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Geological Society of America

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This report is preliminary and has not been edited
or reviewed for conformity with Arizona Geological Survey standards

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FIELD TRIP SUMMARY

by

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INTRODUCTION

This informal guidebook was assembled to serve the broad purposes of the Coal Geology Division's two-day Arizona field trip.

The following remarks are intended to assist in placing the field trip locale into a regional geologic perspective.

Our bus route, beginning in Phoenix, traverses a region having considerable geologic diversity (Figs. 1, 2, 2A). It begins in the classic Basin and Range Province (B&RP) and ends well into the Colorado Plateau Province (CPP). The Boundary between provinces traditionally inspires debate. The recognition of a variously defined Transition Zone (TZ) in central Arizona tends to lessen the either/or discussion that ensues if some form of TZ is not recognized (Fig.1).

GEOLOGY

Basin and Range Province

The name Basin and Range is descriptive and alludes to the alternation of ranges and alluviated valleys that mark the present landscape. Of relatively recent vintage is the realization that the central portions of most valleys are underlain by a relatively thick sequence of basin-fill, the depositional response to the late Tertiary (post 15 m.y.) B&R disturbance, the principal tectonic event responsible for the present landscape (Peirce, 1978). Basin-fill thicknesses of up to 10,000 feet or more have been postulated from geophysical studies. Figure 3 depicts a strong negative gravity anomaly in a valley region just west of Phoenix. The "bull's eye" was drilled in 1968 and the top of a multi-cubic mile halite mass was encountered at a depth of 880 feet below a cotton field. The salt is presently utilized to make salt products sold in Arizona and solution cavities are used for propane-butane storage.

Because of erosional back-wearing (pedimentation) of range blocks subsequent to the B&R disturbance, present valley surfaces are up to several miles wider than the buried paleobasins. The resulting buried topography, though perhaps not yet widely appreciated, has significant land-use impact in this province.

In the Phoenix region, the known stratigraphic column is limited largely to rocks of Precambrian and Cenozoic ages (see geologic map of State). Precambrian rocks are dominated by crystallines of both plutonic and metamorphic origins, and Cenozoic rocks of pre-B&R-disturbance age consist of sediments, volcanics, and perhaps occasional crystalline plutonic and

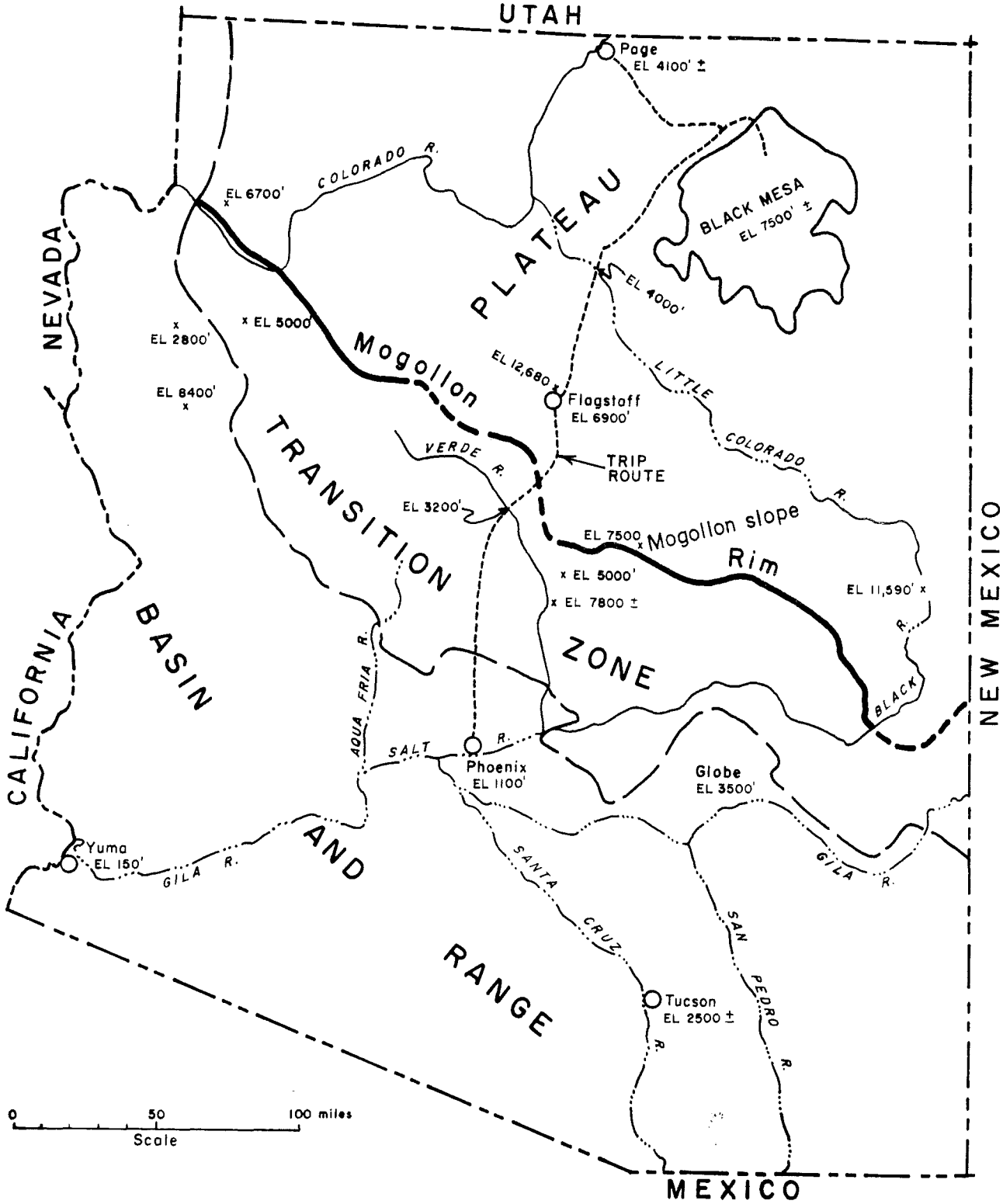


Figure 1. Index map showing trip route, geologic provinces, and selected geographic features.

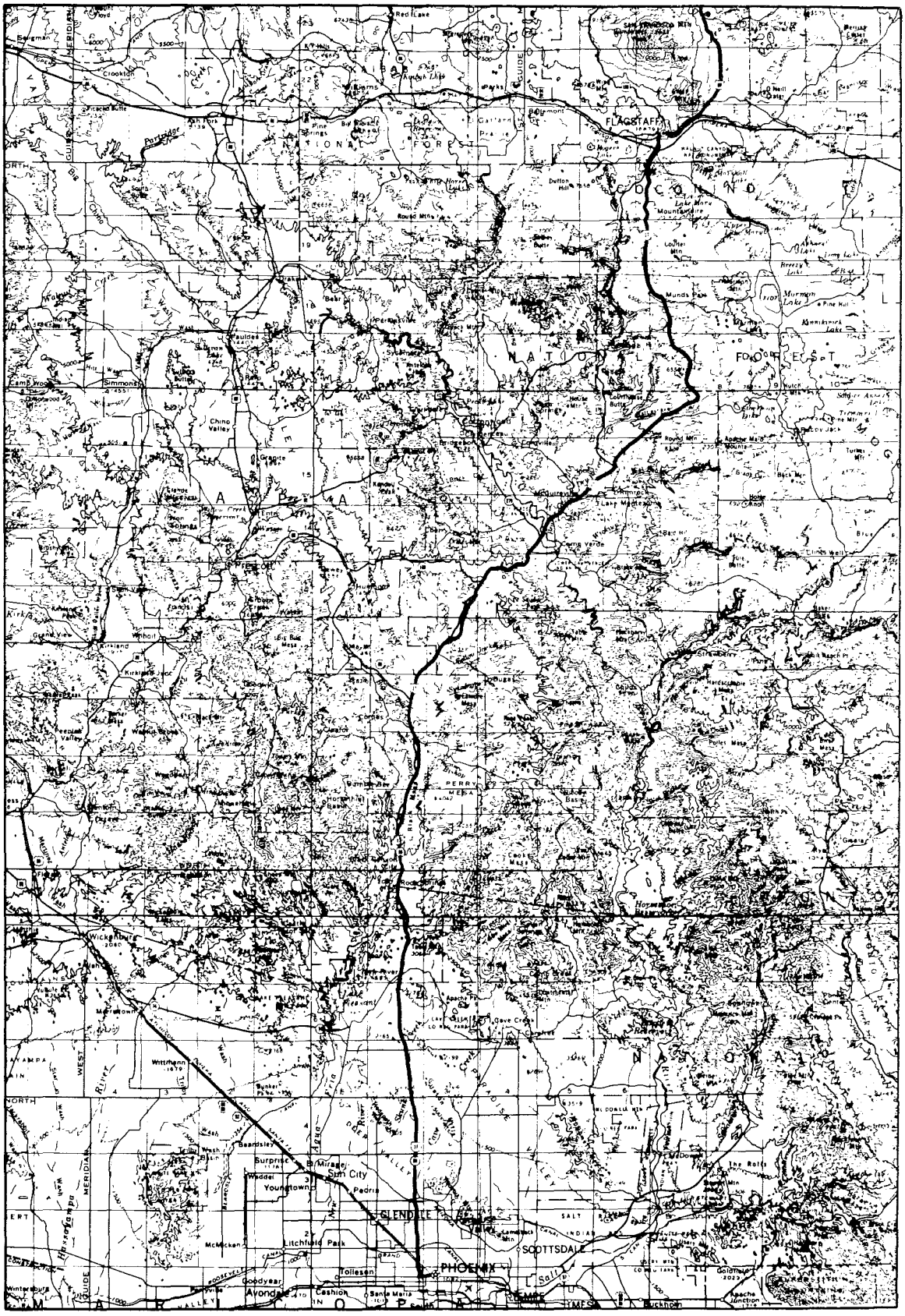


Figure 2. Topographic base with trip route - southern part.

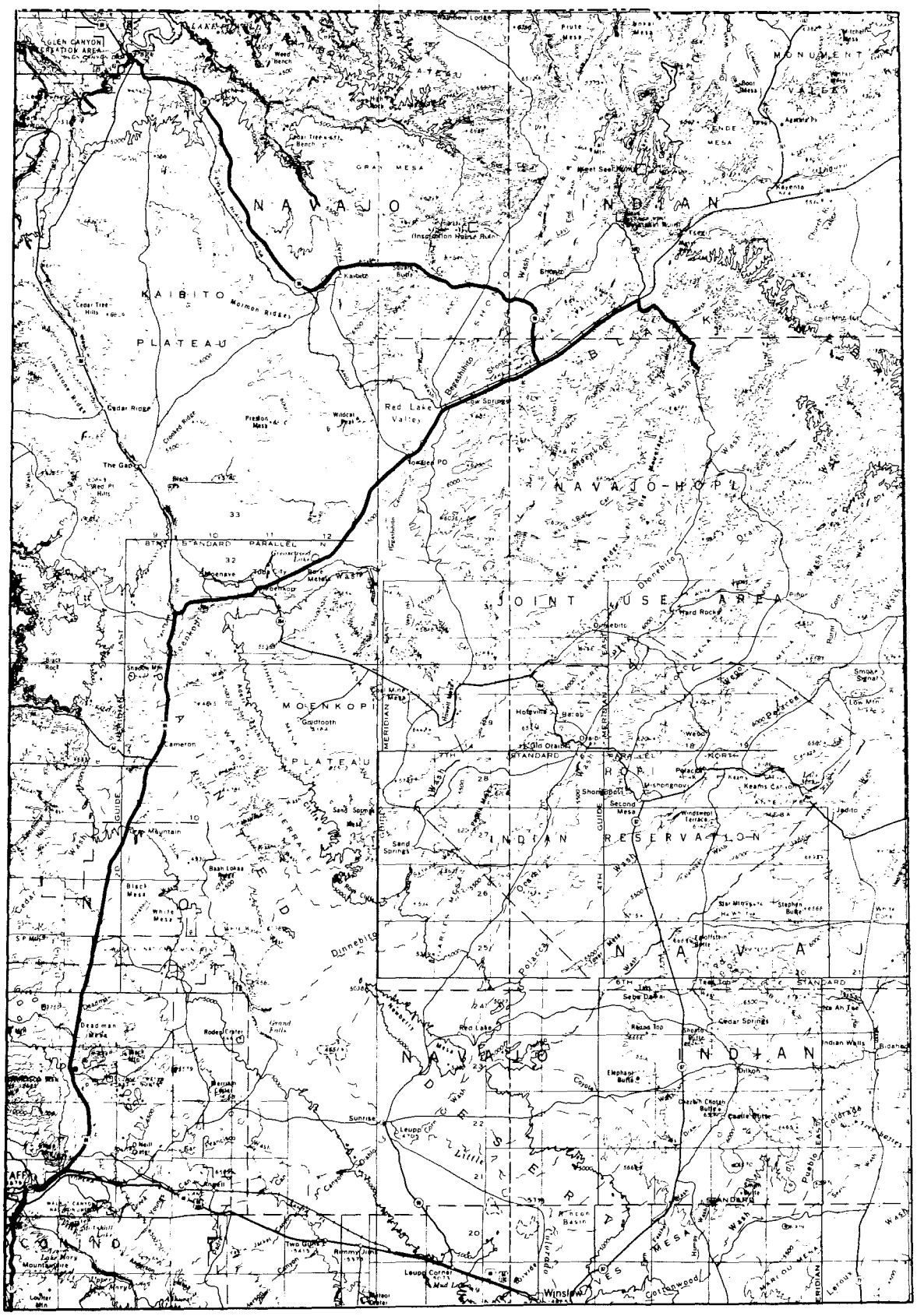


Figure 2A. Topographic base with trip route - northern part.

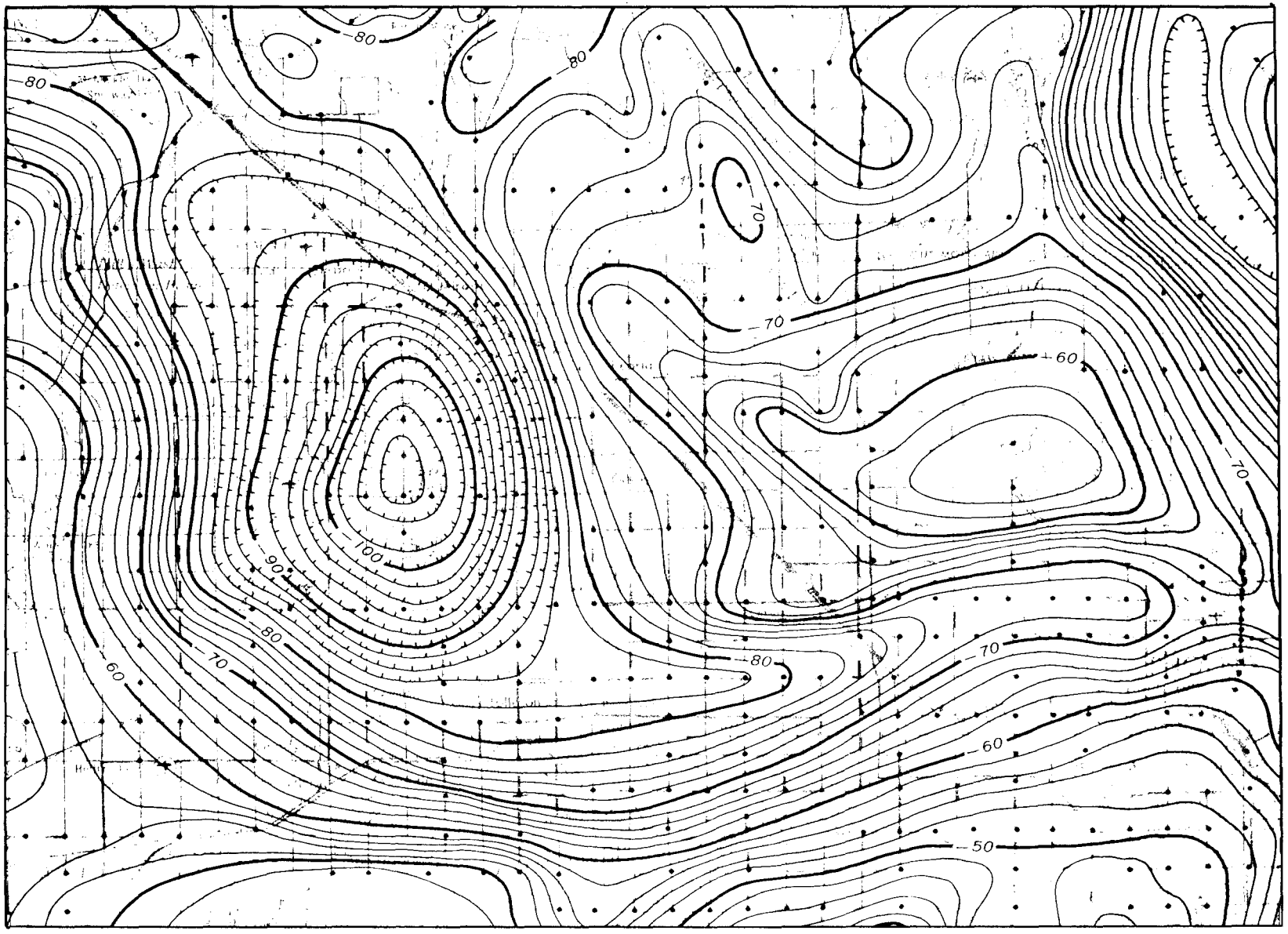


Figure 3. Gravity map showing Luke Basin gravity negative west of Phoenix.

metamorphic rock types. The absence of Paleozoic and Mesozoic sedimentary rocks is a notable regional attribute. The most obvious explanation for absence is in the extensive regional unconformity that characterizes the Precambrian-Cenozoic contact. However, regional geologic considerations suggest Mesozoic denudation and resulting total removal of Paleozoic strata. Removal was facilitated by a slight, regional northeast dip that is recorded in preserved Paleozoic strata north of the B&RP.

From a structural point of view the bottoms of the tectonic basins in the Phoenix region are believed to be the structural low points in Arizona (see Cross-section C-C' on back of geologic map). Using the base of Tertiary rocks as a datum these low points are believed to be on the order of 10,000 feet below sea level. That such basins were frequently closed is evidenced by the thick, non-marine, basin-fill evaporite sequences that have come to light in recent years. Figure 1 shows the continuing relative topographic lowness of the Phoenix area as manifested in the nearby coalescence of an extensive drainage network.

Transition Zone

Forty miles or so north of Phoenix the terrain takes on a different appearance (Fig. 2 and geologic map). It is characterized by an elevational increase and a notable diminution in alluviated valleys. The unconformity between Precambrian crystalline and relatively thin Cenozoic sediments and volcanic units is widely displayed. Most of the Cenozoic rocks are believed to pre-date the Basin and Range disturbance. This is the Transition Zone (TZ). Overall, the TZ does contain basins and some relatively high mountainous topography that is included in what frequently is called the central mountain region. Topographic relief exceeds 5,500 feet and the high point, Mazatzal Peak, is above 7,800 feet in Precambrian Mazatzal Quartzite. Structural relief exceeds 6,500 feet but such contrasts are infrequent. There are many high points of Precambrian rocks above 7,000 feet in the TZ. In contrast, along the southern margin of the CP to the north, the Precambrian-Paleozoic contact ranges in elevation between about 2,000-5,000 feet. The late B. S. Butler told his classes that the Plateau is "structurally low and stratigraphically high" whereas the central mountain region is "structurally high and stratigraphically low." The structural low point on the CP in Arizona is beneath Black Mesa where the Paleozoic-Precambrian contact is about 4,500 feet below sea level (Cross-section C-C'). Thus, the CP rises structurally southward and the TZ likely records relief aspects of this trend. Even in the B&RP there are high points on Precambrian rocks adjacent to the TZ that extend above 8,000 feet.

The last record of topographic continuity between the TZ and CP is found in remnants of "Rim" gravels derived largely from a terrain of Precambrian rocks southerly from the Plateau margin. These gravels have not been precisely dated but are bracketed in the 54 - 28 m.y. range (Peirce, et al, in press). Most likely they are pre-Oligocene in age.

Elevational differences on the surface of Precambrian rocks in the TZ, including places overlain by Tertiary rocks, are caused largely by erosion in some places and faulting in others. The pre-B&R Tertiary rocks, including sediments beneath blanketing flow and pyroclastic units, tend to occupy erosional lows carved into the underlying Precambrian rocks. Whereas

Precambrian rocks might be higher than similar rocks at the CP margin, overlying Tertiary units often are lower than similar rocks at the CP edge where a standard Paleozoic stratigraphic section intervenes (see cross-sections). Whereas the base of the Tertiary along the CP margin ranges between 5,000-7,700 feet, in the TZ the base of the Tertiary is below 5,000 feet over much of the region. In the boundary zone along and adjacent to the plateau edge escarpment, the elevational differential on the base of Tertiary rocks ranges between 1,000-2,000 feet. It is evident from stratigraphic relationships of rocks underlying the Tertiary units that this elevational differential is erosionally caused and is the fundamental reason for the escarpment zone that now marks the southern edge of the physiographic plateau. Most likely, the TZ country also was undergoing erosion which could account for the general lowness of much of the Tertiary relative to the CP margin. The age of this important erosional episode is thought to be pre-Miocene and post-"Rim" gravel.

The highway passes through the triangular shaped Verde Valley at the north edge of the TZ (Fig. 2; Cross-section C-C'). At one time, the valley was a closed basin bounded by faulting on its southwest side and the pre-existent plateau escarpment zone on the north and east sides. Lacustrine and related near-shore, coarse-grained sediments accumulated to a probable maximum thickness of about 1,300 feet. These strata are considered to be Pliocene-Pleistocene in age.

Although more work needs to be done, present indications are that there are at least two episodes of normal faulting in the Verde-plateau edge region both of which post-date the earlier erosional rim-making event. The oldest is closest to the plateau escarpment and appears to be about 12 m.y. or so in age. The Verde Fault, which bounds the Verde Valley on the southwest, may post-date 10 m.y. It is significant that the older faulting is believed to be a manifestation of the onset of the Basin and Range disturbance. However, fault dispacements are measured in hundreds of feet and not the thousands that likely prevailed in the classic B&RP to the south.

Colorado Plateau Province

On this trip route, the southern Colorado Plateau Province is bounded by the Verde Valley. Basaltic flow rocks, in places, either spilled over or accumulated against the pre-volcanic Mogollon Rim. The highway ascends a volcanic ramp that buries the escarpment zone. Basaltic flows are abundant along the southern edge of the Plateau. The highest point in Arizona, at 12,680 feet, is at the top of a volcanic edifice near Flagstaff that towers about 5,500 feet above the normal plateau surface. Over much of its southwestern part, the Plateau is a stripped surface regionally controlled by the Paleozoic-Mesozoic contact (see geologic map). Monoclinal flexures and folds are the most characteristic structures observed on the Plateau and greatly influence topography and the distribution of stratigraphic units. To the northeast, Mesozoic strata are preserved in the Black Mesa structural depression, sometimes called the Black Mesa Basin. Within this large structural low, an erosional remnant, known as Black Mesa, is preserved. One significance of Black Mesa is that it is the largest remnant of coal-bearing strata left in Arizona.

Black Mesa

The coal operation on Black Mesa is the principal focus of this field trip. The general geologic setting of the coal-bearing strata of the larger Black Mesa region is depicted on several of the accompanying illustrations. Only the highlights of these data will be discussed here.

Black Mesa is a relatively isolated geographic feature removed as it is from the principal transportation routes. In fact, the nearby community of Kayenta on the Navajo Indian Reservation was once said to be the most distant from a railroad of any community in the United States (Fig. 4). Even all-weather roads are of relatively recent vintage. Most of the top of the Mesa, except near the coal mining and handling systems, remains generally inaccessible. Forty miles south of the coal operation the Hopi village of Old Oraibi is reputed to be the oldest continuously occupied community in the U.S. (about 1,000 years or so).

Although for years Indians have more or less exploited Black Mesa coal, their underground mines were generally abandoned with the arrival of natural gas in the 50's. Coal had been used principally in small, reservation power plants located near villages, towns, and schools. The locations of these mines are shown on Fig. 4. Figure 5 illustrates the stratigraphic distribution of coal in Black Mesa, and Figure 6, in turn, shows the general formational distribution. Each of the three principal coal-bearing formations has been previously exploited by one or more of the underground mines. (Donkeys were often used and, because of the low roofs, their ears were worn down to stubs).

Large-scale coal mining became feasible with the advent of large coal-fired power plants in the region. Transportation problems were overcome with the development of: (1) large groundwater reserves capable of serving a coal slurry pipeline, and (2) a conveyor belt-electric railroad haulage sustem. A 254-mile-long slurry line now serves the Mohave generating plant on the Nevada side of the Colorado River and an electric railroad serves the Navajo generating plant near Page, Arizona.

The estimated 400 million tons of coal reserves that are to serve these two plants are contained in the Upper Cretaceous Wepo Formation much of which is preserved in a synclinal downwarp (Figs. 4 and 6).

Black Mesa coal deposits represent the largest known non-renewable energy resource in Arizona (Fig. 7). However, the likelihood of significant additional coal development is not clear.

The following section by Garder G. Dahl, Jr. describes the Black Mesa coal operations being conducted by Peabody Coal Company.

Figure 4. Geologic map of Black Mesa showing abandoned coal mines.

EXPLANATION

TERTIARY

Tvs — Volcanics and Sediments

UNCONFORMITY

CRETACEOUS — Mesaverde Group

Ky — Yale Point Sandstone

Kw — Wepo Formation

Kt — Toreva Formation

Km — Mancos Shale

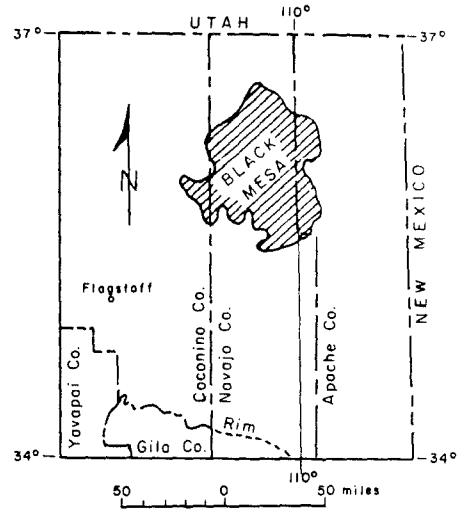
Kd — Dakota Sandstone

UNCONFORMITY

JURASSIC

Jm — Morrison Formation

Jsr — San Rafael Group



LOCATION INDEX

List of Coal Mines

1 Coal Mine Canyon or Tuba City # 3
2 Steamboat
3 Chinle # 1
4 Montezuma
5 Keams Canyon
6 Chinle # 2
7 Oraibi
8 Maloney or Kayenta # 2
9 Kayenta # 1
10 Cow Springs or Tuba City # 4

Sources of Information

Cooley, M.E. and others, 1969
Regional hydrogeology of the Navajo and Hopi Indian Reservations, Arizona, New Mexico and Utah: U.S. Geological Survey Professional Paper 521-A

Wilson, E.D. and others, 1969
Geologic Map of Arizona: Arizona Bureau of Mines and U.S. Geological Survey

Figure 4A. Map Legend for Figure 4.

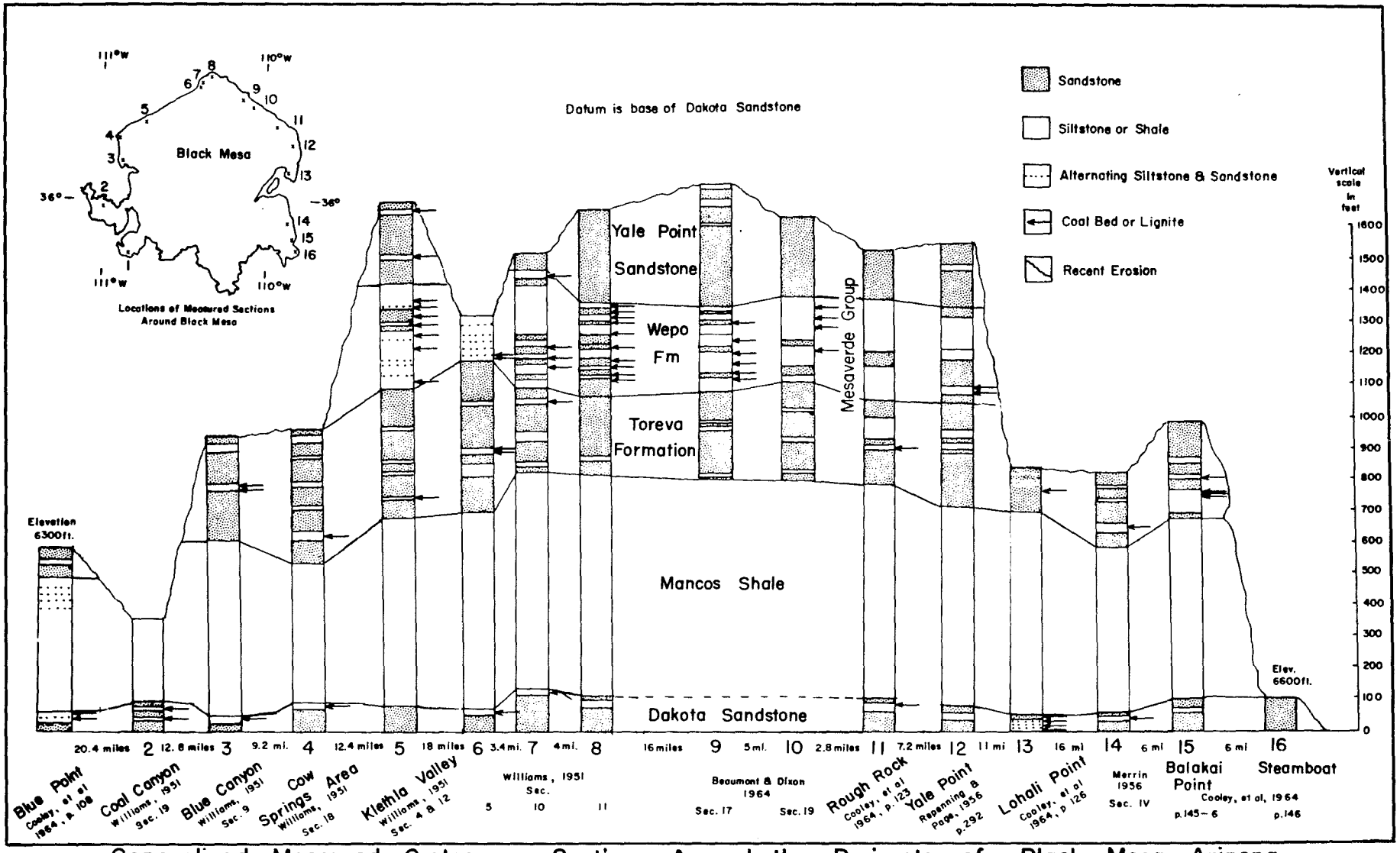


Fig. 5. Generalized Measured Cretaceous Sections Around the Perimeter of Black Mesa, Arizona

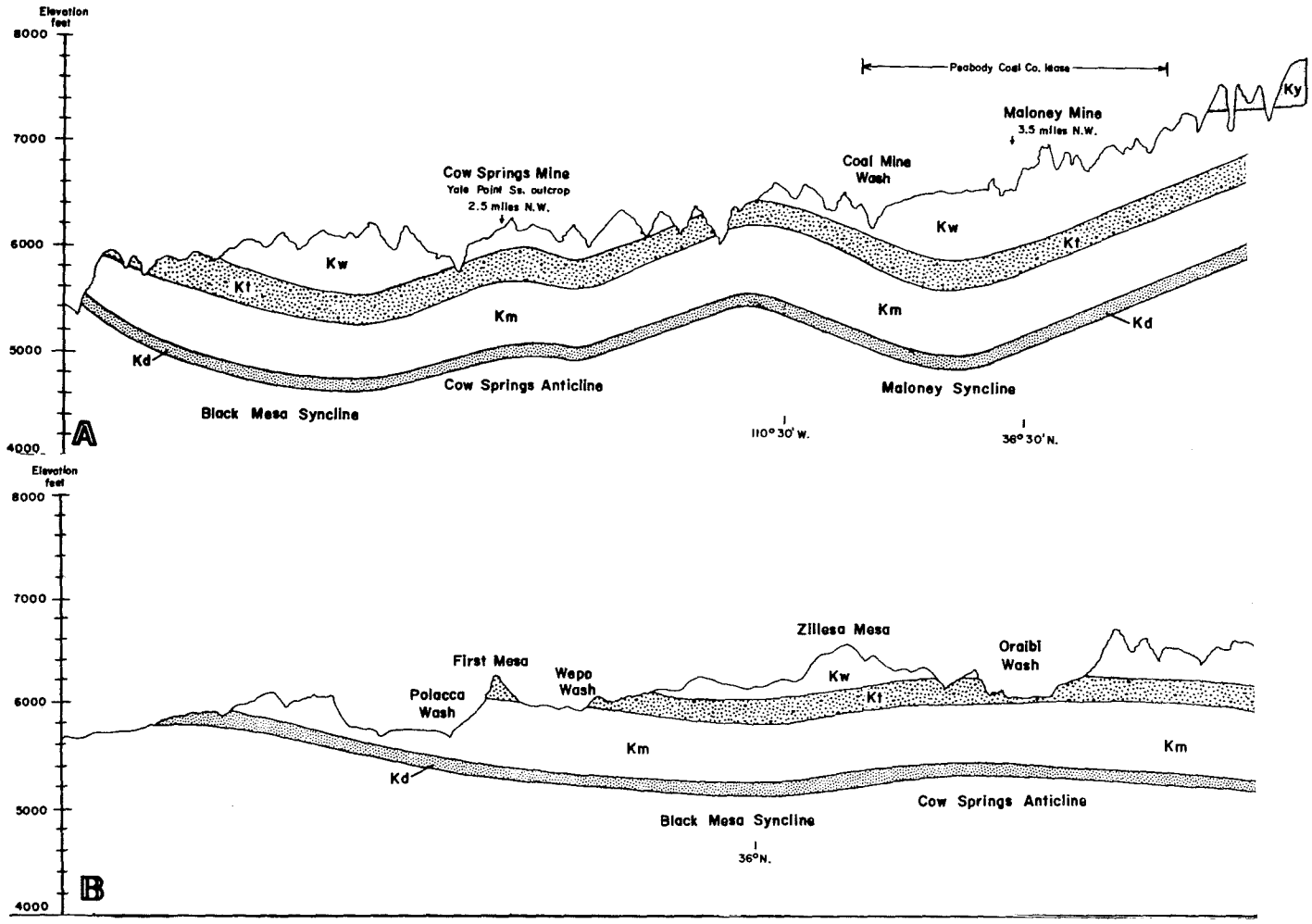


Fig. 6. Geologic cross-sections through Black Mesa showing generalize

COAL
Arizona's Most Important Energy Resource?

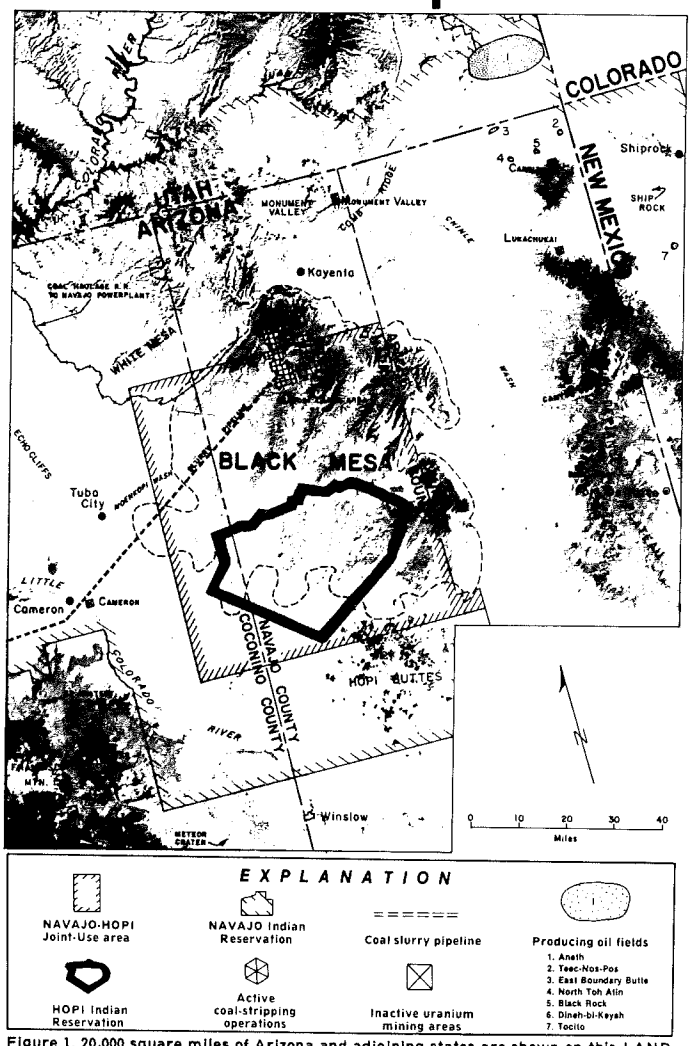


Figure 1. 20,000 square miles of Arizona and adjoining states are shown on this LANDSAT imagery.

by H. Wesley Peirce
Geologist

Coal *is* Arizona's most abundant naturally occurring fuel energy resource. This fact alone seems sufficient justification for considering seriously its possible place in Arizona's critical energy situation. This brief article attempts to encourage and assist state and area leaders in developing a realistic Arizona coal perspective that, hopefully, will lead to a deliberate, responsible course of action designed to assess fully the future viability of Arizona coal resources.

The sum of geologic experience in Arizona indicates that the principal coal resources are on, around, and beneath Black Mesa, a 3,200-square mile geologic remnant located exclusively on Indian lands in parts of Coconino, Navajo, and Apache counties, in the plateau country of northeastern Arizona. Although there are other occurrences of coal and carbonaceous materials in Arizona, they do not appear to contain resources of economic potential beyond possible local usage.

Black Mesa Indian lands containing coal resources are of three basic categories: (1) Hopi land, (2) Navajo land, and (3) Joint Use land that is currently the subject of complex litigation. The present coal operations of the Peabody Coal Company embrace lands of the latter two categories. Figure 1 shows the details of the Peabody Coal Company project on Black Mesa. Coal for the Four Corners power plant in New Mexico is supplied from coal resources on Navajo lands in New Mexico, and additional coal leases on New Mexico Navajo lands have been let. There is no known current coal activity on Arizona Indian lands other than the Peabody operation.

Black Mesa has achieved a type of fame by having its name appear on bumper stickers. However, how much generally is known about it is another matter.

Figure 7. LANDSAT image of northeast Arizona showing location of coal operation, Indian lands, and other energy resources.

BLACK MESA - KAYENTA MINING COMPLEX
BLACK MESA, ARIZONA

by

Gardar G. Dahl, Jr.
Peabody Coal Company

INTRODUCTION

The Black Mesa - Kayenta Mining Complex is located atop Black Mesa approximately 20 miles south of Kayenta, Arizona. It operates on land leased from the Navajo and Hopi Indian Tribes. Kayenta Mine provides coal to Navajo Station at Page, Arizona. Black Mesa Mine provides coal to Mohave Project near Bullhead City, Arizona. All of the coal mined commercially is used for electrical power generation. The surface mines are operated as separate entities with certain common facilities such as central warehousing and other support activities. Mining occurs in the Wepo Formation of the Mesa Verde Group of Upper Cretaceous age.

MINING PROCEDURES

Mining procedures at both operations are essentially identical. They consist of seven phases; reserves and coal quality determination, engineering, site preparation and topsoil recovery, drilling and blasting, overburden and parting removal, coal removal and preparation, and reclamation.

Core samples of the coal are taken well in advance of mining on approximately a 300 foot grid. Whole bench samples are analyzed for; moisture, ash, sulfur, BTU, and pH on an as-received basis. Using appropriate dilution factors, this information is used to project the quality of coal as mined. In addition, the margins of the coal are closely drilled to determine the extent of minable coal. This is necessary because subaerial weathering generally destroys the coal quality to a modest depth; generally 20-30 feet depending on the slope aspect. Slopes with northeastern exposure usually have the greatest depth of weathering. Besides drilling and coring the coal samples, overburden core samples are taken on 40 acre spacing and analyzed for an extensive suite of chemical and physical parameters. These results are used to determine the reclamation potential of various strata overlying the minable coal.

This information is analyzed and then given to the engineering and reclamation staffs for inclusion in the mining and reclamation plans. The mining engineering staff uses the drilling information to help plan the mining sequence and select the optimum placement of the various machines. This forecasting is done so as to provide guidance to the mining operations in the placement of machines, construction of new

facilities such as haul roads, and estimating the quality of the mined coal within a given time frame. Engineering personnel also design and direct installation of necessary sediment control facilities to prevent surface runoff.

Prior to mining, the soil characteristics are measured and where appropriate, topsoil is removed and stockpiled. The areas to be mined have vegetation removed and either salvaged for firewood by local residents or buried prior to topsoil salvaging operations. Topsoil is stored in areas isolated from active mining operations, stabilized and fenced. Concurrently or slightly in advance of topsoil removal and site preparation, sediment control measures are undertaken to prevent impacting surface water quality. These measures include construction of sediment impoundments, diversion ditches and drainage modifications.

Once the site preparation has concluded, the overburden material to the first minable coal bed is drilled on a pre-determined pattern. Approximately 200 feet of pit is drilled at one time. The holes are then filled with the appropriate type of explosive, usually ammonium nitrate and fuel oil (ANFO) prells. The holes are then detonated using a series of cast primers and detonation cord.

After shooting the overburden to the first minable bed, the overburden is removed using either scrapers or large machinery such as draglines. Currently five electric and one diesel-electric draglines are operating on the Mesa. The size of the buckets for these draglines vary from 14 cubic yards to 90 cubic yards.

Following removal of the first overburden sequence, the coal is then drilled and shot using procedures similar to those described above. The coal is then loaded into 150 ton bottom dump coal trucks and hauled to the coal hopper at the preparation plant for blending and crushing.

Since it is a multiple seam operation, the mining sequence described above is repeated until the lowest minable seam is recovered. This requires a fine sense of timing and a very real appreciation of machinery capabilities to prevent production problems. Mining proceeds in a series of parallel linear cuts or strips. Overburden or spoils from an active pit is placed in the proceeding cut thus resulting in a series of parallel spoils piles. Subsequent to mining, the spoils are then graded to a gentle slope, topsoil replaced and reseeded. In all, approximately 500 acres are disturbed by mining each year and approximately 500 acres regraded, topsoiled and seeded. The operations work two production shifts and one maintenance shift six days per week. Currently, approximately 980 people are employed in the operation.

BLACK MESA MINE

Black Mesa Mine was the first Peabody mine to produce coal on Black Mesa. Beginning in 1970, Black Mesa can produce from 4.1 to 4.8 million tons per year for shipping to Mohave Project, 254 miles via slurry pipeline. Water for the slurry line is produced from the Navajo Formation by six high production wells. In all, roughly 3200 acre feet per year are used for slurry operations.

Coal is currently being mined from two active pits and trucked to a central hopper at Black Mesa Mine for preparation for the slurry line. Because of contractual constraints, quality control plays a very important part of the mining and preparation of coal. Daily loading parameters are recommended to the mine superintendent. These recommendations include the suggested amount of coal to be loaded from each operating pit to meet contractual obligations on the amount of allowable ash in the coal.

Coal is preferentially stacked at the hopper to allow selective blending. The coal is ground to -1/4 inch for mixing in the slurry operations and sampled on a regular basis to ensure consistent quality. Once crushed the coal is conveyed to four holding tanks where it is mixed with an equivalent amount of water by weight. From the tanks the slurry mixture is fed to the slurry line where it is pumped 254 miles to the Mohave Generation Plant in southern Nevada. pH of the slurry mixture is carefully monitored, and buffered to maintain a neutral or slightly basic slurry pH in order to keep chemical corrosion of the pipe to a minimum. Corrasion of the pipe is kept to a minimum by the relatively slow speed of the slurry.

KAYENTA MINE

Kayenta Mine was opened in 1973 and can produce 8.3 million tons per year for delivery to the Navajo Station electrical generating plant in Page, Arizona. Coal is crushed at Kayenta Mine and placed on a six mile overland conveyor belt line which carries the coal to four storage silos in Longhouse Valley. Here the coal is loaded onto the Black Mesa and Lake Powell Railroad for shipment to Page. Coal for the operation is currently being produced from four operating pits. As at Black Mesa, the coal is carefully blended and sampled to ensure consistent quality coal for shipment.

GEOLOGY OF THE DEPOSIT

Campbell and Gregory, U.S. Geological Survey, mapped and described the approximate extent of the coal-bearing rocks in Black Mesa (Zilh-Le-Jini) in 1909. Their estimate of reserves for the entirety of Black Mesa was approximately 14 billion tons of which an estimated 8 billion were potentially recoverable. They estimated that the coal would fall on the dividing line between bituminous and subbituminous coal.

In 1956 Repenning and Page described the Late Cretaceous stratigraphy of the Black Mesa. Although mentioned in passing, the occurrences and modes of deposition of coal were not described in detail. The stratigraphic nomenclature used herein is based on that used by Repenning and Page.

Rocks exposed on the margins of Black Mesa are, in ascending order: Navajo Sandstone, Carmel Formation, Entrada Sandstone, Cow Springs Sandstone, and Morrison Formation, all of Jurassic Age. Unconformably overlying the Jurassic-aged rocks are the Dakota Sandstone, Mancos Shale, Toreva Formation, Wepo Formation, and Yale Point Sandstone, all of Upper

Cretaceous age. Although the Dakota, Toreva, Wepo and Yale Point Formations all contain some coal, only the Wepo contains commercially minable coal within the confines of Peabody's Black Mesa Leasehold.

Black Mesa is a structural low as well as topographic high. The most significant structure in the vicinity of the leasehold is the Oljeto Syncline which extends north to south through the western part of the Black Mesa. Other minor folds exist in the area but their areal extent is limited and the folds themselves are not particularly extreme; reflecting gentle changes in dip with only minor faulting. Regional dips are generally to the south. On a local scale, dips rarely exceed 2 to 3 degrees. Faults are normal; displacements rarely exceeding 10 feet. They occur most commonly within five miles of the rim of Black Mesa, and appear to be related to tensional release as a result of the Laramide folding which helped create Black Mesa.

Peirce (1979) stated that the principle coal reserves with Black Mesa are preserved in one of two broad downwarps in the northern part of the Mesa. The western downwarp, the Maloney (Oljeto) contains Peabody's Black Mesa Reserves. The eastern area is as yet undeveloped. The coal-bearing formation is eroded to the south.

Exploration of the area by Peabody Coal Company began in the late 1950's and consisted largely of drilling, coring, and trenching to evaluate the thickness, continuity, and quality of the coal. In all 42 separate sub-areas within the leasehold boundaries were identified to a total minable depth of 130 feet. (Figure 8) These sub-areas are bounded by certain physical constraints such as the extent of subaerially weathered coal or physical outcropping of the coal on the low side and maximum recoverable depth on the high side.

All minable coal is contained in the Wepo Formation of the Mesa Verde Group of Upper Cretaceous age. Coal occurs in eight zones each of which may contain up to five benches. The coal appears to have been deposited in a deltaic environment at the margin of the mid-Continent Upper Cretaceous Seaway. It exhibits a remarkable similarity to the coal in the Kaiparowits Plateau of Southern Utah. Figure 9 shows a typical and somewhat idealized section of the coal-bearing strata near the center of the leasehold.

In ascending order the coal zones have been named: Orange, Brown, Yellow, Bottom Red, Red, Blue, Green, Violet. The term zone is used rather than bed because these zones frequently exhibit divergence and convergence of beds. Bed thicknesses range from a few tenths of feet to a maximum of 28 feet but are most commonly 6 to 8 feet in thickness. Unless unusual circumstances occur, such as being immediately underlain by a thicker bed, 3 feet is considered the minimum recoverable coal thickness.

Because coal quality is an especially important parameter, extensive drilling has been undertaken to more clearly delineate the changes which occur within short distances. In addition to the normal variation in ash and sulfur content, the coal also exhibits occasional thin layers of a light tan substance which have been identified as "tonsteins" or Kaolinite bands.

(Thomas, Personal Communication, 1979) Fossil remains are also frequently encountered in the coal as well as minor amounts of pyrite and gypsum. The following table shows the average coal quality for Black Mesa as reported by the Arizona Bureau of Mines (1977).

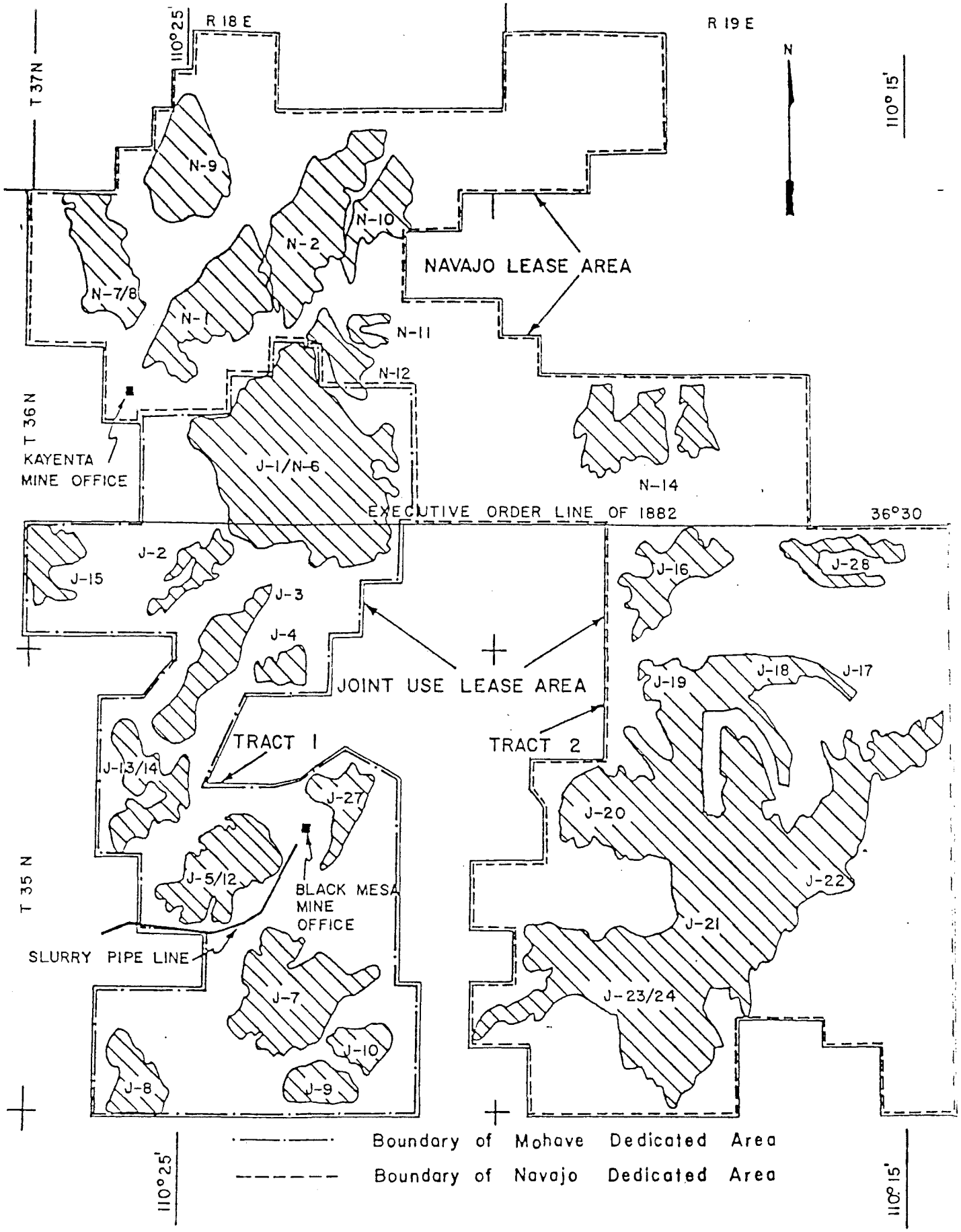


Figure 8. PEABODY COAL COMPANY LEASES

Figure 9. IDEALIZED STRATIGRAPHIC SECTION OF THE WEPO FORMATION

BLACK MESA AREA - ARIZONA

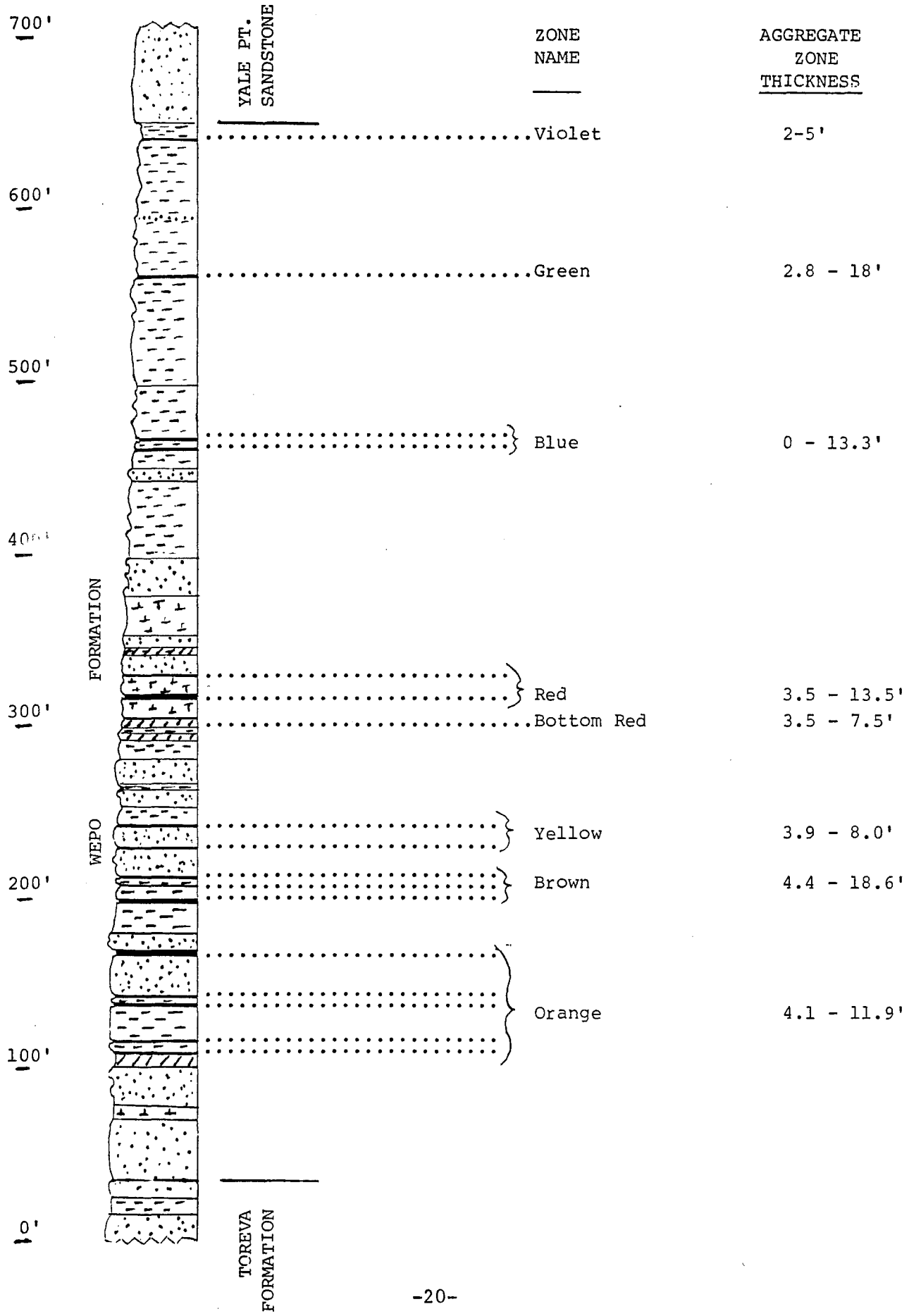


TABLE 1. COAL QUALITY (As reported by Arizona Bureau of Mine Circular - 18, 1977)

AS RECEIVED: PROXIMATE ANALYSIS BLACK MESA COAL

	MEAN	HIGH	LOW
MOISTURE	11.54	21.9	8.6
VOLATILE MATTER	38.47	41.2	31.4
FIXED CARBON	42.71	45.3	39.6
ASH	7.27	9.1	4.7
BTU	10,890	11,560	9,490

AS RECEIVED: ULTIMATE ANALYSIS

HYDROGEN	5.8	6.3	5.4
CARBON	62.5	66.1	54.5
NITROGEN	1.1	1.2	.9
SULFUR	.42	.54	.29
OXYGEN	23.0	30.9	20.7

TRACE ELEMENTS:

	MEAN	MAXIMUM	MINIMUM
Ash%	7.4	13.6	3.2
SiO_2%	36	59	19
Al_2O_3%	15	28	5.9
CaO%	13	27	3.4
MgO%	2.2	6.11	.75
Na_2O%	1.45	4.79	.39
K_2O%	0.38	1.3	<1
F_2O%	6.2	10	2.1
MnO%	0.016	0.035	0.008
T_1O_2%	0.98	1.3	0.78
SO_3%	12	23	6.0
Cc ppm	<1	2.0	<1
Cu ppm	69	127	54
Li ppm	44	89	20
Pb ppm	29	75	20
Zn ppm	54	275	20

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ROAD LOG
FROM PHOENIX TO PAGE
VIA FLAGSTAFF AND BLACK MESA

by
H. Wesley Peirce and Maxine W. Peirce

Saturday, November 3, 1979

Assembly point: Aloha Inn, Phoenix
Transportation: bus
Time: 6:00 a.m.
Distance:

INTRODUCTION

A general geologic overview of the field trip, as well as a description of the Peabody coal operations on Black Mesa, precedes this road log section. Although bus riders cannot easily follow a mileage guide, this log is being compiled for multiple reasons, including use at other times and under other circumstances.

ROAD LOG

0.0 Intersection of 24th Street and Interstate 10. Heading west.

0.3

0.3 Milepost 195. Squaw Peak on skyline at 5:00 (o'clock), eroded from Precambrian crystallines, is a city park area. South Mountain, forming skyline at 9:00, consists of gneisses and granitic rocks mapped as Precambrian and Laramide, respectively. However, both rock types may be mid-Tertiary in age.

0.9

1.2 On south side (left) is an industrial area on floodplain of the Salt River. Encroachment and inadequate flood control regulation upstream cause periodic harassment and property damage along the river.

1.8

3.0 Sierra Estrella Mts. at 10:00, an imposing northwest trending range block, consist of Precambrian metamorphic rocks. The Gila River flows, at times, in the gap between South Mountain and the Estrellas.

4.3

7.3 Junction with Highways 60-89-93. Continue north on Interstate 10.

3.5

10.8 Squaw Peak at 3:00 and Camelback Mt. at 3:30. The latter contains an excellent depositional contact between redbed conglomerates, of suspected Oligocene age, and more resistant Precambrian crystallines, largely granitic. This phenomenon of Tertiary above Precambrian basement is a regional geologic relationship.

0.5

11.3 Glendale Ave. exit. Southwest Salt Co. operation is at Glendale Ave. and Dysart Rd. to the west toward Luke Air Force Base.

2.6

13.9 Arizona Canal passes beneath highway. Water is diverted from the perennial flows of the Verde and Salt rivers for crop irrigation. Elev. - 1236 feet (all elevations will be in feet).

1.1

15.0 Milepost 209. Citrus groves to east. Precambrian crystalline rocks make up Shaw Butte at 3:00 (electronic gear on top - elev. 2149).

3.75

18.75 Bell Rd. exit (west).

2.05

20.8 Milepost 215. Small range blocks crop out between 9:00 and 3:00.

0.7

21.5 Deer Valley exit (east).

.85

22.35 Nearby outcrop at 9:00 is Adobe Mt. Observable outcrop is basalt exposed in a probable fault block with unknown subsurface dimensions. Best guess is that basalt is mid-Miocene (15 m.y.) in age. Note vegetative pattern on scree slope.

3.9

26.25 Central Arizona Project's (CAP) Salt-Gila aquaduct crosses highway. This is part of a facility that will bring Colorado River water to the Phoenix and Tucson regions.

3.65

29.9 Milepost 224. Overpass. Small, northwest trending-northeast dipping nearby range block at 11:00. Basalt cap, dated (KAr) at 15 m.y., overlies sediments of suspected lower Miocene age. A strip of

light-colored, anomalously radioactive lacustrine carbonate rocks can be seen, in places, just below the basalt cap. Elsewhere in Arizona, sediments thought to be of similar age contain important uranium reserves associated with lignitic units (Date Creek area).

1.6

31.5 The relatively high mountains in distance at 12:00 are the Bradshaws in the Transition Zone. They are largely Precambrian crystalline rocks. The highway traverses the lower country on the east side.

1.15

32.65 Roadcut at 3:00 exposes Tertiary volcanics and interbedded sediments.

2.45

35.1 Overpass.

1.95

37.05 Gavilan Peak at 2:30 is a volcanic feature.

0.5

37.55 Bridge over New River. Elev. - 1997. Entering Transition Zone, or central mountain region, and leaving classic Basin and Range Province.

0.2

37.75 Roadcut. Contact of Cenozoic gravels with underlying Precambrian crystalline rocks.

0.5

38.25 High mesa at 2:00 is capped by basalt flows of probable Miocene age.

0.7

38.95 Roadcut. Cenozoic gravels above Precambrian crystallines. Note abundant tall saguaro (sa-wáro) cacti. These are almost exclusive to Arizona.

0.6

39.55 Roadcut at 9:00 in Precambrian schistose rocks.

1.55

41.1 Roadcut. Tertiary volcanics at 9:00.

.85

41.95 Table Top Mt. exit.

0.2

42.15 Milepost 236. Overpass.

0.2

42.35 Light-colored, slightly deformed, Miocene tuffaceous sedimentary rocks.

0.8

43.15 Roadcut in coarse-grained Cenozoic sediments.

1.0

44.15 Milepost 238. Bradshaw Mts. at 11:00 and New River Mts. to east.

1.0

45.15 Roadcuts in Cenozoic gravels. Transmission line crosses highway.

1.3

46.45 Roadcut in Precambrian granitic rock.

0.6

47.05 Roadcut at 9:00 in light-colored Cenozoic sediments.

0.5

47.55 Entering Yavapai County and leaving Maricopa. Roadcut in tuffaceous Tertiary sediments.

0.5

48.05 Detour for bridge out. Lives lost here last spring. Bridge supports were undercut.

0.3

48.35 Cattleguard. Left turn towards Black Canyon City.

0.15

48.5 Stop sign. Right turn.

0.15

48.65 Vocanic capped mesas at 12:00.

0.8

49.45 Black Canyon City. Bradshaw Mts. at 10-11:00.

0.8

50.25 Milepost 244. Black Mesa (no coal here) at 12:00.

1.1

51.35 Road ascends Black Mesa. Probable Miocene volcanics and sediments overlie an irregular erosion surface cut on Precambrian crystallines. Section changes laterally because of intertonguing.

3.4

54.75 Roadcut. Sediments overlie basalt flow at 3:00.

1.2

55.95 Roadcut. Precambrian schist at 3:00.

0.5

56.45 Miocene volcanics overlie Precambrian schist.

0.6

57.05 Summit of Black Mesa. Elev. - 3340.

0.5

57.55 Milepost 251. Precambrian rocks of the Bradshaw Mts. at 9:00 rise like an island high above the Cenozoic rocks of Black Mesa. Canyon to west of Black Mesa is Black Canyon.

2.7

60.25 Abundant prickly pear cactus and occasional juniper trees.

4.8

65.05 Typical southwest terrain of weathered, fractured granite.

3.8

68.85 Prescott exit and turn-off to Cordes Junction and Paolo Soleri's Arcosante.

0.4

69.25 Overpass. Hills at 12:00 in distance are the Black Hills consisting of basalt caps above Precambrian and erosionally thinned Paleozoic rocks.

0.8

70.05 Arcosante at 3:00 consists of rounded concrete structures. One architect's concept of the community of the future.

1.9

71.95 Bridge over Agua Fria River.

0.7

72.65 Milepost 266. Road on almost flat-lying Tertiary basalt.

1.0

73.65 High mesa at 2:00 on skyline is Tule Mesa. The capping flow is 8 m.y. in age by KAr dating. Tule Mesa overlooks the canyon of the Verde River on the east where the relief is more than 3,000 feet. From this we believe that here the canyon-cutting cyle post-dates 8 m.y.

1.6

75.25 Dugas Rd. exit. Access to Tule Mesa via jeep road.

2.4

77.65 Grass-covered rounded forms developed on lava flows and pyroclastic (cinder) deposits.

2.1

79.75 Outcrop at 10:00 of pyroclastics interbedded with lava.

2.0

81.75 Flat-lying lava flow forms bench at 10:00-11:00.

1.0

82.75 Vegetation: grasses and dominant tree is juniper. Elev. - 4300.

1.1

83.85 Complex of Tertiary volcanic and sedimentary rocks.

1.1

84.95 Cherry Road exit.

0.3

85.25 Overpass.

2.3

87.55 Roadcut at 9:00. Cinder deposit. Begin descent into Verde Valley through Black Hills.

0.35

87.9 Roadcut. Faulting at 9:00. Complex assemblage of volcanics and sediments.

1.0

68.9 View at 12:00 of Verde Valley and Colorado Plateau beyond.

1.25

90.15 Elev. - 4000.

0.8

90.95 Roadcuts in Tertiary gravels.

0.4

91.35 Roadcut at 9:00 in Precambrian crystallines.

0.3

91.65 Approximate position of Verde Fault. This is a complex fault zone with a history dating back to Precambrian. Latest movement offsets Miocene volcanics but youngest rocks affected not established. The Verde Valley side is relatively down dropped on the order of 2,000 feet.

0.3

91.95 Roadcuts. Light-colored beds are part of the Verde Formation of Plio-Pleistocene age. Locally, slightly deformed. This formation exceeds 1,000 feet in thickness and is extensively developed in the Verde Valley. It's varied lithologies contribute shales and gypsum to a Portland cement plant near Clarkdale to the west. In the past, sodium sulfate was mined and aborigines obtained salt just east of the highway. Some uranium is known and stimulates continued exploration. The formation is indigenous to the valley. Ponding is believed to have been initiated by faulting.

0.7

92.65 Mogollon Rim (edge of Colorado Plateau) in distant skyline 10:00-12:00.

1.4

94.05 Cottonwood-Clarkdale-Jerome exit.

0.2

94.25 Overpass. Large cottonwoods ahead mark the Verde Valley.

0.7

94.95 Bridge over Verde River. Elev. - 3100.

0.7

95.65 High mesa at 9:00 is Mingus Mt. capped by Miocene basalt flows. High point is 7,700 feet. Scarce drilling data suggest that volcanics of this general age may underlie the Verde Formation. If so, relief on the Miocene volcanics could reach 6,000 feet or so. Jerome, a famous mining camp of the past, is on the northern slope. Mineralization is Precambrian and volcanogenic in style.

1.35

97.0 Overpass. Ledgy, flat-lying strata are resistant, calcareous sediments in the Verde Formation. Fossils in this formation include plants, vertebrates (including elephant), and invertebrates.

3.25

100.25 Exit to Montezuma Well.

0.3

100.55 Dry Beaver Creek.

1.55

102.1 Milepost 295. Enter Coconino National Forest. Vegetation: crucifixion thorn, creosote bush, some yucca, and grasses.

1.75

103.85 Exit to rest area.

2.2

106.05 Exit to Sedona and Oak Creek Canyon.

0.7

106.75 Elev. - 4000.

0.5

107.25 Milepost 300. Entering volcanic terrain. Basalt flows are extensively developed along and adjacent to the southern margin of the Colorado Plateau. Thickness depends upon underlying topography.

1.0

108.25 Roadcuts. Volcanics probably about 7 m.y. in age.

2.05

110.3 Juniper forest.

0.85

111.15 Elev. - 5000.

0.2

111.35 High cliffs at 9:30 on Mogollon Rim are an expression of pre-volcanic topography. Initial cliff development pre-dates 10 m.y. Post-volcanic canyon cutting has enhanced relief. Road on lava flows.

2.1

113.45 Exit to Stoneman Lake.

3.2

116.65 Probable position of buried Mogollon Rim.

0.5

117.15 Elev. - 6000.

0.3

117.45 Milepost 310. Occasional pine tree amongst the junipers.

1.6

119.05 Entering Coconino County.

0.45

119.5 Individual basalt flows separated by red zones.

2.0

121.5 Pine forest.

1.35

122.85 Exit to Rocky Park Rd. Highway on lava flows.

2.0

124.85 Occasional treeless areas are called "parks." They are topographically low and have poor drainage, which discourages growth of pines.

1.7

126.55 San Francisco Peaks near Flagstaff loom on the horizon at 12:00.

1.4

127.95 Exit to Schnebly Hill Rd. To Oak Creek Canyon at Sedona. Elev. - 6485.

2.25

130.2 Munds Park exit. Vocanic terrain.

2.5

132.7 Roadcut. Cinder deposits at 9:00. Cinders are used extensively in highways, railroad ballast, and in building block. Cinders are shipped to Phoenix from the Flagstaff region.

2.35

135.05 Peaks ahead. Mt. Humphreys, at 12,680 feet, is the highest point in Arizona.

3.3

138.35 Roadcut at 9:00. Base of lava flow marked by red zone.

0.2

138.55 Overpass.

2.3

140.85 Roadcut. Rubbly volcanic ejecta.

0.95

141.8 Milepost 334.

1.25

143.05 Paleozoic sedimentary rocks appear on surface.

0.5

143.55 Roadcut. Exposure of Permian Kaibab Limestone. This resistant unit caps much of the southwestern Plateau and is a cliff-maker along the Mogollon Rim and many canyons. Though called "limestone" this unit contains much sand.

1.0

144.55 Flatstaff city limits. Roadcuts in flat-lying Kaibab Limestone.

0.3

144.85 Milepost 337. Mt Humphreys at 12:00.

2.65

147.5 Exit to Lake Mary. Lake Mary "leaks" because of paleokarst in the Kaibab Limestone reservoir floor.

0.55

148.05 Exit. I-40 to Williams

0.3

148.35 Exit. Highway 89A to Sedona.

0.4

148.75 Stoplight. First of several entrances to Northern Arizona University (NAU).

0.8

149.55 Intersection

0.1

149.65 Red blocks in NAU buildings are from the Triassic Moenkopi Formation.

0.35

150.0 Underpass.

0.15

150.15 Stoplight. Turn left on State 180 to Snowbowl. Railroad is Santa Fe. Side trip to Museum of Northern Arizona. Road log will resume upon return to this intersection.

150.15 Stoplight. Intersection of Highways 66-89-180.

0.65

150.8 Red sedimentary rocks at 9:00 behind businesses belong to the Lower Triassic Moenkopi Formation.

1.7

152.5 Microwave and TV towers at 11:00 are on Elden Mountain, a dacite domal feature that is laccolithic to the east where lower Paleozoics are brought to the surface. A 1977 forest fire raged on the mountain and its evidence can be seen near the top right.

1.7

154.2 Junction of Highways 66 and 89. Keep left on 89.

0.7

154.9 Quaternary cinder cones at 12:00-2:00 being quarried for railroad ballast and highway surfacing.

2.8

157.7 Rounded hills at 10:00-3:00 are cinder cones in the San Francisco volcanic field.

1.0

158.7 San Francisco Peaks at 9:00 are the eroded remains of a once higher volcano. Peaks have been glaciated.

2.35

161.05 Milepost 425. Treeless area indicates poorly drained soils.

1.05

162.1 Sunset Crater at 1:30. This is a cinder cone that erupted onto living facilities of the time. It has been dated by tree-rings as having erupted during A.D. 1064. This is the youngest of the volcanic eruptions in this field.

3.6

165.7 Sunset Crater at 3:00.

0.9

166.6 Turn-off at 3:00 to both Sunset Crater and Wupatki National Monuments. Sunset Crater spread an ash layer over about 600 square miles. Population flourished for awhile after the eruption because agriculture was enhanced by the moisture retention powers of the thin ash layer. However, an unexplained decline in population began about 1160 A.D.

0.8

167.4 Cinder bed at 9:00. Road descends through several life zones. Observe vegetation change.

1.8

169.2 Milepost 433. O'Leary Peak, a silicic center, at 3:00. Age may approximate 0.2 m.y.

1.0

170.2 Cinder cones from 9:00 to 11:00. Pumice from a nearby locality was used as pozzolanic material in Glen Canyon Dam concrete. Vegetation is juniper, shrubs and grasses.

4.0

174.2 Milepost 438. Highway on volcanic rocks.

2.05

176.25 Lava flow at 9:00.

0.35

176.6 Elev. - 6000. Vegetation includes sparse juniper. At this elevation south of Flagstaff, we were in a pine forest. We are in the rain shadow of the peaks.

1.3

177.9 Leaving Coconino National Forest.

0.8

178.7 Entering grasslands. Cinder cones at 9:00. Antelopes occasionally seen.

2.4

181.1 Wupatki National Monument turnoff at 3:00. Painted Desert in distance 1:00-3:00.

4.25

185.35 Edge of lava flow at 9:00. Edge of Coconino Plateau at 10:00-11:00.

1.65

187.0 At 3:00, volcanics overlie red sandstones of the Triassic Moenkopi Formation.

0.7

187.7 At 9:00, Moenkopi Formation.

0.3

190.7 At 3:00, slabby Moenkopi sandstone.

0.7

191.4 Milepost 455. Red soils indicate Moenkopi Formation near surface.

1.0

192.4 At 10:00, Paleozoic rocks at north end of Coconino Plateau are folded down sharply along an east-facing monocline.

0.9

193.3 Community of Gray Mountain.

1.1

194.4 Entering the large Navajo Indian Reservation. Road descends along

a monoclinal fold dip slope. Red strata of the Triassic Moenkopi Formation overlie the grey, harder Permian Kaibab Limestone.

1.3

195.7 Contact between the Moenkopi above and the Kaibab below.

0.75

196.45 Slightly north-dipping Moenkopi.

0.85

197.3 At 9:00 a light-colored sandstone caps the Moenkopi Formation. This sandstone is the Shinarump Conglomerate, the basal conglomerate of the Triassic Chinle Formation. The Shinarump contains numerous uranium deposits in this and other Plateau regions. Its channels frequently contain carbon trash which localizes uranium mineralization.

1.15

198.45 Milepost 462. Painted Desert at 3:00. Pastel colors are clays and fine-grained clastics of the Chinle Formation. The clays are bentonitic.

0.55

199.0 Transmission lines cross highway.

1.05

200.05 Chinle Formation. At 12:00 in distance is a conical peak, Tuba Butte, a volcanic neck.

2.2

202.25 Junction with Highway 64 to Grand Canyon to the west.

1.7

203.75 Little Colorado River crossing. Walls are Chinle sandstones. Elev. near 4200 feet.

2.15

206.1 Low weathering forms are claystones of the Chinle Formation. Caps of thin, resistant sandstones are frequent.

3.0

209.1 Milepost 472. Chinle shales at 9:00. Shadow Mt., a volcanic feature, on distant horizon at 9:30. Plateau surface at 1:00-3:00 is Ward Terrace which is supported by the Owl Rock Member of the Chinle Formation.

0.9

210.0 Skyline hogback at 12:00 is Echo Cliffs Monocline.

0.15

210.15 Shadow Mt. and associated lava flows overlie the Chinle Formation.

1.0

211.15 Milepost 474. Transmission lines.

3.2

214.35 Wash crossing. Salt cedars along wash.

1.85

216.2 Painted Desert represents Petrified Forest Member of the Triassic Chinle Formation.

0.85

217.0 Sandstone caps collapse and clays are rapidly eroded.

0.95

217.95 Tuba City turnoff. Highway 160. Turn right.

0.35

218.3 Petrified Forest Member of the Chinle Formation at 9:00.

0.3

218.6 Bridge. Highway begins to ascend through younger strata.

1.05

219.65 Milepost 313. Approximate contact of Petrified Forest Member (below) and Owl Rock Member (above) at 9:00.

1.55

221.2 Orange colored sandstones belong to the Triassic Moenave Formation.

0.35

221.55 Interesting weathering forms in Moenave Formation.

0.35

221.9 Green trees at 9:30 indicate a water source at base of escarpment. This is village of Moenave, type area for the Moenave Formation.

0.65

222.55 Milepost 316.

0.4

222.95 Turnoff at 9:00 to Moenave.

0.95

223.9 Siltstones are in the Triassic Kayenta Formation.

0.65

224.55 Kayenta Formation.

2.0

226.55 Both walls are Kayenta Formation. Sand dunes on top at 3:00.

1.2

227.75 Cliff-capping sandstones are in Kayenta Formation.

0.6

228.35 Junction of U. S. 160 and Arizona 264. Tuba City to left. Hopi country to the right. We stay on 160.

1.15

229.5 Milepost 323. Roadcut at 9:00 exposes cross-bedded eolian sandstone of the Jurassic Navajo Sandstone.

1.0

230.5 Navajo Sandstone at 3:00. Road on modern blow sand.

2.7

233.2 Navajo Sandstone buttes at 9:00.

1.65

234.85 Milestone 328. Mesa on skyline at 9:00 is Preston Mesa - elevation 6830. Mesa at 11:00 is Middle Mesa - elevation 5947 - Carmel Formation (red) above the Navajo Sandstone (light colored). Our elevation is approximately 5000. Conical peak at 10:00 is Wildcat Peak, a volcanic neck.

0.85

235.7 Milepost 329. Low growing, dark green shrub is Mormon Tea (or Navajo Tea - Ephedra). It was used as a substitute for tea by

pioneers and sold by Mormons to wagon trains, hence the name. May be brewed fresh or dried.

2.05

237.75 Skyline at 12:00 is Middle Mesa. Darker cap is Carmel Formation.

4.15

241.9 Junipers selectively grow on and near outcrops of Middle Mesa.

1.4

243.3 Indian dwelling at 3:00 at base of Middle Mesa. Carmel Formation above Navajo Sandstone.

0.65

243.95 Milepost 337. Cross-bedded Navajo Sandstone at 3:00. Wildcat Peak at 11:00. White Mesa at 11:30.

4.15

248.1 Milepost 341. Wildcat Peak at 9:00. White Mesa cliffs are of Jurassic Cow Springs Sandstone. Western edge of Black Mesa at 12:00 to 3:00.

1.0

249.1 Road begins descent on an eastward dipping monoclinal fold.

1.8

250.9 Carmel Formation contact with overlying Cow Springs Sandstone.

0.1

251.0 Red Lake Trading Post at 3:00.

0.6

251.6 Roadcut at 9:00. Reddish Carmel Formation overlying Cow Springs Sandstone. Here the Navajo Sandstone, an important aquifer, is in subsurface. Groundwater from the Navajo supplies the coal slurry line from Black Mesa.

0.6

252.2 Erosional features known as "elephants' feet" are Cow Springs Sandstone. Some cross-bedding visible.

0.05

252.25 Milepost 345.

5.15

257.4 Electrified railroad for coal haulage between Black Mesa and Navajo generating plant near Page, Arizona.

1.05

258.45 Milepost 351. Black Mesa at 3:00. White Mesa at 9:00. Reddish dune sands in middle distance at 9:00.

1.1

259.55 Navajo Sandstone at surface.

1.15

260.7 Cow Springs Trading Post. Jurassic rocks at this northern edge of Black Mesa are inclined in a southerly direction.

6.45

267.15 Milepost 360. Black Mesa escarpment at 11:00-3:00. Broad valley to left of highway and railroad is Klethla Valley, eroded in Navajo Sandstone.

1.65

268.8 Junction. Highway 98 to Page. Highway 160 continues ahead. We will return to this junction and resume this mileage.

ROAD LOG
SIDE TRIP TO COAL OPERATIONS

0.0 Junction of Highways 98 and 160

3.4

3.4 Black Mesa is capped by Upper Cretaceous sandstones and shales. Buttes at 10:00 are Navajo Sandstone (principal aquifer in region). Many large landslides or slumps border Black Mesa. These are characterized by hummocky terrane. The thick Mancos Shale unit underlies the cliff-makers.

7.1

10.5 Coal loading facility at 11:00 fed by conveyor system that ascends the Mesa at 1:00. We will make some short stops to see and hear about this system.

1.6

12.1 Conveyor belt above road.

0.7

12.8 Turnoff to Black Mesa shopping center.

0.05

12.85 Turnoff to Navajo National Monument - 9:00; to Black Mesa - 3:00. Finally!

0.35

13.2 Cliff at 9:00 capped by Dakota Sandstone and underlain by shales of the Recapture Member of the Morrison Formation. Cow Springs Sandstone at base.

0.7

13.9 Slope is position of Cretaceous Mancos Shale.

0.4

14.3 Above the Mancos are the basal sandstones of the Mesa Verde Group.

0.3

14.6 Viewpoint. Pull out for scene at 11:00 (Marsh Pass). We might eat lunch here depending upon timing.

0.4

15.0 Coal handling facility.

0.5

15.5 Crest of Black Mesa near 7000 feet.

1.5

17.0 Overlook of mining activity.

1.85

18.85 Drainage bottom.

1.0

19.85 Mine area parking lot.

(Mine tour not logged. Road log will resume at junction to Page.)

ROAD LOG
RESUMED AT JUNCTION OF HIGHWAYS 160 and 98

268.8 Junction of 160 with 98 to Page. Turn right.

0.1

268.9 Cross coal haulage railroad tracks. Heading north.

1.0

269.9 Cross-bedded Navajo Sandstone.

4.55

274.45 Milepost 356. Navajo Sandstone. Low growing grey-green shrub is Sagebrush. Smaller shrub along road is Turpentine Bush. Navajo Mt. at 11:00 is on the Arizona-Utah border. More about this later.

1.0

275.45 Milepost 355. White Mesa at 10:00 and Square Butte at 10:30. Trees are juniper and pine.

2.35

277.8 Drainage bottom. Walls are Navajo Sandstone.

3.45

281.25 Road to Navajo Mt.

0.5

281.75 Navajo-Carmel contact.

0.25

282.0 Modern sand dunes.

0.8

282.8 Navajo dwellings at 2:00.

0.4

283.2 Carmel Formation in roadcut.

2.5

285.7 Elevation 6687. This is the high point along this road.

1.5

287.2 Scenic viewpoint. Navajo Mountain to the north, over 10,000 feet

in elevation, is laccolithic in origin. Dissected terrane is largely the Jurassic sandstone section. The Navajo Sandstone is succeeded by the Carmel Formation, Entrada Sandstone (often called the Cow Springs Sandstone here), Bluff Sandstone, and the Morrison Formation. The Cretaceous Dakota Formation is the capping unit. Square Butte is at 12:00.

0.45

287.65 Navajo Sandstone in roadcuts.

1.6

289.25 Red and white Carmel Formation at 9:00.

1.45

290.7 Milepost 340. White Mesa at 9:00.

5.05

295.75 Milepost 335.

1.2

296.95 Modern sand dunes.

1.1

298.05 Carmel Formation and Kaibito Wash.

0.25

298.3 Kaibito turnoff.

1.5

299.8 White Mesa at 9:00. Dark cap is the basal Cretaceous unit in northern Arizona, the Dakota Formation. Elsewhere, the Dakota is coal-bearing.

1.0

300.8 Road traversing Kaibito Plateau.

4.1

304.9 Outcrops are the ubiquitous Navajo Sandstone.

7.05

311.95 Navajo at 3:00 capped by orange sandstone of the Carmel.

4.95

316.9 Roadcuts in Carmel Formation.

6.2

323.1 Milepost 308. Navajo Mt. and underlying Mesozoic sandstone sequence. Butte at 12:30 is Leche-E Rock. Red is Carmel; white sandstone is probably Entrada, capped by basal Morrison.

2.0

325.1 Leche-E Rock at 3:00. Stacks of Navajo Power Plant at 12:00.

1.05

326.15 Milepost 304. Carmel Formation.

2.05

328.2 From 1:00 to 3:30 in distance is a section that includes the following: Navajo, Carmel, Entrada, Morrison (Jurassic); Dakota, Tropic, Straight Cliffs, Wahweap, Kaiparowits (Cretaceous); Wasatch (Tertiary).

2.9

331.1 Road to power plant. Page Sandstone. This is a newly proposed unit separated from the underlying Navajo Sandstone by a regional chert-pebble conglomerate.

1.5

332.6 Entering Page - founded 1957. Elevation 4300.

Proceed to motel. On Sunday, we will board bus about 8:30 a.m. and drive to Glenn Canyon Dam Visitor Center. A Bureau of Reclamation representative will take us on a tour of the hydroelectric plant. Lunch will be at the Wahweap picnic area from which we will drive to the Navajo Power Plant for a tour. We will then head for the airport and a flight back to Phoenix.

End of log