Road Log Excerpted From

Geology of the Zuni Plateau

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New Mexico Geological Society
Fifty-fourth Annual Field Conference
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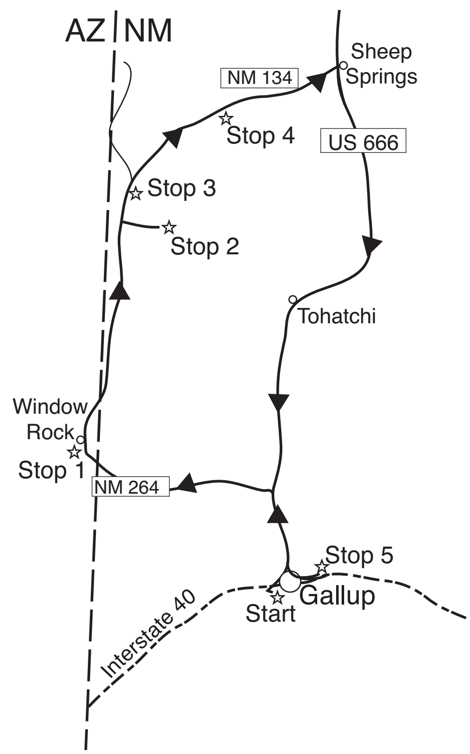
FIRST-DAY ROAD LOG, FROM GALLUP TO GAMERCO, YAH-TA-HEY, WINDOW ROCK, FORT DEFIANCE, NAVAJO, TODILTO PARK, CRYSTAL, NARBONA PASS, SHEEP SPRINGS, TOHATCHI AND GALLUP

SPENCER G. LUCAS, STEVEN C. SEMKEN, ANDREW B. HECKERT, WILLIAM R. BERGLOF, GRETCHEN HOFFMAN, BARRY S. KUES, LARRY S. CRUMPLER AND JAYNE C. AUBELE



Distance:	141.8 miles
Stops:	5

SUMMARY

The first day's trip takes us around the southern flank of the Defiance uplift, back over it into the southwestern San Juan Basin and ends at the Hogback monocline at Gallup. The trip emphasizes Mesozoic—especially Jurassic—stratigraphy and sedimentation in the Defiance uplift region. We also closely examine Cenozoic volcanism of the Navajo volcanic field.

Stop 1 at Window Rock discusses the Laramide Defiance uplift and introduces Jurassic eolianites near the preserved southern edge of the Middle-Upper Jurassic depositional basin. At Todilto Park, Stop 2, we examine the type area of the Jurassic Todilto Formation and discuss Todilto deposition and economic geology, a recurrent theme of this field conference.

From Todilto Park we move on to the Green Knobs diatreme adjacent to the highway for Stop 3, and then to Stop 4 at the Narbona Pass maar at the crest of the Chuska Mountains. The focus at Stops 3 and 4 is the Cenozoic igneous history of the Navajo volcanic field. The trip then returns to Gallup to end at Stop 5 on the Hogback east of town. Here, we discuss Cretaceous stratigraphy and coal geology.

NOTE: Most of this day's trip will be conducted within the boundaries of the Navajo (Diné) Nation under a permit from the Navajo Nation Minerals Department. Persons wishing to conduct geological investigations on the Navajo Nation, including stops described in this guidebook, must first apply for and receive a permit from the Navajo Nation Minerals Department, P.O. Box 1910, Window Rock, Arizona, 86515, 928-871-6587. Sample collection on Navajo land is forbidden.

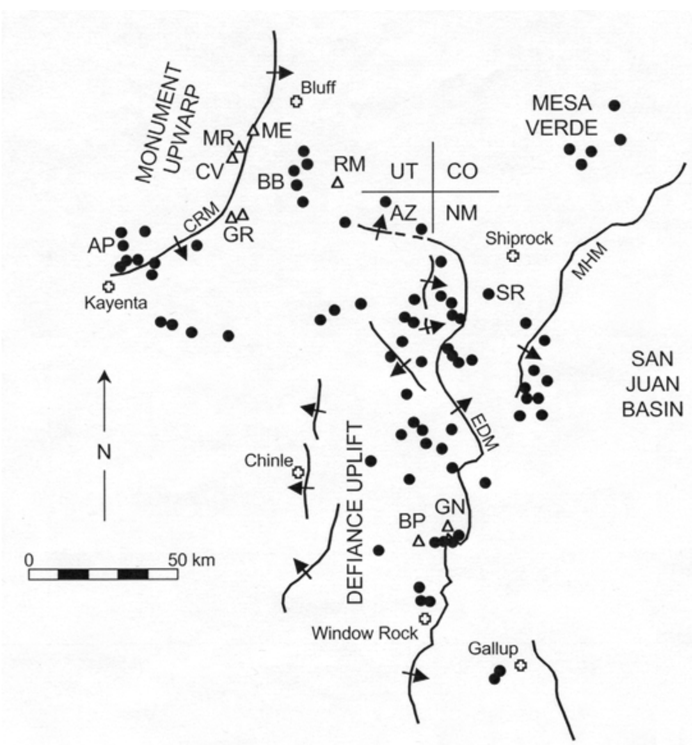


FIGURE 1.20. Map of the central Navajo volcanic field, after Smith and Levy (1976) and McGetchin et al. (1977). Dark circles indicate minettes; open triangles represent SMUs. Monoclines are indicated by heavy lines. Abbreviations: AP = Agathla Peak, AZ = Arizona, BB = Boundary Butte, BP = Buell Park, CO = Colorado, CRM = Comb Ridge monocline, CV = Cane Valley, EDM = East Defiance monocline, GN = Green Knobs, GR = Garnet Ridge, ME = Mule Ear, MHM = Mesaverde Hogback monocline, MR = Moses Rock, NM = New Mexico, RM = Red Mesa, SR = Ship Rock, UT = Utah.

68.0 **Turn right on paved road, NM Highway134,** at the housing development. Entering Navajo Nation Forest. **1.2**

69.2 Crest hill; Chuska Mountains ahead are light colored Chuska Sandstone (tree-covered slopes) over low, red, Middle and Upper Jurassic sandstone cliffs. **0.2**

69.4 Mile marker 21; View of the spectacular, columnar-jointed Palisades at 10:00. This Navajo volcanic landform is an erosional remnant of a deep paleovalley fill of coalesced trachybasalt lava domes and agglomerate, overlying fluvially-reworked tuff beds on top of Chuska Sandstone (Appledorn and Wright, 1957). The lavas issued from several vents now marked by domes. The Palisades rise to an elevation of 2800 m (9200 ft), about 550 m (1800 ft) above the local valley floor. (For purposes of comparison, that is about the same height as Ship Rock.) The south wall of the Palisades, visible from here, is referred to as Falling Iron Cliffs and is a 120-m (400-ft) high, mile-long rampart of myriad columns, each approximately 2-3 m in diameter. **1.5**

70.9 "Tsa'h-be-toh" housing development on left. **0.7**

71.6 Road cuts through cuesta formed by Zuni Sandstone. **0.3**

71.9 Crystal community on left. Crystal (Tó niłts'ílí, "crystal-clear water") began in 1884 around a trading post, had a post office from 1903 to 1941 (Julyan, 1996)

and maintains a community school. **0.3**
72.2 Bowl Canyon turnoff on right leads back to Todilto Park. Road cuts developed in the Zuni Sandstone (Bluff Sandstone). **0.6**
72.8 Second road to Crystal on left. **0.1**
72.9 Bluff sandstones in roadcut. **0.2**
73.1 Lazy C Rodeo Arena on right. **0.1**
73.2 Upper Jurassic Recapture Member of the Bluff on left. **0.7**
73.9 Upper Jurassic Salt Wash Member of the Morrison Formation sandstones in roadcuts. **0.7**
74.6 Approximate base of the Chuska Sandstone on right. The Chuska here overlies a poorly exposed Cretaceous section of Dakota and Mancos strata (Cooley et al., 1969). The base of the Chuska Sandstone is an angular unconformity where the flat-lying Chuska overlies eastward-dipping Mesozoic strata (Fig. 1.21). Road follows Crystal Creek. **0.9**
75.5 Good exposures of Chuska Sandstone at 2:00. **1.2**

THE AGE OF THE CHUSKA SANDSTONE

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The Chuska Sandstone (of Gregory, 1916, 1917) forms the caprock of the Chuska Mountains of the Arizona-New Mexico borderland, from north of Tohatchi, New Mexico to just north of Lukachukai, Arizona. In this region, it is as much as 580 m thick and consists of a relatively thin, basal fluvial unit (the Deza Formation of Wright, 1956) overlain by gray to white, fine- to medium-grained, trough-crossbedded arkosic sandstone of eolian origin (Fig. 1.21). The Cenozoic age of the Chuska Sandstone has never been doubted, but more precise age estimates have varied considerably. This is largely because the Chuska Sandstone has never yielded any fossils or other data by which its age can be estimated directly.

The first estimates of the age of the Chuska Sandstone assigned it to the early Eocene. Dutton (1885, p. 140) first discussed the unit, and, based on gross lithology and stratigraphic position, he correlated it to the lower Eocene "Wasatch beds" (now San Jose Formation) in the east-central San Juan Basin. Dutton (1885, pl. 16) even used the term "Wasatch sandstones" for the unit later named the Chuska Sandstone. When Gregory (1917, p. 81) named the Chuska Sandstone he advocated the same correlation, noting that "its position and lithology suggest correlation with the Wasatch Formation of north-central New Mexico."

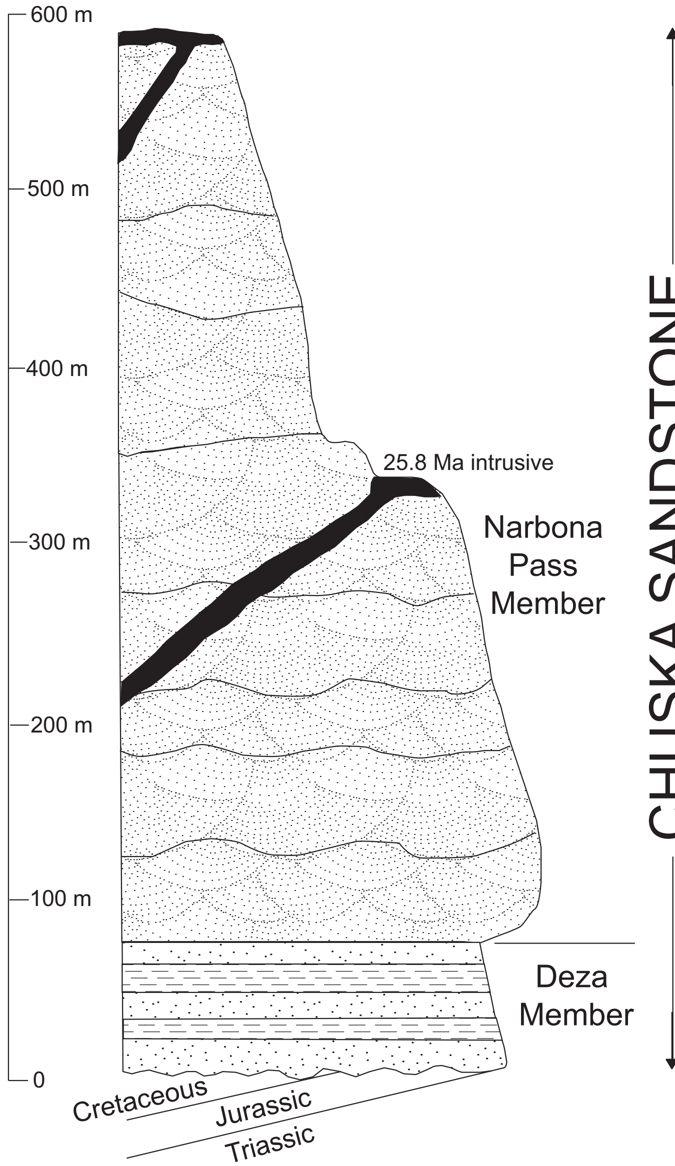

FIGURE 1.21. Generalized stratigraphy of the Chuska Sandstone (modified from Trevena, 1979).

By the 1940s and 1950s, however, several workers assigned the Chuska Sandstone a Neogene age. Pliocene age assignments were based primarily on correlating the Chuska to the Bidahochi Formation of northeastern Arizona (e.g., Reiche, 1941; Hack, 1942; Allen and Balk, 1954; Repenning and Irwin, 1954). Supposed lithologic similarity and correlation of the erosion surface beneath the Chuska, Bidahochi and other Neogene units in the region formed the basis for this correlation.

Wright (1956, p. 428-431) presented a detailed critique of previous correlations of the Chuska Sandstone and well explained their shortcomings. Instead, he advocated a Miocene? age for the Chuska Sandstone, based primarily on then accepted ideas about the geomorphological history of the Colorado Plateau (Gregory, 1947).

More recent data, however, also indicate that Wright's age estimate was incorrect. Several intrusives of the Navajo volcanic field cut the Chuska Sandstone (Fig. 1.21), and thereby provide a way to estimate its minimum age. The oldest age of the intrusives in the field is about 28 Ma (Naeser, 1971; Trevena, 1979; Laughlin et al., 1986; Semken, 2001), thus indicating that the Chuska Sandstone cannot be younger than early Oligocene (the early-late Oligocene boundary is very close to 28 Ma: Berggren et al., 1995). Indeed, Laughlin et al. (1986) report a K/Ar age of 27.7$\pm$0.6 Ma for a dike they termed "Sonsela Butte" that cuts the Chuska Sandstone. So, earlier assignments of a Neogene age to the Chuska Sandstone must be abandoned.

An older age limit for the Chuska Sandstone is less certain, but almost certainly is late Eocene. The mostly eolian Chuska Sandstone bears no resemblance to the fluvial lower Eocene San Jose Formation to the east. Trevena's (1979; Trevena and Nash, 1978) petrographic study of the Chuska Sandstone indicates that it contains abundant detrital alkali feldspar that is highly potassic. About 20% of the plagioclase Trevena analyzed is of volcanic origin, another 19% is of volcanic or plutonic origin, and the remainder appears to have been derived largely from low-grade metamorphic rocks. Crossbed dip directions of eolian sandstone beds in the Chuska Sandstone indicate a source area to the south (Wright, 1956; Trevena, 1979). The large Mogollon-Datil volcanic field to the south, which is of late Eocene-Oligocene age, is the obvious source area for the Chuska Sandstone (Smith et al., 1985). A late Eocene or early Oligocene age for the Chuska Sandstone thus seems certain.

76.7 Cross Crystal Creek. **0.4**

77.1 Good view of Narbona Pass bedded pyroclastic deposits in cliff ahead (Fig. 1.22). **0.4**

77.5 Light colored rocks on left are cross-bedded eolian Chuska Sandstone. **Slow to prepare for Stop 4. 0.9**

78.4 **Turn right into Narbona Pass day-use area. STOP 4. Lunch stop.**

This historically-significant pass through the Chuska Mountains was originally named Béésh líchíí'ii bigiizh, which literally translates as Copper Pass, but actually refers to the locally-abundant copper-colored jasper that Navajos worked into tools.

The first Americans to inspect Narbona Pass were members of a military expedition against the Navajo, led by Colonel John M. Washington and including Lieutenant James Hervey Simpson, of the Army Corps of Topographical Engineers (Fig. 1.23). The expedition ascended the pass on September 2, 1849, en route from Santa Fe to northeastern Arizona. Simpson (1850) published a journal of his geological and other observations on this expedition, including Chaco Canyon, El Morro, and Canyon de Chelly, and his route was traced again by Kues (1992). Of the pass, Simpson wrote: "On the north side is a wall of trap, capped with sandstone, running perpendicularly up from the bottom of the defile to a height of about 600 feet; and, in addition to this, there are two others, but further removed. On the left side is another height, running up from the defile, with an accessible slope, to a height of probably 300 feet. The width of the pass at this point is probably not more than 50 feet, and barely furnishes a passageway…for the artillery" (Fig. 1.23).

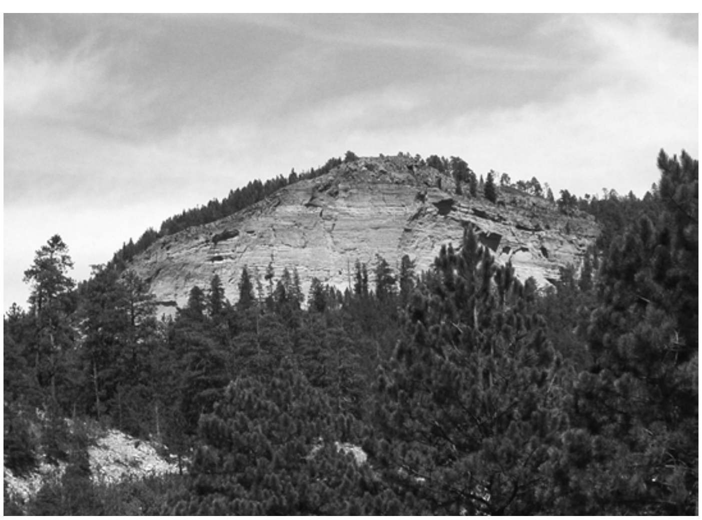

FIGURE 1.22. Bedded pyroclastic deposits at Narbona Pass, mile 77.1.

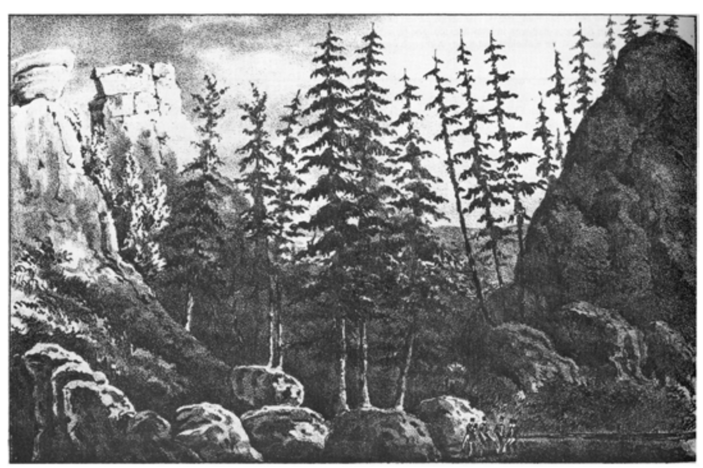

FIGURE 1.23. Simpson's (1850) drawing of Narbona (Washington) Pass.

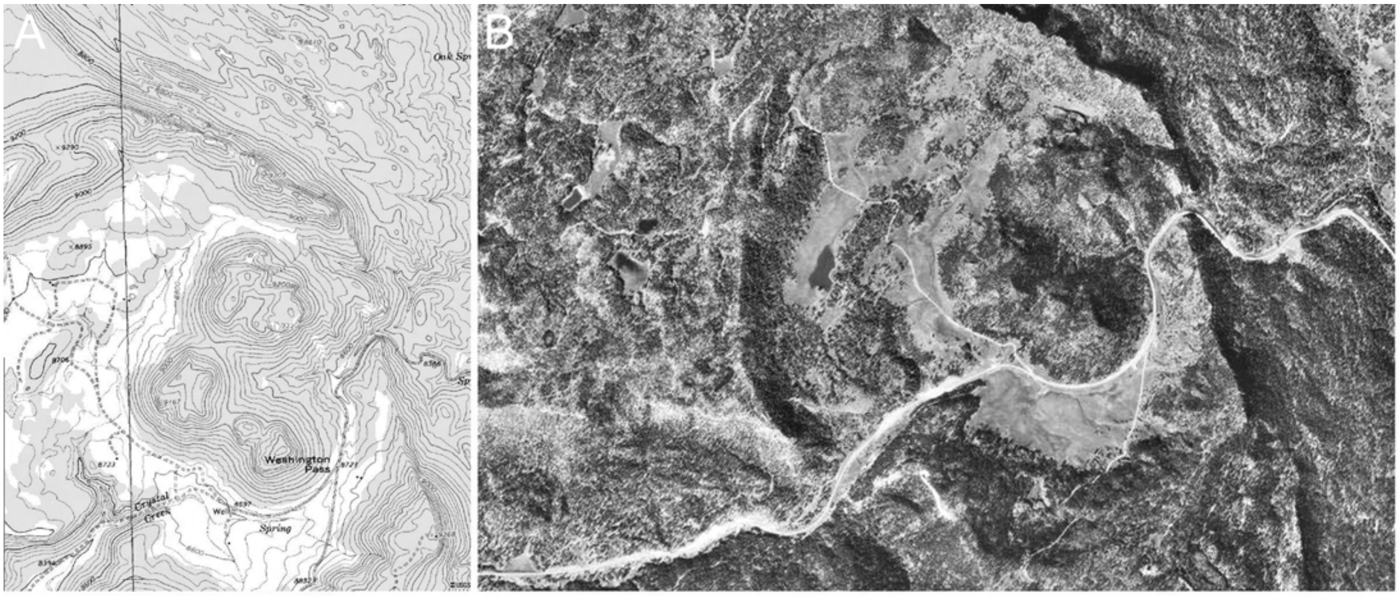

FIGURE 1.24. Topographic map (A) and aerial photograph (B) of Narbona Pass maar.

Several days earlier, Washington's party had met with a large group of Navajos about 20 km (12 mi) northeast of here, near the present-day site of the Two Grey Hills Trading Post (Acrey, 1994). The Diné were led by three respected headmen, Narbona, José Largo, and Archuleta, and were mostly seeking explanations for depredations (including destroyed crops) committed by Washington's soldiers along their route. Washington was focused on pacifying the Navajos by either diplomacy or military force (Acrey, 1994). Although the conference itself concluded well, with a promise by the Diné to hold a treaty council with Washington at Canyon de Chelly, the encounter ended in violence, as recounted by Acrey (1994). A New Mexican claimed to have spotted a stolen horse among the mounted Navajos, and as the soldiers attempted to seize it, the Diné fled. A firefight followed, in which six Navajos, including the 80-year old Narbona, were killed. The honored, elderly headman was summarily scalped by a trophy hunter. This incident ended any real possibility of peace between the Navajos and the Americans until the Treaty of 1868 after Bosque Redondo (Acrey, 1994).

Simpson named this pass Washington Pass for his commanding officer, and that name remains on all but the most recently-published maps. Following community action initiated by Navajo History students at Diné College in the early 1990s, the pass has been officially renamed to honor Narbona.

The Narbona Pass volcanic center (Appledorn and Wright, 1957; Ehrenberg, 1978; Figs. 1.24-1.25) is a partially-eroded maar crater approximately 3.2 km (2 mi) in diameter and 215 m (700 ft) deep. Minette magmas erupted through the Chuska Sandstone from 27.5 to 24.3 Ma (Ar-Ar ages; G. Nowell, pers. comm., 2002). The crater is floored by bedded pyroclastic rocks (some fluvially reworked around the rim) overlain by two mafic trachybasalt flows and a felsic trachybasalt flow, and intruded by two minette plugs and a cluster of minette dikes near the east rim. The lava flows extend beyond the crater rim on the south and west. Rocks in the rim dip steeply inward and are locally sheared and faulted, indicating crater subsidence estimated at 90 m (300 ft) (Appledorn and Wright, 1957).

Like other Navajo volcanic centers (Semken, this volume), Narbona Pass

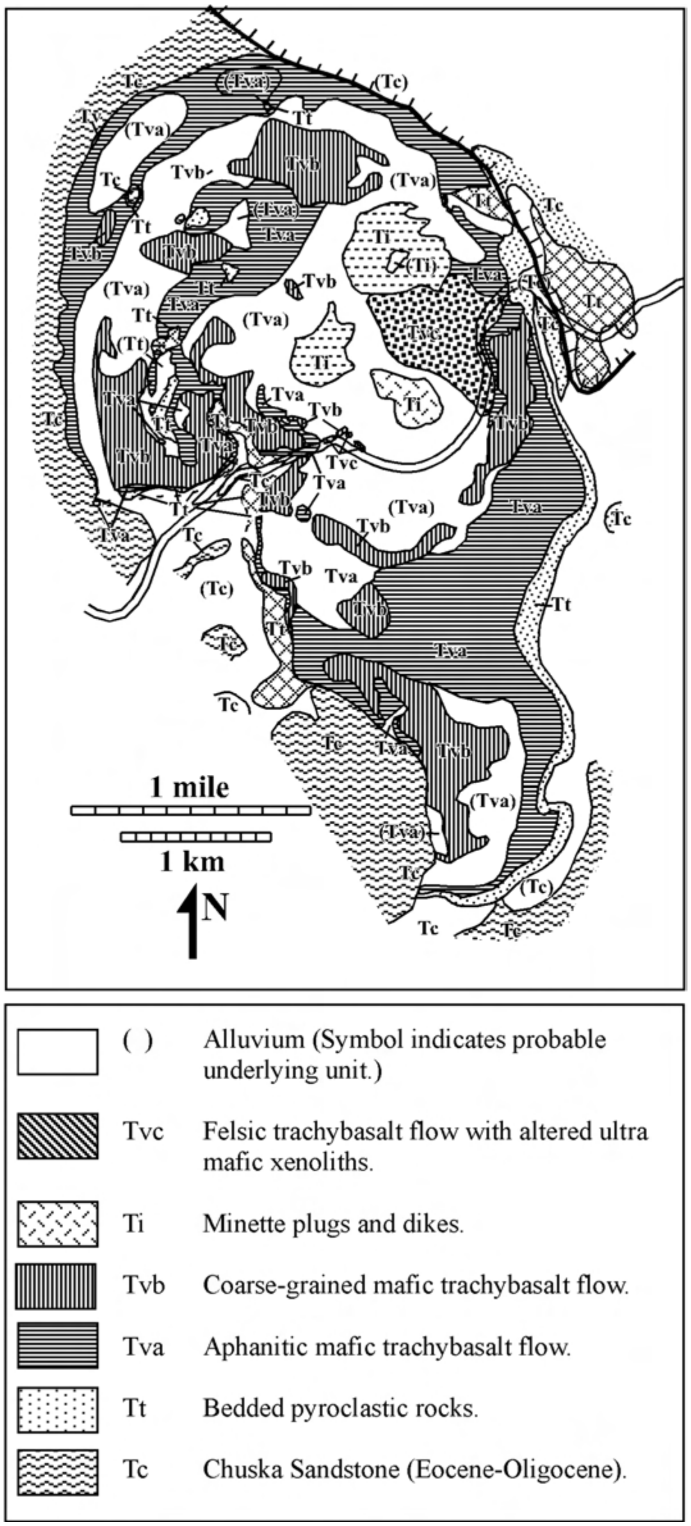

FIGURE 1.25. Geologic map of Narbona Pass maar (after Ehrenberg, 1978).

presents abundant evidence of hydrovolcanic (or phreatomagmatic) eruption. Surge deposits in the rim, silicification of the Chuska Sandstone in a zone immediately beneath the pyroclastic deposits, and abundant reddish-brown (béésh líchíi'ii) to milky-white jasper, chert, and chalcedony bear witness to the presence of hydrothermal water.

After stop, **leave the day-use area and turn right**; elevation 2536 m (8320 ft). **0.1**

78.5 Cross Crystal Creek, which cuts through the crater rim ahead. Ridge of Chuska Sandstone high on left. The highway is on Quaternary alluvium, colored dark by volcanic fragments. **0.05**

78.55 Columnar-jointed trachybasalt flow (Fig. 1.26), the middle in a sequence of three flows (flow **b** of Appledorn and Wright, 1957) sits on greenish-tan, bedded pyroclastic deposits above road level at 11:30. **0.05**

78.6 Milepost 12. Note the smoothing and rounding of the trachybasalt columns, 10-15 m high, above on the left. **0.3**

78.9 Pieces of trachybasalt **b** lava from the columnar-jointed flow can be studied in the float here. The rock is coarse-grained, with 1-3 mm phenocrysts of phlogopite, olivine, and clinopyroxene in a matrix of poikilitic sanidine crystals 0.5 to 1.0 mm in diameter (Ehrenberg, 1978). The coarse phenocrysts readily weather out of the

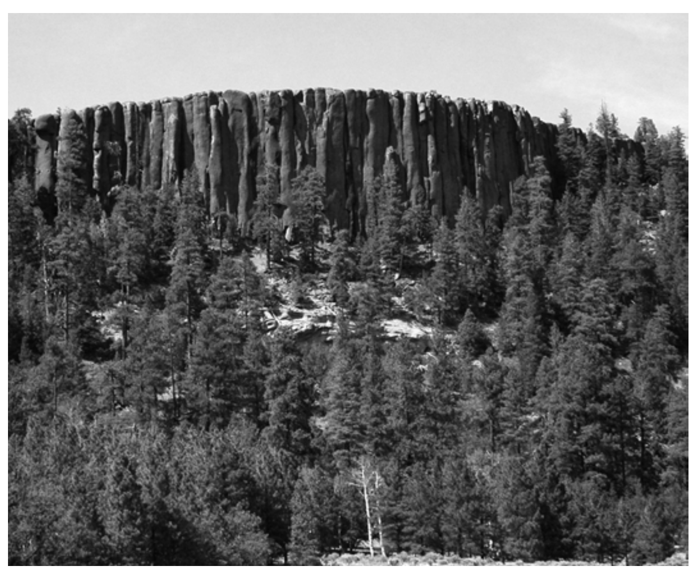

FIGURE 1.26. Columnar-jointed trachybasalt **b** flow at Narbona Pass.

rock, creating spheroidal shapes and the rounded columns of the flow above. **0.1**

79.0 "Watch for Rocks" sign; cross a branch of Crystal Creek and proceed into the western entrance of Narbona Pass maar (Fig. 1.24). **0.1**

79.1 Outcrop of Narbona Pass Member of Chuska Sandstone held up by volcanic rocks in the west rim of Narbona Pass crater. The sandstone at the base of the exposure is light tan, cross-bedded, friable, and highly permeable. This is the type section of the Narbona Pass Member of the Chuska Sandstone of Lucas and Cather (this guidebook). Upsection, it has been sheared and faulted by crater subsidence, and silicified by hydrothermal fluids associated with the phreatomagmatic eruption of the volcano. Note the prominent vertical spine about one-third of the way along the outcrop, probably a silicified fracture. **0.05**

79.15 The uppermost Chuska Sandstone here has been strongly silicified in a band approximately 5-8 m thick and roughly parallel to the overlying pyroclastic beds. The contact between the sandstone and the pyroclastics (Fig. 1.27) marks the edge of the maar crater rim.

The bedded pyroclastics are more than 100 m thick in this part of the west rim and at the east portal of the pass, but thin to less than 1 m in other parts of the crater rim, indicating that the pyroclastics were probably erupted into valleys or canyons in the Oligocene Chuska Mountains, similar to the one we are currently following (Appledorn and Wright, 1957). The pyroclastics consist of interbedded sandy tuffs and coarser tuff-breccias. Low-angle cross-beds, dunes, and scours are present in the tuff beds. Some beds bear evidence of fluvial transport back toward the center of the crater, and a thin layer of chert and limestone within the tuffs may reflect a brief fluvial or lacustrine interval between pyroclastic blasts (Ehrenberg, 1978).

The sand-sized to gravel-sized clasts in the tuff-breccia beds are an approximately equal mixture of minette or trachybasalt and igneous and metamorphic basement rocks. These pyroclastics were probably deposited by ballistic fall-back during a periodic sequence of hundreds of explosions, alternating with quiet periods of fluvial reworking (Ehrenberg, 1978). **0.05**

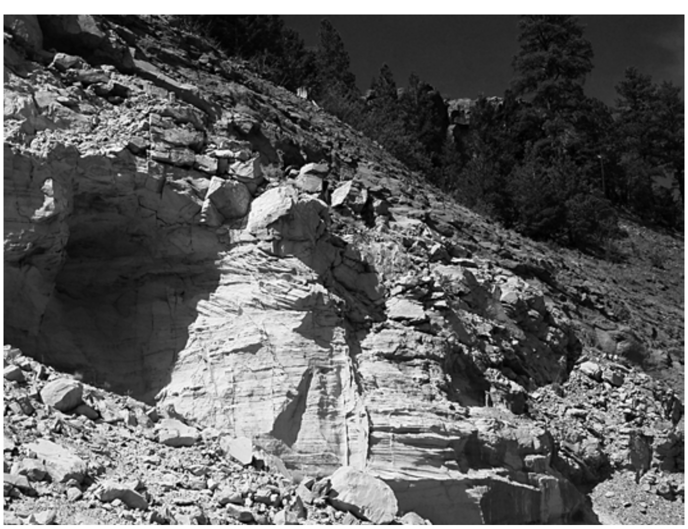

FIGURE 1.27. Narbona Pass Member of Chuska Sandstone and overlying pyroclastic beds at mile 79.15.

79.2 Note the steep inward dip of the pyroclastic deposits and the overlying trachybasalt flow (visible on high), reflecting crater subsidence. **0.05**

79.25 Weathered top of the bedded pyroclastic deposits and scoriaceous base of the oldest lava flow (flow **a** of Appledorn and Wright, 1957). This is a greenish-grey to black aphanitic trachybasalt with 0.5-1.0 mm phenocrysts of phlogopite and olivine. Flows **a** and **b** have been mapped separately (Fig. 1.25) on the basis of their differing textures, but Appledorn and Wright (1957) observed that the contact between the two flows is sharp and unweathered, and suggested that **a** and **b** may simply be different facies of a single trachybasalt flow. **0.1**

79.35 Jasper, chert, chalcedony, and botryoidal silica clasts mingled with lava in the float. Thick, cliff-forming trachybasalt **a** above the highway may mark a small lava lake. **0.03**

79.38 At the "curve right" sign, note two hills formed by minette intrusions ahead. The western hill, at 10:00, is a dome-like pile of trachybasalt blocks intruded by minette dikes. The southern hill, at 12:00, is a columnar-jointed minette plug. The minette in both intrusions is lithologically similar to flow **a** (Ehrenberg, 1978). A third intrusion is hidden behind these two, but will become visible farther along the highway. Just ahead, the trachybasalt **a** flow dips beneath the alluvium. **0.02**

79.4 NM-134 curves right and enters the eroded, alluvium-filled bowl of the Narbona Pass maar crater. The **a** and **b** flows hold up the south crater rim visible across the bowl. **0.1**

79.5 Trachybasalt and minette talus cover the slope on the left. **0.1**

79.6 Pass graded road on the left, Navajo Route 30 to Todacheene Lake (within the crater) and across the north rim to Berland Lake. **0.05**

79.65 NM-134 curves left. The highway is still on alluvium atop the **a** flow (Appledorn and Wright, 1957). Note the deep incision of the alluvium by arroyos feeding Crystal Creek on the right. **0.05**

79.7 Milepost 11. Alluvium well-exposed along the left side of the highway. **0.3**

80.0 The garage on the right houses snow equipment needed for winter access to a Federal Aviation Administration (FAA) radar station and lookout tower on the south rim (not visible from here). **0.1**

80.1 Summit of Narbona Pass, elevation 2658 m (8721 ft). Navajo Route 30 on the right leads to the FAA station and continues south along the ridge, atop trachybasalt flows that extend for more than 2 km south of the crater. **0.1**

80.2 Youngest lava flow (flow **c** of Appledorn and Wright, 1957) exposed in the roadcut on the right. This rock is a felsic trachybasalt: a light greenish-grey aphanitic flow with small phenocrysts of phlogopite and clinopyroxene, and larger weathered inclusions of spinel peridotite, websterite, and crystalline basement rocks. The larger inclusions compose about five volume percent of the rock (Ehrenberg, 1978). Most of the peridotite inclusions have weathered out, so that the flow is vuggy and seemingly vesicular from a distance, but the websterite and basement inclusions are fresher. Trace-element and Sr isotopic studies by Roden (1981) indicate that felsic minette magmas such as this originated by fractionation of mafic minette in the upper-mantle source region. The rock also includes lenses and marbling of minette similar to that of the adjacent plugs, perhaps reflecting assimilation (Ehrenberg, 1978) or incomplete magma mixing. This flow overlies the mafic trachybasalts and issued from the northeast, apparently from a vent alongside the northernmost minette plug (Ehrenberg, 1978). **0.1**

80.3 NM-134 descends toward the east portal of Narbona Pass. Felsic trachybasalt **c** is exposed in the roadcut on the left. The northernmost minette plug, 235 m (770 ft) tall and called "Sun Resting" by some Diné (Van Valkenburgh, 1941), is at 11:00. The east rim of the crater is visible at 12:00. **0.1**

80.4 "Sun Resting" plug looms straight ahead (Fig. 1.28). We will now go back down

FIGURE 1.28. "Sun Resting" minette plug at east portal of Narbona Pass.

through the Narbona Pass eruptive sequence as we leave the crater. **0.1**

80.5 NM-134 curves right and begins a steep descent. Coarse-grained trachybasalt **b** sits on weathered aphanitic trachybasalt **a** across the arroyo on the right. **0.2**

80.7 Milepost 10. Trachybasalt **a** in roadcuts on both sides. **0.1**

80.8 Sharp right curve across the arroyo and through the east portal. Pyroclastic beds in the roadcut on the right are about 35 m thick and capped by scoriaceous trachybasalt **a**. The prominent prow of pyroclastics to the left of the highway is more than 120 m thick and features interbedding of steeply cross-bedded tuffs and horizontally-bedded tuff-breccias. Ehrenberg (1978) interpreted the cohesive, well-sorted, more-resistant bedded pyroclastics here in the east rim of Narbona Pass as base-surge flow deposits. **0.1**

80.9 Lower pyroclastic beds here are covered by alluvium and talus. **0.2**

81.1 Highway cuts through reworked pyroclastic beds. **0.2**

81.3 Trachybasalt rubble on the right and in the roadcut ahead, on top of deeply-weathered and possibly reworked pyroclastics. NM-134 snakes down onto the scarp of a vast Quaternary landslide (Fig. 1.2). **0.1**

81.4 Several good and well-used springs are found in the Chuska Sandstone immediately north of here. View ahead into San Juan Basin. The Chaco River drainage extends toward us from Chaco Canyon in the southeast, before curving northward toward the San Juan River at Shiprock. **0.6**

82.0 Sharp curve left; begin descent down enormous Quaternary landslide deposit composed mostly of Chuska Sandstone. Landslide deposits extend along the Chuska Mountain front more than 40 km north and 24 km south of here, and in this vicinity, more than 12 km out into the basin (Fig. 1.2). **1.5**

83.5 View of two well-exhumed Navajo volcanic field minette diatremes at 9:00 (Ford, Bennett). Bennett Peak (Tsé naajiin, "it is black rock downward") is on the left, and the smaller Ford Butte is on the right; both are composed of tuff-breccia and intruded by small minette dikes. They are about 20 mi from here. G. Nowell (pers. comm., 2002) obtained an Ar-Ar age of 24.5 Ma for Bennett Peak. **1.5**

85.0 Leaving Navajo Nation Forest. **0.3**

85.3 View to north of Ship Rock (Tsé bit'a'í, "rock with wings"), 40 mi distant, largest and best-known exhumed diatreme in the Navajo volcanic field (see Semken, this guidebook). Bennett Peak and Ford Butte are again visible in the middle distance. The diatremes on the west flank of the San Juan Basin are aligned along Laramide monoclines, roughly parallel to the mountain front. **0.1**

85.4 Roadcuts to north are of landslide debris, primarily Chuska Sandstone. **0.5**

85.9 Upper Cretaceous Tohatchi Formation outcrops on both sides of road. (Tó hách'í, "where water is customarily scratched out," referring to the high water table at Tohatchi Wash to the south, where shallow, hand-dug holes fill with water; Young and Morgan, 1987). **1.0**

86.9 Tohatchi Formation outcrops on both sides of road again. The Upper Cretaceous Tohatchi Formation is at least 160 m of nonmarine siliciclastic strata exposed in western New Mexico along the SE and E flank of the Chuska Mountains. The Tohatchi Formation conformably overlies the Menefee Formation, is unconformably overlain by the Paleogene Deza Member of the Chuska Sandstone and consists of a lower, sandstone-dominated member and an upper, mudstone-dominated member.

Dinosaur fossils found throughout the Tohatchi Formation indicate a Late Cretaceous age, and extensive palynomorph assemblages refine this age assignment to early Campanian (see Lucas et al., this guidebook). The presence in the Tohatchi Formation of such pollen species as

Accuratipollislactiflumis,*Brevimonosulcites corrugatus*, *Callialasporites dampieri*, *Microfoveolatosporis pseudoreticulatus*, *Periretisynolporites chinookensis*, and *Rugubivesiculites reductus* suggest links to upper Santonian assemblages of the Milk River and lower Eagle formations of Alberta-Montana. However, other Tohatchi species such as *Aquilapollenites attenuatus*, *A. trialatus*, *A. turbidus*, *Pulcheripollenites krempii* and *Tricolpites reticulatus* are more closely related to assemblages from the Pakowki Formation and Judith River Group of Alberta and the Claggett and Judith River formations of Montana. The palynomorph assemblages in the Tohatchi Formation thus fall within the *Aquilapollenites senonicus* Interval Zone of early Campanian age. Therefore, the Tohatchi Formation is not, as has been thought for 50 years, a correlative of part of the upper Campanian Pictured Cliffs-Fruitland-Kirtland formations succession to the east. Instead, the Tohtachi Formation is the uppermost part of the Mesaverde Group in western New Mexico, younger than the underlying Allison Member of the Menfee Formation locally, and older than the late Campanian turnaround of the Cliff House-Pictured Cliffs shoreline to the east (Fig. 1.29). **2.3**

89.2 Leave landslide deposits and emerge on coal-bearing Menefee Formation outcrops on left and right. **1.0**

90.2 Enter greater Sheep Springs (Tooh halt-sooí, "spring in the meadow") (population 237 by the 2000 census). In 1892, a Lieutenant W. C. Brown visited the springs and reported them a well-known camping place. Charles Newcomb established a trading post in 1912 about 1.5 mi east of the springs that became the nucleus for the present community (Julyan, 1996). **0.5**

90.7 Slow down for Intersection with US-491; Highway is developed on Menefee Formation. View of minette diatremes; Bennett Peak at 9:00, Ford Butte at 9:30.

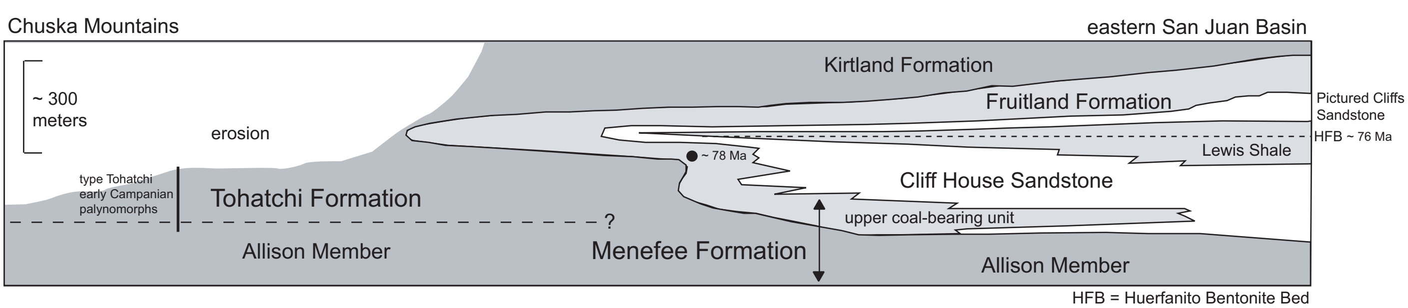

FIGURE 1.29. Restored cross section (based in part on O'Sullivan et al., 1972, fig. 8) showing correlation of Tohatchi Formation in Chuska Mountains to units in the eastern San Juan Basin. Ar/Ar age of upper Menefee Formation from Amarante et al. (2002) and of Huerfanito Bentonite Bed from Fassett et