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CENOZOIC GEOLOGY OF THE CHUSKA MOUNTAINS

By

JOHN W. BLAGBROUGH

INTRODUCTION

The Chuska Mountains are a narrow upland about 60 miles long extending northwestward across the New Mexico-Arizona state line on the Navajo Indian Reservation (Fig. 1). The Chuskas are separated from the Carrizo Mountains to the north by Red Rock Valley. The upland is capped by Chuska Sandstone which rests unconformably on eastward-dipping Mesozoic strata along the Defiance monocline. The range is on the northeastern flank of the Defiance uplift along the southwestern edge of the San Juan Basin.

The Chuska Mountains are an isolated area of Tertiary sediments and volcanic rocks on the Colorado Plateau. A consideration of the characteristics and origin of the sedimentary deposits and volcanic rocks and their relationships to the erosion surfaces aids in understanding the Cenozoic history of the region.

The range is a large upland area which was defined by late Tertiary time and, owing to its altitude and areal extent, received more precipitation and had lower temperatures than the surrounding terrain during the Pleistocene. As a result, the geomorphic processes that prevailed produced colluvial deposits around the flanks which are not found in the adjacent lowlands.

The Chuska Mountains still receive more precipitation than surrounding lowlands. Annual precipitation for the mountain crest may exceed 20 inches as compared to about 12 inches at Tohatchi, Lukachukai, and Mexican Springs (Nakaibito). The mean annual temperature is probably about 40 degrees F. (Watson and Wright, 1963, p. 540).

A dense forest of Colorado blue spruce, alpine fir and Douglas fir grow above 9,000 feet in the vicinity of Roof Butte. Much of the upland is covered with Ponderosa pine, and dense groves of aspen and oak interspersed with meadows of mountain grass. Ponderosa pine, oak, and pinon pine grow abundantly on slopes above 7,000 feet; and spruce, fir and aspen grow in some canyons that indent the flanks.

The Chuskas form a divide between Chaco River drainage on the east, Chinle Wash drainage on the west, and Red Wash drainage on the north. These three master streams flow northward to the San Juan River. Because of a greater southwestward slope of the upland, there is more runoff in the western drainage, and only the streams on the western flank have perennial flow.

PHYSIOGRAPHIC AND GEOLOGIC SETTING

The Chuska Mountains rise abruptly from surrounding lowlands. Elevations at the base of the mountains generally range from 6,500 to 7,000 feet, and the crest is 2,000 to 2,500 feet above the Defiance Plateau to the west and 3,500 feet above the Chuska Valley to the east.

The upland surface of the Chuska Mountains is a dissected plateau with an average elevation of about 9,000 feet. Mesas, buttes, and knobs rise from 300 to 400 feet above the general level of the plateau. Roof Butt is formed by two volcanic necks and is at the northern end of the range. It rises about 800 feet above the plateau and the eastern peak attains an elevation of 9,808 feet, the highest in the Chuskas.

The Chuska Mountains are eroded in Chuska Sandstone and volcanic rocks of Tertiary age. Prominent cliffs which are below and bound most of the upland surface are broken by canyons that cut into the uplands.

The Lukachukai Mountains are a northwesterly-extending spur of the Chuska Mountains, separated from the main upland by a saddle eroded in the lower beds of Chuska Sandstone. Beautiful Mountain is northeast of the Chuskas and is an isolated remnant capped by a Tertiary sill. Sonsela Buttes, prominent outliers on the western flank, are capped by lava flows.

The topography of much of the upland surface of the Chuska Mountains is subdued and many of the streams flow through wide, shallow valleys with U-shaped profiles. These landforms contrast sharply with the rugged topography of sharp, angular slopes and V-shaped stream valleys within and around the margins of the mountains.

Some streams flow through U-shaped valleys within the mountains and then through V-shaped gaps where they have notched the flanks of the plateau.

The subdued topography is attributed to an older erosion cycle operating under climatic conditions which differ markedly from those of the present. The more rugged land forms are believed to have developed during a more recent period of erosion.

One of the most striking features of the upland surface of the Chuska Mountains is the many lakes and swamps which partly fill rock basins. Only a few of these have been integrated into the modern drainage. The diameters of the basins range from less than 100 feet to more than one-quarter of a mile. Their shapes range from roughly oval to very irregular and maximum water depth does not exceed 25 feet.

Some of the basins are on knobs rising above the general level of the plateau surface and contain lakes. Many of the lakes and swamps evaporate completely in the late summer or early fall, or during dry years. Shallow notches on some of the depression rims indicate that there has been occasional overflow. Wright (1964) postulates that the depressions formed as a result of collapse of cemented sandstone layers above vacuities produced by piping of uncemented sand out to the escarpment of the mountains.

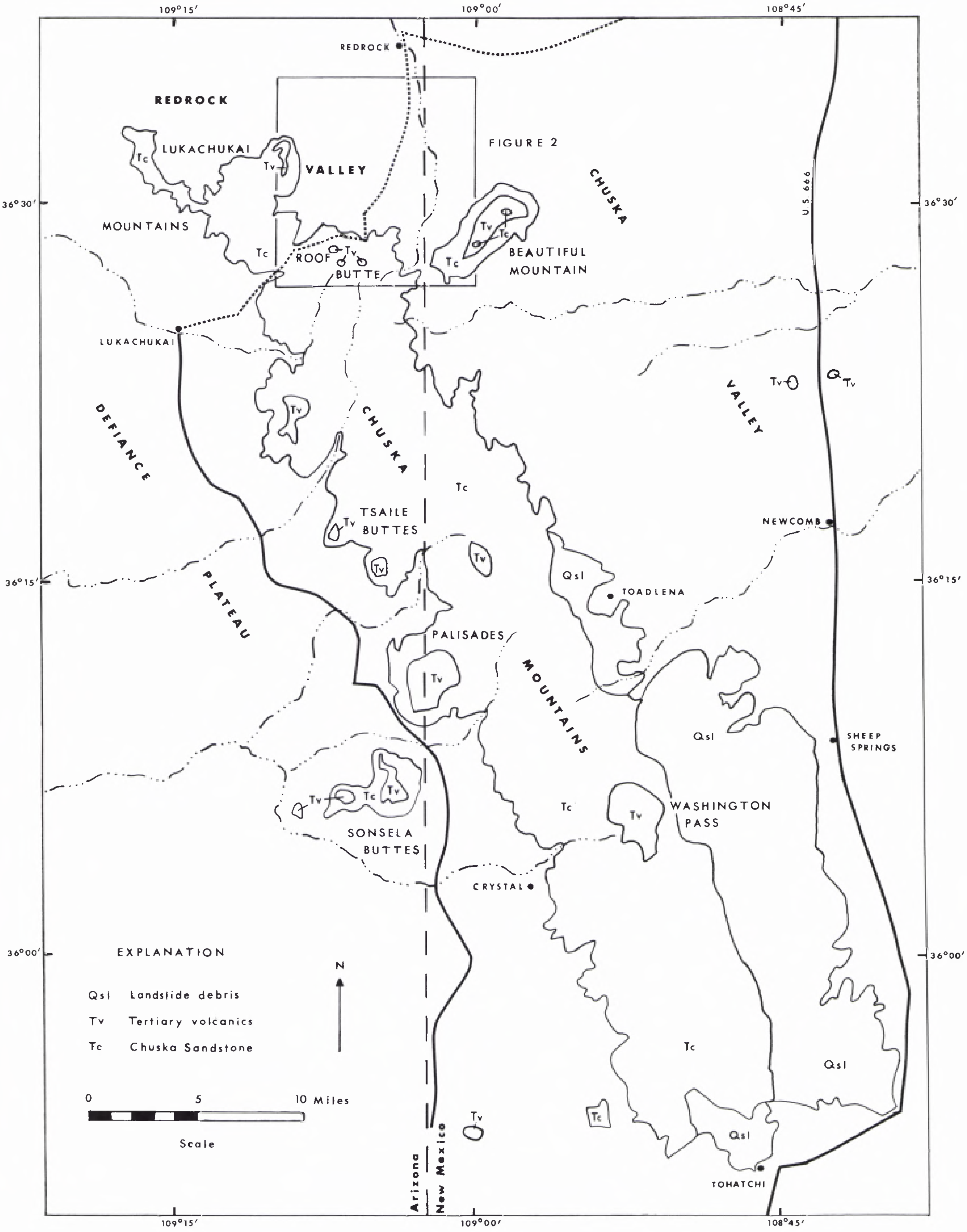

FIGURE 1.

Geologic map of Chuska Mountains showing outcrop of Chuska Sandstone, Tertiary volcanics, and Quaternary landslide debris. Adapted from O'Sullivan and Beaumont (1957) and O'Sullivan and Beikman (1963).

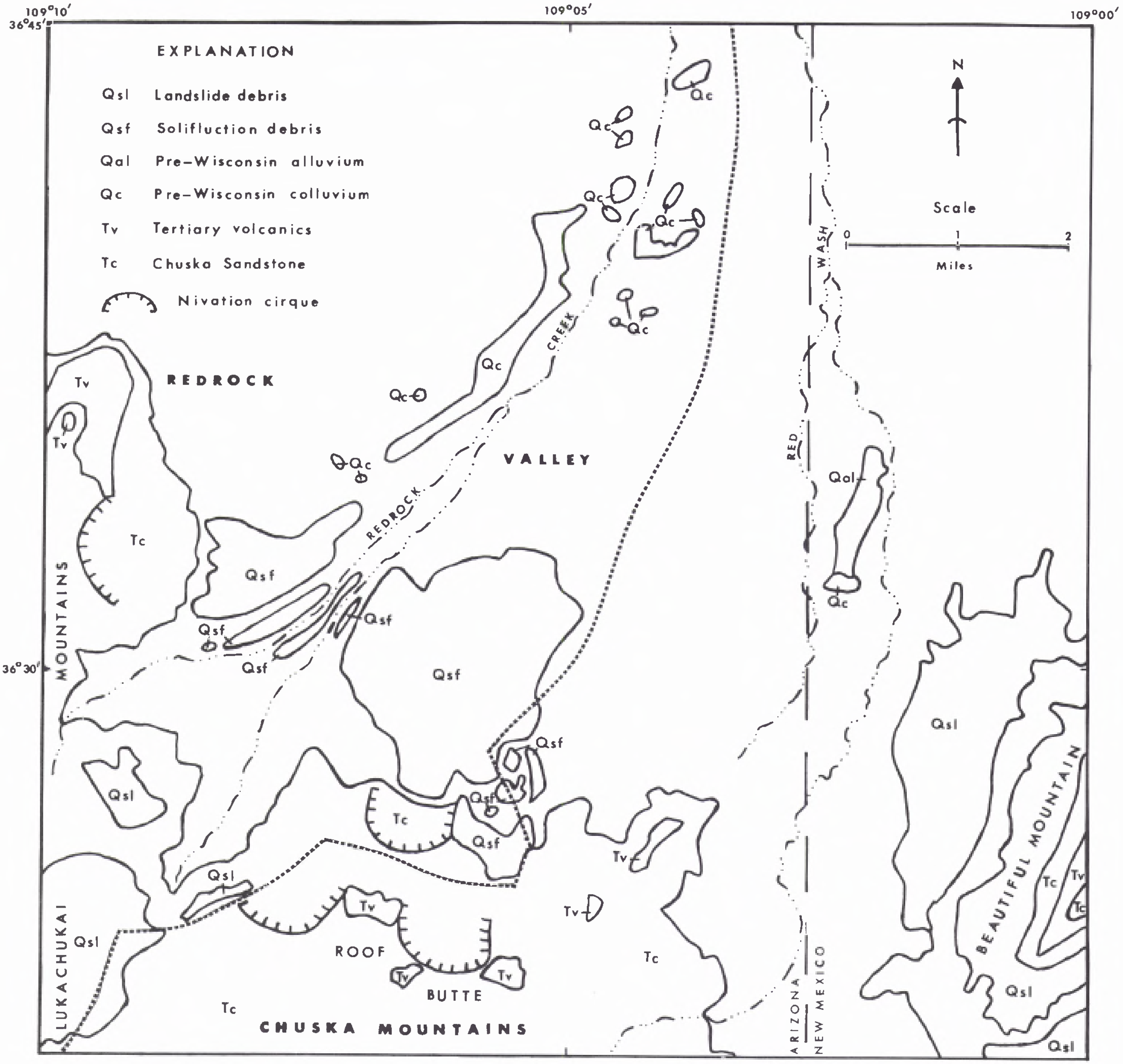

FIGURE 2.

Colluvial deposits on northern flank of Chuska Mountains and in Redrock Valley. Location of map area is shown in Figure 1.

Four cirque-like features on the northern flank of the Chuska Mountains (Fig. 2) are characterized by steep, semicircular walls and floors which slope gently outward. The distance from headwalls to lips ranges between one-quarter to half a mile and their length along the lip is from half to three-quarters of a mile.

The features have northern, northeastern, and northwestern exposures and are eroded in Chuska Sandstone and Tertiary volcanic rocks. (Figs. 3 and 4) They are thought to have formed by frost wedging, and freezing and thawing combined with mass-wasting around large snow banks.

In this paper the features will be called nivation cirques. They differ from cirques eroded by glacial ice in that their floors are irregular and not eroded below their lips. The preservation of the nivation cirques on steep mountain slopes where erosion is intense indicates a late Pleistocene (Wisconsin(?)) age.

FIGURE 3.
Northern flank of Chuska Mountains. Large nivation cirque is between two Tertiary volcanic necks that form Roof Butte. Solifluction debris is in foreground and Quaternary alluvium forms plain in middle ground.

Lacustrine sediment partly fills many of the rock basins and alluvium is in the larger valleys. Talus surrounds some of the mesas, buttes and knobs that rise above the general level of the upland. Except for these, there is a general lack of surficial deposits. No soil or regolith is developed and bedrock is either exposed or covered by a few inches of sand derived from underlying Chuska Sandstone.

ROCK UNITS

Chuska Sandstone

The Chuska Sandstone is described by Wright (1954 and 1956) and Repenning, Lance, and Irwin (1958). It is, in general, a gray cross-bedded sandstone with a maximum thickness of about 1,800 feet and an average thickness of 1,000 feet.

Two types of sandstone are present throughout the Chuska section. One is composed of coarse to fine-grained, rounded to subround quartz with prominent accessory mineral grains. It is usually firmly cemented with calcium carbonate cement and generally forms ledges. In some places opal and chalcedony are also cementing agents. The other sandstone is loosely cemented and forms slopes which are generally covered by float from the overlying ledge-forming sandstone. The loosely cemented sandstone contains fine-to-very fine-grained quartz. The Chuska Sandstone is predominately cross-bedded in beds 4 to 20 feet thick. The cross-bedding is of the trough type in which each set has a curved surface of erosion on its lower boundary. It is considered to be largely of eolian origin and was probably deposited in a desert basin by winds blowing from the south and southwest (Wright, 1956).

The lower 250 feet of Chuska Sandstone at the southern end of the range is a cross-bedded, fine-grained, loosely cemented, slope forming quartz sandstone having beds two to four feet thick interbedded with siltstone lentils, claystone, bentonitic clay, white ash beds, and layers of gypsum. A conglomerate from two to ten feet thick forms the base and is composed of well-rounded pebbles averaging from a quarter of an inch to two inches in diameter.

The cross-bedding in this lower 250 feet is either of the trough or planar-tabular type. The beds are thought to be largely fluvial in origin and probably were deposited by southerly flowing streams (Repenning, Lance, and Irwin, 1958, p. 124).

Wright (1954, p. 1831-1833) named this lower, predominately fluvial 250 feet of Chuska Sandstone the Deza Formation. Repenning, Lance, and Irwin (1958, p. 123) do not accept the Deza Formation as a map unit because good exposures are not plentiful and the Deza-Chuska contact is gradational and difficult to map.

The age of the Chuska Sandstone is uncertain because fossils suitable for dating have not been found. Gregory (1917, p. 15 and 81) assigns the Chuska an Eocene(?) age because of similarities in lithology and position to the Wasatch Formation (now called the San José Formation) in the San Juan Basin.

The Chuska Sandstone currently is given a Pliocene(?) age by the U. S. Geological Survey because of tentative correlations with the Bidahochi Formation of Pliocene age in northeastern Arizona (Repenning, Lance, and Irwin, 1958, p. 124). Wright (1956, p. 429) assigns a Miocene(?) age to the Chuska because of the magnitude of the disconformity between the Chuska Sandstone and overlying volcanic rocks of Pliocene age.

Volcanic Rocks

The Chuska Mountains are in the Navajo-Hopi volcanic province which is distinguished by the relatively high proportion of pyroclastic deposits to lava flows, and by the alkalic composition of the rocks (Williams, 1936). The Chuska Mountains volcanic area includes also the volcanic

FIGURE 4.
Nivation cirque, eroded in Roof Butte, on, northern flank of Chuska Mountains. Tertiary volcanic necks are on right and extreme left. Knob in middle in the remnant of a lava flow. Chuska Sandstone is exposed in foreground.

rocks in Redrock Valley, Chuska Valley and on the Defiance Plateau. Gregory (1917) and Williams (1936) discuss the volcanics in the Chuskas, and five areas are described in detail by Appledorn and Wright (1957).

The northern escarpment of the Chuska Mountains is formed in large part by volcanic rocks that intrude and overlie Chuska Sandstone. Beautiful Mountain is capped by a sill that is overlain by isolated outcrops of Chuska Sandstone. The northern projection of the Lukachukai Mountains into Redrock Valley is rimmed by a sill and is capped by a lava flow that had its source in an adjacent volcanic cone. Roof Butte is formed by two explosive pipes and the remnant of a lava flow (Figs. 3 and 4).

Tertiary volcanic rocks intrude and overlie Chuska Sandstone and Mesozoic strata in three areas on the western flank of the range north of Crystal. Tsaile Buttes are formed by eroded plugs, cones and flows. The Palisades are an erosional remnant of coalesced domes of lava and agglomerates from several closely spaced vents. The Lava rests on a sandy tuff. East Sonsala Butte is capped by lava flows and West Sonsola Butte is the remnant of a lava dome and a crater filled with coarse explosive breccia.

The depression at Washington Pass near the southern end of the range is floored by lava flows underlain by fluvial pyroclastic debris and overlain by a rubble dome intruded by plugs and dikes. Structural features in the volcanics and Chuska Sandstone suggest minor caldera subsidence.

The volcanic rocks are primarily minette or its extrusive equivalent sanidine trachybasalt. Both are potash rich alkalic rocks. The volcanics are dated as Pliocene because they are genetically related to Pliocene igneous rocks of the Hopi Buttes in northeastern Arizona (Williams, 1936, p. 163). The middle volcanic member of the Bidahochi Formation in the Hopi Buttes area may be middle Pliocene in age because it is underlain by strata that are definitely early Pliocene in age and overlain by beds that are of late middle Pliocene age (Repenning, Lance, and Irwin, 1958, p. 128-129). This suggests a middle Pliocene age for the volcanics in the Chuska Mountains.

QUATERNARY COLLUVIAL DEPOSITS

Colluvial deposits cover extensive areas on the slopes of the Chuska Mountains and extend into surrounding lowlands. They include landslide debris, solifluction debris, and pre-Wisconsin colluvium that may have been deposited by snow avalanches. These sediments are not forming today and it is assumed that they accumulated under climatic conditions that differed markedly from those of the present.

Landslide debris

Large areas around the flanks of the Chuska Mountains are covered by landslide debris composed of angular blocks of Chuska Sandstone and volcanic rock (Fig. 5). One large area of debris has been mapped for 25 miles along the eastern flank of the mountain from Toadlena southward to the southern end of the range (Watson and Wright, 1963). The landslide debris in this is differentiated on the basis of elevation, distance from the source, and degree of erosion and down wasting of the blocks into upper, middle, and lower levels.

The upper level is at an elevation of 8,400 feet and consists of distinct ridges and troughs parallel to the main escarpment. Remnants of individual blocks 1,000 feet long, 100 feet wide, and 100 feet high are on the ridges. Since coming to rest, many of the larger blocks have broken into smaller fragments which have migrated down slope

FIGURE 5.
Landslide debris composed of angular blocks of Tertiary volcanic rock (minette) on northern flank of Beautiful Mountain.

FIGURE 6.
Solifluction debris composed of Tertiary volcanic rock and Chuska Sandstone on northern flank of Chuska Mountains. The deposit is underlain by Chinle Formation. Arrow identifies hammer. Lukachukai Mountains in background.

into the troughs. On the second level at about 8,000 feet, the ridge pattern is disconnected and subdued as a result of much downwastage. The blocks which cap the ridges generally are smaller than those in the level above.

The lowest level of debris is at about 7,600 feet and has been down-wasted until it is discontinuous hummocks of blocks on underlying Cretaceous shale as much as eight miles from the mountain front. No ridge pattern is apparent and the deposit is dissected considerably.

The origin of the landslide debris is related to the lithology and structure of rocks on the crest of the mountain. Tertiary volcanic rocks and well-cemented Chuska Sandstone which compose the landslide blocks form the escarpment above the debris areas. These are underlain by beds of poorly-cemented Chuska Sandstone. Individual blocks of capping volcanic rocks or Chuska Sandstone separated along vertical joints and horizontal planes, then moved down slope without the backward rotation that is found in toreva blocks.

Sliding was on friable beds of Chuska Sandstone and Cretaceous shale. A high water table during pluvial stades of the Pleistocene and extreme conditions of sand flow, in a process called piping, may have augmented separation of ridge-blocks and sliding (Watson and Wright, 1963, p. 541-543). Some of the blocks may have slid down deep snow banks and lodged at the base (Allen and Balk, 1954, p. 135).

Frost wedging probably played a part in the separation of blocks from the escarpment front. Gentle slopes beneath some areas of landslide-debris and the hummocky topography indicate that the blocks probably moved by solifluction or frost heaving.

The lower level of landslide debris may predate the Wisconsin inasmuch as pediments cut into the lower level are graded to terraces which are traceable via the Chaco, San Juan and Animas Rivers to the base of Wisconsin moraines in the San Juan Mountains (Watson and Wright, 1963, p. 547). The pediments were eroded into the lower level after long downwasting and erosion of the landslide mass. The preservation of ridges and troughs indicates that the middle and upper levels probably formed during pluvial stades of the Wisconsin.

Solifluction debris

Solifluction debris lies below nivation cirques on the northern flank of the Chuska Mountains (Fig. 2). The debris is distinguished from areas of landslide debris by the lobate shape, location on gentler slopes, and the continuity of debris in the outcrop area. The largest lobe has a maximum width of two and one-half miles and its terminus is approximately four miles north of the northern flank of the mountain. The debris has a maximum thickness of about ten feet and is composed of large angular boulders of Chuska Sandstone and volcanic rock (Fig. 3 and 6). The average diameter of the boulders is about 6 feet and the maximum is approximately 20 feet.

The solifluction lobes have been considerably dissected along the mountain front and at some localities isolated remnants rise from 10 to 20 feet above surrounding terrain. On lower slopes the debris has been cut by streams which have eroded gullies through the boulder cover into the underlying Chinle Formation.

The solifluction lobes are on slopes greater than five degrees and the debris overlies lower beds of Chuska Sandstone and the Chinle Formation, both of which contain strata that becomes plastic when saturated. This property played an important part in their formation because it enabled fragments of considerable size to be transported down slope and led to the development of a lobate form.

Moisture probably was supplied by melting snow and

FIGURE 7.

Large boulder of Chuska Sandstone in pre-Wisconsin colluvium in Redrock Valley. The colluvial debris is on a surface that slopes valleyward at an angle of about two and one-half degrees and the block is seven miles from its source in the Chuska Mountains. Carrizo Mountains on horizon. Walker Peak, a Tertiary volcanic neck, in middle ground.

ground ice. The subsoil may have been frozen for much of the year preventing loss of water by downward seepage, and down slope movement probably was augmented by frost heaving.

Debris forming the solifluction sheets was dislodged from nivation cirques and cliffs on either side by frost wedging. Much of the dislodgment took place along bedding planes and joint surfaces, as indicated by the rectangular shape of the debris. These deposits probably developed during a periglacial stade of the Wisconsin because they retain their lobate form and have been only moderately dissected.

Pre-Wisconsin colluvium

Colluvial deposits are on dissected pediment surfaces in Redrock Valley and on the Defiance Plateau. The debris is between 50 and 150 feet above the modern drainage and the pediments slope valleyward with angles of about two and one-half degrees. The debris has been mapped seven miles from its source in the Chuska Mountains and outcrops generally are downslope from the mouths of canyons eroded in the flanks.

The colluvium is between 10 and 30 feet thick and is underlain by the Chinle Formation and Wingate Sandstone of Triassic age, and the Morrison Formation of Jurassic age. It is composed of large angular blocks of Chuska Sandstone and volcanic rocks having average diameters of about 8 feet and maximum diameters of 25 feet (Fig. 7).

The rock fragments are in a matrix of sand and silt, and minor lenses of subangular to subrounded boulders are interbedded with the debris. The surfaces of many of the outcrops are covered by eolian and fluvial sand and silt that obscures the debris; the colluvium is exposed usually around the rims of the pediment remnants where it has slumped over underlying bedrock.

The topography developed on the debris is flat-to-gently rolling and only a few boulders project through the cover of sand and silt. Fluvial deposits of subangular to subrounded boulders with average diameters of about three feet are on the same pediment surfaces and down slope from colluvial debris. The colluvium appears to grade into the fluvial deposits although it could have overridden the alluvium and both deposits subsequently beveled by erosion.

A pre-Wisconsin age for the colluvium is suggested by its subdued topography, scarcity of boulders on its weathered surface, and the dissection of some 150 feet of bedrock which has taken place since the debris was deposited.

The older, pre-Wisconsin colluvium resembles landslide debris and solifluction lobes on the flanks of the Chuska Mountains in texture and composition. The younger colluvium is on slopes having angles greater than five degrees, lacks lenses of subangular to subrounded boulders and does not grade into fluvial sediment. It is restricted to the flanks of the mountain whereas the pre-Wisconsin colluvium extends a considerable distance into adjacent lowlands. For these reasons its does not seem probable that the older colluvium was deposited as landslide debris or solifluction lobes.

Hunt (1967, p. 292) attributes similar colluvial deposits along north-facing escarpments west of the Abajo Mountains in southeastern Utah to debris avalanches that formed during the Pleistocene when extensive snow fields melted. The pre-Wisconsin colluvium in the Chuska Mountains may have formed in a similar way. Snow avalanches could carry large angular blocks displaced by frost action a considerable distance from the mountain front. Water from melting snow in the avalanches could have deposited the water-worn boulders found both within and beyond the terminus of the colluvium.

The snow fields probably accumulated during a periglacial stade prior to the Wisconsin and the pre-Wisconsin colluvium may be correlative with the lower area of landslide debris on the eastern flank of the mountain.

EROSION SURFACES

Three erosion surfaces are developed in the Chuska Mountains and pediments are cut around the flanks. The pediment surfaces are local features whose development was determined by the lowering of base level of ancestral Red Wash, Chinle Wash, and Chaco River. They are generally veneered with Quaternary alluvial and colluvial deposits which have protected them from erosion. All the pediments probably were formed during the Pleistocene; older pediments are erosional remnants between 50 and 200 feet above the modern drainage. Younger surfaces are better preserved and developed near present-day streams.

Cooley (1958, p. 147) named the surface beneath the Chuska Sandstone the Tsaile erosion surface. It is essentially planar and truncates all Laramide structures. As a result the contact of the Chuska with underlying strata is conspicuously angular and the sandstone rests on beds of Triassic, Jurassic, and Cretaceous age.

The Tsaile surface has altitudes between 7,800 and 8,200 feet. It is nearly flat but in the southern part of the range local channels about 15 feet deep are filled with fluvial conglomerate of basal Chuska Sandstone. The Tsaile surface formed in early Tertiary time after the Laramide disturbance and before the deposition of the Chuska Sandstone.

An ancient erosion surface is preserved locally beneath the volcanic rocks in the Chuska Mountains. Lava and pyroclastic debris were deposited on hill slopes, ridges, and benches, as well as in valleys (Appledorn and Wright, 1957). The maximum relief in any general area is approximately 1,200 feet and the average is about 200 feet. The surface is at elevations ranging between 7,600 and 8,800 feet and was developed on the Chuska Sandstone and strata of Mesozoic age. It may be correlative with the Hopi Buttes surface beneath the middle volcanic member of the Bidahochi Formation in northeastern Arizona (Repenning, Lance, and Irwin, 1958, p. 123).

The physiographic relationship between the volcanic rocks and the Chuska Sandstone suggest that the Chuska is older than Pliocene. The volcanics were extruded after the deposition, cementation and erosion of at least 2,000 feet of Chuska Sandstone and underlying strata (Wright, 1956, p. 429). This indicates a long interval between the deposition of the Chuska Sandstone and extrusion of the volcanics. Since the volcanics are middle Pliocene in age, the Chuska may be as old as the Miocene.

The erosion surface on the crest of the Chuska Mountains is here referred to as the Tunitcha surface using the Navajo name for the northern part of the range. The Tunitcha surface is composed of a flat-to-gently rolling plateau which forms the main upland and the wide, mature valleys eroded in the plateau. Crests of mesas, buttes, and knobs extending above the plateau may be remnants of the surface that is preserved beneath the volcanics.

The Tunitcha surface is at an elevation of about 9,000 feet, and is developed on the Chuska Sandstone and volcanic rock of Pliocene age. It probably formed in the early Pleistocene under climatic conditions that were more humid than those of the present.

GEOLOGIC HISTORY

Mesozoic strata underlying the Chuska Sandstone were folded at the end of the Cretaceous and truncated by the Tsaile erosion surface early in the Tertiary. During Miocene(?) time, southward flowing streams deposited the basal Chuska Sandstone on the Tsaile surface. Fluvial sedimentation was succeeded by eolian deposition, and approximately 1,800 feet of highly cross-bedded Chuska Sandstone was laid down by southerly and southwesterly winds.

After the deposition and cementation of the Chuska Sandstone a second erosion cycle developed an irregular topography of hills, ridges and valleys, and approximately 2,000 feet of Chuska Sandstone and Mesozoic strata were removed from the western edge of the mountains. The Chuska Mountains began to assume their present form during this period of erosion.

Lava flows and pyroclastic debris were extruded over isolated areas of the second erosion surface in the middle Pliocene. The Chuska Sandstone and volcanic rocks of Pliocene age on the crest of the mountains were beveled by the Tunitcha surface early in the Pleistocene.

Erosion has removed most of the early Pleistocene deposits from the flanks of the Chuska Mountains so that little is known about this interval. Periglacial conditions prevailed in the mountains prior to the Wisconsin Stage and probably during the Illinoian Stage. Landslide debris accumulated on the eastern flank and snow avalanches may have caused the deposition of colluvium on the northern and western slopes. These deposits were considerably eroded and modified before the beginning of the Wisconsin Stage.

Climatic changes in the Wisconsin resulted in the formation of four nivation cirques on the northern flank of the mountains; solifluction lobes developed on the slopes below. Landslide debris associated with two pluvial stades accumulated on the eastern flank.

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