Prepared in cooperation with the Navajo Nation

Geologic Map of the Winslow 30′ × 60′ Quadrangle, Coconino and Navajo Counties, Northern Arizona

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Pamphlet to accompany
Scientific Investigations Map 3247

View looking north from the Painted Desert Overlook north of Winslow, Arizona, showing the colorful, easily eroded beds of the Petrified Forest Member of the Upper Triassic Chinle Formation. Buff-colored ledges above red beds in the distance are strata of the overlying Owl Rock Member of the Chinle Formation. Photograph by George Billingsley, 2009.

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Introduction

This geologic map of the Winslow 30′ × 60′ quadrangle, Arizona, is a cooperative effort of the U.S. Geological Survey (USGS) and the Navajo Nation to provide regional geologic information for resource management officials and visitor information services of the Navajo Nation. Field work on the Navajo Nation was conducted with the cooperation of, and under a written permit from, the Navajo Nation Minerals Department. Any persons wishing to conduct geologic investigations on the Navajo Nation must first apply for, and receive, a permit from the Navajo Nation Minerals Department, P.O. Box 1910, Window Rock, Arizona, 86515, telephone (928) 871–6587.

The Winslow quadrangle, which encompasses approximately 5,018 km^2 (1,960 mi^2) within Coconino and Navajo Counties of northern Arizona, is bounded by longitude 110° to 111° W. and latitude 35° to 35°30′ N. South of the Navajo Nation, private and State lands form a checkerboard pattern along the south edge of the quadrangle (fig. 1).

The geologic map of the Winslow quadrangle was prepared by the USGS Navajo Land Use Planning Project in cooperation with the Navajo Nation and funded through the USGS National Cooperative Geologic Mapping Program to provide connectivity to the regional geologic framework of the Grand Canyon area of northern Arizona. The Winslow geologic map will benefit local, state, federal, Navajo, and private land-resource managers who direct environmental and land-management programs such as range management, biological plant and animal studies, flood control, water resource investigations, and natural hazards associated with sand dune mobility. The geologic information will support future and ongoing geologic investigations and associated scientific studies within the Winslow quadrangle.

Geography

The Winslow quadrangle, which lies within the southern Colorado Plateaus geologic province (herein called the "Colorado Plateau"), is locally subdivided into six physiographic parts: the Little Colorado River Valley, Painted Desert, Newberry Mesa, Ives Mesa, Marcou Mesa, and the Hopi Buttes (fig. 1). Elevations range from 2,067 m (6,782 ft) at the Radio Facility within the Hopi Buttes (Tsezhin Bii) to about 1,428 m (4,685 ft) at the Little Colorado River northwest of Leupp (fig. 1).

Settlements within the Winslow quadrangle include Winslow (the largest), Leupp, Dilkon, Indian Wells, Tolani Lake, Bird Springs, and Teesto (fig. 1). The town of Old Leupp (west edge of sheet 1) was abandoned in the 1940s due to potential flood problems and moved 1.5 km (1 mi) west to Sunrise, now called Leupp.

State Highway 77 provides access to the east half of the Winslow quadrangle; State Highway 87 provides access to the central part; and State Highway 99 provides access to the west half. Navajo Highway 15 provides access from Leupp eastward across the central part of the Winslow quadrangle to Bird Springs, Dilkon, and Indian Wells (fig. 1). Navajo Highway 2 provides access northward from Leupp to Tolani Lake. Unimproved dirt roads provide access to remote parts of the Navajo Reservation. Some roads are maintained by the Navajo Nation Roads Department in Window Rock, Arizona, and others are maintained locally by local Chapter governments (Leupp, Tolani Lake, Bird Springs, Dilkon, Teesto, Indian Wells, White Cone, and Greasewood Springs Chapters). Four-wheel-drive vehicles are recommended for driving on dirt roads of the Navajo Nation owing to mud or snow in the winter months and sandy conditions in the spring and summer months. Extra water and food is highly recommended for travel in this region.

Previous Work

An early reconnaissance photogeologic map that includes the Winslow quadrangle was compiled by Cooley and others (1969 [sheet 4 of 8; scale 1:125,000]) for the Navajo and Hopi Indian Reservations of Arizona, New Mexico, and Utah. This map was not registered to a topographic base map at the time because a base larger than 1:250,000-scale did not exist. The map by Cooley and others (1969), which was used as part of the Flagstaff 1° × 2° quadrangle by Ulrich and others (1984), is adjacent to the following 1° × 2° quadrangle maps: the Marble Canyon quadrangle by Haynes and Hackman (1978); the Shiprock quadrangle by O'Sullivan and Beikman (1963); and the Gallup quadrangle by Hackman and Olson (1977). Two large-scale geologic maps and reports within the Hopi Buttes (Tsezhin Bii) Volcanic Field were produced by Vazquez (1998, 1999) and Hooten (1999a, 1999b). The geology in these two large-scale maps, although too detailed to include in this map, does provide significant information and insight about the complexity of diatreme volcanoes of the Hopi Buttes area. The Quaternary geology of all previous maps has been modified and significantly updated to match the consistency and detail of the Cameron 30′ × 60′ quadrangle map (Billingsley and others, 2007), which adjoins the northwest corner of the Winslow map.

Mapping Methods

The geologic map of the Winslow quadrangle was produced by stereoscopic analysis of aerial photographs, augmented by extensive field checking. Primary resources include color aerial photographs at 1:24,000-scale, flown in 2004, 2005, and 2006, and also at 1:40,000-scale, flown in 2005. The geologic linework originally was compiled onto 1:24,000-scale paper USGS topographic maps. The 32 draft paper maps then were scanned and georeferenced to the corresponding 7.5′ topographic map digital raster graphics (DRGs) in ArcGIS. Geologic features were digitized and symbolized from the field sheets, and additional field checks were performed where needed.

Many of the Quaternary alluvial and eolian deposits have similar lithologic and geomorphic characteristics and were mapped almost entirely by photogeologic methods. Pliocene(?), Pleistocene, and Holocene surficial deposits were differentiated chiefly on the basis of differences in morphologic character and physiographic position as observed on color aerial photographs

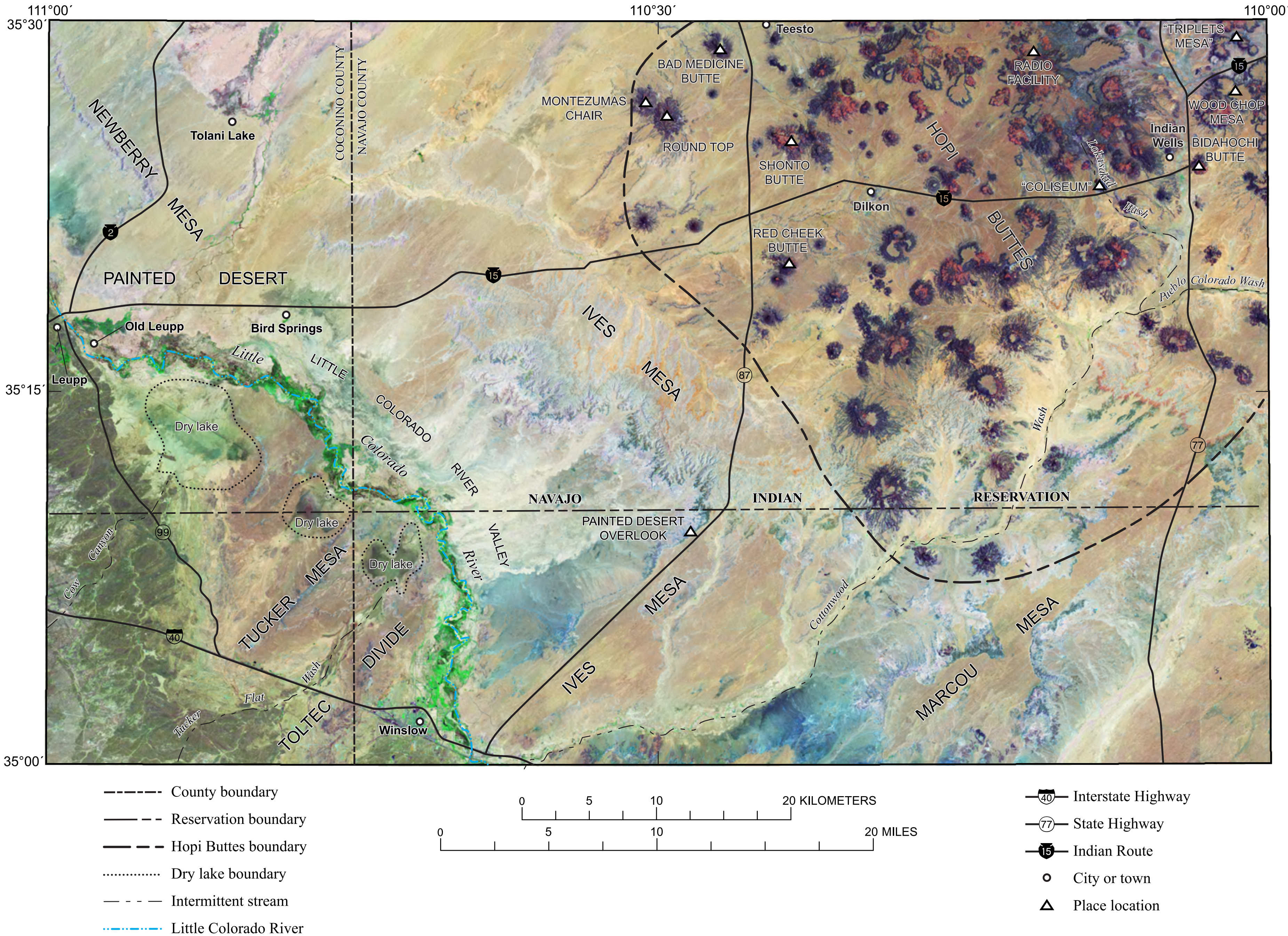


Figure 1. Index map of Winslow 30' × 60' quadrangle, Arizona, showing physiographic, cultural, and geologic locations mentioned in text.

and in the field. Older alluvial and eolian deposits are significantly eroded, whereas younger deposits are only slightly eroded and are actively accumulating material. Surficial unit contacts that are adjacent to alluvial, eolian, and bedrock map units are approximate.

Special Note

The channel of the Little Colorado River was mapped by stereo-photographic methods using 2005 color digital orthophoto quadrangles (DOQs) and drawn on 1979 and 1986 1:24,000-scale USGS topographic base maps. The present-day (2005) river channel morphology does not match that depicted on the 1979 and 1986 topographic base maps because of changing geomorphic conditions of the Little Colorado River.

Map Scale

Although the nominal scale of a USGS 30′ × 60′ topographic quadrangle is 1:100,000, we present the geologic map of the Winslow quadrangle in two panels at the 1:50,000-scale in order to preserve geologic features that were mapped and compiled at the 1:24,000-scale but are too detailed to show at the 1:100,000-scale. For map plotting purposes and readability, we present the geologic map as west (sheet 1) and east (sheet 2) panels, each consisting of sixteen 7.5′ quadrangles. The consolidation of sixteen 1:24,000-scale maps into a single panel gives the user a greater synthesis of the regional geology, and yet each panel retains the detail of the original mapping scale. In some areas, the details may be hard to read on plotted maps, but because these maps are available online, any difficulty in reading the "busy" areas of the map can be remedied by magnified viewing on screen. A third sheet contains a Correlation of Map Units, a List of Map Units, and an explanation of map symbols that are applicable to both map sheets. This pamphlet contains the complete Description of Map Units for all units on both map sheets.

Geologic Setting

The Winslow quadrangle is characterized by gently dipping Paleozoic and Mesozoic strata, which dip 1° to 2° northeastward in the southwestern part of the quadrangle (sheet 1) and become nearly flat-lying in the northeastern part of the quadrangle (sheet 2). In the northeastern part (sheet 2), a shallow Cenozoic erosional basin developed about 20 m.y. ago, which subsequently was filled with flat-lying Miocene and Pliocene lacustrine sediments of the Bidahochi Formation, as well as associated volcanic rocks of the Hopi Buttes Volcanic Field. The lacustrine sediments and volcanic rocks unconformably overlie Triassic, Jurassic, and Cretaceous strata (fig. 2; see also, Ort and others, 1998).

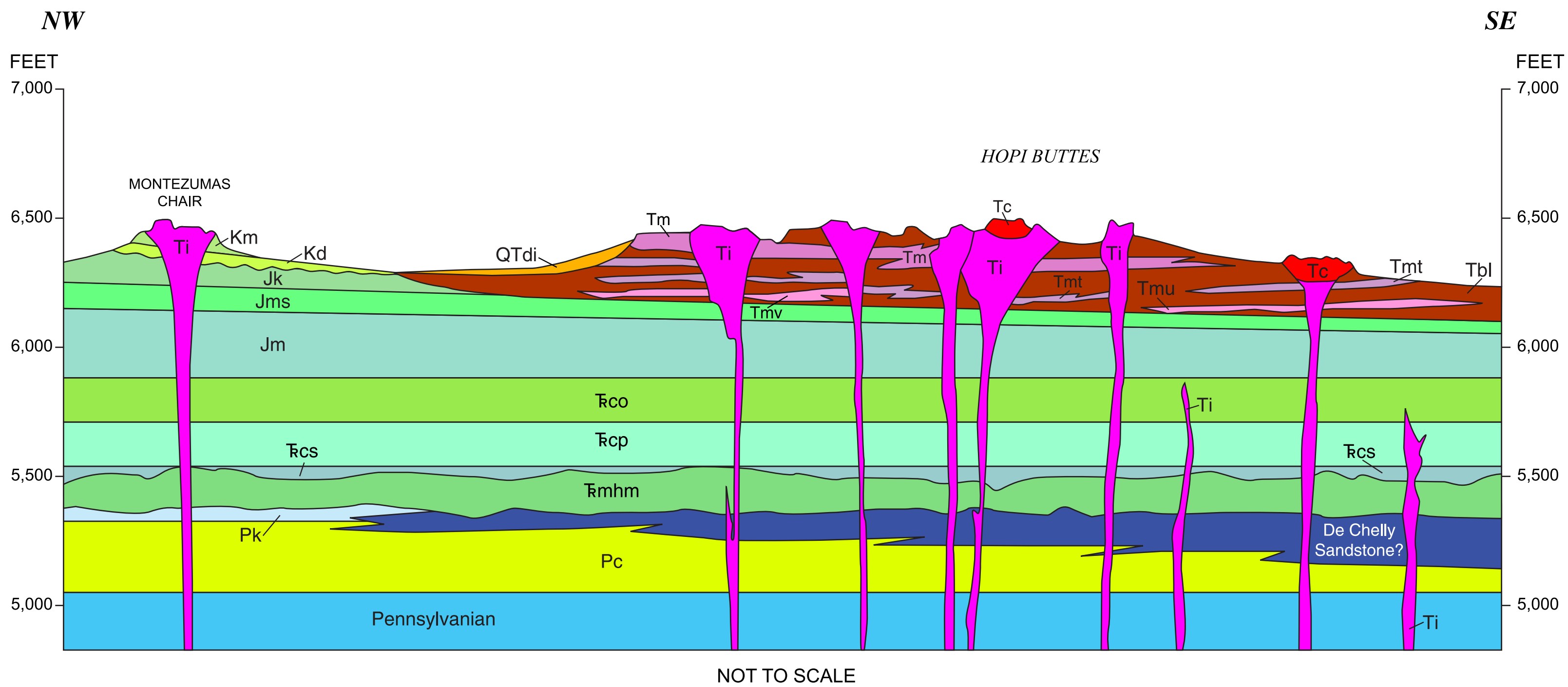
Beginning about early Pliocene time, the Little Colorado River and its tributaries began to remove large volumes of Paleozoic and Mesozoic bedrock from the map area. This erosional development has continued through Pleistocene and Holocene time. Fluvial sediments accumulated episodically throughout this erosional cycle, as indicated by isolated Pliocene(?) and Pleistocene Little Colorado River terrace-gravel deposits (QTg4) on Tucker Mesa and Toltec Divide west of Winslow and younger terrace-gravel deposits (Qg4) along the margins of the Little Colorado River Valley (sheet 1). These gravel deposits suggest that the ancestral Little Colorado River and its valley has eroded and migrated northeastward toward its present location and largely parallels the strike of the Chinle Formation. Today, the Little Colorado River meanders within a 5-km (3-mi) wide valley between Winslow and Leupp, where soft strata of the Chinle Formation is mostly covered by an unknown thickness of Holocene flood-plain deposits (Qf, Qf1, Qf2, Qf3). In modern times, the Little Colorado River channel has changed its position as much as a 1.5 km (1 mi) during flood events (Block and others, 2009), but for much of the year the channel is a dry river bed. Surficial alluvial and eolian deposits cover extensive parts of the bedrock outcrops over the entire Winslow quadrangle (sheets 1, 2).

Paleozoic Rocks

In the southwest quarter of the Winslow quadrangle (sheet 1), tributary drainages to the Little Colorado River have eroded small canyons that expose about 50 m (165 ft) of Paleozoic strata. The oldest unit exposed is in Cow Canyon (southwest edge of sheet 1) where approximately 11 m (35 ft) of Permian Coconino Sandstone crop out. Subsurface well logs indicate that the red sandstone at the base of the Coconino Sandstone (not exposed at the surface) is likely to be the northern extent of the Schnebly Hill Formation (Blakey, 1990) that is exposed in the Verde Valley southwest of the Winslow quadrangle. The Coconino Sandstone and the underlying Schnebly Hill Formation are important water-bearing sandstones in the subsurface of the southwestern part of the Winslow quadrangle (sheet 1; see also, Hoffmann and others, 2005). The combined thickness of the Coconino Sandstone and the Schnebly Hill Formation is about 366 to 396 m (1,200 to 1,300 ft; Hoffmann and others, 2005).

The Coconino Sandstone is unconformably overlain by 9 m (30 ft) of the Permian Toroweap Formation, present in the subsurface in the vicinity of Leupp (sheet 1). Elsewhere, it is unconformably overlain by the Permian Kaibab Formation (Hoffman and others, 2005). The Coconino Sandstone (and the underlying Schnebly Hill Formation) may be equivalent to, or may be a northeastward facies change into, the DeChelly Sandstone (Baars, 2000), present in the subsurface northeast of the Winslow quadrangle. However, this correlation is speculative and will remain so until future drilling information can confirm or refute it.

A regional unconformity known as the "Tr-1" (Pipiringos and O'Sullivan, 1978), which has erosional relief of less than 2 m (6 ft), separates the Kaibab Formation from the overlying Triassic Moenkopi Formation. This unconformity is easily recognized by a color change from the gray-white sandy limestone



QTdi	"Dilkon deposits" (Pleistocene? and Pliocene?)
Ti	Intrusive dikes, plugs, or necks (Miocene)
Tc	Volcanic-crater sedimentary rocks (Miocene)
Tm	Mafic monchiquite and basanite flows (Miocene)
Tmt	Mafic tuff-and-ash deposits (Miocene)
Tmu	Mixed monchiquite and basanite flows and tuff deposits, undivided (Miocene)
Tbl	Bidahochi Formation, lower mudstone and argillaceous sandstone member (Miocene)
Km	Mancos Shale (Upper Cretaceous)
Kd	Dakota Sandstone, undivided (Upper Cretaceous)
Jk	Kayenta Formation (Lower Jurassic)
Jms	Moenave Formation, upper sandstone member (Lower Jurassic)
Jm	Moenave Formation (Lower Jurassic)
TRco	Chinle Formation, Owl Rock Member (Upper Triassic)
TRcp	Chinle Formation, Petrified Forest Member (Upper Triassic)
TRcs	Chinle Formation, Shinarump Member (Upper Triassic)
TRmhm	Moenkopi Formation, Holbrook and Moqui members, undivided (Middle? and Lower Triassic)
Pk	Kaibab Formation (Cisuralian)
Pc	Coconino Sandstone (Cisuralian)

Figure 2. Schematic cross section northwest to southeast across Hopi Buttes area (sheet 2), showing Tertiary erosion surface that was cut into Jurassic and Cretaceous rocks and was subsequently filled with Miocene rocks of the Bidahochi Formation and the volcanic rocks of Hopi Buttes Volcanic Field (width of section, about 40 km).

of the Kaibab Formation to the light-red sandstone and siltstone of the Moenkopi Formation. Erosional depressions and channels between the Kaibab and Moenkopi Formations were subsequently filled with angular and subangular chert and sandstone breccia or conglomerate less than 0.5 m (2 ft) thick derived from Permian erosion of the Kaibab Formation.

Mesozoic Rocks

Erosion by the Little Colorado River and its tributaries has exposed about 548 m (1,800 ft) of Mesozoic sedimentary rock strata in the Winslow quadrangle (sheets 1, 2). West to east across the quadrangle, the Mesozoic rocks undergo abrupt facies and thickness changes within each formation. The Mesozoic rocks are, in ascending order, the Moenkopi Formation (Middle? and Lower Triassic), the Chinle Formation (Upper Triassic), the Moenave Formation (Lower Jurassic), the Kayenta Formation (Lower Jurassic), the Dakota Sandstone (Upper Cretaceous), and the Mancos Shale (Upper Cretaceous).

Moenkopi Formation

Overlying the Kaibab Formation is a sequence of reddish sandstone ledges and siltstone slopes of the Moenkopi Formation, which is exposed in the southwestern one-third of the Winslow quadrangle (sheet 1) but is partly covered by surficial deposits of the Little Colorado River between Leupp and Winslow. The Moenkopi Formation thins slightly from west to east across the southwest quarter of the quadrangle (south half of sheet 1) and averages about 67 m (220 ft) thick. The Moenkopi Formation is unconformably overlain by light-brown sandstone and conglomeratic-sandstone ledges of the Shinarump Member of the Chinle Formation. An unknown amount of the upper part of the Moenkopi Formation was removed by Triassic erosion prior to deposition of the overlying Chinle Formation.

As defined by McKee (1954), the following four formal and informal members of the Moenkopi Formation are recognized in the Little Colorado River Valley, in ascending order: the Wupatki Member, the lower massive sandstone member, the Holbrook Member, and the Moqui Member. The Wupatki Member, which thins west to east and pinches out just west of the city of Winslow, is too thin (4.5 m [15 ft] thick) to show at map scale and is herein included as part of the lower massive sandstone member (Ŧms). The lower massive sandstone member unconformably overlies the Kaibab Formation in the Winslow area and forms a small, continuous, light-red cliff or ledge that gradually thins to less than 3 m (11 ft) southeastward across the southwestern part of the Winslow quadrangle (sheet 1).

The overlying Holbrook and Moqui Members, undivided (Ŧmhm) make up the bulk of the Moenkopi Formation, as defined by McKee (1954) and Hager (1922). The lower, slope-forming Moqui Member (McKee, 1954) is exposed along "Moqui Wash" (known today as Tucker Flat Wash) 13 km (8 mi) west of the city of Winslow and is 26 m (85 ft) thick. The Moqui Member weathers to a red slope below the cliff-forming, brown Holbrook Member. Sandstone beds of the Holbrook Member, as originally defined by Hager (1922), form an irregular line of bluffs north of the Little Colorado River Valley between Holbrook and Cameron, Arizona (south and northwest of the Winslow quadrangle, respectively). The Holbrook and Moqui Members are herein mapped as undivided because of their variable thicknesses, as well as the difficulty in distinguishing them from the overlying sandstone cliffs and bluffs of the Shinarump Member of the Chinle Formation.

The regional uplift that terminated the deposition of the Moenkopi Formation caused an erosional unconformity between the Moenkopi Formation and the overlying Chinle Formation (Blakey, 1990; Riggs and Blakey, 1993). This unconformity is known as the "Tr-3" unconformity (Blakey, 1994; Blakey and Ranney, 2008). Depth of the drainages that eroded into the Moenkopi Formation averaged about 10 m (30 ft) in the southwestern part of the Winslow quadrangle (sheet 1). These eroded streams and valleys began to accumulate mud, sand, gravel, and conglomerate that formed the basal deposits of the Shinarump Member of the Chinle Formation.

Chinle Formation

The Triassic Chinle Formation is the most colorful formation in the Winslow quadrangle (sheets 1, 2) and is subdivided into the following three mappable subunits, in ascending order: the Shinarump Member, the Petrified Forest Member, and the Owl Rock Member as defined by Repenning and others (1969).

The Shinarump Member of the Chinle Formation is found in scattered outcrops between Leupp and Winslow that are largely covered by fluvial deposits of the Little Colorado River. The Shinarump Member, which is between 6 and 24 m (20 and 80 ft) thick, contains numerous petrified logs and petrified-wood fragments in irregular sandstone and siltstone beds that are of variable thickness and locally pinch out or intertongue laterally within the unit. The contact between the Shinarump Member and the overlying Petrified Forest Member is gradational and highly variable.

The Petrified Forest Member is the middle section of the Chinle Formation and forms the multicolored blue, red, and gray-green, soft hills of the "painted desert" badlands northeast of the Little Colorado River Valley. The Painted Desert Overlook, 19 km (13 mi) northeast of the city of Winslow along State Highway 87, provides spectacular views of these deposits.

Akers and others (1958) subdivided the Petrified Forest Member into three subunits on the basis of their slight lithologic and color differences. The boundaries between these three subunits are variable and gradational throughout the Winslow quadrangle and become indistinct in lithology and color on a regional scale. For this reason, they are herein collectively mapped as the Petrified Forest Member of the Chinle Formation. The Petrified Forest Member is between 122 and 150 m (400 and 500 ft) thick throughout the Winslow quadrangle (sheets 1, 2).

Overlying the Petrified Forest Member is the Owl Rock Member of the Chinle Formation. The contact between the Owl Rock and the Petrified Forest Members is highly gradational in the lateral and vertical sense but is commonly marked at or near the base of the lowest siliceous limestone bed of the Owl Rock Member. The Owl Rock Member consists of a sequence of gray, ledge-forming, siliceous limestone beds that are interbedded with light-red and yellow-gray, slope-forming, calcareous siltstone. At some locations, as many as seven siliceous limestone beds that form flat-ledge outcrops are present within the Owl Rock Member. These beds are resistant to erosion and form the cap rock for Newberry Mesa, Ives Mesa, and Marcou Mesa northeast of the Little Colorado River (fig. 1).

The unconformable contact between the Owl Rock Member and the overlying Moenave Formation is marked by a sharp contrast in color and lithology between the blue-gray mudstone of the Owl Rock Member and the orange-red sandstone of the Moenave Formation. This regional unconformity, which is known as the "J-O" unconformity (Pipiringos and O'Sullivan, 1978; Peterson and Pipiringos, 1979), separates Triassic rocks from their overlying Jurassic rocks. The thickness of the Owl Rock Member is about 67 m (220 ft), gradually thinning out southeastward across the Winslow quadrangle (sheets 1, 2).

Moenave Formation

The red, slope-forming siltstone and sandstone strata of the Jurassic Moenave Formation (Jm) unconformably overlie that of the Owl Rock Member of the Chinle Formation throughout the Winslow quadrangle (sheets 1, 2). The environmental and regional correlations, as well as paleogeographic reconstructions for the fluvial and eolian systems of the Moenave Formation and the Wingate Sandstone, are described by Edwards (1985), Clemmensen and others (1989), Nations (1990), Blakey and others (1992), Riggs and Blakey (1993), and Blakey and Ranney (2008). Regional and local trends suggest that some of the fluvial-dominated cycles of the upper Moenave Formation correlate well with the eolian-dominated cycles of the Wingate Sandstone northeast of the Winslow quadrangle (Blakey, 1994). However, the Wingate Sandstone in southern Utah and in the Monument Valley area of northeastern Arizona thins southward and may not extend this far south into Arizona (Anderson and others, 2000). As a result of this uncertainty, the term Wingate Sandstone is not used for the sandstone sequence above the Moenave Formation in the Hopi Buttes area (sheet 2), as mapped by Cooley and others (1969), but it is herein informally mapped as the upper sandstone member of the Moenave Formation (Jms) until further correlative stratigraphic studies can be done.

The Wingate Sandstone as mapped by Cooley and others (1969) includes a lower white and upper light-red sandstone that overlies the Moenave Formation in the southwestern part of the Hopi Buttes area. These white and light-red sandstones are herein informally mapped as the upper sandstone member of the Moenave Formation (Jms) for the following reasons: (1) these sandstones have gradational and intertonguing contacts between them and also with the underlying Moenave Formation; (2) both sandstones undergo facies changes eastward in which they become a light-red sandy siltstone east of Dilkon and Indian Wells (fig. 1), becoming indistinguishable from the upper part of the Moenave Formation; and (3) no unconformities are apparent within or below each sandstone unit with the upper part of the Moenave Formation.

The Moenave Formation commonly weathers as a red slope throughout the east half of the Winslow quadrangle (sheet 2) except where beds of the upper sandstone member (Jms) form weak, white-gray or light-red ledges in the southwestern part of the Hopi Buttes area (best exposed at Red Cheek Butte; fig. 1). In the southern part of the Hopi Buttes (sheet 2), some of the upper sandstone beds of the Moenave Formation have been removed by Tertiary erosion, and what remains is unconformably overlain by dark-brown and white mudstone and argillaceous sandstone that forms the lower part of the Bidahochi Formation (Tbl). Overall, the Moenave Formation is between 73 and 98 m (245 and 320 ft) thick.

Kayenta Formation

The purple-red, slope-forming siltstone and sandstone sequences of the Kayenta Formation (Jk) unconformably overlie the white-gray upper sandstone member of the Moenave Formation in the northern-central part of the Hopi Buttes area near State Highway 87 (sheet 2). Northwest of the Winslow quadrangle, the Kayenta Formation unconformably overlies red sandstones of the Moenave Formation, having an erosional relief of from 2 to 15 m (6 to 50 ft) (Nations, 1990). This contact is referred to as the "sub-Kayenta unconformity" ("J-sub-K"), as defined by Riggs and Blakey (1993) and Blakey (1994).

North and west of the Winslow quadrangle, the following units are present, in ascending order: the Kayenta Formation, the Navajo Sandstone, the Entrada Sandstone, the Dakota Sandstone, and the Mancos Shale (Billingsley and others, 2007). Along the very north-central edge of the Winslow quadrangle, the Navajo Sandstone (or the Entrada Sandstone; not mapped separately) may be present at Round Top butte, Montezumas Chair, and Bad Medicine Butte west of State Highway 87, but the outcrop is too limited in extent and exposure to determine. The gray, small-scale trough-crossbedded sandstone outcrop at Round Top butte is likely the southern extension of the Entrada Sandstone (not mapped). This sandstone and the underlying Kayenta Formation have largely been removed by Early Cretaceous erosion, and what remains has been subsequently overlain by Cretaceous rocks of the Dakota Sandstone and the Mancos Shale west of State Highway 87 and also near Teesto at the north-central edge of the Winslow quadrangle (sheets 1, 2).

Between State Highways 87 and 77, in the northern-central part of the Hopi Buttes, Tertiary erosion has removed most of the Cretaceous and Jurassic rocks down to the Moenave Formation. This erosion surface is subsequently overlain by Miocene rocks of the Bidahochi Formation and by the volcanic rocks of Hopi Buttes Volcanic Field along the north edge of the Winslow quadrangle (sheet 2; see also, fig. 2).

Dakota Sandstone and Mancos Shale

The Cretaceous Dakota Sandstone (Kd) is present at Montezumas Chair, Round Top butte, and Bad Medicine Butte west of State Highway 87 in the northwestern part of the Hopi Buttes (fig. 1). The Dakota Sandstone consists of a lower sandstone member, a middle carbonaceous member, and an upper sandstone member, all having gradational contacts between them (O'Sullivan and others, 1972); however, all three members are too small to show at map scale and are herein collectively mapped as the Dakota Sandstone, undivided.

The lower sandstone member of the Dakota Sandstone occupies shallow channels of a regional Cretaceous unconformity eroded into the underlying Jurassic Kayenta Formation (or the Entrada Sandstone?) at Montezumas Chair and Round Top butte. The middle carbonaceous member of the Dakota Sandstone contains a thin coal bed less than 0.5 m (2 ft) thick that was partly mined in the late 1940s or early 1950s and is now marked by numerous abandoned prospects on the east and north sides of Round Top butte. The upper sandstone member is thin and lenticular with a gradational contact with the overlying Mancos Shale (Km).

Most of the blue-gray, slope-forming Mancos Shale has been removed from the Hopi Buttes area by Tertiary erosion and what remains is largely covered by extensive landslide (Ql) or talus and rock-fall (Qtr) deposits. Neither the original thickness of the Mancos Shale nor the extent of volcanic intrusion is known.

Cenozoic Sedimentary and Volcanic Rocks

The Miocene sedimentary and volcanic rocks of the Hopi Buttes Volcanic Field are important because they contain critical landscape information about the early erosional development of this part of the Colorado Plateau; however, the type section for the Miocene and Pliocene Bidahochi Formation is outside of the map area, and an equivalent section does not recur within the Winslow quadrangle. Consequently, we have informally redefined the stratigraphic nomenclature for this map.

Bidahochi Formation

The Bidahochi Formation was originally defined by Repenning and Irwin (1954) and Shoemaker and others (1957, 1962) who separated it into the following three informal members, in descending order: an upper fluvial member, a middle volcanic member, and a lower mudstone and argillaceous sandstone member (all Miocene and Pliocene). These subdivisions are based on a section referenced at White Cone Peak, a natural landmark about 6.5 km (4 mi) northeast of White Cone, Arizona, just northeast of the Winslow quadrangle.

The upper fluvial member of the Bidahochi Formation (Miocene and Pliocene) is not present within the Winslow quadrangle but is present just north and northeast of the quadrangle. The lower mudstone and argillaceous sandstone member (Tbl) is present within the Hopi Buttes area of the Winslow quadrangle (sheet 2). This lower part of the Bidahochi Formation unconformably overlies the lower part of the Moenave Formation (Jm) in the southeast quarter of the Winslow quadrangle; upper strata of the Moenave Formation (Jms), in the northeast quarter; and the Kayenta Formation (Jk), in the Teesto area, along the north-central edge of the quadrangle (fig. 2). For mapping purposes, the originally defined middle volcanic member is herein redefined as part of the volcanic rocks of Hopi Buttes Volcanic Field, on the basis of field observations, recent studies, and measured sections published by Dallegge and others (1998a, 1998b), Ort and others (1998), Dallegge and others (2001), and Dallegge and others (2003; see their table 1).

The Miocene and Pliocene age of the Bidahochi Formation is based on vertebrate fossil faunas (Morgan and White, 2005), fossil fish (Spencer and others, 2008), paleomagnetic studies (Lindsey and others, 1984), and radiometric data (Dallegge and others, 2003). Vertebrate fossil collections from the (upper) Bidahochi Formation at White Cone Peak (northeast of the quadrangle) indicate a late Miocene through Pliocene age (Lindsay and others, 1984). Fossil teeth, which were used to identify rodents, moles, shrews, frogs, and rabbits (Baskin, 1979; Lindsay and others, 1984), are most common in the upper member of the Bidahochi Formation above the 6.69 Ma volcanic-age locality near White Cone Peak (Scarborough and others, 1974). Fossil fish were also reported by Uyeno and Miller (1965) from the upper member of the Bidahochi Formation near White Cone Peak and at the "Coliseum" diatreme (fig. 1) west of Indian Wells. Uyeno and Miller (1965) suggested a large, permanent aquatic habitat associated with swift flowing rivers at the time that the Bidahochi Formation was deposited in this area. The fish fossils at White Cone Peak are found in distal fluvial-overbank or deltaic-lacustrine deposits (Spencer and others, 2008). The fish fossils at the "Coliseum" are found within white, 1-m (3-ft) thick lacustrine sediments that are interbedded with thick volcanic tuffaceous ash and pyroclastic surge and air-fall deposits (Tc). At the "Coliseum," no connection is apparent between the lacustrine volcanic-crater sediments (Tc) or other local volcanic maar-sediments to the lower or upper members of the Bidahochi Formation, aside from fish fossils. A volcanic ash bed (located outside the quadrangle about 9.5 km [6 mi] northeast of Indian Wells, between Wood Chop Mesa and "Triplets Mesa") that lies about 75 m (246 ft) above the base of the lower part of the Bidahochi Formation yielded an $^{40}Ar/^{39}Ar$ age of 13.71±0.08 Ma (Dallegge and others, 1998a; Ort and others, 1998; Dallegge and others, 2001; Dallegge and others, 2003; see also, table 1, this report).

The vertical transition between the originally defined lower, middle, and upper members of the Bidahochi Formation is not evident within the east half of the Winslow quadrangle. Only the lower member is present in the quadrangle below the volcanic rocks of Hopi Buttes Volcanic Field; for this reason, the lower mudstone and argillaceous sandstone Bidahochi Formation (Tbl) within the Winslow quadrangle is considered to be Miocene age only (sheet 2). North of White Cone Peak and along State Highway 77, the white upper fluvial member of the Bidahochi Formation appears to be interbedded, intertonguing, or in gradational contact with the lower mudstone and argillaceous sandstone member, and no unconformity is apparent between them.

Field observations of the Bidahochi Formation by the authors and by Dr. Michael Ort (Northern Arizona University) suggest that the lower and upper members of the Bidahochi Formation are time correlative across the landscape but at different elevations. In other words, the mudstone and argillaceous deposits likely were deposited at the same time as the upper fluvial deposits, which were interrupted periodically by volcanic ash-fall deposits. Moreover, the upper fluvial deposits contain numerous eolian and fluvial sandstone lenses that likely were deposited upland and downwind of the mudstone and argillaceous playa deposits, making both previously defined upper and lower members of the Bidahochi Formation time equivalent.

Volcanic Rocks of Hopi Buttes Volcanic Field

The volcanic rocks of Hopi Buttes Volcanic Field were described by Williams (1936) and well documented by White (1991). The originally defined middle volcanic member of the Bidahochi Formation (Repenning and Irwin, 1954; Shoemaker and others, 1957, 1962) is herein redefined for mapping purposes as part of the volcanic rocks of Hopi Buttes Volcanic Field because of the following: (1) the volcanic rocks form a mappable sequence of multiple related volcanic rock types, (2) they are time equivalent with parts of the lower member of the Bidahochi Formation, and (3) they are interbedded only within the lower part of the Bidahochi Formation at varying stratigraphic positions and do not appear to regionally separate the upper and lower members of the Bidahochi Formation as originally described at White Cone Peak.

The volcanic rocks of Hopi Buttes Volcanic Field are not mapped in detail because of multiple intertonguing, crosscutting unconformities and overlapping stratigraphic complexities between several volcanic eruptional events that distributed a variety of volcanic rock types in different parts of the Hopi Buttes, as was shown by Vazquez (1998, 1999) and Hooten (1999a, 1999b). For mapping purposes, the volcanic rocks are herein subdivided into intrusive dikes, plugs, or necks (Ti); volcanic-crater sediment deposits (Tc); mafic monchiquite and basanite flows (Tm), as defined by Vazquez and Ort (2006); mafic tuff-and-ash deposits (Tmt); and mixed monchiquite and basanite flows and tuff deposits, undivided (Tmu).

Justification for separating the volcanic rocks from the original middle volcanic member of the Bidahochi Formation is as follows: (1) the volcanic and associated volcanic-crater sedimentary rocks can be mapped as separate rock types; (2) the thin deposits of volcanic ash and tuff that separated the originally defined upper and lower members of the Bidahochi Formation at White Cone Peak are absent northeast of that landmark; (3) the volcanic deposits are interbedded within the lower Bidahochi Formation about 50 m (165 ft) below the top of White Cone Peak and at several discontinuous horizons; (4) the volcanic rocks either overlie or are adjacent to Triassic, Jurassic, and Cretaceous rocks at different locations throughout the Hopi Buttes; (5) the volcanic rocks are unevenly distributed, having variable thicknesses and numerous local unconformities; (6) the volcanic-crater sedimentary rocks (Tc) are interbedded with or overlain by other volcanic rocks that are locally disconnected from the Bidahochi Formation at multiple topographic horizons above and below Bidahochi horizons throughout the volcanic field; and (7) the volcanic-crater sedimentary rocks may not be connected to the Bidahochi Formation.

The age of the volcanic rocks of Hopi Buttes Volcanic Field ranges between 7.5 and 6.5 Ma (Vazquez, 1998, 1999; Vazquez and Ort, 2006). Vazquez (1999) obtained $^{40}Ar/^{39}Ar$ ages of 7.21±0.45 Ma, 6.99±0.75 Ma, 6.53±0.69 Ma, and 6.81±0.06 Ma from different vents outside the quadrangle near Wood Chop Mesa in the northeastern part of the Hopi Buttes (table 1). Thus, an average age of 7 Ma for the volcanic rocks of Hopi Buttes Volcanic Field in this area is not far above the $^{40}Ar/^{39}Ar$ 13.71±0.08 Ma age (Dallegge and others, 1998a, 1998b) for the lower mudstone and argillaceous sandstone of the Bidahochi Formation at White Cone Peak and Wood Chop Mesa.

In 1964, a radiometric date of 4.2 Ma was reported by Evernden and others (1964) from the middle (volcanic) member of the Bidahochi Formation at White Cone Peak; however, it was determined later that the dated volcanic unit came from a diatreme volcano just north of White Cone Peak (Scarborough and others, 1974). The air-fall tuff at White Cone Peak yielded an age of 6.69±0.16 Ma; thus, the volcanic ages in the 2 to 4 Ma age range likely are incorrect because they do not fit within the 6.5 to 7.5 Ma average age range (table 1).

At White Cone Peak, one to four tuffaceous volcanic deposits (0.05 to 2 m [1 to 5 ft] thick) are interbedded within various levels of mudstone and argillaceous sandstone of the lower Bidahochi Formation. The interbedded volcanic rocks are about 50 m (165 ft) below the upper white fluvial parts of the Bidahochi Formation. These interbedded tuffaceous volcanic rocks thin and pinch out northeast and north of White Cone Peak and, therefore, do not provide a consistent marker bed division between the lower and upper deposits of the Bidahochi Formation.

Quaternary Surficial Deposits

Surficial Mapping Approach

During the last several years, surficial deposits on the Colorado Plateau have largely been ignored because their significance to landscape and biological development was not recognized. Today we are beginning to learn the importance of these geologic deposits to other scientific discipline studies in biology and climatic change, as well as evolution of the landscape.

Surficial sedimentary deposits that have accumulated on the land surface over the last several hundred thousand to a million years or more (that is, Quaternary and latest Tertiary age) are generally unconsolidated or weakly consolidated as thin deposits that can be several tens of meters thick. Surficial deposits have accumulated through the actions of running water or wind, or a combination of both fluvial and eolian processes. Steeper slopes of buttes and mesas often have landslide, talus, and rock-fall deposits. Alluvial deposits of major washes and floodplains are often remobilized by wind, providing a major source of sand for nearby or distant eolian sand-dune and sand-sheet deposits. Extensive eolian deposits commonly are stabilized by vegetation in most areas, but their transport can be partially reactivated during severe drought or storm conditions.

Mapping surficial deposits across an area as large as the Winslow quadrangle poses unique challenges. First, natural exposures that reveal lithologic details below the upper surface of these materials are not common; hence, map units have to be defined and then projected laterally using criteria other than lithologic content and internal stratigraphic details. Second, in the time available to make the map, we could not visit more than a few locations where such lithologic and stratigraphic details are revealed. Third, although their fairly recent geologic age is obvious, very little age data for surficial materials is available that would allow them to be assigned confidently to the Holocene, Pleistocene, Tertiary, or their various subdivisions. Finally, a map-unit naming scheme that combines information about lithology, geologic age, and genesis is difficult to develop and communicate to map users. To accommodate these issues, we adopted the following strategy for classifying and mapping surficial materials and assigning them a geologic age: The materials are classified and named using genesis (for example, alluvium, eolian, talus, landslide), geologic age (for example, lower Holocene, middle Pleistocene), and lithology (for example, sand, gravel) as classifying criteria. This strategy has evolved from previous surficial mapping methods of the Grand Canyon region of northern Arizona that have slowly developed over the last decade (Billingsley and Workman, 2000; Billingsley and Wellmeyer, 2003; Billingsley and others, 2006a, 2006b, 2007, 2008).

The discontinuous aspect of surficial deposits across the Grand Canyon region does not lend itself to easy projection and correlation of deposits that may or may not be the same age. This strategy depends on the relative correlation and projection of map units, but it does not necessarily place these map units accurately within the Quaternary and latest Tertiary global chronology.

Information about the surficial deposits has been obtained mainly by aerial-photographic interpretation; age determinations, which are generalized, are based mainly on geomorphologic criteria such as the relative position in local alluvial-terrace sequences, the degree of erosional dissection of alluvial fans, and the superposition or stabilization of sand-dune and sand-sheet deposits. Therefore, all age assignments for surficial materials are provisional, and the age of a specific unit in one area may not be the same as that indicated for the same unit in another area. Names of units that have time implications such as young, intermediate, old, and older are intended only to indicate local relative stratigraphic position, not a unit's actual age uniformly throughout the map area.

Local Surficial Deposits

The Little Colorado River, which is the principal drainage within the Winslow quadrangle, is typically a dry river most of the year. The Little Colorado River flows northwest across the southwest quarter of the Winslow quadrangle (south half of sheet 1) toward the Colorado River in the Grand Canyon. Fluvial deposits of the Little Colorado River and its tributaries provide the principal supply of sand and silt that form extensive eolian-sand deposits that are generally transported by southwesterly winds to the northeast.

The surface water that flows down Tucker Flat Wash, Cow Canyon, and numerous unnamed tributaries in the southwest quarter of the Winslow quadrangle (south half of sheet 1) drain northeast toward the Little Colorado River and into internal drainage basins (dry lakes in fig. 1) before reaching the river. These large playa lakes or ponded areas (Qps) are caused by overbank flood-plain sediment accumulations along the current and old natural channel levees of the Little Colorado River. These ponded areas can become temporary shallow lakes several feet deep during wet climatic conditions, either when the Little Colorado River overflows its floodplain levees or when significant water flows down the tributary drainages. Tucker Flat Wash is largely a low-gradient alluvial-plain drainage consisting of fine-grained sediment that is subject to intense dust storm activity during dry windy conditions.

Eolian deposits have accumulated as thick sand dunes or sand sheets transported to the northeast by southwesterly winds during dry climatic conditions on and against the southwest slopes of Newberry, Ives, and Marcou Mesas northeast of the Little Colorado River Valley. These eolian deposits are gradually eroded by local storm water runoff and transported back to the Little Colorado River where they are often recycled and blown back to the mesas. Eventually these sediments are transported by fluvial processes into and through the Grand Canyon.

Other surficial deposits in the Winslow quadrangle consist of numerous landslides (Ql) and associated talus and rock-fall deposits (Qtr) and older alluvial fan deposits commonly found around and below volcanic outcrops of the Hopi Buttes area. Man-made diversion dams, stock tanks, and gravel pits are shown on the maps to illustrate the human impact upon the landscape.

Structural Geology

During the Laramide orogeny, about 80 to 40 Ma, compressional stresses acting on the southern Colorado Plateau region produced several east-dipping monoclinal structures west and north of the Winslow quadrangle (Huntoon, 2003). One Laramide monocline present in the southwest corner of the Winslow quadrangle is herein named the Winslow Monocline (sheet 1). Strata along the Winslow Monocline dip northeastward between 6° and 15°, the steepest dips being in the lower hinge of the fold. The vertical relief of strata averages about 60 m (200 ft) up-to-the-southwest. Red rocks of the Moenkopi Formation are being rapidly eroded off the upper limb of the Winslow Monocline, exposing the resistant sandy limestone of the Kaibab Formation. Several gentle, parallel, northeast-plunging anticlines and synclines are perpendicular to the general northwestern trend of the axial trace of the Winslow Monocline. The monocline may form an important barrier or control to local groundwater flow by directing flow within buried sedimentary strata to the northwest toward Blue Springs in the Little Colorado River Gorge northwest of the Winslow quadrangle (Billingsley and others, 2007).

Paleozoic and Mesozoic strata in the west half of the Winslow quadrangle (sheet 1) exhibit a regional northeasterly dip of about 1° to 2° that gradually diminishes toward the northeast quarter of the Winslow quadrangle (north half of sheet 2). Strata of the Cenozoic Bidahochi Formation (sheet 2) are basically flat lying and have not been tectonically altered other than by localized diatreme volcanic eruptions in Miocene time.

Cenozoic extensional faulting during late Pliocene time (younger than 3 Ma) has produced several small northwest-trending graben and horst structures that are similar to those northwest of the Winslow quadrangle (Billingsley and others, 2007). Small faults and folds have not been identified in the northeast quarter of the Winslow quadrangle, but these likely are veiled by soft-sediment deformation within the thick mudstone and siltstone strata of the Chinle Formation. Recent earth-crack and sinkhole development within or near graben structures has temporarily interrupted runoff in some tributaries to the Little Colorado River near Leupp (sheet 1).

In the Kaibab Formation, circular, bowl-shaped depressions characterized by inward-dipping strata are likely to be the surface expressions of collapse-formed breccia pipes originating from the dissolution of the deeply buried Mississippian Redwall Limestone or another similar buried limestone deposit (Wenrich, 1989). Collapse features are not common in the Winslow quadrangle and may reflect the lack of limestone deposits and (or) limestone dissolution at depth.

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DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

Qaf **Artificial fill and quarries (Holocene)**—Alluvium and bedrock material removed from barrow pits and trench excavations and used to build livestock tanks, drainage diversion dams, roads, and other man-made construction projects (not all highway road excavations are mapped). No distinction between cut or fill excavations is made on map. Agricultural fields are not shown

Qs **Stream-channel deposits (Holocene)**—White to light-red and gray, interbedded silt, sand, and clay, mixed with gravel, pebbles, and cobbles; poorly sorted. Pebbles and cobbles dominantly are angular to rounded, red, white, gray, and black chert clasts; subrounded to rounded red sandstone clasts; and angular to subrounded mafic monchiquite and basanite clasts in Hopi Buttes area. Deposits intertongue with, overlap, or are inset against adjacent surficial deposits (Qa1, Qa2, Qa3, Qv, Qg1, Qg2, QTdi), and they overlap or erode into flood-plain deposits (Qf, Qf1, Qf2, Qf3), ponded sediments (Qps), and mixed alluvium and eolian deposits (Qae). Stream channels subject to high-energy flows and flash-flood debris flows. Little or no vegetation in stream channels except for salt cedar (tamarisk), russian olive, and cottonwood trees along Little Colorado River and several large washes. Contacts with other alluvial deposits are gradational and approximate. Stream-channel deposits of Little Colorado River are mapped as shown on 1:24,000-scale color aerial photographs flown in 2005 (Block and others, 2009). Channel of Little Colorado River meanders within its floodplain valley between Winslow and Leupp. Downstream (northwest) of Leupp, Little Colorado River channel is confined within narrow bedrock strata of the Moenkopi and Kaibab Formations. Thickness, 2 to 9 m (6 to 30 ft)

Qf **Modern flood-plain deposits (Holocene)**—Gray-brown to light-red clay, silt, and fine-grained sand; weakly consolidated by clay and calcite cement. Deposits include some lenticular gravel, subangular to rounded pebbles, and cobbles; intertongue with or are overlapped by adjacent fluvial or eolian surficial deposits (Qs, Qv, Qa1, Qps, Qd, Qes). Forms shallow flats 0.5 to 1 m (2 to 3 ft) above stream-channel deposits (Qs). Subject to overbank flooding in lateral and vertical sense along Little Colorado River and larger tributary valleys. Supports sparse to light growths of sagebrush, grass, tumble weed, and thick growths of salt cedar (tamarisk) trees and other high-desert shrubs that trap and accumulate more recent eolian-sand deposits. Thickness, 0.05 to 2 m (2 to 6 ft)

Qps **Ponded sediments (Holocene)**—Gray to brown clay, silt, sand, and thin gravel lenses along margins; weakly consolidated by clay, calcite, and gypsum cement. Locally includes small chert and limestone fragments or pebbles derived from nearby bedrock outcrops. Deposits commonly occupy man-made or natural internal drainage depressions. Desiccation cracks commonly form on dry hardpan surfaces that often restrict plant growth. Sandy ponded areas support growths of seasonal grass, especially downwind (northeast) of local parabolic dunes below and on Newberry, Ives, and Marcou Mesas. Thickness, 1.5 to 9 m (5 to 30 ft)

Qd **Dune sand and sand-sheet deposits (Holocene)**—*Hopi Buttes area* (sheet 2): Light-red and white, fine-grained quartz sand; locally derived mainly from other surficial units whose sediments are easily eroded by wind (Qs, Qf, Qf1, Qf2, Qf3, Qg1, Qg2, Qg3, Qa1, Qa2, Qa3, Qae, QTdi). Originally those sand grains were derived from erosion of nearby bedrock outcrops of the Moenave, Kayenta, and Bidahochi Formations and include fragmented grains of volcanic rock (Tm, Tmt, Tmu). Forms lumpy, undefined sand-dune or sand-sheet deposits often concealed beneath moderate growths of grass, sagebrush, and pinyon pine and juniper woodlands at higher elevations of volcanic mesas and buttes. *Little Colorado River area* (sheet 1): White to light-red, fine- to coarse-grained, windblown sand; composed primarily of quartz, chert, and some feldspar grains locally derived from other surficial deposits eroded by wind (Qs, Qf, Qf1, Qf2, Qf3, Qa1, Qa2, Qa3, Qg1, Qg2, Qg3, Qae). Contacts are approximate and subtly gradational with adjacent alluvial deposits and bedrock and are likely to change on yearly basis under influence of variable weather conditions such as strong windstorms and sheet-wash erosion associated with local severe thunderstorms. Locally includes topographically controlled climbing and falling sand-dune and sand-sheet ramp accumulations on gentle slopes or steep bedrock terrain northeast of Little Colorado River Valley. Contacts between young sand-dune and sand-sheet deposits (Qd, Qes) and old sand-dune and sand-sheet deposits (QTd, QTes) are difficult to constrain by empirical observation but, as mapped, show boundaries that illustrate potential differences between young and old sand accumulations on Ives Mesa, on Marcou Mesa, and in some areas of Hopi Buttes. Supports moderate growths of grass and high-desert shrubs that help stabilize all eolian-sand accumulations during wetter conditions. Thickness, 1 to 61 m (3 to 200 ft)

Qes **Eolian sand-sheet deposits (Holocene)**—Extensive sand-sheet deposits northeast and east of Little Colorado River Valley, especially in and along large tributary washes and over gently sloping terrain below Newberry, Ives, and Marcou Mesas. Forms thin sand-sheet deposits on alluvial fan slopes of various ages and on “Dilkon deposits” (QTdi) slopes in Hopi Buttes area. Commonly intertongues with surficial deposits (Qae, Qdp, Qdb); contacts are gradational in both lateral and vertical sense. Supports moderate growths of grass and small high-desert shrubs that help stabilize or trap accumulating deposits. Thickness, 0.3 to 4.5 m (1 to 15 ft)

Qdl **Linear-dune deposits (Holocene)**—White, gray, and light-red, fine- to medium-grained, well-sorted quartz sand accumulations that are aligned in general northeast direction. Commonly transitional with other eolian surficial deposits (Qd, Qes, Qdp, Qdb). Linear dunes generally are 12 to 24.5 m (40 to 80 ft) wide and less than 0.8 km (0.5 mi) long, but they can extend over 5 km (3 mi) or more in length on Ives and Marcou Mesas. Thickness, 2 to 9 m (6 to 30 ft)

Qdp **Parabolic-dune deposits (Holocene)**—White, gray, and light-red, fine- to coarse-grained, well-sorted quartz sand arranged into individual parabolic dunes; most commonly present as complex intertonguing parabolic-dune deposits below and on Newberry Mesa (sheet 1). Ponded sediments (Qps) commonly form in low internal-drainage areas within parabolic-dune complexes. Contacts merge with adjacent eolian and alluvium deposits and bedrock outcrops. Supports sparse grassy vegetation. Thickness, 2 to 9 m (6 to 30 ft)

Qdb **Barchan-dune deposits (Holocene)**—White, gray, and light-red, fine- to coarse-grained, unconsolidated, well-sorted quartz sand that forms isolated barchan dunes and (or) complex barchanoid dunes; found mainly on Newberry Mesa northeast of Tolani Lake (sheet 1) and along tributary drainages to Little Colorado River. Subject to changing aerial extent and shape on yearly basis owing to seasonal windstorms. Supports sparse grassy vegetation in wet conditions. Thickness, 2 to 12 m (6 to 40 ft)

Qa1 **Young alluvial fan deposits (Holocene)**—*Southwest of Little Colorado River Valley* (sheet 1): Gray-brown silt, sand, gravel, pebbles, cobbles, and boulders; weakly consolidated by calcite, gypsum, and minor amounts of salt cement. Silt and sand is derived primarily from eroded outcrops of the Kaibab and Moenkopi Formations that also supply dissolved calcite, gypsum, and minor amounts of salt that precipitates as cement. Pebbles, cobbles, and boulders are subangular to rounded limestone, chert, and sandstone clasts locally derived from bedrock. Also includes small, subrounded to rounded pebbles and cobbles of basalt, andesite clasts, and pyroclastic fragments derived from San Francisco Volcanic Field west and southwest of quadrangle. Supports light to moderate growths of sagebrush, cactus, and grass. *North and northeast of Little Colorado River Valley* (sheet 2): Gray, light-brown, and light-red clay, silt, sand, pebbles, and cobbles of chert, limestone, and sandstone; derived from local Mesozoic sedimentary rocks and monchiquite, basanite, and decomposed tuff from local outcrops of the volcanic rocks of Hopi Buttes Volcanic Field. Commonly is overlapped by or intertongues with various Quaternary surficial deposits (Qs, Qps, Qf, Qd, Qes, Qv, Qg1, Qae). Clay, silt, and sand are derived primarily from local outcrops of the Chinle, Moenave, Kayenta, and Bidahochi Formations; also derived from Cretaceous rocks north and northeast of quadrangle that commonly supply cementing ingredients of clay, calcite, gypsum, and minor amounts of salt for all surficial alluvial deposits north and northeast of Little Colorado River. Subject to extensive sheet-wash erosion, wind erosion, flash-flood debris flows, and minor arroyo erosion. Thickness, 1 to 6 m (3 to 20 ft)

Qg1 **Young terrace-gravel deposits (Holocene)**—*Southwest of Little Colorado River* (sheet 1): Light-brown, pale-red, and gray, well-sorted, interbedded clay, silt, sand, gravel, pebbles, cobbles, and some boulders. Includes abundant rounded and well-rounded clasts of quartzite, quartz, chert, and assorted metamorphic crystalline rocks derived from Tertiary rocks south, southeast, and southwest of quadrangle. Also includes well-rounded gray limestone, white chert, and red sandstone clasts derived from local Permian and Triassic strata south and southwest of Little Colorado River Valley, as well as subrounded to well-rounded clasts of yellow, red, gray, and brown quartzite, black chert, and multicolored petrified-wood fragments locally derived from the Shinarump Member of the Chinle Formation. Includes minor amounts of rounded basalt clasts originating from San Francisco Volcanic Field southwest of quadrangle. Supports light to moderate growths of grass, cactus, and high-desert shrubs; subject to flash-flood erosion and sheet-wash flooding. *North and northeast of Little Colorado River* (sheet 2): Gray, brown, and light-red clay, silt, sand, and chert-pebble gravel. Clasts include pebbles and cobbles of chert, sandstone, and limestone derived from the Owl Rock Member of the Chinle Formation below Newberry, Ives, and Marcou Mesa areas; also include numerous subangular fragments of coarse gravel, pebbles, and cobbles of black monchiquite, basanite, and gray tuff locally derived from Hopi Buttes area. Unit grades downstream into flood-plain deposits (Qf, Qf1, Qf2) in principal-tributary washes where gradients are low. Locally overlaps alluvial deposits (Qa1, Qf, Qv) and often is covered by young eolian deposits (Qd, Qes). Supports light or no vegetation, mainly grass and desert shrubs. Forms benches about 1 to 3.5 m (3 to 12 ft) above stream-channel (Qs) or modern flood-plain (Qf) deposits. Thickness, 2 to 6 m (6 to 20 ft)

Qf1 **Young flood-plain deposits (Holocene)**—Gray-brown clay, silt, and fine- to coarse-grained sand; weakly consolidated by clay content. Forms benches 1 to 3 m (3 to 10 ft) above stream-channel (Qs) or modern flood-plain (Qf) deposits. Subject to cut-bank channel erosion in Little Colorado River Valley and local streams in large tributary washes. Overlapped by thin accumulations of young surficial deposits (Qd, Qes, Qps, Qa1). Supports thick growths of salt cedar (Tamarisk) trees, grass, tumble weed, camel thorn bush, and various other high-desert shrubs. Often subjected to overbank flooding by Little Colorado River and local tributary streams. Thickness, 1 to 6 m (3 to 20 ft)

Qa2 **Intermediate-age alluvial fan deposits (Holocene)**—Lithologically similar to young alluvial fan deposits (Qa1); partly cemented by calcite, gypsum, and clay. Surfaces are partly eroded by arroyos as deep as 1 to 3 m (3 to 10 ft) and commonly covered by eolian deposits (Qd, Qes) north and northeast of Little Colorado River Valley. Commonly is overlapped by or intertongues with fluvial deposits (Qa1, Qv, Qtr, Qg1, Qg2). Includes minor amounts of subrounded to subangular basalt clasts of San Francisco Volcanic Field in southwestern part of quadrangle (sheet 1); also includes abundant subangular chert clasts north and northeast of Little Colorado River Valley and abundant volcanic clasts and lithic fragments in Hopi Buttes Volcanic Field. Supports light to moderate growths of grass, sagebrush, and cactus throughout. Thickness, 2 to 15 m (6 to 50 ft)

Qg2 **Intermediate-age terrace-gravel deposits (Holocene)**—Gray and brown silt, sand, gravel, and lenses of small gravel or conglomerate; weakly consolidated. Lithologically similar to young terrace-gravel deposits (Qg1). Silt and fine-grained sand matrix is mixed with subangular to rounded pebbles and boulders of local bedrock. Forms benches that range in height from 4.5 to 9 m (15 to 30 ft) above modern streambeds and from 2 to 6 m (6 to 20 ft) above young terrace-gravel deposits (Qg1) in upper reaches of tributary washes. In large principal-tributary washes, unit grades downstream into intermediate-age and old flood-plain deposits (Qf2, Qf3). Supports growth of grass and variety of high-desert shrubs. Subject to cut-bank or headward erosion by local streams. Locally intertongues with, is overlain by, or is inset into other surficial deposits (Qa1, Qa2, Qv, Qae, Qtr, Ql). Thickness, 2 to 7.5 m (6 to 25 ft)

Qf2 **Intermediate-age flood-plain deposits (Holocene)**—Gray-brown clay, silt, and fine-grained sand; weakly consolidated by clay and calcite cement. Lithologically similar to young flood-plain deposits (Qf1) but forms flat benches 3 to 4.5 m (10 to 15 ft) above stream-channel (Qs) or modern flood-plain (Qf) deposits. Subject to cut-bank and headward erosion by local stream channels. Overlapped by various accumulations of thin surficial deposits (Qd, Qes, Qps, Qa1). Supports sparse to moderate growths of grass, tumble weed, and other high-desert shrubs in north half of quadrangle (sheets 1, 2); thick to moderately thick growths of grass, camel thorn bush, tumble weed, salt bush, and other desert shrubs along with scattered cottonwood, salt cedar (tamarisk), and willow trees in Little Colorado River Valley (sheet 1). Eolian-sand accumulations commonly cause temporary blockage of local runoff that forms ponded sediments (Qps) on flat flood-plain deposits (Qf2, Qf3) in Little Colorado River Valley and in wide, principal-tributary washes. Subject to overbank flooding in Little Colorado River Valley and along local washes. Thickness unknown but may exceed 30 m (100 ft) in some areas; visible thickness, 3 to 9 m (10 to 30 ft)

Qf3 **Old flood-plain deposits (Holocene)**—Gray-brown clay, silt, and fine sand; also includes thin lenses of stream gravel and interbedded alluvial fan gravel along margins. Lithologically similar to younger flood-plain deposits (Qf, Qf1, Qf2). Forms wide, flat benches, 4.5 to 10.5 m (15 to 35 ft) above local stream-channel (Qs) and other flood-plain (Qf, Qf1, Qf2) deposits. Subject to cut-bank erosion and extensive headward erosion by local streams. Overlapped by thin accumulations of young surficial alluvium or eolian deposits (Qd, Qes, Qps, Qae, Qa1, Qa2). Supports sparse to moderate growths of grass and variety of small high-desert shrubs throughout quadrangle. Subject to local overbank flooding or channel erosion. Thickness unknown in Little Colorado River Valley but may exceed 14 m (45 ft) in some areas upstream of Leupp where bedrock is exposed (sheet 1); in other areas upstream of Leupp, visible thickness, 3 to 14 m (10 to 45 ft)

Qae **Mixed alluvium and eolian deposits (Holocene)**—Gray, light-red, and brown clay, silt, and fine- to coarse-grained sand interbedded with lenses of pebbly gravel. Deposits on Newberry and Ives Mesas (sheet 1) contain white, angular to subangular chert fragments locally derived from the Owl Rock Member of the Chinle Formation. Deposits within Hopi Buttes (sheet 2) contain black, white, and gray, angular to subrounded volcanic fragments locally derived from nearby volcanic outcrops. Unit has accumulated by both alluvial and eolian processes, resulting in interbedded sequence of thin-bedded, mixed clay, silt, sand, and small gravel, typical of young fluvial (Qa1, Qa2) and eolian (Qd, Qes) deposits. Subject to sheet-wash erosion during wet conditions and accumulation of eolian-sand deposits during dry conditions. Commonly overlies young fluvial and eolian surficial deposits (Qf, Qf1, Qf2, Qf3, Qa1, Qa2) and often is overlapped by young or fresh eolian-sand deposits (Qd, Qes). Supports light to moderate growths of grass, cactus, and small high-desert shrubs. Thickness, 1 to 6 m (3 to 20 ft)

Qsd **Silt-dune deposits (Holocene)**—Brown and gray clay, silt, and very fine sand; unsorted. Forms small, rounded dunes locally derived from dry-lake surfaces where ponded sediments (Qps) are transported by southwesterly winds in dry conditions and accumulate on and near northeastern shores of temporary lakes southwest of Little Colorado River (fig. 1; see also, sheet 1). Supports little to no vegetation. Thickness, 2 to 6 m (6 to 20 ft)

Qg3 **Old terrace-gravel deposits (Holocene)**—Red and purple clay, silt, sand, and subrounded to rounded pebbles and cobbles. Multicolored chert clasts are locally derived from the Chinle Formation; subrounded black volcanic clasts are locally derived from the volcanic rocks of Hopi Buttes Volcanic Field. Forms isolated flat terrace deposits about 17 m (55 ft) above local stream channels and about 7.5 to 9 m (25 to 30 ft) above principal-tributary drainages east and southeast of Hopi Buttes. Unit grades downstream and coalesces or intertongues with old flood-plain deposits (Qf3) along principal drainages downstream to Little Colorado River Valley. Thickness, 7.5 to 24 m (25 to 80 ft)

Qv **Valley-fill deposits (Holocene and Pleistocene?)**—Gray and light-brown clay, silt, sand, and gravel lenses; weakly consolidated by gypsum, calcite, and clay cement. Includes rounded clasts of limestone and subrounded to angular chert; also includes subrounded to angular basalt clasts southwest of Little Colorado River Valley and rounded to subrounded clasts of Triassic sedimentary rocks and mafic volcanic rocks in Hopi Buttes area. Intertongues with or overlaps alluvial fan (Qa1, Qa2) and young terrace-gravel (Qg1) deposits, representing low-energy, low-gradient fluvial deposition. Subject to sheet-wash flooding and temporary ponding. Supports moderate growths of grass at lower elevations in central part of quadrangle (sheets 1, 2) and moderately thick growths of sagebrush, grass, cactus, and some juniper trees at higher elevations above 1,867 m (5,500 ft). Thickness, 1 to 6 m (3 to 20 ft)

Qa3 **Old alluvial fan deposits (Holocene and Pleistocene)**—*Hopi Buttes area* (sheet 2): Gray and light-brown silt, sand, and gravel, mixed with assorted brecciated, subangular, and subrounded pebbles and cobbles of black monchiquite and gray tuff; weakly consolidated by calcite and gypsum cement. Commonly overlies “Dilkon deposits” (QTdi) and is overlain by young eolian and mixed alluvium deposits (Qd, Qes, Qae). Includes large boulders, small cobbles, and pebbles of volcanic rocks derived from nearby talus and rock-fall deposits (Qtr) and landslide deposits (Ql). Supports moderate growths of grass, sagebrush, cactus, cliff rose bush and scattered pinyon pine and juniper tree woodlands. *Below Newberry, Ives, and Marcou Mesas* (south halves of sheets 1 and 2): Lithologically similar to younger alluvial fan (Qa1, Qa2) and older alluvial fan (QTa) deposits near and northeast of Little Colorado River; consists of unsorted, brown and red-purple clay, silt, sand, and angular gray chert pebbles and small boulder debris; weakly consolidated by clay and calcite cement. Supports sparse or no vegetation. Thickness, 1.5 to 7.5 m (5 to 25 ft)

Qtr **Talus and rock-fall deposits (Holocene and Pleistocene)**—Brown, gray, slope-forming, unsorted mixture of clay, silt, sand, and small, large, and very large angular boulders; on steep slopes below all ledges of the Owl Rock Member of the Chinle Formation and volcanic mesas and buttes of Hopi Buttes area. Contacts gradational with adjacent surficial deposits: landslide deposits (Ql), “Dilkon deposits” (QTdi), alluvial fan deposits (Qa1, Qa2, Qa3), and fluvial and eolian surficial deposits (Qg1, Qg2, Qg3, Qae, Qv). Subject to extensive sheet-wash erosion, headward erosion, and arroyo cutting. Unit may become unstable in wet conditions. Only thick or extensive deposits are shown. Thickness, 2 to 11 m (6 to 35 ft)

Ql **Landslide deposits (Holocene and Pleistocene)**—Weakly consolidated masses of unsorted, angular rock debris. Includes detached, stratified blocks that have rotated backward and slid downslope as loose, coherent masses and deformed strata. Often includes and is associated with local talus and rock-fall deposits (Qtr) adjacent to and below landslide masses. Older landslide deposits weather and erode to form thick gentle slopes of “Dilkon deposits” (QTdi). Landslide masses in Hopi Buttes area commonly include soft mudstone and argillaceous sandstone strata of the lower Bidahochi Formation (Tbl), causing some landslides to become unstable during wet conditions, especially where landslide masses steeply rest against, or overlie, soft sediments of the lower Bidahochi Formation. Thickness, 3 to 61 m (10 to 200 ft)

Qg4 **Older terrace-gravel deposits (Pleistocene)**—Gray and light-brown clay, silt, sand, gravel, cobbles, and boulders; weakly cemented by clay, calcite, and gypsum; poorly sorted. Includes abundant rounded and well-rounded clasts of quartzite, quartz, chert, and assorted metamorphic crystalline rocks derived from scattered Tertiary rocks south, southeast, and southwest of quadrangle; also includes well-rounded white chert, gray limestone, and red sandstone clasts locally eroded from Permian and Triassic strata south of Little Colorado River Valley, as well as well-rounded clasts of yellow, red, gray, and brown quartzite, black chert, and subrounded clasts of petrified wood locally derived from the Shinarump Member of the Chinle Formation. Forms terrace deposits about 17 m (55 ft) above stream-channel deposits (Qs) along principal tributary washes near Little Colorado River and as much as 25 m (80 ft) above stream-channel (Qs) and flood-plain (Qf, Qf1, Qf2, Qf3) deposits of Little Colorado River. Commonly covered by thin deposits of subrounded to rounded, wind-polished pebble and cobble clasts that form thin veneer of desert pavement on surface of deposits near Little Colorado River Valley. Unit is about 12 to 30 m (40 to 100 ft) below oldest terrace-gravel deposits (QTg4) of Little Colorado River at Tucker Mesa and Toltec Divide west of Winslow (fig. 1; see also, sheet 1). Thickness, 2 to 25 m (6 to 80 ft)

QTd **Old sand-dune deposits (Pleistocene and Pliocene?)**—Tan, light-red, and light-yellow, coarse- to fine-grained sand and silt; weakly consolidated. Forms isolated sand deposits on eroding bedrock ridges or slopes of badland topography below Marcou and Ives Mesas (fig. 1). Unit is extensively eroded and is assumed to represent remnants of old eolian sand-dune or sand-sheet deposits. Thickness, 1 to 12 m (3 to 40 ft)

QTes **Old eolian sand-sheet and dune deposits (Pleistocene and Pliocene?)**—Light-red to light-brown, very fine- to medium-grained sand and silt. Found as isolated deposits along eroding edges of Ives and Marcou Mesas, as well as on “Dilkon deposits” (QTdi) and below old alluvial fan deposits (Qa3). Extensively eroded unit is preserved mostly under younger alluvium and eolian deposits (Qae, Qa1, Qa2, Qa3, Qd, Qes). Contains white carbonate-soil horizon in upper 1 m (3 ft) in most outcrops. Thickness, 1 to 3 m (3 to 10 ft)

QTa **Older alluvial fan deposits (Pleistocene and Pliocene?)**—Gray and light-brown clay, silt, sand, and gravel; poorly sorted; weakly consolidated. Includes carbonate-soil horizon (Gile and others, 1981; Machette, 1985) in upper 1 to 1.5 m (3 to 5 ft). Consists mainly of erosional outwash debris from bedrock outcrops of the Petrified Forest and Owl Rock Members of the Chinle Formation below Newberry, Ives, and Marcou Mesas; also contains angular fragments and clasts of monchiquite and basanite volcanic rocks from Hopi Buttes, mixed with fluvial and eolian silt and sand on Marcou Mesa. Supports moderate growths of grass and small desert shrubs. Thickest and most extensive deposits form southwestern extent of Ives Mesa. Commonly covered by thin to thick eolian-sand (Qd, Qes), mixed alluvium and eolian (Qae), and alluvial (Qps, Qv) deposits. Thickness, 1 to 49 m (3 to 160 ft)

QTg4 **Oldest terrace-gravel deposits (Pleistocene and Pliocene?)**—Gray and light-brown silt, sand, gravel, pebbles, and cobbles; poorly sorted; weakly consolidated by calcite and clay cement. Pebbles and cobbles are mostly small, well-rounded, black chert; gray, light-red, and brown quartzite; and yellow to white quartz. Includes well-rounded, reddish-brown quartzite boulders as much as 30 cm (1 ft) in diameter on Tucker Mesa and Toltec Divide (sheet 1). Pebbles and cobbles weather out and form protective armored surface that help preserve underlying fine-grained silt and sand deposits. Extensively eroded and gullied; locally fills channels eroded into underlying sandstone strata of the Moenkopi Formation or of the Shinarump Member of the Chinle Formation on Toltec Divide and Tucker Mesa west and northwest of Winslow. Deposits are about 30 to 60 m (100 to 200 ft) above modern Little Colorado River drainage. Although deposits of this unit on Toltec Divide, on small isolated unnamed hills southwest of Toltec Divide (south of Interstate 40), and on Tucker Mesa (west of Toltec Divide) are mapped as being similar in age, deposits on Tucker Mesa may be slightly older, as they appear to be about 30 m (100 ft) higher than deposits on Toltec Divide (sheet 1). Deposits are likely those of ancestral Little Colorado River; current location of Little Colorado River suggests northeastward migration of river and its valley of as much as 7.5 to 10.5 km (5 to 7 mi). Supports little to no vegetation. Thickness on Tucker Mesa, 6 to 7.5 m (20 to 25 ft); thickness on Toltec Divide, 6 to 18 m (20 to 60 ft)

QTdi **“Dilkon deposits” (Pleistocene? and Pliocene?)**—Unit was informally defined by Sutton (1974) as “Dilkon terrace” for its relatively unbroken and extensive deposits near Dilkon; however, we herein informally map them as “Dilkon deposits” because they form extensive and discontinuous alluvial pediment slopes, not stream terraces, within Hopi Buttes Volcanic Field (sheet 2). [Note that, at some lower elevations and valleys east and southeast of Hopi Buttes (sheet 2), especially adjacent to mesas and buttes in Bidahochi Wash, Pueblo Colorado Wash, and Cottonwood Wash areas, “Dilkon deposits” as mapped on higher ridges could be interpreted as old alluvial fan deposits (Qa3), on the basis of their limited lateral extent and sandier material composition; however, we chose to map them as “Dilkon deposits” because they are more similar to this unit’s description.] Unit is composed of mixed gray fluvial and eolian silt and sand that supports abundant clasts of subrounded and subangular pebbles and cobbles of black monchiquite, basanite, and gray volcanic tuff derived from the volcanic rocks of Hopi Buttes Volcanic Field. Unit, which is weakly to moderately consolidated by calcium cement, overlies eroded bedrock of the Moenave Formation (Jm) in southern part of Hopi Buttes; the upper sandstone member of the Moenave Formation (Jms) in central part; and outcrops of the Dakota Sandstone (Kd), the Mancos Shale (Km), the Bidahochi Formation (Tbl), and older surficial deposits (QTa, QTes) on north and east slopes of Hopi Buttes. Commonly overlain by young alluvial and eolian deposits (Qa1, Qa2, Qa3, Qd, Qes, Qae). Includes as many as 10 caliche paleosols and alluvial gravels 0.5 to 1.2 m (2 to 4 ft) thick. Overlaps or intertongues with local landslide (Ql) and talus and rock-fall (Qtr) deposits below mesas and buttes; contacts are gradational and approximate between landslide deposits and talus and rock-fall deposits. Thickness, 4.5 to 25 m (15 to 80 ft)

QTs **"Shonto deposits" (Pleistocene? and Pliocene)**—Unit was informally defined by Sutton (1974) as "Shonto terrace" because of its presence as isolated higher alluvial remnants above "Dilkon deposits" (QTdi) southwest of Shonto Butte (T. 23 N., R. 18 E.); however, we herein informally map them as "Shonto deposits." Unit is composed primarily of bench-forming, subangular to angular fragments of monchiquite, basanite, and volcanic tuff mixed with minor amounts of alluvial and eolian silt and sand; weakly consolidated by calcium cement. Includes angular monchiquite and basanite boulders as large as 40 cm (16 in) in diameter. Forms isolated deposits 12 to 19 m (40 to 60 ft) above "Dilkon deposits" (QTdi) and is capped by 0.6 to 1.8 m (2 to 6 ft) of caliche-cemented, subangular and angular volcanic rocks and gravel derived from Shonto Butte; includes monchiquite boulders. Thickness, 8 to 18 m (20 to 60 ft)

VOLCANIC ROCKS

Volcanic rocks of Hopi Buttes (Tsezhin Bii) Volcanic Field (Miocene)—Unit was originally defined as the middle volcanic member of the Bidahochi Formation (Repenning and Irwin, 1954; Shoemaker and others, 1957, 1962); however, we herein redefine them as the volcanic rocks of Hopi Buttes Volcanic Field because it forms a mappable sequence of volcanic rocks that intertongues with deposits of the lower Bidahochi Formation (Tbl) of Miocene age near White Cone Peak northeast of quadrangle and in northeast quarter of quadrangle (sheet 2)

Ti **Intrusive dikes, plugs, or necks (Miocene)**—Black, dark-gray, and brown intrusive monchiquite, basanite, and unsorted scoriaceous and palagonitic tuff; highly eroded. Includes clinopyroxene, pyroxenite inclusions in limburgite, and olivine phenocrysts (Lewis, 1973). Forms impressive towering, circular or oblique circular monoliths or buttes about 122 to 427 m (400 to 1,400 ft) in diameter that display numerous cooling joints. Some larger intrusions commonly are capped by basanite or monchiquite flows or brown to gray welded-tuff beds. Smaller dikes and plugs of various widths (0.5 to 9 m [1 to 30 ft] or more) commonly are associated with larger necks and plugs that generally align along northwest-trending bedrock fractures and joints

Tc **Volcanic-crater sedimentary rocks (Miocene)**—Commonly deposited within circular maar crater-vent depressions that display inward-dipping stratified pyroclastic and surge deposits interbedded with lacustrine sedimentary deposits. Consists of undivided epiclastic and lacustrine volcanic and fluvial sedimentary rocks of gray, light-yellow, and tan to white claystone, thin-bedded calcareous siltstone and sandstone, globular or bedded travertine, and gypsum interbedded with interbedded pyroclastic and mafic gray tuff and white ash. Bedded ash and tuffaceous conglomerate and sandstone deposits are moderately well sorted and commonly show intense soft-sediment deformation. Within "Coliseum" diatreme between Indian Wells and Dilkon (Na Ah Tee Canyon 7.5′ quadrangle; see also, fig. 1), 1-m (3-ft) thick sandy sediments contain fish fossils (Uyeno and Miller, 1965) that may suggest an environmental-sedimentary connection to the upper Bidahochi Formation north and northeast of quadrangle. Fossil algae and plant fragments are tentatively identified in other nearby maar volcanic-crater sediments. Thickness, 0.5 to 36+ m (1 to 120+ ft)

Tm **Mafic monchiquite and basanite flows (Miocene)**—Black, dark-gray, and brown porphyritic monchiquite and basanite. Contains olivine, clinopyroxene, and phlogopite phenocrysts. Thick monchiquite flows display prominent columnar cooling joints. Includes xenoliths of crystalline metamorphic rocks near vent areas on Wood Chop Mesa (fig. 1; sheet 2). Include abundant kaersutite megacrysts near top of some bedded deposits in Wood Chop Mesa area. $^{40}Ar/^{39}Ar$ age on kaersutite about 0.7 km (0.5 mi) east of Wood Chop Mesa (just east of sheet 2) is 6.81±0.06 Ma (Vazquez, 1999). $^{40}Ar/^{39}Ar$ ages of basanite flows in Wood Chop Mesa area are 6.99±0.75 Ma, 6.53±0.59 Ma, and 7.21±0.45 Ma (Vasquez, 1999). Thickness, 3 to 43+ m (6 to 140+ ft)

Tmt **Mafic tuff-and-ash deposits (Miocene)**—Gray and white palagonitic lithic tuff and pyroclasts of porphyritic monchiquite or basanite fragments containing phenocrysts and glomerocrysts of clinopyroxene, olivine, and some phlogopite. Includes palagonitic tuffs containing welded ash to lapilli tuff, local bomb-rich layers, and multiple deposits of air-fall ash and surge deposits (Hooten and Ort, 2002). Commonly merges into or is interbedded with siltstone and travertine sediments of volcanic-crater sedimentary rocks (Tc) in maar depressions. Forms isolated deposits topographically above or below outcrops of the Bidahochi Formation throughout Hopi Buttes (sheet 2). Thickness, 2 to 55+ m (6 to 180+ ft)

Tmu **Mixed monchiquite and basanite flows and tuff deposits, undivided (Miocene)**—Gray or brown monchiquite and basanite flows interbedded with mafic tuff-and-ash deposits. Contains abundant phenocrysts and glomerocrysts of clinopyroxene, olivine, and phlogopite. Includes several mixed flows and pyroclastic deposits from multiple volcanic eruptions in north half of Hopi Buttes area (sheet 2). Thickness, 9 to 146+ m (30 to 480+ ft)

SEDIMENTARY ROCKS

[Consists of Cenozoic, Mesozoic, and Paleozoic sedimentary rocks (Tertiary, Cretaceous, Jurassic, Triassic, and Permian sedimentary rocks)]

Bidahochi Formation (Pliocene and Miocene)—Originally defined by Repenning and Irwin (1954) and Shoemaker and others (1957, 1962) as the following three informal members, in descending order: the upper fluvial member, the middle volcanic member, and the lower mudstone and argillaceous sandstone member (Pliocene and Miocene). However, we herein redefine the Bidahochi Formation to include only two of the original members, the upper fluvial member (present northeast of quadrangle) and the lower mudstone and argillaceous sandstone member; only the lower mudstone and argillaceous sandstone member (Tbl) is present within quadrangle (sheet 2). Lower member of the Bidahochi Formation is either associated with or below the Miocene volcanic rocks of Hopi Buttes (Tsezhin Bii) Volcanic Field; thus, it is considered to be Miocene (not Pliocene and Miocene) in age within map area (sheet 2) because it is stratigraphically within or below the Miocene volcanic rocks of Hopi Buttes. The middle volcanic member of the Bidahochi Formation is herein redefined as the volcanic rocks of Hopi Buttes (Tsezhin Bii) Volcanic Field

Tbl **Lower mudstone and argillaceous sandstone member (Miocene)**—White, greenish-gray, and yellowish-gray claystone, light-red and red-brown mudstone and siltstone, gray sandstone, and thin-bedded conglomerate, all primarily of lacustrine origin; interbedded with thin, gray, silicic ash-tuff beds in lower part; slope forming. Unit is easily eroded below outcrops of volcanic rocks in Hopi Buttes area, producing weak support of overlying volcanic rocks that results in formation of landslide (Ql) or talus and rock-fall (Qtr) deposits that cover substantial areas of outcrop of this unit. Sanidine minerals from felsic vitric-ash bed in lower part at “Triplets Mesa” (informally named in Dallegge and others, 1998a) less than 1 km east of quadrangle (sheet 2) yielded $^{40}Ar/^{39}Ar$ age of 13.71±0.08 Ma (Dallegge and others, 1998a, 1998b). In northwestern part of Hopi Buttes (sheet 2), unit unconformably overlies gray Cretaceous rocks and reddish siltstone and sandstone of the Kayenta Formation (Jk); in central and northeastern part, red and white strata of the upper sandstone member of the Moenave Formation (Jms); in southwestern and southern part, red strata of the Moenave Formation (Jm); and in extreme southeast quarter, gray limestone and red siltstone of upper part of the Chinle Formation (T̵Rco). Unit represents sedimentary deposits within Tertiary erosional basin present in eastern two-thirds of Hopi Buttes area (fig. 2). Thickness, 150 m (492 ft)

Km **Mancos Shale (Upper Cretaceous)**—Blue-gray to medium-gray, thinly laminated to thin-bedded, slope-forming, carbonaceous bentonitic claystone, siltstone, and mudstone, interbedded with light-gray, fine- to medium-grained sandstone and thin-bedded limestone. Contact with the underlying Dakota Sandstone (Kd) is gradational. Cretaceous strata at Bad Medicine Butte, Montezumas Chair, Round Top butte, as well as at unnamed buttes north of Teesto (fig. 1), are mostly covered by landslide (Ql) and talus and rock-fall (Qtr) deposits. Thickness, 30+ m (100+ ft)

Kd **Dakota Sandstone, undivided (Upper Cretaceous)**—*Lower sandstone unit (not mapped separately)*: Light-orange to light-gray, silty sandstone and conglomeratic sandstone; well cemented; forms cliff. Fills channels eroded as much as 1 to 3 m (3 to 10 ft) deep into underlying gray sandstone beds that may be the Entrada Sandstone (not mapped) just above the Kayenta Formation (Jk). Lower sandstone is locally discontinuous in short lateral distance. Includes red and gray, well-rounded chert and quartzite pebble clasts less than 5 cm (2 in) in diameter within conglomeratic-sandstone lenses. Unit unconformably overlies gray-white sandstone beds that may overlie the Entrada Sandstone (not mapped) at Bad Medicine Butte, Montezumas Chair, and Round Top butte (figs. 1 and 2). *Middle unit (not mapped separately)*: Dark-gray-brown, carbonaceous, flat-bedded mudstone, siltstone, and black coal, interbedded with brown, conglomeratic, crossbedded lenticular sandstone. Coal beds, which generally are less than 0.5 m (2 ft) thick, have been partly mined, probably in late 1940s and early 1950s, but now are abandoned as prospects on east and north side of Round Top butte and Bad Medicine Butte. Gypsum is common constituent as thin to thick stringers and pockets and isolated crystals. Contact with underlying lower sandstone unit is gradational, as is contact with the overlying Mancos Shale (Km). Thickness, 9 to 24 m (30 to 80 ft).

Unconformity between unit and underlying Triassic and Jurassic rocks has been established as regional angular unconformity, on the basis of deposition of unit overlying younger rocks north of quadrangle and older rocks south and southeast of quadrangle (fig. 2). Although these relations do establish angularity of pre-Dakota unconformity, angularity is so small that it is not apparent at most outcrops within Navajo Nation (Harshbarger and others, 1958)

Glen Canyon Group (Jurassic)—Overlies the Triassic Chinle Formation and includes the Jurassic Moenave Formation (Jm, Jms), the Wingate Sandstone in Utah and northeastern Arizona, the Kayenta Formation (Jk), and the Navajo Sandstone (the Wingate Sandstone and the Navajo Sandstone are not present in quadrangle). Contact between the Moenave and Chinle Formations is arbitrarily placed at lithologic, topographic, and color change between underlying purple and white mudstone, sandstone, and gray limestone of the Owl Rock Member of the Chinle Formation (₮co) and overlying red to orange-red mudstone, siltstone, and sandstone of the Moenave Formation (Jm), which may be equivalent to the Wingate Sandstone. In addition, the Jurassic Entrada Sandstone may be present at Bad Medicine Butte, Montezumas Chair, and Round Top butte (fig. 1), pinching out just east and south of these buttes; further study is needed to confirm if the Entrada Sandstone is present in this part of quadrangle

Jk **Kayenta Formation (Lower Jurassic)**—Purple, lavender, and light-red, slope-forming, fluvial crossbedded mudstone, siltstone, and fine-grained silty sandstone. Includes gray-white, slope-forming, very fine grained, trough-crossbedded sandstone in upper part that may be the Entrada Sandstone, which overlies the Navajo Sandstone northwest of quadrangle; the Navajo Sandstone pinches out just north of quadrangle (Billingsley and others, 2007). Unit is mostly covered by landslide deposits (Ql), talus and rock-fall deposits (Qtr), and "Dilkon deposits" (QTdi). Includes minor lenticular thin-bedded ledges of medium-grained sandstone in middle and lower part. Contact with the underlying upper sandstone member of the Moenave Formation (Jms) is gradational and marked at topographic and lithologic change to cliff-forming light-red or gray-white sandstone. Thickness, 98 to 122 m (320 to 400 ft)

Jm **Moenave Formation (Lower Jurassic)**—Orange-red and light-red, slope-forming, flat-bedded and low-angle crossbedded, fine- to coarse-grained siltstone and silty sandstone. Unit generally weathers as slope, except in western part of Hopi Buttes where gray-white and light-red strata of the upper sandstone member (Jms) forms rounded cliffs or ledges of sandstone. Forms Red Rock Cliffs northwest of quadrangle (Billingsley and others, 2007). Upper part of unit is partly removed by Tertiary erosion in northern-central and southeastern part of Hopi Buttes where overlain by dark-brown or white mudstone and siltstone of the lower mudstone and argillaceous sandstone member of the Bidahochi Formation (Tbl). Unit is unconformably overlain by purple-red siltstone and sandstone of the Kayenta Formation (Jk) in northwestern part of Hopi Buttes (sheet 2). Contact with the underlying Owl Rock Member of the Chinle Formation (₮co) is gradational. Thickness, 92 to 134 m (300 to 440 ft)

Jms **Upper sandstone member (Lower Jurassic)**—Consists of two subunits (not mapped separately), a lower gray-white sandstone subunit and an upper light-red sandstone subunit, that weather to rounded cliff outcrops as exposed at Red Cheek Butte (fig. 1; sheet 2). Lower gray-white subunit is cliff-forming, medium- to fine-grained, low-angle-crossbedded sandstone that gradationally overlies red and orange-red sandstone and siltstone slopes of the

Moenave Formation (Jm) in southwestern and central part of Hopi Buttes (east edge of sheet 1; west edge of sheet 2). Lower gray-white sandstone subunit, which extends northwest of quadrangle to Moenkopi Plateau (Billingsley and others, 2007), is disconformably overlain by light-red, cliff-forming, fine-grained, low-angle-crossbedded sandstone subunit as exposed at Red Cheek Butte (fig. 1; sheet 2). Upper light-red sandstone subunit is thickest near Dilkon. Both gray-white and light-red sandstone subunits undergo eastward facies change to red siltstone and sandstone fluvial beds in upper part of the Moenave Formation (Jm) in southeastern part of Hopi Buttes where it has been partly removed by Tertiary erosion. In southern part of Hopi Buttes (fig. 2), unit is unconformably overlain by red-brown or white mudstone and argillaceous sandstone of the lower mudstone and argillaceous sandstone member of the Bidahochi Formation (Tbl); in northern-central part, by gray-white mudstone and argillaceous sandstone of the lower member (Tbl) of the Bidahochi Formation; and in northwestern part, by purple and red-brown siltstone and sandstone of the Kayenta Formation (Jk). Thickness, 25 to 30 m (80 to 100 ft)

Chinle Formation (Upper Triassic)—Consists of the Owl Rock, the Petrified Forest, and the Shinarump Members (Repenning and others, 1969)

Ƭco **Owl Rock Member (Upper Triassic)**—Gray-red and light-purple, slope- and ledge-forming, nodular limestone, interbedded with purple, light-blue, and light-red calcareous claystone, siltstone, and sandstone. Limestone beds are gray, cherty, lenticular, silty, irregularly bedded, and 0.5 to 1.5 m (1 to 5 ft) thick, and they extend laterally several kilometers, forming as many as seven resistant limestone ledges at Newberry Mesa and northern part of Ives Mesa (fig. 1). Includes upper red, slope-forming siltstone and claystone interval that gradually thickens from 12 m (40 ft) in northwestern part of quadrangle (sheet 1) to 43 m (240 ft) near east-central edge of quadrangle (sheet 2). Unit contains abundant mud pellets and silicified clay and concretionary chert nodules and generally maintains consistent thickness across quadrangle. Contact with the underlying Petrified Forest Member (Ƭcp) is gradational and is arbitrarily placed at lowest limestone bed, or at nodular calcareous gray-white siltstone in slope below lowest limestone bed. Thickness, 80 to 92 m (260 to 300 ft)

Ƭcp **Petrified Forest Member (Upper Triassic)**—Purple, blue, light-red, red-purple, and gray-blue, slope-forming mudstone and siltstone, interbedded with white to yellow-white, coarse-grained, lenticular sandstone. Includes lenticular alluvial stream-channel features that exhibit large-scale, low-angle trough-crossbedding. Petrified logs and petrified-wood fragments are common in white or yellow-white sandstone beds. Blue and red claystone beds weather into rounded hills or slopes that have rough, puffy, popcorn-like surfaces owing to swelling clay. Contact with the underlying Shinarump Member (Ƭcs) is gradational and is arbitrarily placed at lithologic and topographic change from claystone and siltstone slopes of unit to coarse-grained conglomeritic sandstone ledges of the Shinarump Member. Thickness, 107 to 131 m (350 to 430 ft)

Ƭcs **Shinarump Member (Upper Triassic)**—White, light-brown, and yellowish-pink, cliff-forming, coarse-grained sandstone and conglomeratic sandstone. Includes cliff-forming, low-angle-crossbedded sandstone, interbedded with purple, light-red, and blue, slope-forming, poorly sorted siltstone and mudstone in upper part (sheet 1). Lithology is highly variable but relatively homogeneous from regional viewpoint, consisting of about 75 percent sandstone, 20 percent conglomerate, and 5 percent mudstone. Pebbles generally are black, brown, and gray, well-rounded quartzite and chert. Petrified logs and petrified-wood fragments are abundant at some localities but generally are scattered throughout unit. Unit is mostly covered by flood-plain deposits in Little Colorado River Valley. Forms cap-rock ledges of Tucker Mesa and Toltec Divide (southwestern part of sheet 1) where it overlies similar coarse-grained channel sandstones of the Holbrook and Moqui Members, undivided, of the Moenkopi Formation (Ƭmhm). Sandstones of unit often are distinguished from underlying sandstones of the Moenkopi Formation by presence of scattered, well-rounded pebble clasts versus no pebble clasts present in the Moenkopi Formation sandstone beds. Contact with underlying red siltstone and sandstone of the Moenkopi Formation is unconformable. Thickness, 18 to 24 m (60 to 80 ft)

Moenkopi Formation (Middle? and Lower Triassic)—Red, slope-forming, fine-grained, thin-bedded, shaley siltstone and sandstone. Includes the following two subunits, in ascending order: the lower massive sandstone member, and the undivided Holbrook and Moqui Members. The lower massive sandstone member also includes the Wupatki Member of the

Moenkopi Formation (McKee, 1954) because it generally is less than 4.5 m (15 ft) thick and pinches out in southwest quarter of quadrangle just west of Winslow (sheet 1). Overall, unit has unconformable contact with the underlying Kaibab Formation (Pk), representing regional Permian–Triassic unconformity. Thickness, 67 m (220 ft)

Ꞧmhm **Holbrook and Moqui Members, undivided (Middle? and Lower Triassic)**—Reddish-brown, slope-forming, alternating sequence of claystone, siltstone, and sandstone (McKee, 1954). Includes large- to medium-scale trough-crossbedding and abundant cusp-type ripple marks that testify to isolated fluvial-channel origin of the Holbrook Member; meander channels of the Holbrook Member are easy to recognize on 1:24,000-scale color aerial photographs between Winslow and Leupp. Commonly also includes sandstone and siltstone beds of the Moqui Member, making it an undivided map unit. Includes interbedded thin-bedded limestone, conglomeratic sandstone lenses, and gypsiferous siltstone and numerous gypsum veins in the Moqui Member. Thickness, about 25 to 37 m (80 to 120 ft)

Ꞧmss **Lower massive sandstone member (Lower Triassic)**—Light-red and light-brown, cliff-forming, crossbedded, fine-grained calcareous siltstone and sandstone. Unit gradually thins eastward to Winslow and forms isolated sandstone knobs along Interstate 40 (sheet 1). Salt weathering of sandstone forms weathered holes and fluted shapes in sandstone outcrops. Includes basal thin-bedded red siltstones of the Wupatki Member of the Moenkopi Formation (southwest edge of sheet 1). Unconformable contact with the underlying Kaibab Formation (Pk) is marked at distinct color change from red strata of the Moenkopi Formation to gray strata of the underlying Kaibab Formation. Thickness, about 3 to 26 m (10 to 53 ft)

Pk **Kaibab Formation (Cisuralian[1])**—Light-gray, cliff-forming, fine- to medium-grained, thin- to medium-bedded (0.3 to 2 m [1 to 6 ft]), fossiliferous, sandy, cherty limestone; weathers to dark gray. Characterized by gray to white, fossiliferous chert nodules and white chert lenses parallel to limestone bedding; chert weathers to dark gray to black. Some chert nodules contain concentric black and white bands. Includes breccia chert beds as much as 1 m (3 ft) thick in upper part, near contact with the overlying Moenkopi Formation. Unit thins eastward to less than 8 m (25 ft) southeast of quadrangle. Thickness (Hoffmann and others, 2005), 24 to 40 m (80 to 130 ft)

Pc **Coconino Sandstone (Cisuralian)**—Tan to white, cliff-forming, fine-grained, well-sorted, crossbedded quartz sandstone. Contains large-scale, high-angle planar-crossbedded sandstone sets that average about 11 m (35 ft) thick. Upper part may be sandstone beds of the Toroweap Formation. Drill holes near Leupp indicate that only 6 to 9 m (20 to 30 ft) of the Toroweap Formation (sandstone) is present in that area (Hoffmann and others, 2005). Sharp planar contact with underlying the Schnebly Hill Formation of Blakey (1990) is present in subsurface of southwestern part of quadrangle (sheet 1). This unit and the Schnebly Hill Formation are important water-bearing sandstone aquifers in subsurface of southwest quarter of quadrangle (south half of sheet 1) (Hoffmann and others, 2005) and perhaps also east and south of quadrangle. Thickness (Hoffmann and others, 2005), 366 to 396 m (1,200 to 1,300 ft). Only top 11 m (35 ft) of unit is exposed in Cow Canyon (southwest edge of sheet 1)

[1]Please note that Lower Permian is now referred to as Cisuralian.

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Table 1. Geochronologic data from Hopi Buttes Volcanic Field, Little Colorado River area; reprinted "as is" from Priest (2001) with permission from publisher (Grand Canyon Association, Grand Canyon, Arizona) (written commun., August 19, 2009).

Sample number	Age (Ma)	Reliability (ka)	Sample locality and type	General Locality	Latitude	Longitude	Reference	Comments
970712F	15.46	±0.58	Bidahochi Fm, felsic ash bed	Hopi Buttes; Member 1 at East Point Mesa	35.389	109.951	Dallegge, 1999	
970719E	15.19	±0.11	Bidahochi Fm, felsic ash bed	Hopi Buttes; Member 2 at SW end of Wood Chop Mesa	35.424	110.041	Dallegge, 1999	
970705C	14.81 to 71.98		Bidahochi Fm, felsic ash bed	Hopi Buttes; Member 5 N of Greasewood Trading Post	35.558	109.832	Dallegge, 1999	
970705C	13.85	±0.02	Bidahochi Fm, felsic ash bed	Hopi Buttes; Member 5 N of Greasewood Trading Post	35.558	109.832	Dallegge, 1999	
HB96-1	13.71	±0.08	Bidahochi Fm, felsic ash bed	Hopi Buttes	35.319	110.292	Dallegge and others, 1998[1]	
UAKA 73-137	13.85	±0.20	Bidahochi Fm air-fall tuff	Hopi Buttes	35.634	110.082	Reynolds and others, 1986	Vitric tuff lying in upper unit 5 of Bidahochi beds, ~8 m stratigraphically above basalt (UAKA 73-133) dated 6.86 my. Date probably too old due to excess argon.
UAKA 74-132	8.49	±0.27	Hopi Buttes Diatreme 14	Hopi Buttes; ring dike at S edge of diatreme 14, elev 1823 m	35.326	110.327	Damon and Spencer (written commun, 2000)	Dense monchiquite basalt.
UAKA 74-131	7.84	±0.74	Hopi Buttes Diatreme 14	Hopi Buttes; top of butte SE of diatreme 14, elev 1957 m	35.323	110.319	Damon and Spencer (written commun, 2000)	Monchiquite basalt, fine grained, olivine slightly altered.
UAKA 76-11	7.84	±0.185	Bidahochi basalt bomb	Hopi Buttes; bomb at top of bed correlative w/Bidahichi Fm.	35.556	110.09	Damon and Spencer (written commun, 2000)	Source of tuff is unnamed diatreme in SW S15, T2N, R21E; elev 1897m.
UAKA 76-12	7.82	±0.18	Bidahochi dike	Hopi Buttes; dike strikes N45E	35.561	110.093	Damon and Spencer (written commun, 2000)	Monchiquite basalt dike that intrudes a sequence of tuffs including the one from which RLS 7510-9 was taken. Appears to feed a flow that partially caps an unnamed diatreme 4.8 km SSW of White Cone settlement.
980118B	7.71	±0.06	Phlogopite, mafic tuff	Hopi Buttes; Member 5 at Flat Tire Mesa	35.546	110.152	Dallegge, 1999	
UAKA 74-146	7.35	±0.17	Bobcat Butte diatreme	Hopi Buttes, spatter of Bobcat Butte diatreme	35.473	110.406	Damon and Spencer (written commun, 2000)	Vesicular monchiquite basalt w/pyroxene and biotite phenos to 3 cm.
	7.21	±0.45	Lava groundmass	Hopi Buttes; Martinez maar			Vasquez, 1998	
UAKA 76-10	7.01	±0.16	Na-Ah-Tee 2 basalt	Hopi Buttes; near top of hill w/ microwave tower (Na-Ah-Tee 2), elev 2065 m	35.471	110.188	Damon and Spencer (written commun, 2000)	Monchiquite basalt, fine grained.
UAKA 76-20	7	±0.24	Hopi Buttes diatreme	Hopi buttes; diatreme centered in S20, 6 mi SW of White Cone Trading Post	35.549	110.156	Damon and Spencer (written commun, 2000)	Monchiquite basalt, very dense w/porphyritic olivine. Appears to be a dike emplaced between vent tuffs and outer sedimentary rocks.
	6.99	±0.75	Lava groundmass	Hopi Buttes; Haskie maar			Vasquez, 1998	
UAKA 73-133	6.86	±0.16	Bidahochi Fm basalt	Hopi Buttes; S end of Roberts Mesa	35.629	110.099	Reynolds and others, 1986	Basalt on top of middle volcanic member of Bidahochi Fm.
	6.81	±0.06	Amphibole megacryst	Hopi Buttes; Churro maar			Vasquez, 1998	
UAKA 74-134	6.81	±0.4	Petrified Forest maar	Petrified Forest	35.076	109.802	Damon and others, 1996	Probably related to Hopi Buttes maars. Dense monchiquite basalt w/xenoliths of baked ss, maar is ~1.6km in diameter.

[1] Note that this reference (Dallegge and others, 1998) from original volume (Priest, 2001) has become "Dallegge and others, 1998a" in this report.

Table 1. Geochronologic data from Hopi Buttes Volcanic Field, Little Colorado River area; reprinted "as is" from Priest (2001) with permission from publisher (Grand Canyon Association, Grand Canyon, Arizona) (written commun., August 19, 2009).—Continued

Sample number	Age (Ma)	Reliability (ka)	Sample locality and type	General Locality	Latitude	Longitude	Reference	Comments
UAKA 73-133	6.86	±0.16	trachybasalt	Hopi Buttes; 3.5 km NW of White Cone Trading Post			Reynolds and others, 1986	
UAKA 74-145	6.62	±0.14	Bobcat Butte diatreme	Hopi Buttes; Bobcat Butte	35.472	110.404	Damon and Spencer (written comun, 2000)	Basalt dike cutting all units at Bobcat Butte, including lakebeds at top of the butte.
UAKA 76-8	6.6	±0.15	Flat Mesa basalt	Hopi Buttes; lava flow capping Flat Mesa ~1 m above base of flow, elev 1951 m	35.463	110.245	Damon and Spencer (written comun, 2000)	Monchiquite basalt, very dense and fine grained. Basal 30–50 cm is brecciated.
UAKA 76-7	6.56	±0.17	Gray Mesa basalt	Hopi Buttes; near margin of flow capping Tesihim Butte, 1 m above base, elev 1914 m	35.475	110.113	Damon and Spencer (written comun, 2000)	Monchiquite basalt, dk gray, slightly vuggy. Basal part of flow is brecciated and overlies bedded tuffs.
UAKA 76-9	6.55	±0.14	Tesihim Butte basalt	Hopi Buttes; near margin of flow capping Tesihim Butte, 1 m above base, elev 1914	35.543	110.099	Damon and Spencer (written comun, 2000)	Monchiquite basalt, dk gray, vuggy, porphyritic.
	6.53	±0.59	Lava groundmass	Hopi Buttes; Haskie maar			Vasquez, 1998	
UAKA 85-88	6.26	±0.29	Woodruff Butte basalt	Holbrook area; monchiquite basalt on top of Woodruff Butte	34.799	110.041	Damon and others, 1996	
UAKA 76-6	5.98	±0.13	Deshgish Butte basalt	Hopi Buttes; top of Deshgish Butte, elev ~1946 m	35.52	110.068	Damon and Spencer (written comun, 2000)	Dense porphyritic basalt from a dike or pressure ridge. May be feeder dike for flow that caps the butte.
HB1	5.7	±1.10	Hopi Buttes diatreme	Hopi Buttes; Hoskietsko Butte	35.378	110.058	Reynolds and others, 1986	Gabbro xenolith from sml monchiquite diatreme; apatite age reflects cooling of the diatreme during or subsequent to emplacement.
UAKA 74-133a	4.41	±0.18	White Cone basalt	Hopi Buttes; near top of first diatreme N of White Cone Peak, N edge, elev 2022 m	35.596	110.042	Damon and Spencer (written comun, 2000)	Basalt spatter flow in agglomerate.
UAKA 74-147a	4.23	±0.59	Hokietsko Butte basalt	Hopi Buttes; dike at NW edge of Hokietsko Butte at elev 1743 m	35.377	110.059	Damon and Spencer (written comun, 2000)	Basalt dike is the latest recognized event at this butte.
KA-1027	4.2		Bidahochi Fm trachybasalt	Hopi Buttes; White Cone Peak	35.579	110.056	Reynolds and others, 1986	Trachybasalt separating upper and lower members of Bidahochi Fm.
HB2	2.17	±0.20	Hopi buttes diatreme	Hopi Buttes; Coliseum diatreme	35.383	110.137	Reynolds and others, 1986	Granodiorite xenolith from diatreme, age is average of 3 grains and reflects annealing before or during emplacement of diatreme.
UAKA 72-62	0.529	±0.079	Tappan Springs basalt	San Francisco Volcanic Field	35.887	111.455	Reynolds and others, 1986	Flow has been downcut by LCR and cut by NE trending graben at Moenkopi Wash, occupies channel of ancestral Colorado River.