Creek looking northerly.

Figure 28 Kennecott Copper Company-Ray open-cut copper mine. Light-colored bands in distant Dripping Spring range are deformed Paleozoic strata. Looking easterly.

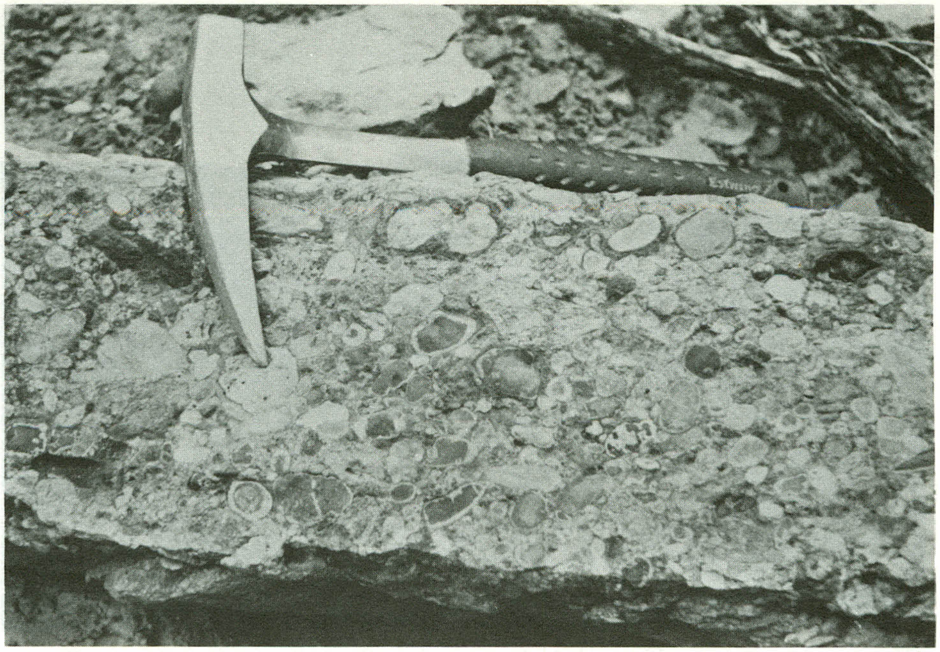

Figure 29 Float block of conglomerate

Figure 30 Coaly unit in Fossil Creek Canyon.

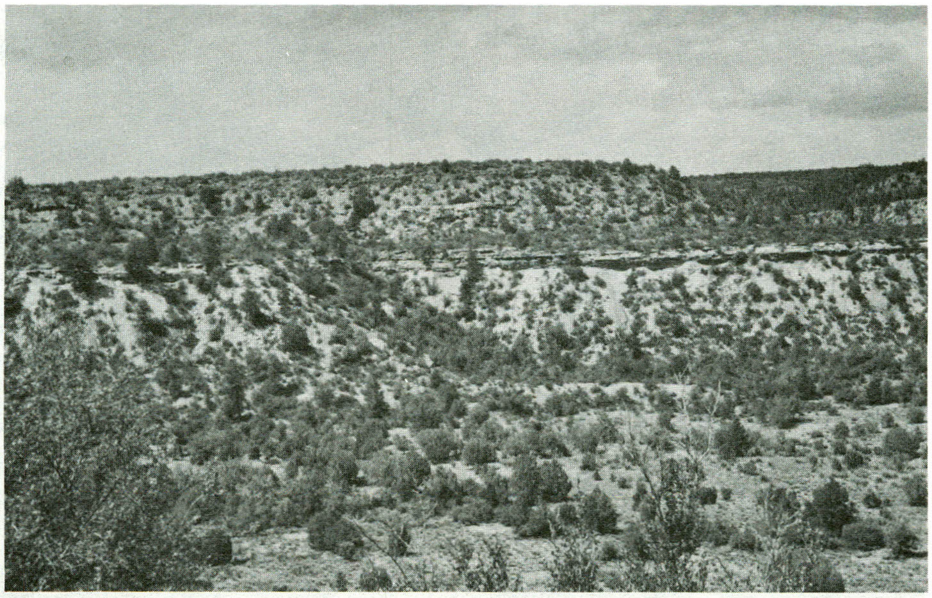

Figure 31 Base of central bench-maker contains plant fossils and anomalous copper-uranium in unit B-1 (Cibecue Member of the Supai Formation of Finnell). Near Cibecue looking northerly.

Figure 32 Horizon of plant fossils, some copper and radioactivity, in unit B-1 near Cibecue (See Figure 31).

Figure 33 Impressions of plant fragments in block to left—mud cracks in block to right of pick. Same area as Figures 31-32.

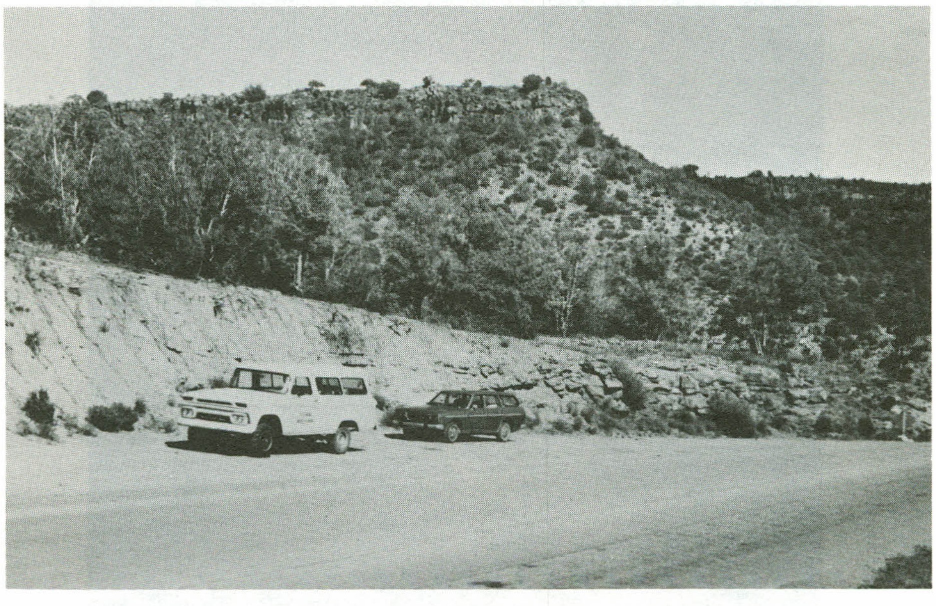

Figure 34 Conglomerate to right of vehicles grades rapidly to light-colored shales and contains minor anomalous uranium and copper. Occurrence is in unit B-2 near Carrizo Creek. Corduroy Creek basalt flow (1.5 m.y.) forms cap in background. Looking northeasterly.

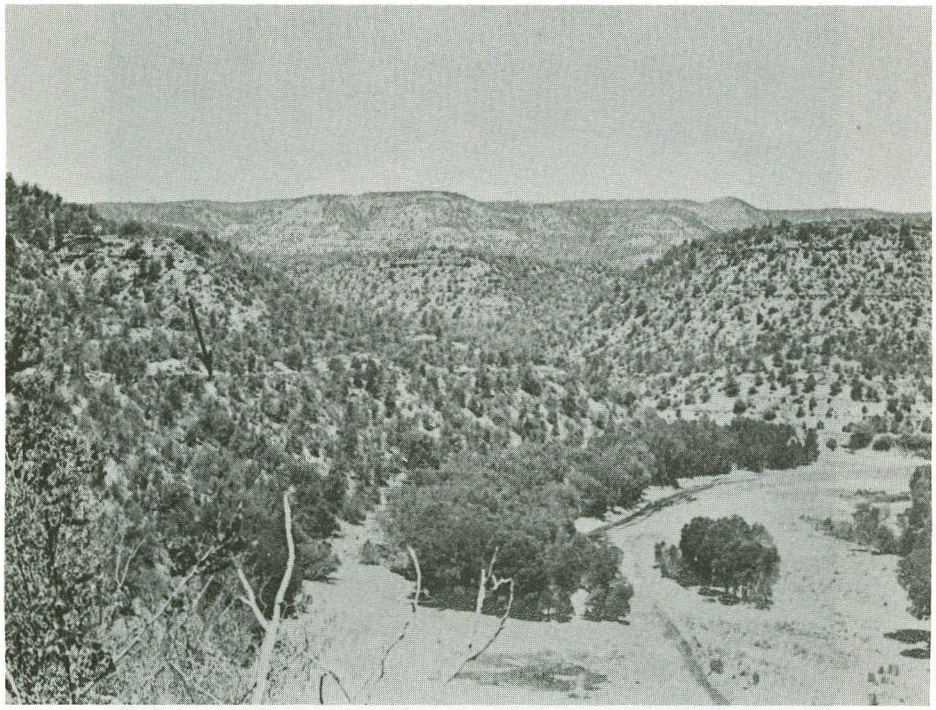

Figure 35 Top of nearest ledge-maker is Pennsylvanian-Permian (Naco-Supai formations) boundary of Winters, and B-2—B-1 contact of this report (See Figure 27). Looking northwesterly.

Figure 36 Bone fragment to right of handle occurs in conglomerate and arkosic fluvial sandstone of unit B-2 near confluence of Amos Wash with White River.

Figure 37 Conglomerate unit (See Figure 36) illustrating stratification and textural contrasts. Looking northerly.

Figure 38 Fossil Creek Canyon area. Light-colored zone in foreground and capping conglomerate are in unit "B" and contain some mineralization. Supai Formation in distance thinly capped by Cenozoic volcanics. Looking northerly.

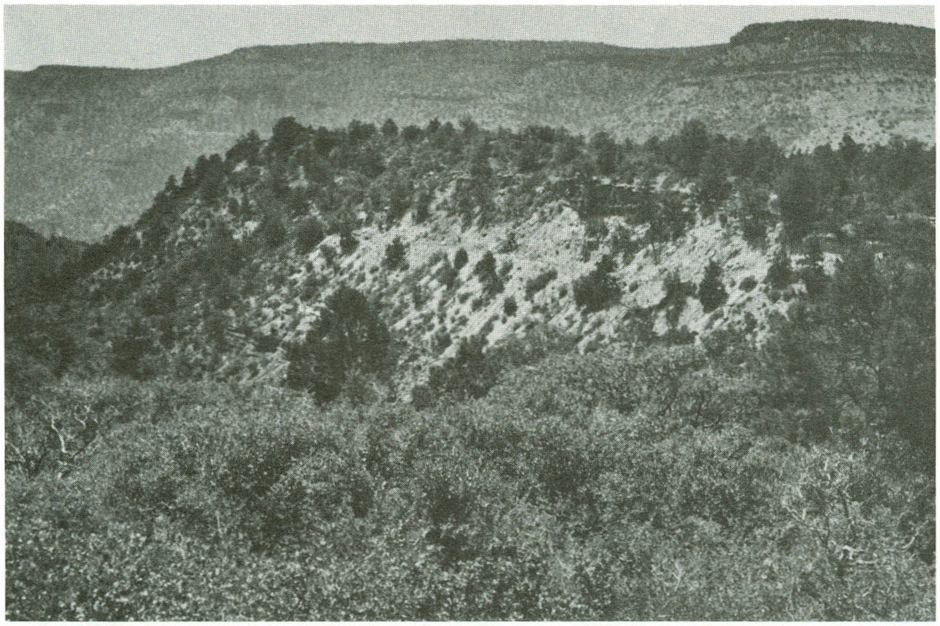

Figure 39 Similar to Figure 38 showing cut beneath conglomerate cliff. Cut was made in 1960 to expose mineralized carbonaceous beds. Thick pile of Cenozoic volcanics in distant background is piled against the ancestral Mogollon Rim. Looking northwesterly.

Figure 40 Resistant, ledge-making, weakly mineralized capping conglomerate in Fossil Creek Canyon. Looking westerly.

Figure 41 Fossil plant impressions in sandy zone from channel-fill complex. Block displaced in making cut. Carbon generally not preserved at this locality.

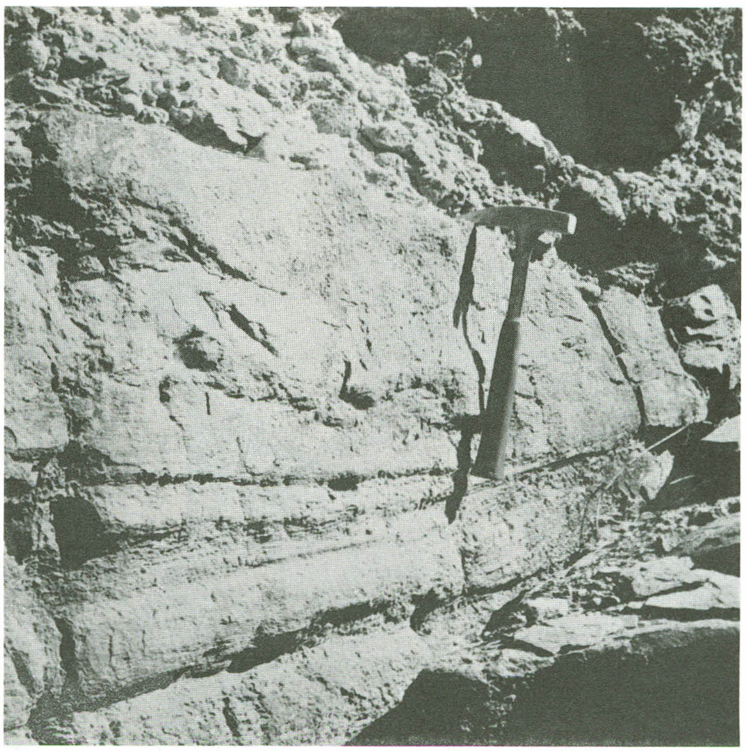

Figure 42 Sandstone-conglomerate contact. Conglomerate clasts largely are dense and calcareous. Base of light-colored zone (Figure 38)-Fossil Creek Canyon.

Figure 43 Promontory Butte uranium prospect in unit "B". Mineralized zone exposed in foreground bench. Note channeling in high left wall and outcrop of the Ft. Apache marker unit in center distant background. Mogollon Rim capped by Permian sandstones. Looking northerly.

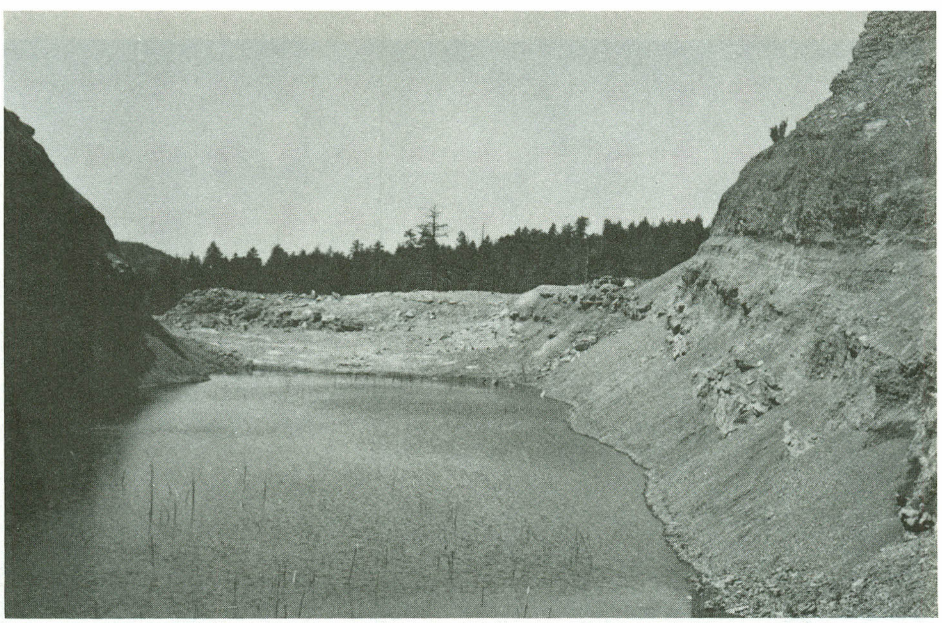

Figure 44 Looking southward from back of cut. Mineralized bench at front dips toward observer and is capped by greenish-gray shales containing abundant carbonized films of plant fossils.

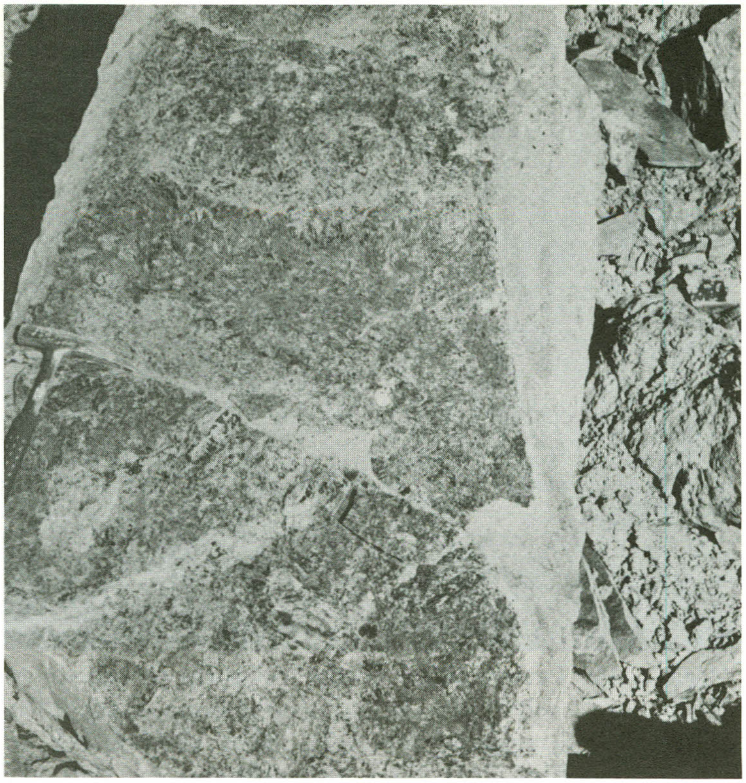

Figure 45 Uraniferous sandstone slab exhibiting carbonized plant scraps. Promontory Butte prospect.

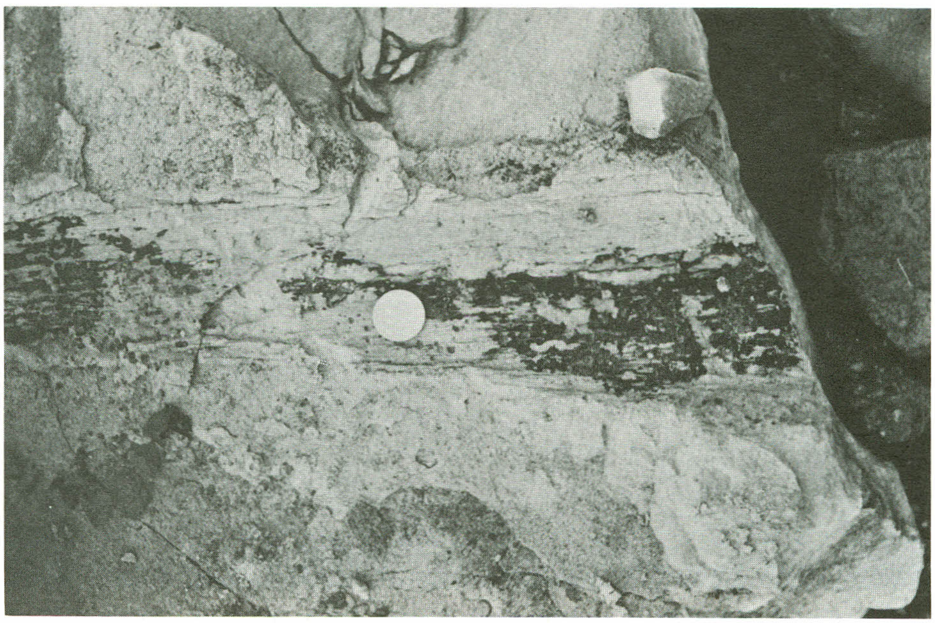

Figure 46 Plant imprints with partially preserved carbonized material impregnated with a uranium mineral believed to be uraninite. Promontory Butte prospect.

Figure 47 Channel-fill mineralized complex is believed to represent point-bar deposits. Note shift of channel to left and upward merging with inclined shales. Looking easterly.

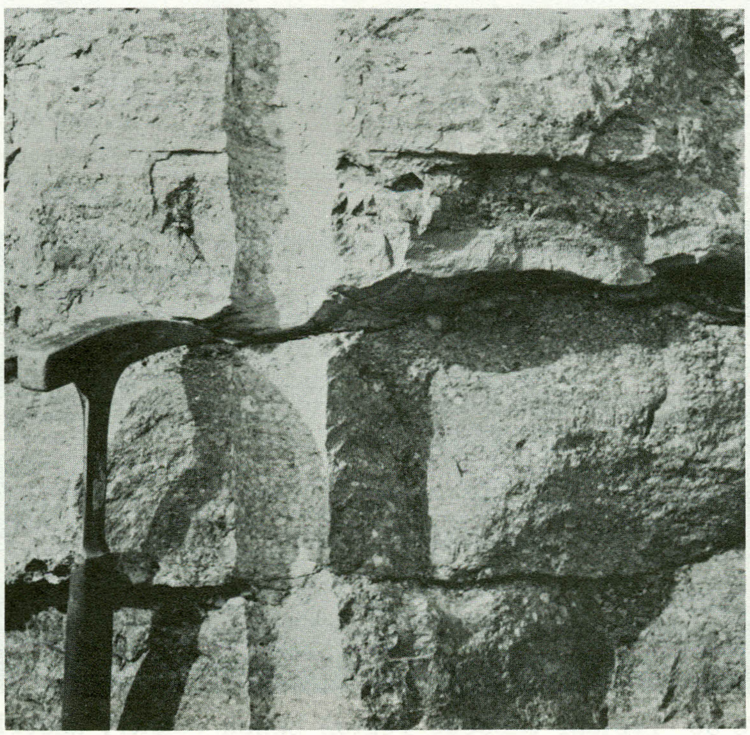

Figure 48 Well indurated, light-colored, sulfide and uranium-bearing conglomerate at Promontory Butte.

Figure 49 Prospect pit in cupriferous and anomalously radioactive conglomerate and sandstone—Colcord Road.

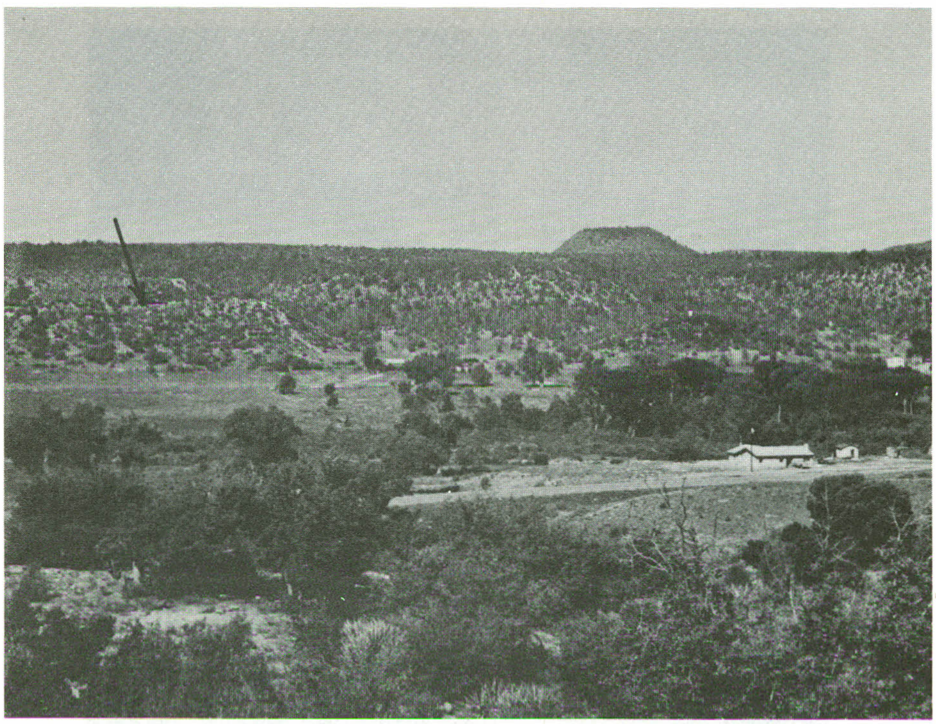

Figure 50 Typical Cibecue region bench country underlain by channel deposits of unit B-2. Looking west toward Lonely Mountain, a remnant of unit B-1. Arrow points to conglomerate outcrop shown in Figures 51-52.

Figure 51 Channel-fill conglomerate pinches to left and thins to right. Cibecue area looking westerly.

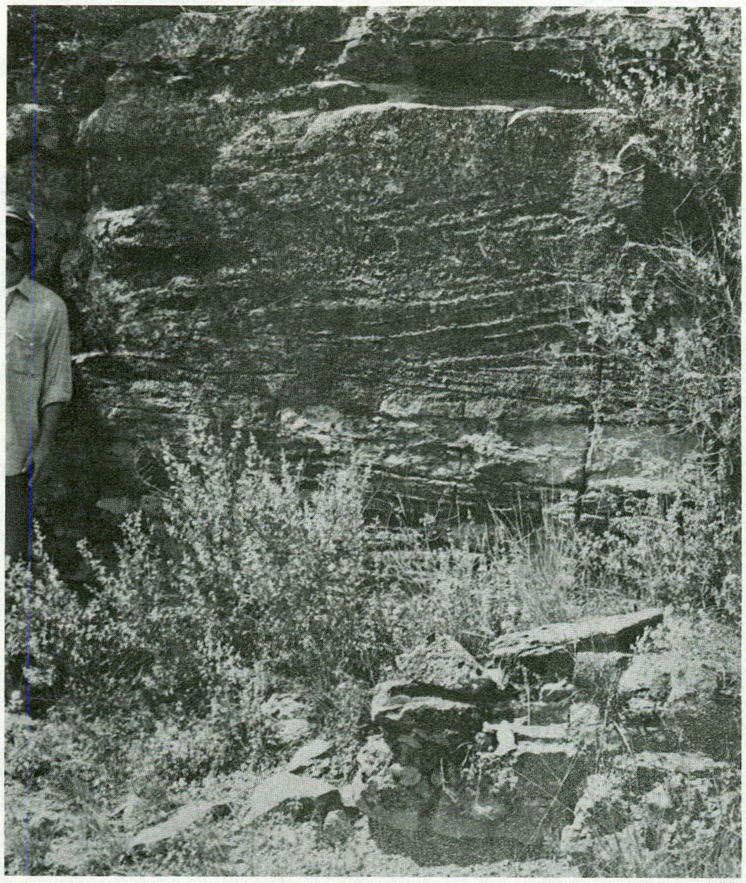

Figure 52 Cross-stratification in resistant conglomerate ledge shown in Figure 51.

Figure 53 Regionally extensive marine bench-making unit at top of B-2 (See Figure 27, 35). Looking southwesterly.

Figure 54 Cross-stratified channel-fill conglomerate at Amos Wash locality. Looking northerly.

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APPENDIX

TABLE II--BASIC WELL INFORMATION*

WELL NO.	ABM	OGCC	NAME	ELEV	DEPTHS TO STRAT UNITS (feet)	UNIT THICKNESSES (feet) unit	cum.	REMARKS
Coconino County					**			***
1	2066	351	Willet No. 1	7199	Base FA 1274?	"A" 620	620	No Gamma Ray log; Oak Cr.
			State	GR	Top "B" 2100	"B" 240	860	Canyon area--conglomerates
			24-20N-5E		Top "C" 2340	"C" 414	1274	in lower part "B" in out-
			SW of NW		Top R 2754	R 30	1304	crops--no known anomalous
					Top M 2784	M 71	1375	radioactivity
					Top PC 2855			
2	---	436	Oil Discovery	7000	T. Naco 2400	Naco 500	500	No GR log; no logs or
			#1 Fed	GR	T. R 2900	R 145	645	samples--tops are those
			17-19N-6E		T. M 3045	M 65	710	reported; no known anom.
			NE of SE		T. PC 3110			rad.
3	1359	186	Roy Owens #1	5724	B. FA 1742	"A" 508	508	GR log; some increase back-
			Diablo-Amarillo	GR	T. "B" 2250?	"B" 370	878	ground rad. 2470-2590
			12-20N-11E		T. "C" 2620?	"C" 450	1328	
			NE of NW		T. R 3070	R 110	1438	
					T. M 3180	M 380	1818	
					T. PC 3560			
4	1677	240	Pickett #1 Padre	6250	B. FA 1810	"A" 605	605	GR log; Limestone pebble
			Canyon-State	GR	T. "B" 2415	"B" 340	945	conglomerates 2685-2700 and
			26-20N-10E		T. "C" 2755	"C" 380	1325	2732-2745; abv. background
			NW of SE		T. R 3135	R 65	1390	rad. at 2150-2154 and 3042
					T. M 3200	M 391	1781	
					T. PC 3591			
5	2062	376	Steinberg #1A	6260	T. "C" 2650	"C" 485	485	GR log; samples and logs
			Flowalt-Babbit	GR	T. R 3135	R	--	from 2270 in "B"; Ls peb. cgls
			24-19N-10E		T. M ?	M	--	2568-2593 and 2623-2633; no
			SE of SW		T. PC 3613		963	anom. rad. Basement granitic

*See Figure 8 for locations
**FA=Ft. Apache; R=Redwall Ls; M=Martin Fm; SS=Sandstone; PC=Precambrian
***See Arizona Bureau of Mines Bulletin No 185 for additional basic data

Table II, continued

WELL NO.	ABM	OGCC	NAME	ELEV	DEPTHS TO STRAT UNITS (feet)		UNIT THICKNESSES (feet) unit		cum.	REMARKS
Coconino Cty, cont.										
6	--	475	Pease #1 Federal	7368	B. FA	2065	"A"	535	535	GR log; No spls; poss.
			21-15N-10E	GR	T. "B"	2600	"B"	380	915	cgls 2860-2890 and 2948-
			SW of NW		T. "C"	2980	"C"	430	1345	2980; unexplained anom.
					T. R	3410?	R	100	1445	rad. just above Coconino
					T. M	3510?	M	85	1530	Sandstone at 680-710
					T. PC	3595?				
7	2559	464	Eastern Pet. #1	6904	B. FA	1782	"A"		578	GR log; poss. cgls. 2600-
			Fed Moqui Bardo	GR	T. "B"	2300	"B"	410	928	2630; no anom. rad.
			10-14N-11E		T. "C"	2710?	"C"	550	1478	
			NW of SW		T. R	3260	R	301	1779	
					T. M	3561	M	130P*	1909	
					TD 3691 in M		*partial			
8	1013	71	Monsanto #1 Fed	6854	B. FA	1655	"A"		525	GR log; poss. cgls. in "B";
			Cabin Wash	GR	T. "B"	2180?	"B"	570	1095	no anom. rad.; basement
			30-14N-14E		T. "C"	2750	"C"	560	1655	granitic
			SW of NE		T. M	3310	R	0	---	
					T. PC	3650	M	340	1995	
Navajo County										
9	443	20	Eisele-McCauley	5558	B. FA	1630	"A"	570	570	No GR log; data weak;
			#1	DF	T. "B"	2200?	"B+C"	1200	1770	Lower Desmoines fusulinid
			1-16N-16E		T. "C"	?	M-R	300	2070	rept. 3360-70
			SW of SW		T. R-M?	3400				
					T. PC	3700				
10	1017	86	Pan Amer #1	5678	B. FA	1845	"A"		675	GR log; above background
			Aztec-B	GR	T. B-1	2520	B-1	305	980	rad peaks at 2990, 3008,
			9-16N-18E		T. B-2	2825	B-2	265	1245	3010 in B-2; 3185, 3330 in
			SW of NE		T. "C"	3090	"C"	487	1732	"C". Generally gray zone
					T. R	3577	R	99	1831	3000-3200--some carb. sh and
					T. M	3626	M	209	2040	probably cgls. Basement
					T. PC	3835				granitic.

Table II, continued

WELL NO.	ABM	OGCC	NAME	ELEV	DEPTHS TO STRAT UNITS (feet)		UNIT THICKNESSES (feet)	unit	cum.	REMARKS
Navajo Cty, cont.										
11	40	--	Union-Continental	6112	B. FA	1925?	"A"		625	No GR log; spls and core
			#1 Aztec	GR	T. B-1	2550?	B-1	325	950	descrip; gray interval in
			19-15N-18E		T. B-2	2875?	B-2	250	1200	"C": 3238-3382; sh w/"car-
			NE of NE		T. "C"	3125?	"C"	647	1847	bonized" wood 3339-3349;
					T. R	3772	R	40	1887	sh w/pyrite and carbon. mat-
					T. M	3812?	M	38P	1925	ter 3349-3357; cgls described
					TD 3850	in M				(abv from core descrip.)
12	1354	175	Calif Oil #1A	5830	B. FA	1532	"A"		668	GR log; entire interval cored;
			State	GR	T. B-1	2200	"B"	680	1348	Anom. rad. in "B" 2411-2420
			12-14N-18E		T. B-2	?	"C"	67P	1415	(carb. frags in dk ls and blk
			NW		T. "C"	2880?				sh; 2582-2587, 2605-2615
					TD 2947	in "C"?				(carb in Ls peb cgl-dk dol-
										dk Ls)
13	961	--	Union-Continental	6034	B. FA	1760	"A"		785	No GR log; spls and core des-
			#1 NMA	GR	T. B-1	2545?	B-1	185	970	crip; sh, gray to blk,carbon.
			34-15N-19E		T. B-2	2730?	B-2	358	1328	wood, pyrite 3189-3199; sh,
			SW of NE		T. "C"	3088?	"C"	456	1784	gray to blk, carbonized plant
					T. M	3544	M	49	1833	material 3290-3298; cgls rept.
					T. PC	3593				(abv from core descrip); base-
										ment granitic
14	2016	291	Taubert & Steed	6002	B. FA	1690	"A"		890	GR log; rad. anom. 2862-2868,
			#1 Babbitt	GR	T. B-1	2580	B-1	280	1170	2884-2895--gray carb sh?
			35-14N-19E		T. B-2	2860	B-2	300	1470	Basement granitic
			NE of NE		T. "C"	3160?	"C"	528	1998	
					T. R	3688?	R	6	2004	
					T. M	3694?	M	106	2110	
					T. PC	3800				

Table II, continued

WELL NO.	ABM	OGCC	NAME	ELEV	DEPTHS TO STRAT UNITS (feet)		UNIT THICKNESSES (feet) unit		cum.	REMARKS
Navajo Cty, cont.										
15	39	--	Lockhart #1	6012	B. FA	1710	"A"		780	No GR log on hand; Ls peb
			Aztec	GR	T. B-1	2490	B-1	410	1190	cgl 3015-3020 in core
			33-14N-20E		T. B-2	2900	B-2	247	1437	descrip; Virgilian fusu-
			NE of SE		T. "C"	3147	"C"	503	1940	linids rept 3166.
					T. R	3650	R	7	1947	
--	1011	61	Lydia Johnson #1		T. M	3657	M	70	2017	Lyd Johnson hole: Ls peb
			Aztec		T. PC	3727				cgls rept at 2935-2945,
			33-14N-20E							2970-2975. Basement
			C of NE							granitic
16	1006	85	Pan Amer #1	5429	B. FA	1745	"A"		655	GR log; slt anom. rad. 2923-
			Aztec-A	GR	T. B-1	2400	B-1	365	1020	2930--poss. cgl. zone in
			5-16N-20E		T. B-2	2765	B-2	325	1345	no. 15, 3165-70, 3372-3385;
			SE of NE		T. "C"	3090	"C"	499	1844	sh, carb at 3200-3210 in
					T. R	3589	R	71	1915	spls, some pyrite? 3220-3230
					T. M	3660	M	264	2179	in spls. Highest rad. at
					T. PC	3924				3877-3890 in basal paleo-
										zoic sand--prob. Dev.;Base-
										ment granitic.
17	622	--	Great Basin #1	5270?	B. FA	1660?	Total interval			No GR log; apparently "C"
			Taylor-Fuller		T. PC	3530?		1870		on PC granite
			21-17N-20E							
			NW of NW							
18	2099	460	Cree #1 Scorse	5070	B. FA	1590	"A"		630	GR log; Ls peb cgl 2620-
			Fee	GR	T. B-1	2220	B-1	240	870	2630, 2690-2700; abv back-
			33-18N-20E		T. B-2	2460	B-2	360	1230	ground rad at 2485, 2705,
			SW of SW		T. "C"	2820	"C"	513	1743	2745, 2795; anom rad (high-
					T. M	3333	M	201	1944	est sed in hole) 2960-
					T. PC	3534				2970; basement granitic

Table II, continued

WELL NO.	ABM	OGCC	NAME	ELEV	DEPTHS TO STRAT UNITS (feet)	UNIT THICKNESSES (feet) unit	cum.	REMARKS
Navajo Cty, cont.								
19	8	--	Gen'l Pet #14-6 Creager-State 6-19N-23E SW of NW	5720 DF	B. FA 2635 T. B-1 3300? T. PC 3345	"A" B-1 45	665 710	No GR log; 1200 feet Paleozoic rocks, including "C" and B-2, pinch by onlap between here and no. 18. Basement granitic.
20	1009	76	Pan Am #1-B NMA 25-12N-23E SW of NE	6244 GR	B. FA 1955 T. B-1 2855 T. B-2 3180 T. "C" 3470 T. M 4157 T. PC 4385?	"A" B-1 325 B-2 290 "C" 687 M 228	900 1225 1515 2202 2430	GR log; anom. rad. 2985-3010 in B-1, 3205-3212--sh w/sulfide?, and poss cgl, 3580; minor rad peaks at 3335-40,3375-80. Virgilian fusulinid-Triticites Cullomensis rept 3485. Basement meta. See Fig. 9.
21	2076	368	Tenneco IX Ft. Apache 31-10N-21E NE of SE	6626 GR	B. FA 1540 T. B-1 2275 T. B-2 2517 T. "C" 2840 T. R 3517 T. M 3625 T. SS 3830 T. PC 3980?	"A" B-1 242 B-2 323 "C" 677 R 108 M 205 SS 150	735 977 1300 1977 2085 2290 2440	GR log; anom. rad. 2354-2371, sh w/sulfides, 2530 and 2540, sh w/carbon. and malachite, 2768-2775, sh, carb (highest peak in hole). Minor peaks from sh, carbon between 2950-3160. Basement granitic. See Fig. 9.
Apache County								
22	2065	370	Tenneco #1 Fed B 4-10N-24E SW of NE	6852 GR	B. FA 2330 T. B-1 3155 T. B-2 3490 T. "C" 3685 T. R 4398 T. M 4490 T. SS 4570 TD 4657	"A" B-1 335 B-2 195 "C" 713 R 92 M 80 SS 87P	825 1160 1355 2068 2160 2240 2327	GR log; 3360-3395 sh, carb, abv background rad; anom rad. 3570-3585 (highest in hole) poss. cgl, carbon.; other sh, carb peaks 3610-3619, 3650, 3682. Minor peaks from sh, carbon between 3619-4100. See Fig. 9.

Table II, continued

WELL NO.	ABM	OGCC	NAME	ELEV	DEPTHS TO STRAT UNITS (feet)	UNIT THICKNESSES (feet) unit	cum.	REMARKS
Apache Cty, cont.								
23	1333	66	Mae Belcher #1 State 20-9N-31E SE of NW	7273 GR	B. FA 2085 T. A-2 2385 T. B-1 absent? TD 2921	A-1 300 A-2 536	 836	No GR log; basal cgl. in lower Supai rept. at 2852--contain clasts of Precambrian rocks
24	1363	207	Eastern Pet #1-A Coyote Cr. 27-10N-30E	6945 GR	B. FA 1500 T. B-1 absent? T. PC 2321	"A"	821	No GR log; 1400 ft of Paleozoic rocks, including "C", B-1, B-2, pinch between here and No. 22. Basement granitic
25	1020	98	Pan Amer #1-A NMA 12-13N-25E SE of SE	5875 GR	B. FA 1820 T. B-1 2695 T. B-2 2990 T. "C" 3185 T. PC 3634	"A" B-1 295 B-2 195 "C" 449	875 1170 1365 1814	GR log; anom rad. (highest in hole) 3075-3080, poss. cgl, carbon; minor rad. peak 3100-3105. Cgls 3110-3230, 3260-3310, and 3475-3535 w/ rad. peaks between 3250-3600. Cgls reflect granitic and quartzite content. Basement meta. See Fig. 9.
26	6	--	Franco-Arizona #1 Gov't 14-14N-26E	5672 GR	B. FA 1840? T. PC 2545	"A" 705	705	No GR log; 1100 feet of Paleozoic rocks, including "C", B-2, & B-1, pinch between here and No. 25 less than 6 mi. distant. Basement is granitic
27	7	--	Argo #1 State 22-15N-29E	5900 GR	B. FA 1680 T. PC 2350	"A" 670	670	No GR log; basement is quartzite
28	2503	442	Crest #1 Spurlock 3-17N-26E	5961 GR	B. FA 2410? T. B-1 3200 T. B-2? 3390 T. PC 3600	"A" B-1 190 B-2 210	790 980 1190	GR log; anom rad. not recognized. Basement is granitic

Table II, continued

WELL NO.	ABM	OGCC	NAME	ELEV	DEPTHS TO STRAT UNITS (feet)		UNIT THICKNESSES (feet)	unit	cum.	REMARKS
Apache Cty, cont.										
29	1015	57	Kerr-McGee #1	5587	B. FA	2005	"A"		755	GR log; anom. rad. 3196-
			Hortenstine	GR	T. B-1?	2760	B-1	290	1045	3202 (high in hole), poss.
			23-18N-25E		T. B-2	3050?	B-2	215	1260	cgls, sh, carb.; cgls
					T. "C"	3265	"C"	139	1399	w/ss 3150-3220, 3270-3404.
					T. PC	3404				Cgls & ss arkosic w/quartz-
										ite frags. Basement is
										meta. See Fig. 9.
30	989	74	Brown & Asso.	5803	B. FA?	1320	"A"	580	580	GR log; highest rad. in
			#2 Chambers-	DF	T. "B"	1900	"B"	205	785	hole--numerous peaks 1900-
			Sanders		T. PC	2105				2105. Basement granitic
			27-21N-28E							
			SW of NE							

TABLE III--Uranium (10 ppm+), Vanadium, Copper

Locality Spl Nos.	U (ppm)	V (ppm)	Cu (ppm)	Remarks
Fossil Creek		From "B"		
1-20	90	275	1800	Coal
2-21	70	200	1100	Coal
Prom. Butte		From "B"		
3-24	550	20	1250	Sandstone
4-46	216	65	930	?
5-51	200	10	30	?
6-32	170	-5	235	cgl
7-52	75	10	8100	?
8-34	65	15	10	Sandstone
9-33	50	480	125	Sandstone
10-30	46	5	15	Sandstone
11-25	30	10	190	Sandstone
12-7	30	10	130	Siltstone
13-27	28	10	70	Siltstone
14-54	28	5	12000	?
15-28	26	40	170	Sandstone
16-39	26	15	150	cgl
17-6	26	40	75	cgl
18-40	24	5	70	Sandstone
19-29	24	30	85	cgl
20-37	22	40	80	cgl
21-3	22	30	170	Sandstone
22-41	22	15	770	?
23-55	20	20	5800	?
24-38	20	5	40	cgl
25-36	19	30	200	Siltstone-plants
26-2	17	5	190	Sandstone
27-35	14	10	105	cgl
28-1	13	5	230	cgl
29-26	12	90	105	cgl
30-31	10	5	55	cgl
Cibecue		From B-2		
31-8	80	-5	125	Sandstone
32-7	50	40	900	Siltstone
33-13	28	15	195	Siltstone
34-30	24	15	350	Siltstone
35-25	22	15	900	?
36-24	20	-5	375	Sandstone
37-15	18	5	680	Mudstone
38-10	16	-5	510	cgl

(continued)

Table III--continued

Locality Spl Nos.	U (ppm)	V (ppm)	Cu (ppm)	Remarks
Cibecue		From B-2	(continued)	
39-33	16	-5	25	Sandstone
40-26	14	15	75	Sandstone
41-23	13	-5	315	cgl
42-2	12	15	530	cgl
43-4	12	5	340	cgl
44-19	12	-5	65	Mudstone
45-21	11	-5	185	Sandstone
46-27	11	5	135	Sandstone
47-28	11	5	135	Sandstone
48-31	10	15	295	Sandstone
49-32	10	-5	340	Sandstone
		From B-1		
50-9	60	55	3250	Siltstone-plants
51-8	24	80	445	Siltstone-plants
Carrizo Crk		From B-2		
52-14	13	15	1150	Mudstone
53-16	11	-5	230	cgl
54-18	10	5	290	cgl
55-14	14	10	670	Modern root zone in siltstone

TABLE IV--Miscellaneous Analyses

Locality	ppm								%			
Spl No.	Au	Ag	Cu	Pb	Zn	Mo	Ni	U	CaO	MgO	CO_2	Remarks
Colcord Rd												
1-1	-.02	1.0	2200	45	10	-2	25	14	47.4	0.56	36.0	cgl
2-2	-.02	9.6	14000	30	10	-2	20	7	20.3	0.33	15.0	Sandstone
Fossil Crk												
3-4	-.02	1.4	3300	20	10	-2	15	8	13.8	0.58	11.5	Sandstone
4-5	-.02	-0.2	245	40	5	2	20	-2	52.9	0.70	39.5	Ls, blk
5-6	-.02	0.6	550	40	5	-2	25	3	47.0	0.51	36	cgl
Carrizo Crk												
6	-.02	-0.2	160	25	5	-2	15	13	23.8	0.38	17.5	cgl
Cibecue												
7	-.02	0.4	240	45	10	-2	30	12	45.6	1.1	34.5	cgl
Defiance Granite												
8	-.02	1.2	5	15	65	-2	5	3				Granite
Prom Butte												
9-1	.04	21	9000	105	15	12	30	1600	28.2	2.8	22	cgl
10-13	-.02	8.2	1300	380	1300	32	40	330	41.1	3.7	31	cgl
11	-.02	10	800	205	475	22	65	1450	33.0	2.3	25	cgl

TABLE V--Some Outcrop Locations

Fossil Creek

Access: State 87 to Strawberry; west on Fossil Creek-Camp Verde road to jeep trail at elev. 5640 shown on Strawberry quadrangle, 7.5' series. Exposures in cuts at elev. 5120 below and west to northwest of Nash Point. Also exposures in cuts ½ mile north of Fossil Creek 1/8-1/4 mile east of Mud Tanks Draw at elev. 4640-80. Four-wheel-drive vehicles only and then drive with caution--road subject to washouts at canyon crossings.

Promontory Butte Prospect

Access: State 260 east of Payson; Promontory Butte 15' quadrangle; turn to north in east ½ sec. 26, T. 11 N., R. 12 E. opposite Boy Scout Ranch. Main cut near center of sec. 24--another smaller cut ½ mile to west.

Colcord Road--Turkey Mountain

Access: State 260 east of Payson; Woods Canyon 15' quad; junction to SE in sec. 34, T. 11 N., R. 13 E. is Colcord Road; small prospect pit to north about 100 yds and just west of local access road to north in SE¼, SE¼ sec. 35.

Big Spring Canyon

Access: State 288 south of State 260 and north of Young; Young and Chediski Peak 15' quads; junction to east--Young quad--in sec. 27, T. 10 N., R. 15 E.; 3/4 mile to Ft. Apache Reservation boundary (gate locked at times). Big Spring Canyon drains southwest to Canyon Creek near Chediski Farms in central western part of the Chediski Peak quad. Access also from Cibecue off State 77 (see Cibecue). Conglomerates near road just east of canyon crossing.

Cibecue

Access: State 77; Carrizo 7.5' and Cibecue 15' quads; junction to northwest from State 77 in Carrizo quad; principal conglomerate sample site in road cut in SW corner of map where road Y's near 4840 benchmark south of Cibecue. Anomalous uranium occurrence in B-1 along walls of "cemetery" canyon west of Cibecue Creek and 1.5 miles north of Cibecue.

Carrizo Creek

Access: State 77 between Show Low to north and Salt River to south; Carrizo quad; conglomerate in road cut ½ mile south of Carrizo Creek crossing; pull-out wide spot on north side.

Amos Wash

Access: State 73 and Indian Route 9 south along Amos Wash--junction shown on Cone Butte 7.5' quad; conglomerate-bone locality ¼ mile north of Gaging Station on White River near side road to west at elev. 4680; forms ledge on the northwest-southeast spur.

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The Arizona Bureau of Geology and Mineral Technology was established in 1977 by an act of the State legislature. This act represents a reorganization of the Arizona Bureau of Mines which first was created in 1915 and placed under the authority of the Arizona Board of Regents. This authority has not changed. The Bureau continues its service in the fields of geology, metallurgy, and mining in response to public inquiries, state agency requirements, and various research grants. In order to carry out these functions, two basic branches now are recognized:

Geological Survey Branch

This branch is charged with the responsibility of acquiring, disseminating, and applying basic geologic data that are designed to (a) enhance our understanding of Arizona's general geologic and mineralogic history and to assist in determining the short and long range influences these have on human activity, and (b) assist in developing an understanding of the controls influencing the locations of metallic, nonmetallic and mineral fuel resources in Arizona.

Mineral Technology Branch

This branch conducts research and investigations into, and provides information about, the development of Arizona's mineral resources, including the mining, metallurgical processing, and utilization of metallic and nonmetallic mineral deposits. These activities are directed toward the efficient and safe recovery of Arizona's mineral resources as well as insuring that recovery and treatment methods will be compatible with the basic environmental needs of the state.

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