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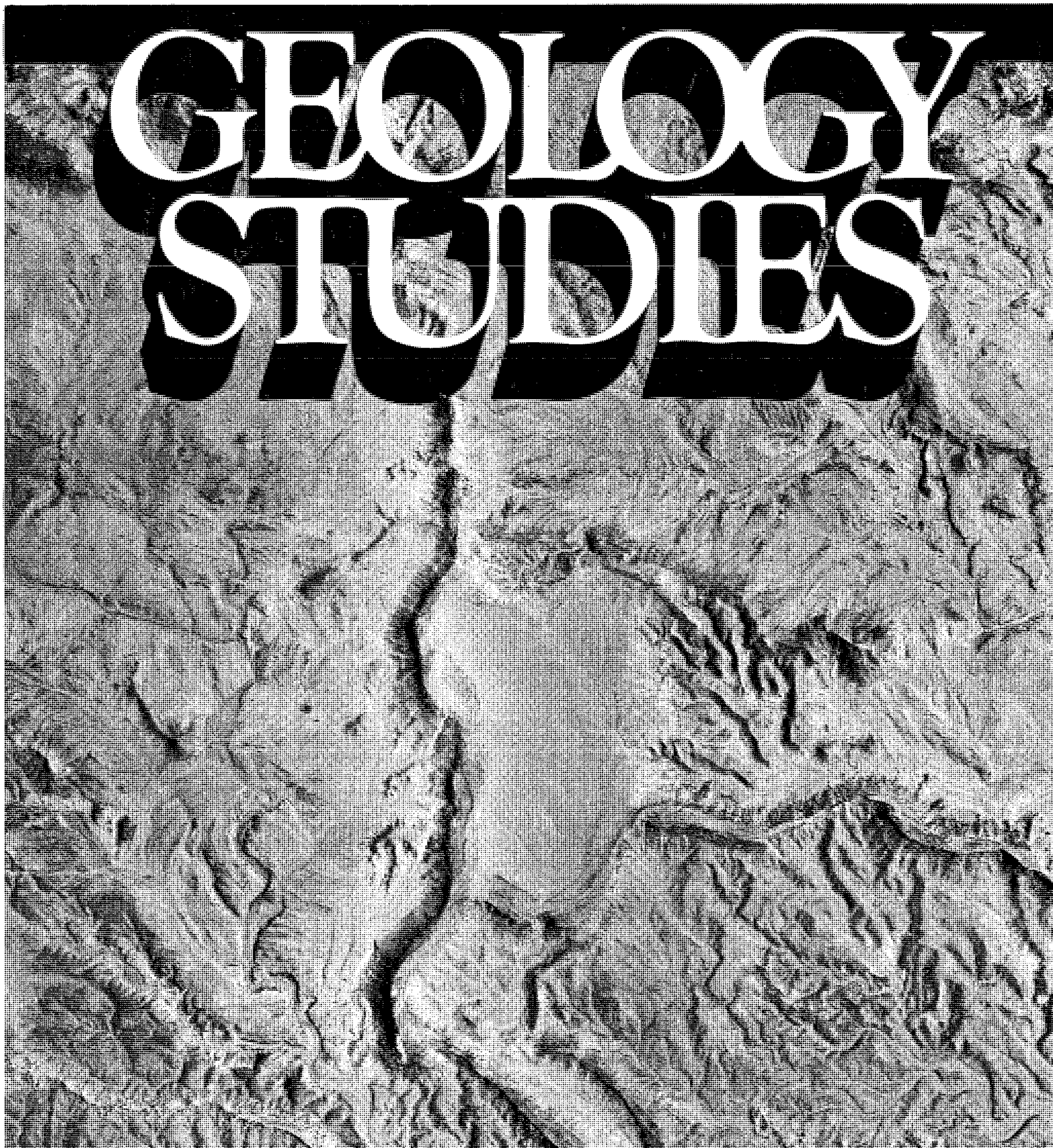

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Cover: Aerial photograph showing exhumed stream paleochannels in the Cedar Mountain Formation near Green River, Utah. Courtesy Daniel R. Harris.

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Sandstone and Conglomerate-Breccia Pipes and Dikes of the Kodachrome Basin Area, Kane County, Utah*

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ABSTRACT.—Most light greenish gray sandstone and conglomerate-breccia pipes and dikes of Kodachrome Basin cut orangish brown silty sandstone of the Jurassic Gunsight Butte Member of the Entrada Formation. A few pipes and dikes also cut the Jurassic Wiggler Wash and Winsor Members of the Carmel Formation. None were observed in the Henrieville Sandstone or in rocks younger than the Winsor Member. The country rock is generally little disturbed by these ovate to irregularly elongate sandstone pillars, which, in their present eroded form, average 18 m high and 8 m in diameter. Pipes and dikes in the Kodachrome Basin area have been grouped as follows: (1) sandstone pipes, (2) conglomerate-breccia pipes, (3) thick, extensive dikes, and (4) thin dikes.

Control for localization of these bleached sandstone and conglomerate-breccia pipes was probably joint intersections. Dikes occur along local fractures and taper away from the pipes or large dikes with which they are associated. Bleaching of the country rock commonly extends a few centimeters beyond the normal fractured edge, but conglomerate and breccia do not. Pipe filling is normally massive, except for faint concentric layering immediately inside the more resistant sandstone shell or rind and some horizontal irregular stratification in a few pipes.

Fragments show great size variation, ranging from sand and silt to blocks 3 m across. Quartz sand is the basic constituent of the pipes, but they also contain pebbles of lithic fragments, mostly chert. Large blocks are mainly sandstone and siltstone like that in the country rock.

The pipes and dikes are thought to have originated as injections of liquefied sand, perhaps triggered by an earthquake and possibly initiated by cold springs. Bleaching is likely due to upwelling gypsiferous water from either the Paria River or the Wiggler Wash Member of the Carmel Formation or both.

INTRODUCTION

Sandstone and conglomerate-breccia pipes and dikes of Kodachrome Basin in southeastern Utah (fig. 1) are well exposed by erosion. They are often now expressed as pinnacles or spires that average 18 m high and 8 m wide. Their light greenish gray color contrasts sharply with the dominantly orange brown to light brown Gunsight Butte Member of the Entrada Sandstone (figs. 2, 3), in which most of the pipes and dikes occur.

Pipe filling is commonly bleached to a light greenish gray and has a coarser average grain size than the surrounding country rocks. Some pipes contain pebble conglomerate and breccia. The study is aimed at description and interpretation of the origin of these anomalous features.

Location

The study area is located east of the Paunsaugunt Plateau and Pink Cliffs and west of the northern end of the East Kaibab Monocline, within the west central part of the Kaiparowits Plateau (fig. 4). Kodachrome State Reserve headquarters, nearly centrally located in the thesis area, lies 43 km southeast of Bryce Canyon National Park headquarters and 14.5 km southeast of Cannonville, Utah.

Main access to the area is via Utah 12, with a local road extending into the area south from Cannonville (fig. 1).

The study area extends southward from the Kane County line to the county gravel road between Shepard Point and Dry Valley. It includes all or part of secs. 1–5 and 8–12 of T. 38 S, R. 2 W, in the southeast corner of the Cannonville and the southwest corner of the Henrieville 7½-minute quadrangles.

Previous Work

Thompson and Stokes (1970, p. 14) mentioned the pipes briefly, calling them sandstone cylinders or sand-filled pipes. Bowers (1975) mapped the Henrieville Quadrangle, which includes half the study area, but did not call attention to the pipes and dikes. Mr. Tom Shakespeare, head ranger at Kodachrome Basin State Reserve, has indicated that, to his knowledge, little has been done on the geochemistry, petrography, sedimentary structures, or occurrence of the pipes and dikes of Kodachrome Basin.

Other sandstone pipelike structures are found at Judd Hollow, Arizona, near the Arizona-Utah border. Phoenix (1958) concluded that the sandstone pipes found in the Carmel Formation there and the shoreline spring pits described by Emery (1950) were similarly formed. Several hundred sandstone pipes occur in the Laguna District, Valencia County, New Mexico. At least two pipes are mineralized. Some authors have interpreted them to be collapse features initiated by springs aided by solution of the underlying gypsum (Hilpert and Monech 1969, Schlee 1963, Monech and Schlee 1967). Others, such as Wylie (1963) and Gabelman (1957), concluded that the pipes are collapse features produced by upwelling igneous gases. The Judd Hollow pipes and the Laguna pipes are two of ten occurrences of clastic pipelike structures in the Colorado Plateau which Gabelman (1957) called collapse-plug pipes.

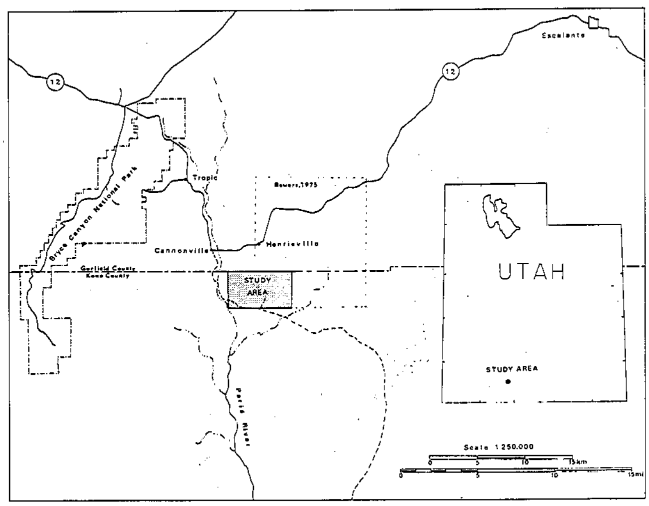

FIGURE 1.—Index map.

*A thesis presented to the Department of Geology, Brigham Young University, in partial fulfillment of the requirements for the degree Master of Science, August 1979. Thesis chairman: J. Keith Rigby.

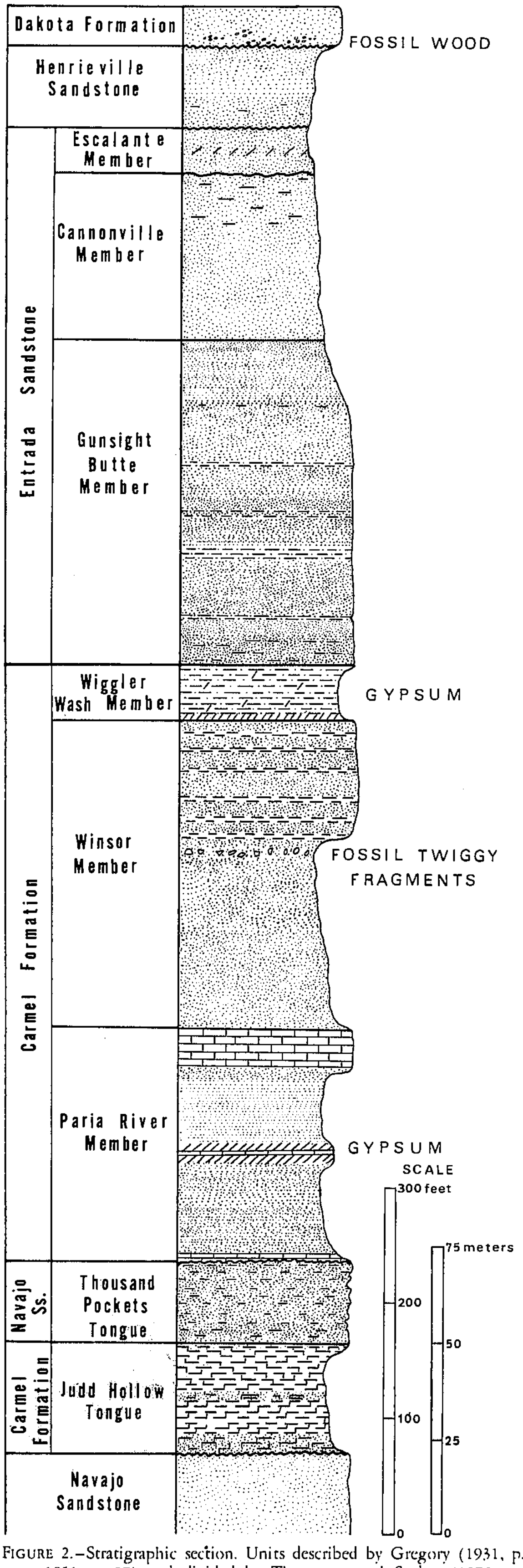

FIGURE 2.–Stratigraphic section. Units described by Gregory (1931, p. 84–85; 1951, p. 57) and divided by Thompson and Stokes (1970, p. 35, 36, 46–48).

The sandstone pipes of Eagle County, Colorado, east of the Colorado Plateau in the Rocky Mountains, in Permian (?) beds of the Maroon Formation, were formed by freshwater springs rising through salty, partially consolidated silt (Gabelman 1955). The sandstone pipes and dikes of Cimarron Valley area, Union County, New Mexico, also east of the Colorado Plateau, are emplaced in the Triassic Dockum Group, Sloan Canyon Formation, and Sheep Pen Sandstone by means of liquefaction of the lower units of the Dockum Group.

Cylindrical sandstone structures also occur in the Cambrian Potsdam Sandstone in Kingston, Ontario, and in adjacent areas in New York State. Some of the origins proposed for these sandstone structures are (1) concretionary growth with or without organic cores (Kavanaugh 1888-89, p. 292–94; Ells 1902, p. 176; Miller 1906, p. 134–35); (2) whirlpool action because of eddy currents (Baker 1916, p. 79); (3) freshwater springs rising through salt-laden sediments (Hawley and Hart 1934, p. 1017–34); (4) earthquakes (Shrock 1948, p. 220–21); (5) slumping into previously formed cavities (Dietrich 1952, p. 1244).

Reports of sandstone clastic dikes are scattered in the literature. Some of the better-known occurrences are presented in order of their increasing distance from Kodachrome Basin. Pebble dikes of the East Tintic District, Utah, are tabular bodies of brecciated rock and were produced by rapidly expanding gases, most likely steam, generated when introducing monzonite encountered groundwater (Shepard et al. 1968, p. 945). Sandstone dikes of the South Platte area, Colorado, originated in the Cambrian Sawatch Formation and were forced into fissures in the Precambrian Granite of the Pikes Peak Batholith (Vintanage 1954). Three hundred fifty sandstone dikes and sills are placed in the upper Cretaceous Moreno Shale of the Panoche Hills, California, and were injected by liquefaction of sands of the underlying formation (Smyers and Peterson 1971). Many of the other occurrences of sandstone dikes are also injection of sand from either above or below. Some of them are in the Cretaceous Horsetown and Chico beds of the northwestern Sacramento Valley, California (Diller 1889); in the Huronian rocks of the Espanola and Serpent Formations of Ontario (Young 1968), and in the Dalradian rocks in Scotland (Smith and Rast 1958).

Methods of Study

The area was mapped on 1:20,000 aerial photographs in the field. Sandstone and conglomerate-breccia pipes and dikes were described in the field, and samples were taken from nearly all accessible structures. Oriented samples were collected from pipes 45, 47, and 48 (fig. 5) along a cross-traverse through these structures. Measurements of selected pipes and dikes were made using a fiberglass tape and a Brunton compass. Reference photographs were taken of most cylinders and dikes. Structures within the pipes and areas that show wall-rock relationships were also photographed. Joint orientations were interpreted from aerial photographs and were measured on the ground at three locations in the thesis area.

Thin sections were made of sandstones from characteristic pipes and dikes, as well as from country rock. A few thin sections were studied petrographically to determine mineral content, but most were studied with a binocular microscope for determination of grain-to-grain relationships and depositional structures. Slices of friable rocks were impregnated with epoxy resin in a vacuum oven prior to sectioning. Alizarine Red S was used to stain thin sections to determine calcite content.

Samples of selected pipes and dikes and country rocks were disaggregated in water and sieved using Tyler Standard Screens. Insoluble residue analyses were also run on disaggregated samples.

Structure and Regional Setting

The study area lies in the southwest corner of the Canyonlands Region of the Colorado Plateau (Thornbury 1965, fig. 22.8; fig. 4). In general the Colorado Plateau is a relatively stable region of large-magnitude folds, faults, and uplifts. Adjustments are prone to be deep seated and vertical (Stokes and Heylum 1965, p. 3). Basins, uplifts, monoclinal flectures, domes of igneous and salt intrusions, and platforms are characteristics of the plateau region. The dominant joint systems of the Colorado Plateau are northwest, northwest, and east-west (Kelley 160, p. 12).

The Paria Amphitheater, in which the investigation area lies, is on the gently sloping north flank of the Kaibab Uplift. The northern end of the East Kaibab Monocline, the eastern margin of the Kaibab Uplift, has a trend of N 25° W and is less than 16 km east of the study area (fig. 4). The monocline is an asymmetric fold with maximum dips of 65°. The maximum dip on the northern end, which is east of the study area, is 45° (Babenroth and Strahler 1945, p. 147).

The Paunsaugunt and Sevier faults lie west of the area. They are major transition faults between the plateau and the Great Basin (fig. 4).

Tectonically the region has been relatively stable and blocklike. The late Paleozoic orogeny, which produced the Colorado Mountains, caused some folding across this part of the plateau in particular. Gentle subsidence characterizes structural patterns during deposition of the Mesozoic rocks. The southern Colorado Plateau area was stable to slightly uplifted at intervals of the Mesozoic.

Monoclinal development was probably due to uplifts during the Laramide orogeny. Joint patterns and Laramide features appear to have formed along Precambrian lines (Stokes and Heylmun 1965, p. 4). The Paunsaugunt and Sevier faults are Tertiary basin-and-range block faults.

Broad folds have produced dips of generally less than 5° in the vicinity of the study area. The average dip of the study area is 4° to the northeast. Anticlinal axes on the nose of the Kaibab Uplift are generally 4.8 km apart and trend north-south (Doelling 1975, p. 64). Two most prominent joint directions

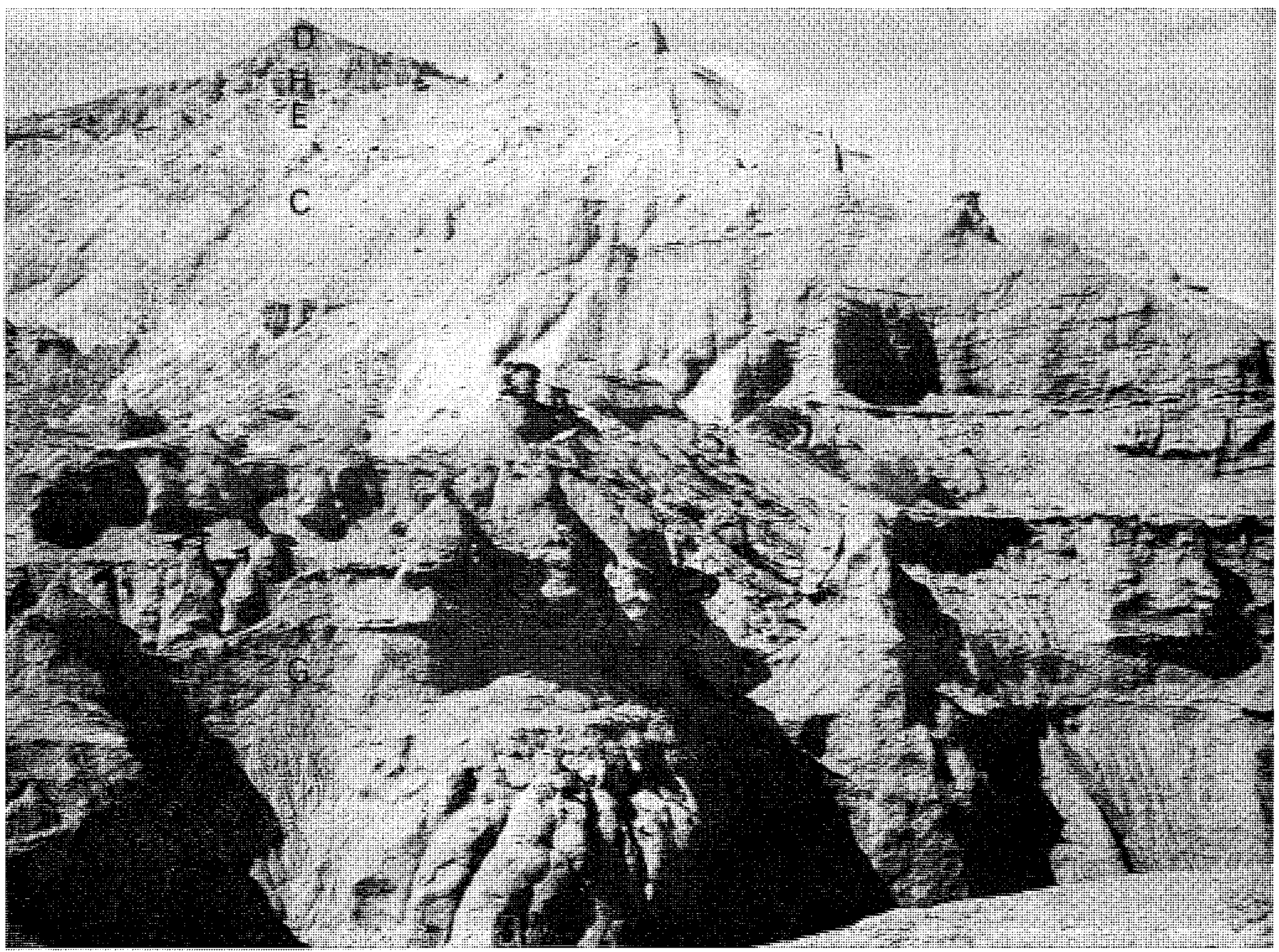

FIGURE 3.—Photograph of stratigraphy from middle upper Gunsight Butte Member of Entrada Sandstone up to Dakota Formation. G, Gunsight Butte Member of Entrada Sandstone; C, Cannonville Member of Entrada Sandstone; E, Escalante Member of the Entrada Sandstone; H, Henrieville Sandstone; D, Dakota Formation. Thin dikes cut Gunsight Butte Member in foreground.

in the study area are N 60° W and N 30° E; several other directions are present as well (fig. 5).

Acknowledgments

The writer expresses gratitude to Dr. J. Keith Rigby, thesis chairman. Dr. Lehi F. Hintze served as the thesis committee member. Dr. W. Revell Phillips helped with petrographic identification of some of the minerals. Dr. W. D. Tidwell and Gregory Thayn helped with the silicified woods.

Thanks are expressed to Mr. Tom Shakespeare, ranger at Kodachrome Basin State Reserve, and to his wife and children, for letting me stay in their home while doing fieldwork.

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STRATIGRAPHY

Units exposed in the study area, from the bottom up, include the Winsor and Wiggler Wash Members of the Carmel Formation, the Entrada Sandstone, the Henrieville Formation, and the Dakota Formation (figs. 2 and 3). The Navajo Sandstone and the lower units of the Carmel Formation are also discussed because of their possible relationship to the sandstone pipes and dikes. Nomenclature of the San Rafael Group follows that established by Thompson and Stokes (1970). Thicknesses of units are taken from a section measured by Gregory (1931, p. 84–85, and 1951, p. 57) immediately west of the study area. This section was subsequently divided into different units and thicknesses by Thompson and Stokes (1970, p. 35–36, 46–48).

Navajo Sandstone

The Carmel Formation generally overlies the Navajo Sandstone, but in the vicinity of the thesis area, these units intertongue. The Navajo Sandstone tongues thin and terminate to the west, and the interlayered Carmel tongues diminish to the east. The lowermost tongue of the Carmel Formation wedges out west of the study area, a few kilometers east of Zion National Park; and the white Temple Cap Member of the Navajo Sandstone blends with the main cross-bedded, gray Navajo Sandstone (Thompson and Stokes, 1970).

Gregory (1951, p. 58) records an unconformable surface, marked by channels and patches of limestone and conglomerate, at the contact between the Judd Hollow Member of the Carmel Formation and the Navajo Sandstone southwest of the thesis area. These coarse beds are a possible extension of the chert-pebble unconformity at the top of the Navajo Sandstone found in areas to the east (Pipiringo and O'Sullivan 1975).

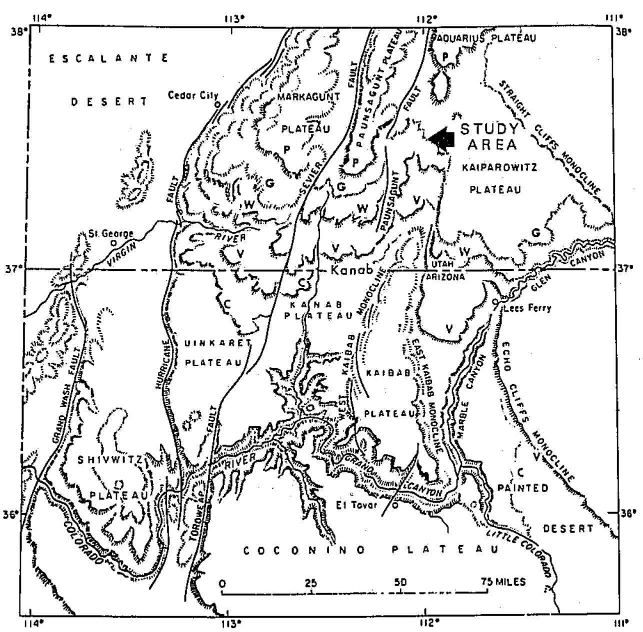

FIGURE 4.–Physiographic map of southwestern Colorado Plateau showing relationship of study area (arrow) to regional features. Cliffs of Grand Staircase: C, Chocolate Cliffs; V, Vermilion Cliffs; W, White Cliffs; G, Gray Cliffs; P, Pink Cliffs (modified after Rigby 1977).

Carmel Formation

The Carmel Formation is 185 m thick (Thompson and Stokes 1970, p. 36), excluding the Thousand Pockets Tongue of the Navajo Sandstone which overlies the Judd Hollow Tongue of the Carmel Formation in this area.

Judd Hollow Tongue

Twenty-three meters thick, the Judd Hollow Tongue is considered to be the partial eastern equivalent of the Kolob Limestone Member of the Carmel Formation that is exposed in the Mount Carmel area (Thompson and Stokes 1970, p. 7). The Judd Hollow Tongue consists of red sandy shale, gray brown calcareous sandstone, blue gray calcareous shale or limestone, and gray calcareous sandstone. The Crystal Creek Member of the Carmel Formation, which is recognized to the west at Skutumpah Creek (Thompson and Stokes 1970, p. 8), has been incorporated into the Judd Hollow Tongue in the Kodachrome Basin area.

Thousand Pockets Tongue of the Navajo Sandstone

The Thousand Pockets Tongue of the Navajo Sandstone is one of the reasons for the long-standing correlation problems in the region. It is 21 m thick southwest of the study area. The tongue is "rooted" to the main Navajo Sandstone near Glen Canyon along the Utah-Arizona border and tapers to a feather edge near Skutumpah Creek, southwest of the Kodachrome Basin area. Erosional unconformities overlie and underlie the Thousand Pockets Tongue.

Paria River Member

The Paria River Member of the Carmel Formation overlies the Thousand Pockets Tongue of the Navajo Sandstone. It consists of limestone, sandstone, and gypsum in the Kodachrome Basin area and is 61 m thick at its type section near the southwest corner of the study area.

Winsor Member

The Winsor Member of the Carmel Formation conformably overlies the Paria River Member and is 81 m thick in the Kodachrome Basin area. Winsor beds crop out extensively in this portion of southern Utah. The member is composed of thick to massive beds of white, pink, and brown sandstone, alternating with relatively thin beds of red siltstone or mudstone. The unit is poorly cemented and friable, and it forms slopes.

Wiggler Wash Member

The Wiggler Wash Member overlies the Winsor Member and is 17 m thick in its type section near the southeast corner of the study area. The member consists mostly of interbedded gypsum and siltstone, with a 15-cm limestone cap. The gypsum diminishes to a 0.3-m bed, the limestone disappears, and the siltstone dominates the 14-m section on the west side of the study area. .

Entrada Sandstone

The Entrada Sandstone is a complicated rock body with rapid facies changes. It is composed of three members in the study area, including, from the bottom up, the Gunsight Butte, the Cannonville, and the Escalante.

Gunsight Butte Member

The Gunsight Butte Member of the Entrada Sandstone is at the interface of the red silty sandstone and the red cross-bedded sandstone facies in the Kodachrome Basin. Although it is in the red silty sandstone facies, the lower 66.5 m is cross-bedded. Minor beds of purplish shale are scattered throughout the unit. The lower cross-bedded sequence forms cliffs.

Cannonville Member

The striped Cannonville Member overlies the Gunsight Butte Member with a gradational contact. Discontinuous red and white banding is characteristic of Cannonville beds and contrasts with the dominantly red Gunsight Butte Member of the red silty and red cross-bedded Entrada sequences. Cannonville beds consist of fine-grained to silty sandstone with weak to moderate cementation. The unit forms a major slope. The top of the Cannonville Member is placed at the medial Entrada unconformity (Thompson and Stokes 1970). In the Cannonville area, the unconformity is marked by a friable, thin-bedded, silty sandstone at the base of the Escalante Member of the Entrada Sandstone. This sandstone is interpreted as reworked upper Cannonville beds (Thompson and Stokes 1970).

Escalante Member

The Escalante Member of the Entrada Sandstone is a slope-forming unit. It consists of a light colored sandstone like the

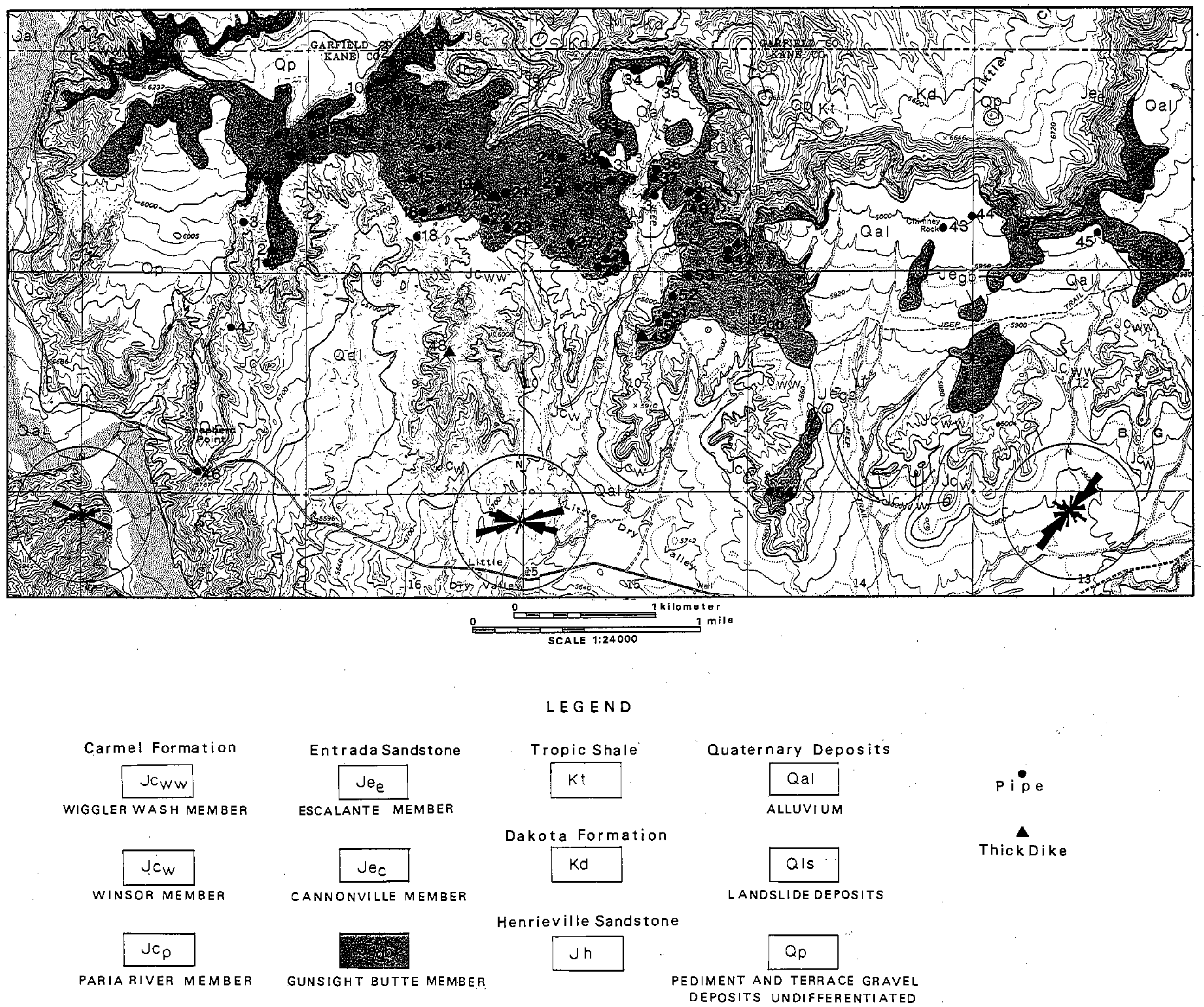

FIGURE 5.—Map of location of pipes and dikes with relationship to outcrop bands. Joint directions are shown on rose diagrams.

gray and green sandstone-claystone facies of the member at its type area.

Pre-Morrison Unconformity

The pre-Morrison unconformity occurs at the top of the Escalante Member. The Summerville Formation has been cut out at the unconformity in the study area. The units are present farther east near the Straight Cliffs (Thompson and Stokes 1970, p. 24–26).

Henrieville Sandstone

The Morrison Formation is represented in the study area by the Henrieville Sandstone, an equivalent to the Salt Wash Member of the Morrison Formation (Thompson and Stokes 1970, p. 28). A measured section by Thompson and Stokes (1970) between Dry Valley and Grosvenor Arch, 16 m southeast of the study area, records the Salt Wash Member (?) of the Morrison Formation above the Henrieville Sandstone. The Salt Wash there consists of sandstone and conglomerate. The latter beds are composed of pebbles of chert, quartzite, and felsite with small and large chunks of agatized wood.

The Henrieville Sandstone is a yellowish to greenish light gray sandstone with minor interbedded siltstone and claystone. The formation is bounded, above and below, by unconformities and probably has limited lateral extent. The Paria Amphitheater is its main outcrop area (Thompson and Stokes 1970, p. 26–28).

Sub-Cretaceous Unconformity

Erosion at the sub-Cretaceous unconformity cuts out the Cedar Mountain Formation and much of the Morrison Formation or its equivalent in the study area. In general this unconformity, as well as previous ones, bevels successively older formations toward the southwest. A thin conglomerate sheet marks the surface.

Dakota Formation

The Dakota Formation in this area consists of sandstone and coarse grit, with lenses of conglomerate, pebbles of gray quartzite and white chert—as much as 2.5 cm in diameter—and fragments of clay shale, mud balls, and bits of carbonized wood (Gregory 1951, p. 57). The Dakota Formation caps ridges north of the study area.

DISTRIBUTION OF PIPES AND DIKES

In the study area, 41 of the 54 pipes cut the Gunsight Butte Member of the Entrada Formation or are encased by it; 4 of the 54 cut the Wiggler Wash Member of the Carmel Formation; and 4 cut the Winsor Member of the Carmel Formation (fig. 5). This distribution could have been biased by a real difference in occurrence but more probably reflects greater erosion of the softer Wiggler Wash and Winsor beds and destruction of the pipes.

All the pipes represent segments above their bases. In no single pipe is the basal termination exposed. Similarly, tops of all the pipes are eroded. However, no pipes were seen in the Henrieville Sandstone in nearby exposures. They probably do not cut beds that young. Pipes were not observed in beds of the lower Carmel Formation either.

The pipes are not aligned in any single direction, and their occurrences cannot be reliably predicted. In some areas sets of three pipes form linear series, but these sets do not trend in the same direction. A single set or pair of joint directions do not adequately describe the occurrence of the pipes. The pipes and dikes are not clustered in long rows as would be expected if they were controlled by major tectonic features.

Most pipes are somewhat ovate in map view (figs. 6–11) with their elongation parallel to one of the prominent joint sets (fig. 5). It is conjectured that pipes occur at joint intersections.

Dikes occur along fractures, apparently of negligible displacement, that may record settling or minor readjustments of rocks in the area.

DESCRIPTION OF REPRESENTATIVE PIPES AND DIKES

No single pipe shows all the collective characteristics of the pipes. Ten pipes, one thick extensive dike, and a dike complex are described below because collectively they show most of the characteristics of pipes and dikes.

Pipe 3

Pipe 3 is in NW ¼, NE ¼, sec. 8, T. 38 S, R. 2 W. It is on a hill north of Shepard Point 800 m northeast of the dirt road that branches from the main county gravel road halfway between Shepard Point and the Paria River crossing (fig. 5). It is surrounded by beds of the Wiggler Wash Member of the Carmel Formation.

Pipe 3 has an irregular outline (fig. 6) and an approximate diameter of 8 m and stands 8.5 m tall. Beds surrounding the pipe are calcareous, but the pipe contains only minor amounts of $CaCO_3$, thus being similar to other pipes that occur in the Winsor Member of the Carmel and Gunsight Butte Member of the Entrada Formation. It shows horizontal jointing, which is not apparent in many other pipes (fig. 12). Blocks of sandstone and mudstone form a roughly horizontal unit at its base. Bleaching of rims of sandstone blocks and the pebbly pipe material surrounding light greenish gray sandstone areas show well in this pipe (figs. 13, 14).

A linear zone of light greenish gray sandstone, without conglomerate or breccia like that found in it, extends toward the southeast from the pipe. This zone is thought to be a poorly exposed or incompletely penetrated dike.

Pipe 26, not described, is illustrated in figure 15.

Pipe 27

Pipe 27 is located in the SW ¼, SW ¼, sec. 3, T. 38 S, R. 2 W, roughly 750 m west of the road leading to the camp-

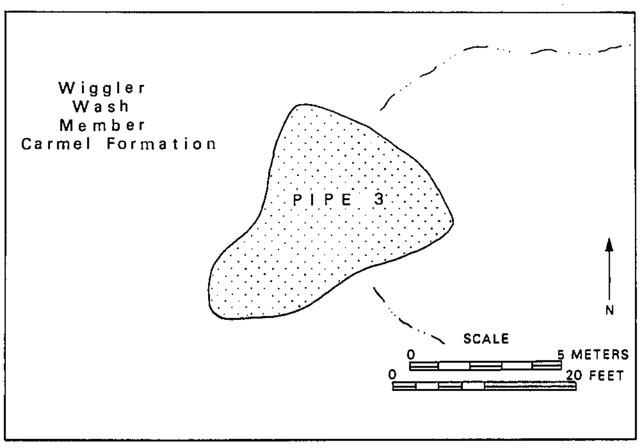

FIGURE 6.—Map outline of pipe 3.

ground at Kodachrome Basin (fig. 5). It lies west of the sandstone ridge and is held up by an erosional remnant of the Gunsight Butte Member of the Entrada Formation. Near the crest of a small anticline in the lower units of the Gunsight Butte Member, pipe 27 is an erosional remnant 16 m high and 4.5 m in diameter. Its axis is inclined 88° to the east.

The pipe cuts across Entrada beds in its lower half but rises above the country rock and there increases in diameter in its exposed upper half. The interior is mixed conglomerate and breccia, and its outside is a bleached sandstone rind. Vertical striations are preserved on the west wall, near the sandstone cliff.

Pipe 28

Another pipe is located 21 m southwest of the westernmost exposure of the upper branch of the lower dike in the Entrada Sandstone. This sandstone pipe is approximately 6 m high and 5 m in diameter. It is reddish sandstone, like the country rock, but lacks the bedding. The massively bedded pipe structure has a few grit pieces and areas of bleaching.

Pipe Area 29

The area is a pipe and dike complex located in SE ¼, SW ¼, sec. 3, T. 38 S, R. 2 W, or 300 m west of the road to the

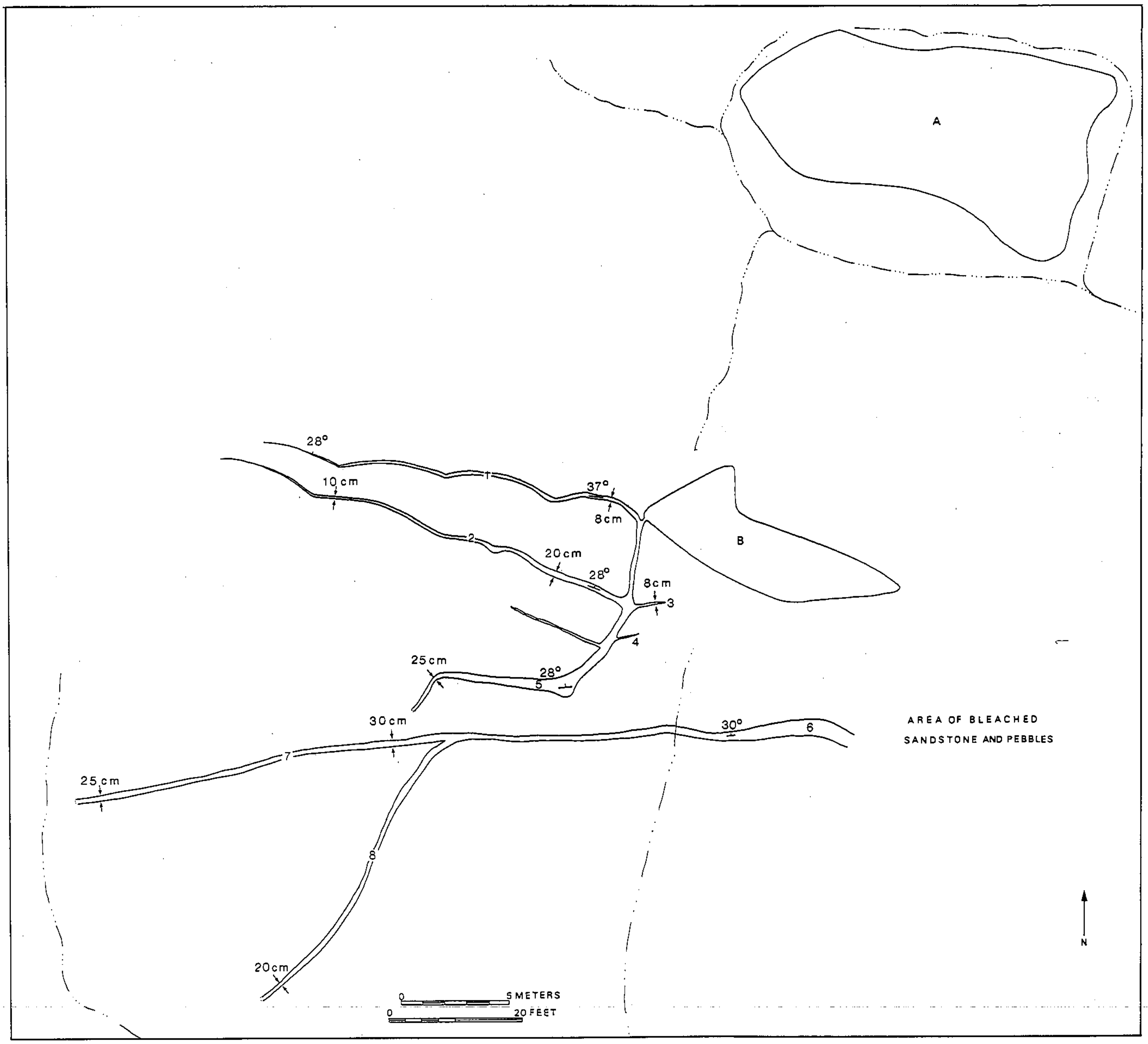

FIGURE 7.—Map outline of pipe area 29 showing relationships of pipes to dike complex. A, pipe 29; B, pipe 15 m south of pipe 29; 1–8, dikes in the complex.

campground in Kodachrome Basin (fig. 5). The pipe complex contains at least three, possibly four, pipes, together with a series of interrelated dikes (fig. 16): A main dike with tributaries and another separate one, here called the lower dike (fig. 7).

Pipe 29, the largest and northernmost of the pipes in the complex, is set slightly east of the sandstone cliffs of the Gunsight Butte Member. The pipe is 14 m high and has an irregular diameter of approximately 14 m (fig. 7). Its center has been more deeply eroded than the eastern and western margins. The pipe carried blocks of sandstone and fragments of calcareous shale but is a bleached sandstone pipe. An apple-green ferruginous stain occurs on some minor areas of the western sandstone border.

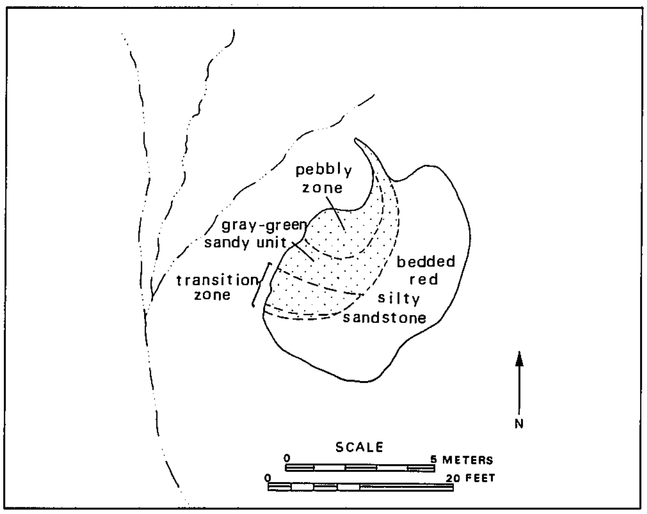

FIGURE 8.—Map outline of pipe 35 showing transition zone, pebbly zone, and sandstone shell.

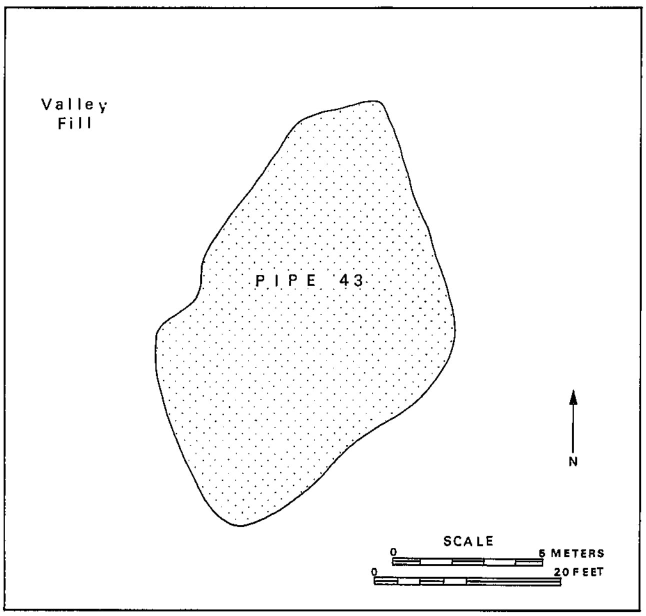

FIGURE 9.—Map outline of pipe 43.

A second discordant bleached sandstone mass occurs 15 m south-southeast of the pipe described. This light greenish gray pipe connects with a complex of dikes (figs. 16[B], 17[B]).

The main thin dike, 0.3 m thick (fig. 8[5]), has a variable south and southwest strike (fig. 7). Several smaller dikes strike northwestward (fig. 18[1,2]) and thin distally from 20 cm at their intersection with the main dike to only a bleached zone along local fractures. The thin dikes are mappable for a total distance in excess of 30 m from the main dike to their feather edges. Some of these small dikes also wedge out upwards.

The main dike leads out from the sandstone pipe and continues southward for 8.5 m but then bends at a 120° angle, to strike more westerly, almost parallel to a still thicker and lower dike (figs. 7, 17[5]). The main dike bends again and apparently converges with the lowermost dike under cover.

The eastern end of this lower dike, thickest in the complex, is 40–50 cm thick and contains a 20–25-cm-thick central zone of pebble conglomerate (fig. 19). It has an upper and lower

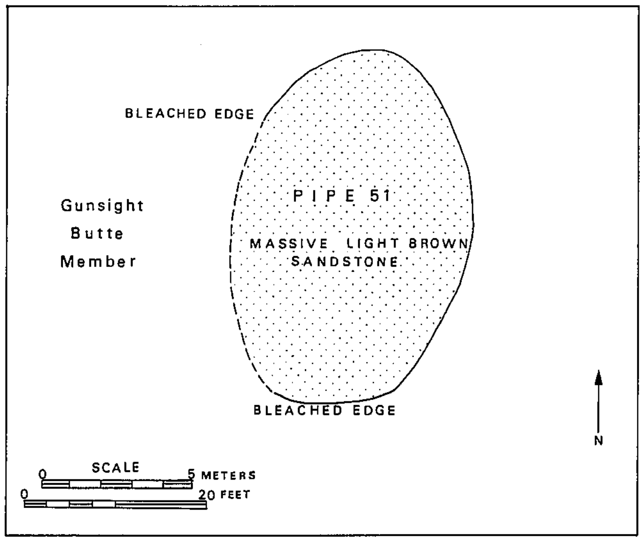

FIGURE 10.—Map outline of pipe 51.

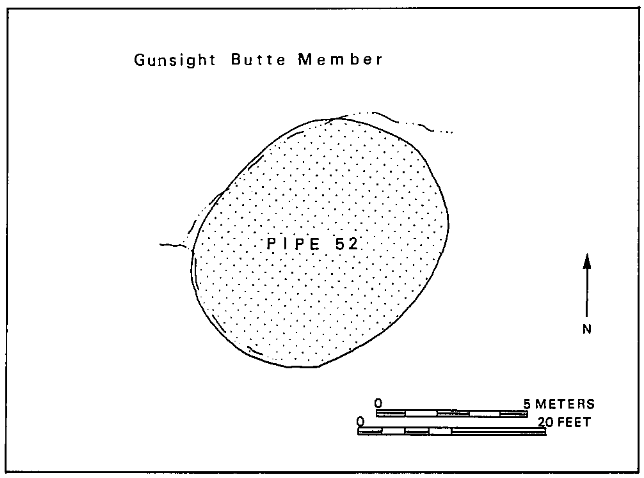

FIGURE 11.—Map outline of pipe 52.

bleached sandstone border zone 5–8 cm thick. Flat pebbles in the central conglomerate zone are aligned at a maximum of 30° to the bleached sandy marginal rinds in places (fig. 19). The pebble dike thickens toward the east and loses its distinctive dikelike character in a nondescript slope of pebbles and bleached sandstone (fig. 16). The bleached area may be a third, but poorly consolidated, pebbly pipe or a poorly exposed complex of pebbly dikes. Ten meters to the west, along strike and away from the main pipe area, the lower dike thins and branches. The pebbly interior zone has wedged out before the first branch in the dikes. It is mappable an additional 17 m as a sandstone dike (fig. 17[7,8]). Its distal limits could not be established because of alluvial cover although bleached fractures do occur in the cliff face where the dike might project into the Gunsight Butte country rock west of the covered zone.

Pipe 34

Pipe 34 lies in NE ¼, NW ¼, sec. 3, T. 38 S, R. 2 W (fig. 5), 400 m north of the campground, set off a short distance south of the amphitheater wall on a ridge of horizontally stratified upper reddish Gunsight Butte Sandstone. It is 7 m high and has an oval cross-section in plain view. It is 5 m wide in the northwest direction, but only 1.5 m wide in the northeast direction. Contact of the pipe with the country rock is covered, but the massive pipe contrasts sharply with the horizontally bedded Gunsight Butte rocks that lie against it on the lower half of its northwest edge. This pipe is not greenish gray like most other pipes, but is light brown, lighter than the reddish country rock. It appears to be sandstone with approximately 5 percent shaly fragments 5 cm or less in length.

Pipe 35

Pipe 35 is located in NE ¼, NW ¼, sec. 3, T. 38 S, R. 2 W (fig. 5), 300 m north of where the road enters the campground. It stands as an isolated pinnacle on the valley floor northwest of a sandstone ridge, and is, in part, supported by an erosional remnant of the Gunsight Butte Member of the Entrada Formation (fig. 20). The fingerlike pipe itself is an erosional remnant of the southeast corner of a larger feature and has an arcuate map plan at ground level (fig. 8).

Pipe 35 is 12 m high and 6 m wide, as it is now exposed. The northeastern contact of the pipe with the reddish sandstone country rock is sharp. Inside the fracture contact and out from the main body of the pinnacle is a 20–30-cm light greenish gray sandstone border. The border is mostly without pebbles of chert or other rock fragments although there are sand-size fragments of those rocks. The sandstone border is thicker on the west side of the pipe, probably because that edge is gradational into the country rock. This gradation passes through four zones (fig. 2). The first and most interior zone is a light greenish gray sandstone 1.5 m thick. The second is a brownish sandstone darker than the country rock. It is of reworked silty sandstone and contains gritty pieces. The third zone is of lighter brown sandstone with a fairly uniform texture. It probably includes "islands" of country rock in a matrix of unbleached or slightly bleached unsorted pipe material (fig.

FIGURE 13.–Sandstone block of pipe 3 with bleached edge.

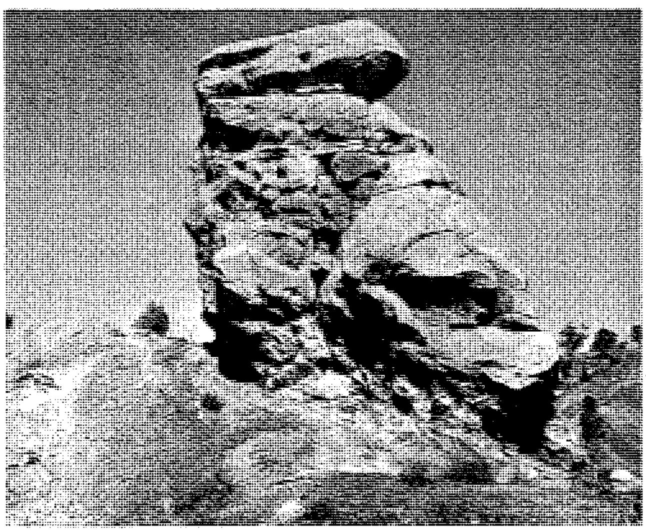

FIGURE 12.–Mudstone and sandstone blocks at base of pipe 3 and horizontal joints within pipe, which cuts Wiggler Wash Member of Carmel Formation.

FIGURE 14.–Interior of pipe 3 showing internal differences of pebbly material and bleached sandstone material.

21). The fourth and outer zone is recognizable country rock. This gradational edge is found in the lower few meters of the pipe on the west side. In other areas of the pipe, including above this area, the sandstone border is roughly 20–30 cm thick.

Within the Gunsight Butte bedded country rock, a 20-m-thick, purplish shale layer bends down slightly at the edge of the pipe at the uniformly brown zone. Two 1-to-1.5-m slabs of purplish shale, peppered with pebbles and sand grains, occur near the interior edge of the light greenish gray zone. They are rotated from horizontal with their southeastern edges up (fig. 22). Long, thin blocks are also rotated in the interior of the pipe, all with their eastern edges up (fig. 20). The interior of the pipe is a less well-cemented, less resistant, pebbly core which is roughly 1.5 m across. The concave interior of the outer sandy shell on the north side of the pipe, in particular, was apparently produced by erosion of this pebbly core. Erosion of this less resistant zone has exposed the interior surface of the sandstone border and the outer edge of the pebbly central zone along much of the height of the pipe.

Pipe 38

Pipe 38 is located in NE ¼, NE ¼, sec. 3, T. 38 S, R. 2 W. It is 150 m east of the road (fig. 5). The oval pipe is on the valley floor and largely surrounded by alluvium. It is south of nearby cliffs of the Gunsight Butte Member, into which it must have been emplaced, and is mainly isolated from country rock, except on the western margin where orangish brown sandstone extends halfway up the side of the pipe.

Pipe 38 dips 78° to the east and reaches 15 m in height and 5 m in diameter. Where preserved, the western contact with wall rock is sharp, with only 7–8 mm of bleaching beyond the contact fracture. Inside the fracture a more resistant sandstone border or rind is well defined, particularly on the north side. The outer surface has pockmarks from weathering and parallel fractures which dip 14° to the west. Layers, concentric with the exterior, occur inside the sandy border zone. In some areas this layered border is banded with light yellow-stained sandstone and light yellow limonite and black specks. Some parts of the border zone are also stained apple green, a color similar to the ferrous stain in sandstone on the outer part of pipe 29. The pipe is fairly homogenous gritty sandstone and is massive, except for faint concentric layering near the border. Gritty fragments of chert and quartzite are mostly less than 1 mm in diameter.

Pipe 43

Pipe 43 is located in SE ¼, SE ¼, sec. 2, T. 38 S, R. 2 W (fig. 5). A ranch access road comes within 15 m of it. The squarish pipe (fig. 9) is surrounded by alluvium but probably was emplaced in horizontally stratified upper beds of Gunsight Butte Member which have been eroded away leaving the pipe standing as an isolated pinnacle.

It is 17.5 m in diameter and 29 m high. The pipe does not have a sandstone border as presently exposed, but it could have been eroded away (fig. 23). Pebbles of the pipe are somewhat stratified. Fragments include the distinctive apple-green coated chert, reddish brown chert, gray and brown quartzite pebbles, orangish brown blocks of sandstone, and laminated crinkly mudstone. The mudstone blocks average 1.5 m but range up to 3 m in length. They are at least 20 cm thick, sometimes thicker. Crudely interlayered pebble conglomerate and coarse greenish gray to tan sandstone extend throughout the height of the pipe, but the coarse blocks are concentrated in the lower exposed part (fig. 24). Stratification of pebbles is not common, but such a textural distribution is present in many of the conglomerate-breccia pipes.

Dike 49

Dike 49 is located in SW ¼, NE ¼, sec. 10, T. 38 S, R. 2 W. It crops out on the west side of a linear sandstone ridge 250 m north of the road (fig. 5). The dike is in lower to basal beds of the Gunsight Butte Member.

The dike is roughly 10 m long and 3 m thick and is exposed for roughly 14 m. Its general dip is 33° to the southwest but changes to 79° on the southwest edge. The lower contact is gradational. Other contacts, as far as they are exposed, are sharp.

The northwest periphery contains numerous pebbles, as does the lower southwest part of the dike. Other parts, however, are relatively free of pebbles and texturally resemble sandstone pipes (fig. 25). Dike 49 is light greenish gray and, except for its attitude and tabular form, resembles a pipe.

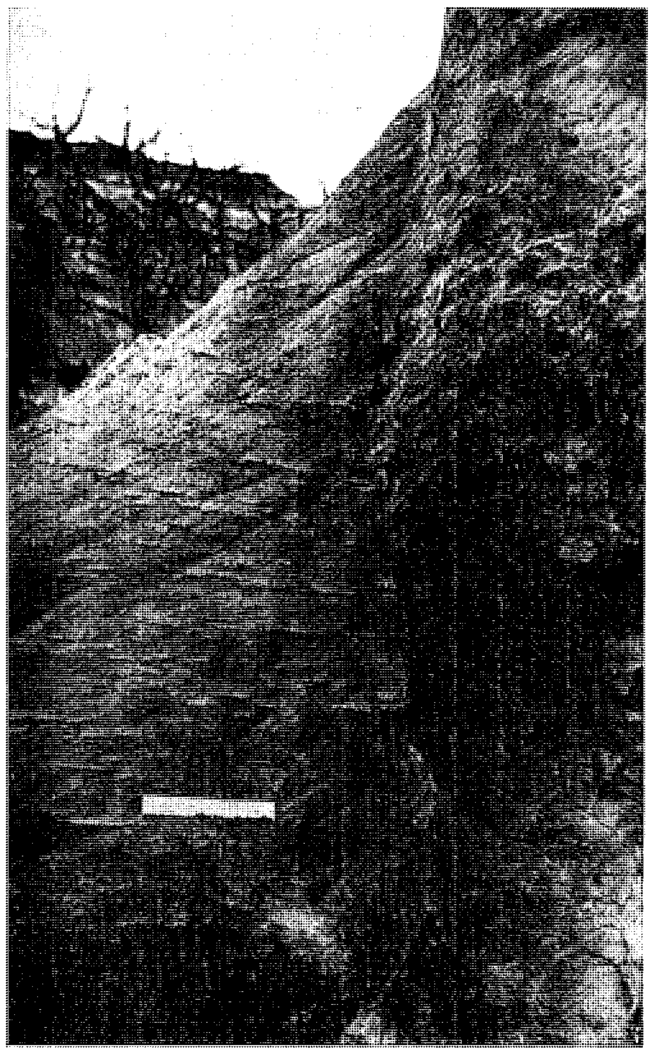

FIGURE 15.—Fracture edge of pipe 26. Pockmarked exterior of pipe 26 at right of fracture near vertical center. Silty sandstone of Gunsight Butte Member with parting at left. Scale, near bottom, is 6-inch ruler.

The major sandstone mass is surrounded by a complex of thin dikes that occur most extensively on the northwest and northeast sides.

Pipe 51

Pipe 51 occurs in NW ¼, NE ¼, sec. 10, T. 38 S, R. 2 W (fig. 5). A few meters north of the road which leads to the campground, it is surrounded by Gunsight Butte beds. The oval cross section, in map view, is shown in fig. 10.

Pipe 51 is 20 m high and 9.5 m in diameter. It tapers vertically to approximately half that diameter at its eroded top. Gunsight Butte beds bend up and terminate against it on its north side. It is a light brown, massive sandstone with a light greenish gray bleached zone near its contact with the reddish country rock.

Pipe 52

Pipe 52 is located in the NW ¼, NE ¼, sec. 10, T. 38 S, R. 2 W. It crops out on a sandstone ridge of Gunsight Butte, 90 m east of the road leading to the campground in Kodachrome Basin (fig. 5), and is accessible via the west side of the sandstone ridge.

The pipe is roughly oval in section (fig. 11) and is approximately 9 m in diameter. It stands 22 m tall, above the middle lower Gunsight Butte beds into which it has penetrated (fig. 26). The pipe has a fracture completely around its circumference and is soft and poorly cemented near the fracture. Bleaching extends 0.3–0.7 m into the country rock beyond the fracture. Layering inside the fracture is accentuated by variations in yellow orange and light yellow limonite stains. The stained and layered zone extends about 0.3 m into the south side of the pipe.

The main mass of the pipe is a light greenish gray conglomerate of unsorted pebbles, including distinctive chert fragments which are reddish-brown when freshly broken but which have an outer bright green reaction rim or rind. The pipe also contains carbonized fossil wood and twig fragments. The central pipe filling is friable and poorly cemented. The more firmly cemented sandstone border has protected the soft interior and is responsible for the topographic expression of the pipe.

COMPOSITION

Country Rock

The Winsor and Wiggler Wash Members of the Carmel Formation and the Gunsight Butte Member of the Entrada Sandstone are the stratigraphic units cut by pipes and dikes in the study area (fig. 5). The sandstone and conglomerate pipes may also occur in other units in the area, but the cliffs formed of these rocks make exposure limited and inaccessible.

The upper part of the Winsor Member of the Carmel Formation is an interlayered sandstone and mudstone-siltstone sequence. Sandstone of the member is friable, and the whole unit

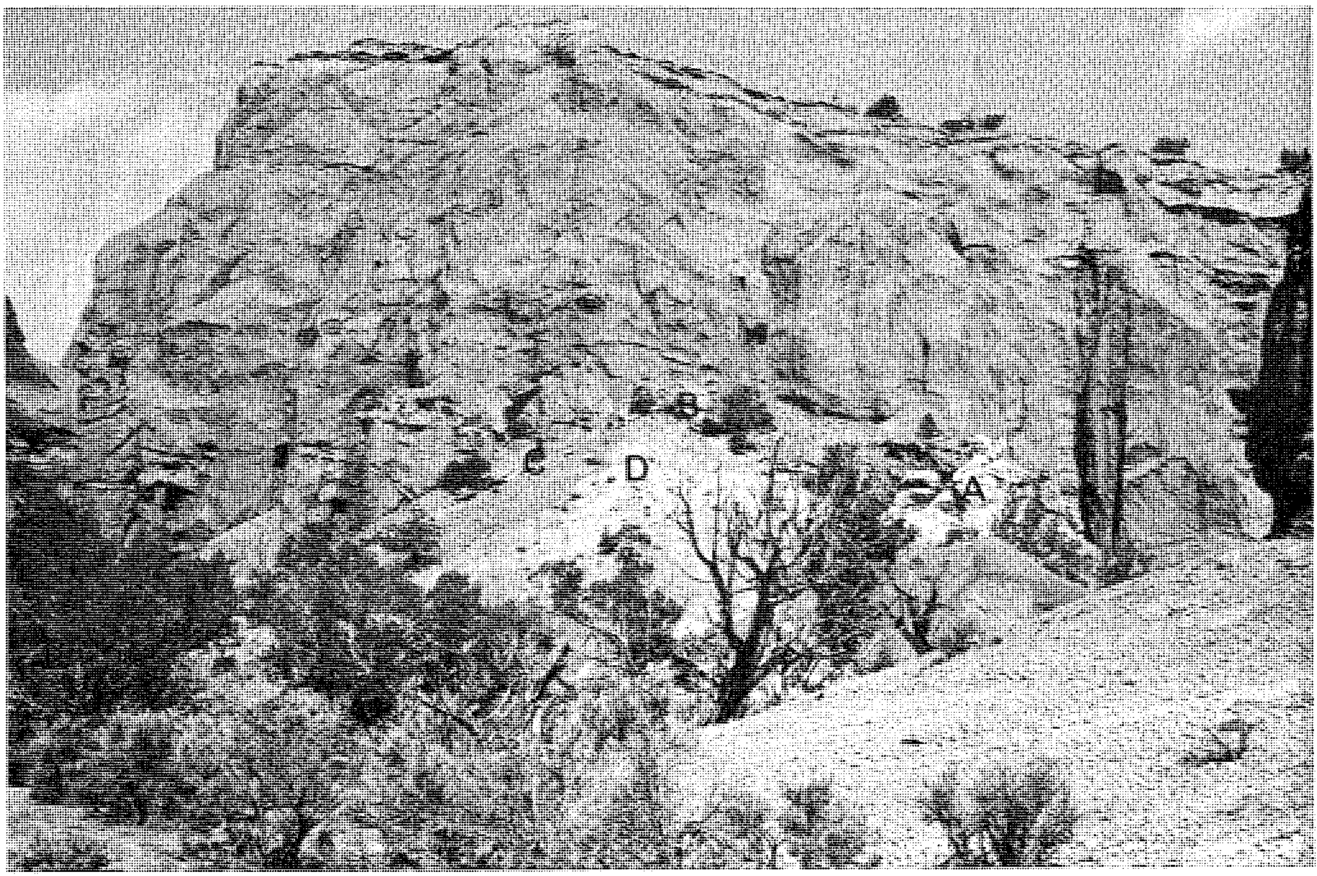

FIGURE 16.–Pipe complex 29. A, pipe 29; B, pipe 15 m south of pipe 29; C, thin dike complex; D, area of bleached sandstone and pebbles. Lower units of red silty facies of Gunsight Butte Member in background; low hill in right foreground is Wiggler Wash Member of Carmel Formation.

weathers to slopes and lowlands. Interbedded mudstone is mottled pale red and grayish yellow green. At least one of the mudstone units contains carbonized fossil wood fragments. The upper part of the massive sandstone below the interbedded siltstone, mudstone, and sandstone unit is a 1–1.5 m bed of conglomerate with angular pebbles of gray, red, and black quartz and chunks and twiglike pieces of petrified wood (Gregory 1951, p. 57). In order of abundance, the lithic fragments include quartzite, granitic rocks, pyroclastic rocks, fine-grained sandstone, limestone, and intermediate intrusive rocks. A thin section of a representative sandstone from the interbedded sequence is composed mainly of subrounded to subangular quartz fragments, minor amounts of plagioclase, and less common potash feldspar, some of which is microcline. The microcline suggests an originally plutonic source in the sand. An iron oxide stain occurs between sand grains, with minor amounts of calcite and an occasional biotite flake in the cement. The igneous materials are fairly fresh (W. R. Phillips pers. comm. 1979).

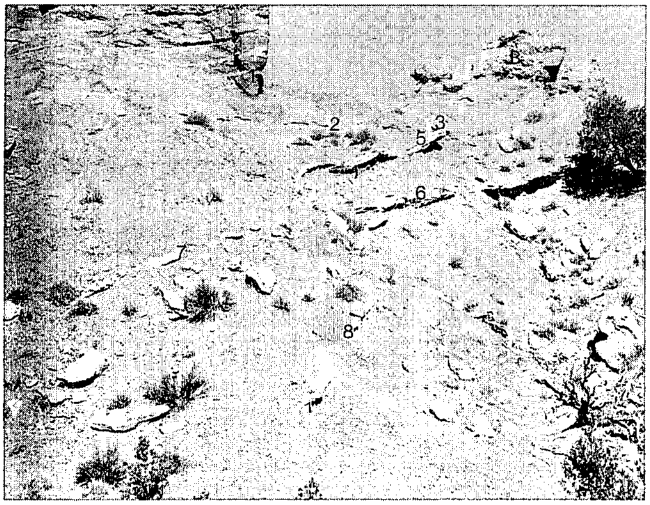

FIGURE 17.–Pipe complex 29 looking northward to thin dike complex. B, sandstone pipe 15 m south of pipe 29; 5, main "feeder" dike; 1, 2, thin dikes branching from main "feeder" dike; 6, lowermost dike; 7, 8, branches of lowermost dike, which contains pebbles a little to left of gully and becomes a thin sandstone dike thereafter.

FIGURE 18.–Thin dike complex showing main "feeder" dike (5) and thin dike extensions from it (1, 2, 3, 4).

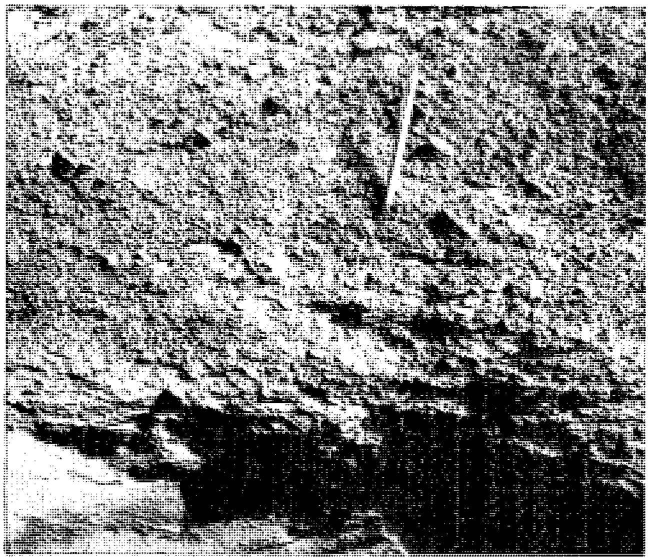

FIGURE 19.–Aligned pebbly interior of lowermost thin dike of pipe complex 29. Lower bleached sandstone border is at lower left.

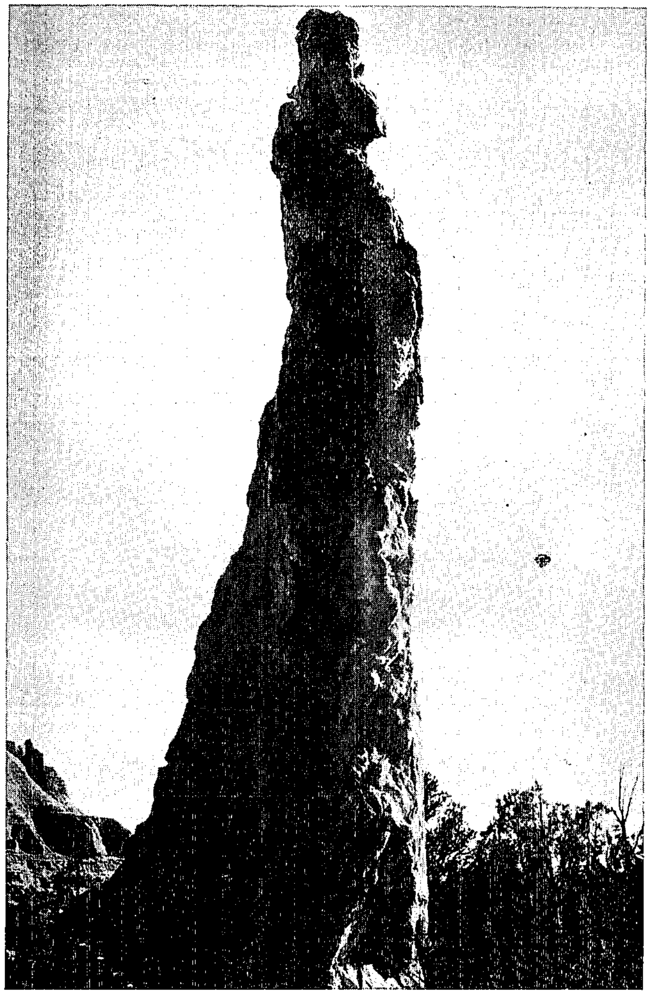

FIGURE 20.–Bedded Gunsight Butte terminates at sandstone "shell" of pipe 35. Interior of pipe is concave with blocks rotated with upper end left (east).

The Wiggler Wash Member of the Carmel Formation is a fissile, gypsiferous, light olive gray marlstone which contains some organic debris.

Three lithologically distinct but characteristic samples from the Gunsight Butte Member of the Entrada Sandstone were studied from the massive, cliff-forming units. All the samples are basically very fine-grained sandstone or coarse siltstone with subangular to subrounded quartz grains, an iron oxide stain, and minor amounts of calcite cement. Biotite is rare. This unit is a massive, light brown cliff former. One-half mile to the north, near pipe 4 and stratigraphically higher than the first sample, the Gunsight Butte Member includes silty sandstone with coarse to very coarse sand grains on the bedding planes. The coarse grains are mostly quartz with a few pieces of chert. In the center of the area, near pipe 52, the member is a horizontally bedded, orangish brown, very fine-grained sandstone with negligible calcium carbonate content. Quartz grains in these beds are generally amber colored and subrounded. Plagioclase and microcline are also present in these thin sections. Some quartz grains from the Gunsight Butte Member samples and other samples of country rock show undulatory extinction. Gypsum is present in hand sample.

Sandstone and Conglomerate Pipes and Dikes

Quartz is the dominant mineral in rocks from the pipes and dikes, as well as in the surrounding country rock. One of the textural features of the structures is their unsorted nature (fig. 25). The large range of grain size shows well on the histogram (fig. 27). The medium to coarse grains are more rounded than fine grains which are subrounded to subangular (fig. 25).

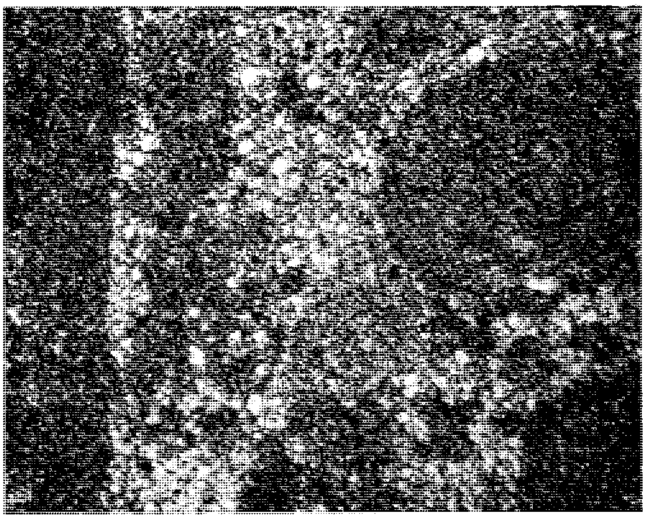

FIGURE 21.–Photomicrograph of gradational edge of pipe 35. Fine-grained dark areas are country rock of Gunsight Butte. Light gray areas are pipe material which show a wide range of grain size. X6.

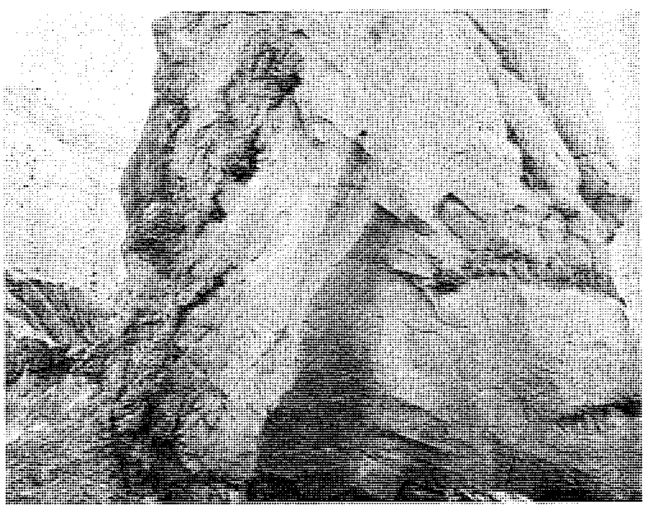

FIGURE 22.–Transition zone and rotated blocks of purplish shale peppered with grains of sand in pipe 35. Purplish shale layer of Gunsight Butte Member of Entrada Sandstone has been warped downward against gradational edge.

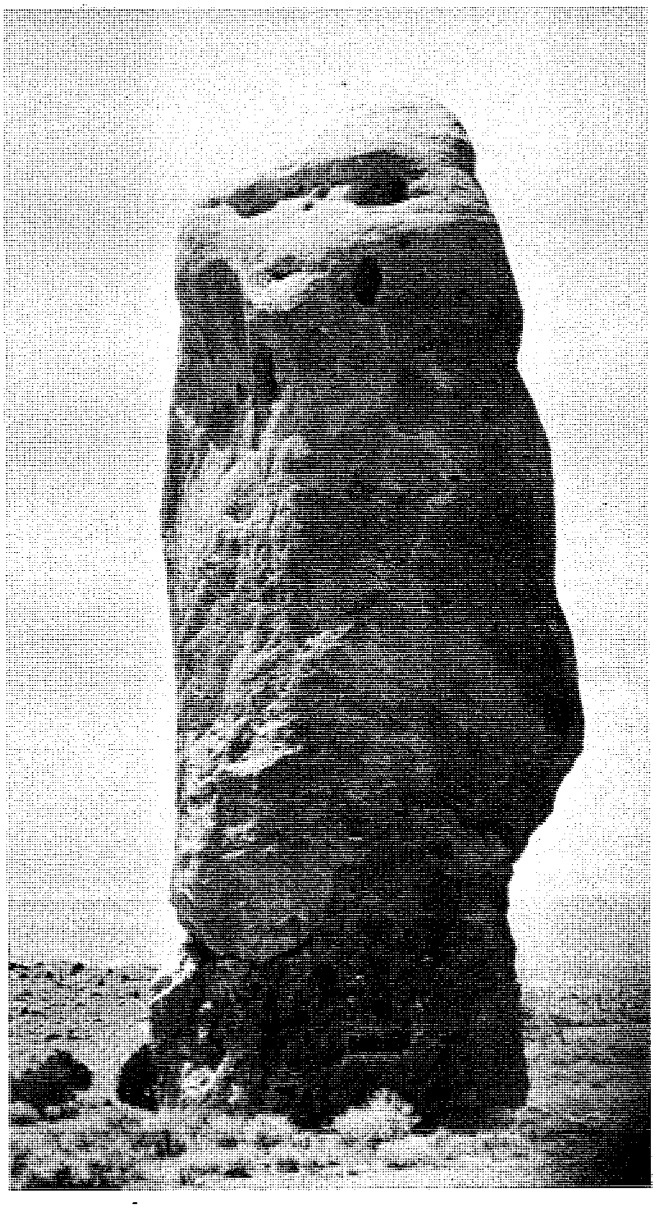

FIGURE 23.–Northern face of pipe 43.

Nearly all quartz grains from the pipes are transparent and colorless. Grains from pipe 4, however, are mostly amber colored. Most grains in pipes and dikes show undulatory extinction.

Composition of the matrix is hard to determine but appears to be of smaller and smaller fragments of quartz and chert. Calcite and gypsum constitute a portion of the cement. Calcite commonly cements the outer part of the pipe. An iron oxide stain, prevalent in the country rock, exists as "ghosts" in some pipes and is nonexistent in others.

Opaque areas in thin sections are probably due to organic fragments or balls of clay. The pipes contain little silt and clay, in contrast with the country rock (fig. 27). Plagioclase and microcline feldspar occur as minor constituents and vary in percentage from pipe to pipe. Biotite also occurs but is rare.

Pipes contain lithic fragments ranging from blocks of sandstone and mudstone to microscopic particles of chert and chalcedony. The blocks are mainly clastic sedimentary rocks from the country rock of the horizon in which it occurs or perhaps from lower units. Mudstone blocks are similar to those in the interbedded sandstone-mudstone sequence of the Winsor Member of the Carmel Formation.

Pebbles found in the pipes are mainly chert and quartzite with chert being most abundant. The chert is usually either dark reddish brown, light gray, or moderate yellowish brown. Pink, olive gray, and other colors are rare. The quartzite is very fine grained and is mostly light gray, reddish brown, light brownish gray, or medium gray. Some of the quartzite contains feldspar laths. Sandstone and shale are the next most abundant fragments. Sandstone is generally yellowish gray or grayish white, some having light brown centers. Shale, siltstone, and marlstone are mostly light greenish gray. Limestone is a minor accessory. The light olive gray limestone is usually partially recrystallized with areas of larger crystals being moderate yellowish brown.

Carbonized fossil wood fragments are found in many pipes but are a fragile and minor constituent. Four pieces of well-preserved silicified fossil wood were found at pipe 11 and preserved in the same manner as fossil wood of the Dakota or Cedar Mountain Formation (Tidwell, pers. comm. 1979). Cross-field pitting in the wood is of the type which occurs in middle to late Jurassic or early Cretaceous plants (Gregory Thayn, pers. comm. 1979). Absence of annular rings suggests a climate without a cold season (Tidwell, pers. comm. 1979).

The main lithic fragments in thin section are chert and chalcedony. Sizes range from the largest particles to the smallest recognizable in thin section. Weathered pyroclastic fragments and fragments containing feldspar laths make up a minor portion of the lithic material. Carbonates and other sedimentary fragments make up the remaining lithic fragments in thin section. Rare isotropic grains are present which could possibly be glass or opal.

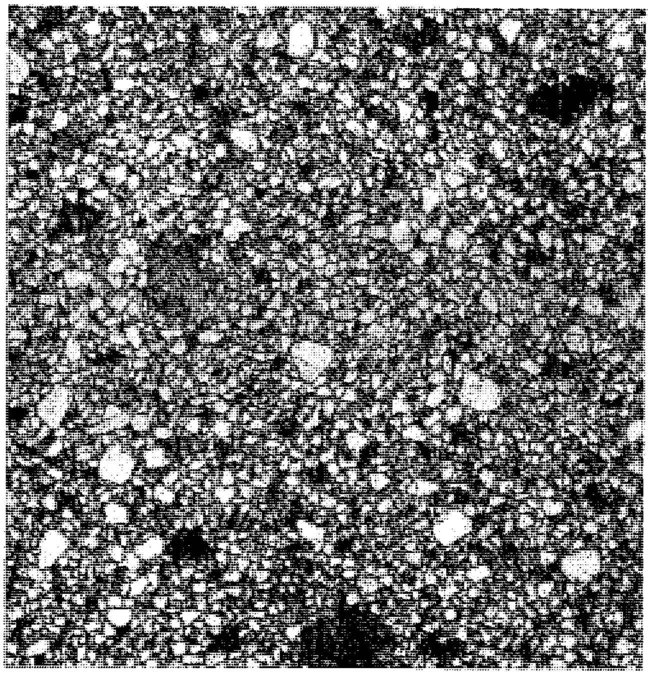

FIGURE 25.—Photomicrograph of a thin section down interior of pipe 47. Sample shows great size range of grains. White grains are quartz; dark grains are chert and clay, or organic fragments; light gray grains are pyroclastic material. X6.

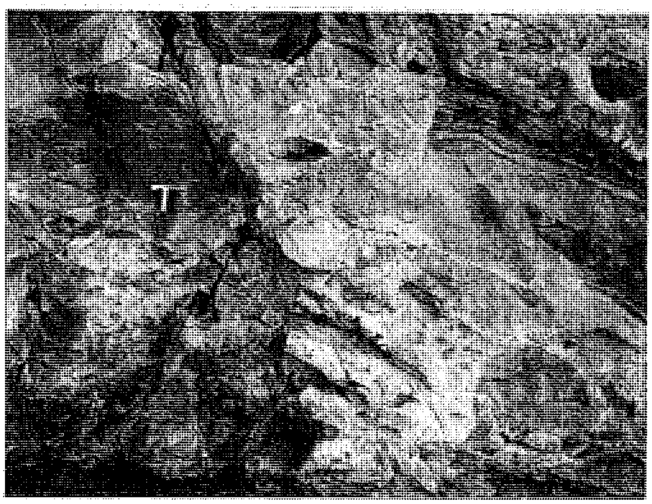

FIGURE 24.—Lower portion of pipe 43 showing sandstone and mudstone blocks and areas of pebbles.

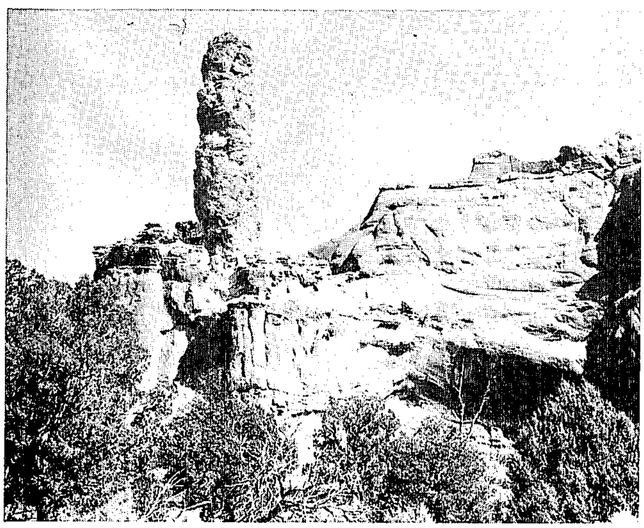

FIGURE 26.—Pipe 52, Gunsight Butte Member of Entrada Sandstone.

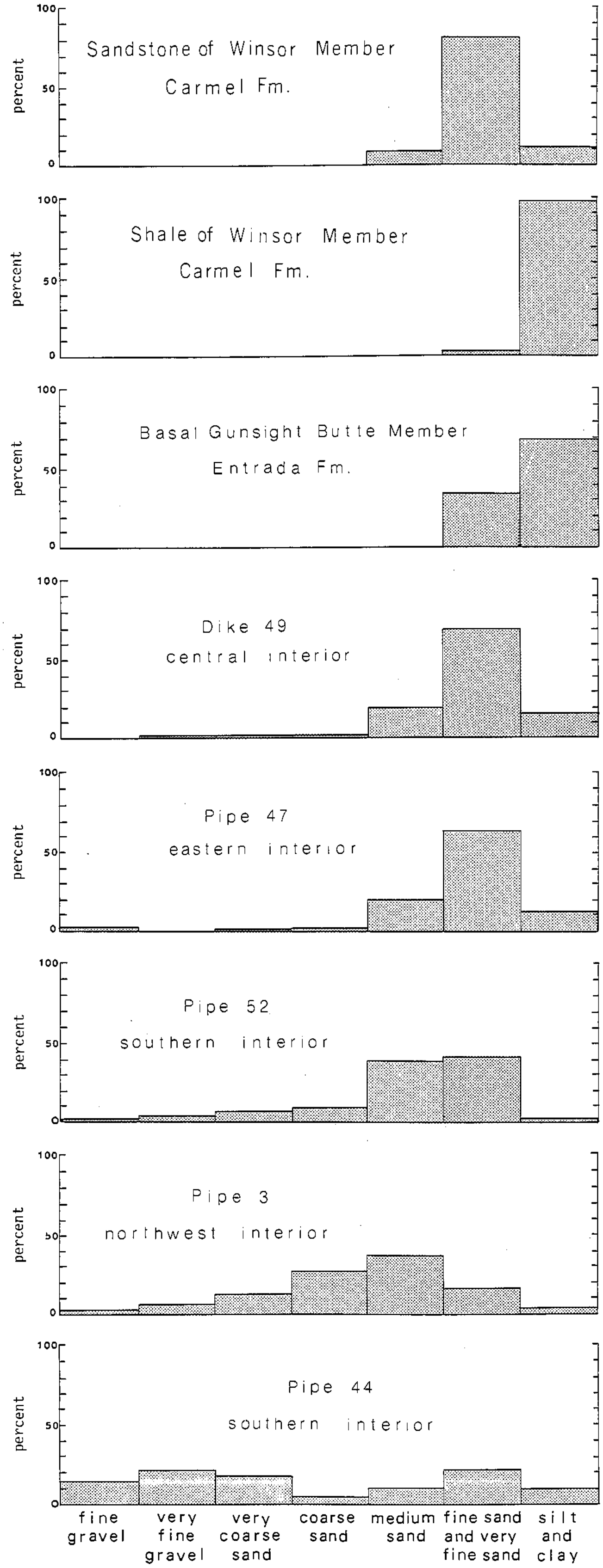

FIGURE 27.–Histogram of grain-size distributions in pipes and country rock.

GENERALIZED TYPES OF PIPES AND DIKES IN THE KODACHROME BASIN AREA

Pipes and dikes have been grouped for convenience of discussion into four generalized types according to their composition, shape, control, and relationships to the country rocks. These divisions are: (1) sandstone pipes, (2) conglomerate-breccia pipes, (3) thick extensive dikes, and (4) thin dikes.

Pipes and dikes in general show as resistant erosional features. Pipes average 18 m high and 8 m wide. The largest pipe is 40 m high and 20.5 m wide. Ordinary pipes average 16 m high and 6.5 m wide. Plugs average 6 m high and 3 m wide. The light greenish gray pillars contrast sharply with the orangish brown to light brown Gunsight Butte Member of the Entrada Formation where most of the pipe occurs.

Fracture and gradational edges, bleaching, an outer shell, faint concentric layering near edges, massive interiors, and great range of grain size seem to be general features of pipes. Dikes are similar to pipes in composition, bleaching, and sandstone border or outer shell.

Sandstone Pipes

Pipe 38 is a good example of a sandstone pipe. Others are pipes 1, 4, 9, 17, 23, 25, 26, 29, 32, 36, 37, 39, 46, 47, 50, and 51.

The border of these pipes is a texturally poorly defined but resistant layer. It is possibly more resistant because of calcium carbonate cement. Fine concentric layering occurs immediately inside the border and extends into the pipe 15–20 centimeters or more. Apart from this weak layering in the outer portions, parallel to the border, these sandstone pipes are fairly homogeneous and massive.

Textural range of the sandstone in these pipes is from very coarse to very fine sand, with the majority of the grains being of fine to very fine sand size (fig. 27). The sand is nearly all quartz, although sand-size chert and other lithic fragments also occur (fig. 25). Content of lithic fragments varies somewhat from pipe to pipe. Silt and clay are found in greater proportion in sandstone pipe than in conglomerate-breccia pipes, but generally make up less of the volume than in bedrock (the Gunsight Butte Member of the Entrada). Sand-size distributions (fig. 27) resemble samples taken from the sandstone of the interbedded sandstone-mudstone sequence of the Winsor Member of the Carmel Formation at Shepard Point.

Conglomerate-Breccia Pipes

Pipe 52 (fig. 26) is a good example of a conglomerate-breccia pipe and is used as the typical one with pipe 43 (fig. 20) as a reference. Other examples of these coarse-textured pipes are 3, 7, 10, 15, 18, 21, 30, 35, 37, 40, 44, and 54.

Conglomerate-breccia pipes are commonly zoned, with a distinct, often more resistant, outer sandstone border or rind around the less resistant pebbly interior. The sandstone rind is typically 20–25 centimeters thick and resembles the outer part of the sandstone pipes. In fact, some of the pipes classed as sandstone pipes could have pebbly interiors, and the two types could intergrade.

The interior of the conglomerate-breccia pipe is normally pebbly and massive. A few pipes, however, show crude stratification, which can be explained in various ways. In pipe 44, for example, it appears to be due to lines of fine material connected to blocks in the exposed surface of the pipe. Irregularities are also caused, on a local scale, by bleached sandstone blocks which have not been assimilated into the pipe (fig. 24).

Sandstone and mudstone blocks localize in certain areas of the pipe and create texturally inhomogeneous areas in the pipe.

Blocks of sandstone and mudstone occur predominantly in conglomerate-breccia pipes, but also occur infrequently in sandstone pipes. Blocks found in sandstone pipes are almost always isolated sandstone masses with a gradational rim or indefinite outline.

Average sand size is coarser in conglomerate-breccia pipes than in sandstone pipes (figs. 25, 28), and the percentage of silt and clay is much less than in either the sandstone pipes or the country rock (fig. 27). The conglomerate-breccia pipes do show great range of grain size, however. Lithic fragments or pebbles in them include both angular and rounded fragments (fig. 28). The most abundant clasts are chert. Reddish-brown is the most common chert color, but many other colors are also present, although minor. Occasional chert fragments are reddish brown with an apple green exterior. Quartzite fragments are the next most abundant lithology. Some of these contain feldspar laths. In addition, well-indurated yellowish gray to white sandstone occurs as pebble fragments, along with fragments of sandstone and shale in each of the pipes from the country rock. Limestone fragments are not abundant but do occur consistently in each of the pipes. The limestone pebbles are generally tabular and light olive gray although not all of them have been worn smooth. Igneous rock occurs in some pipes but is rare in hand sample. In thin section a welded pyroclastic rock (?) occurs in the conglomerate-breccia pipes. Carbonized wood occurs in many of the conglomerate-breccia pipes but is a rare and minor constituent of the total rock volume.

Pipes not classified because of insufficient data are pipes 5, 8, 11, 13, 14, 22, 24, 33, 41, 42, 53.

Thick Extensive Dikes

Dike 49 is a good reference example of features here termed thick extensive dikes. Other similar dikes are those at localities 19, 20, 31, and 48. These structures have the same kind of fracture and gradational contacts that occur in the pipes. Gradational contacts, however, occur most often on the lower contact.

Composition of thick dikes is similar to that of pipes. Most dikes are similar in composition to sandstone pipes, but exceptions are dike 49, which is conglomeratic near its base on the southwest side, and dike 48, which is pebbly throughout. Dike 49 contains lithic fragments, including a few chert pebbles with an apple green exterior. Dikes are controlled by a fracture rather than by joint intersections.

Thin Dikes

The dike complex south-southeast of pipe 29 is excellently exposed and provides characteristic examples of thin dikes. Other areas of thin dikes occur east of pipe 7, between pipes 11 and 12, in the vicinity of pipe 15, between pipes 24 and 26, uphill northeast of pipe 47, and near dike 49.

Thin dikes are up to 1.5 m thick, although most are 0.3 m thick or less. Many thin dikes are traceable laterally for more than 30 m where exposures are good. They are "rooted" in pipes or large dikes and thin away from the main dike "feeder" area. Near their distal margins, thin dikes commonly become only a bleached zone along a joint or fracture until all evidence is lost, not only laterally but vertically. Thin dikes have a tendency to flatten at silty or shaly beds but resume their initial angle of dip above or below these beds (fig. 29). Dikes also change dip and strike along their trace or branch at any particular level. They may converge and can create a network of dikes. They generally maintain a somewhat constant attitude in a limited area, however, and are not meandriform. Compositions of thin dikes show essentially the same range of grain size as pipes and thick extensive dikes (fig. 30). Thin dikes which contain pebbles commonly have a bleached sandstone rind on both sides of the pebbly interior. Thin pebbly dikes become thin sandstone dikes along strike. Pebbles in the dikes are commonly aligned, although not always parallel to the edges of the dike or to bedding planes. Apparently transport of these coarse clastic fragments was difficult. Peterson (1968) also noted this type of flow structure in sandstone dikes of northwest Sacramento Valley, California.

CONCLUSIONS

Observations and Comparisons

Origins of breccia pipes and related features are diverse. Organic fossils, whirlpool action, earthquakes, slumping or collapse into previously formed cavities, collapse associated with spring activity, upward piercement of sediment from below, descending meteoric channels, rising spring water channels, diatremes, cryptovolcanic structures, and concretions have all been proposed as origins for sandstone pipes (Gabelman 1955, 1957). Sandstone dikes have also been reported from many areas, but the majority of the more extensive sandstone dikes are attributed to injection of material from either above or below. Occurrences of pipes with dikes are rare, but Parker (1933) reported one such occurrence in New Mexico. He interpreted the origin of the pipes and dikes there to have been upward injection of water-saturated sand into overlying units.

Dikes of the study area indicate several things. Changing dip and strike show the dikes are probably controlled more by local fractures than by a pervasive regional joint system. Variations or decrease of dip of the dikes at silty beds show compression or slump (Bullock, pers. comm. May 1979). Connection of thin dikes with the main dike or pipe shows that the thin dikes are of the same origin as the main pipe or dike with which they are associated. The thin dikes taper away from the main pipe or dike, hence, were "fed" by the pipe or dike

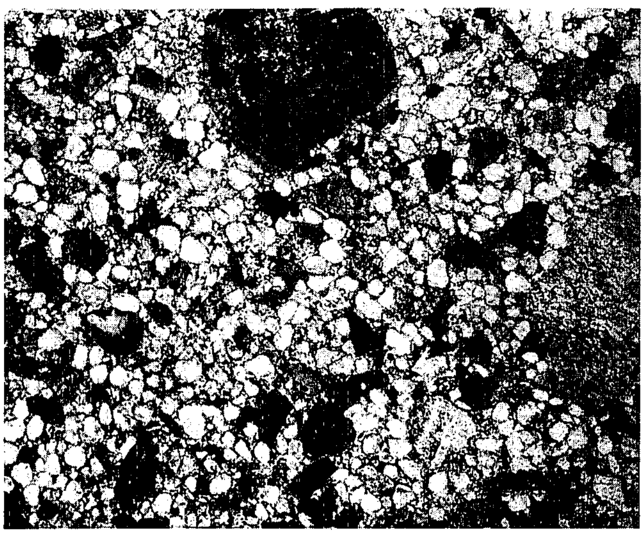

FIGURE 28.—Photomicrograph of thin section of pebbly interior of pipe 3. Dark areas are chert fragments, gray fragments are quartzite or pyroclastic fragments, and white grains are quartz.

rather than being "feeder" dikes. Thin dikes generally taper to a bleached feather edge. A few feather out upwards, indicating they were pressure-induced and not dessication cracks or collapse features. Conglomeratic dikes that taper or wedge out upward reinforce the idea that they are pressure-induced.

Conglomeratic pebbly dikes are commonly zoned with a pebbly center and fine-grained bleached sandstone borders. Pebbles are aligned in many, but the elongation is not parallel to bedding planes of the enclosing country rock, suggesting that the dikes were injected into the country rock.

Faint concentric layering parallel to pipe edges occurs in some pipes and indicates flow of pipe filling. Zonation of material from fine grained on the outside to coarse grained on the interior is characteristic of a flowing body. Even injected material produced by liquefaction shows inward zonation from fine to coarse textures (Bahattacharji and Smith 1964). This zonation is found in the conglomerate-breccia pipes.

Compositions of pipes and dikes in the Kodachrome Basin area show that the pipe-filling material had at least part of its origin somewhere other than in the country rock into which it is emplaced. The grain size of sandstone, grit, and conglomerate within the pipes and dikes is larger than grain size of the country rock (figs. 27, 28). There is little evidence of overgrowths or secondary enlargement of grains. The conglomerate clasts came from some place other than from the rocks in which they were emplaced. Conglomeratic beds do not occur in the Gunsight Butte or in Wiggler Wash Members in the Kodachrome Basin area. The Winsor Member does have a conglomerate layer, but the fragments there are smaller than many pebbles found in the nearby pipes, although both have similar composition.

Carbonized fossil wood occurs in several of the pipes. Similar wood is not found in the Gunsight Butte or the Wiggler Wash Members, but does occur in at least one horizon in the Winsor Member of the Carmel Formation. Carbonized wood similar to that of the Winsor Member was found in pipe 47, in a block of mudstone which was largely bleached like adjacent pipe material. A small unaltered part of the block, however, bears strong resemblance to mudstone of the interbedded sequence of the Winsor Member. Carbonized fossil wood fragments in the pipes could have come from the underlying Winsor beds, and these occurrences strongly suggest that at least some did.

Silicified wood was collected from pipe 11. Preservation of this wood is similar to that in the overlying Dakota or Cedar Mountain Formations (W. D. Tidwell, pers. comm. April 1979). The pitting in the microstructure is of an ancient type and dates the wood as probably from the Early Cretaceous or Middle to Upper Jurassic (Gregory Thayn, pers. comm. April 1979).

The source, or sources, of the conglomerate in the pipes is a puzzle. Coarse conglomerate material might have come from upper beds of the Navajo Sandstone. A chert-pebble conglomerate marking the unconformity at the top of the Navajo Sandstone is 15–40 feet thick in Utah, north of Page, Arizona (Pipiringos and O'Sullivan 1975). This unconformity dies out to the southwest (O'Sullivan and Lawrence 1973), but a channeled surface with patches of limestone and chert is recorded by Gregory (1951, p. 59) at the top of the Navajo Sandstone a short distance southwest of Kodachrome Basin. The chert-pebble beds at the unconformity could be present in the subsurface of the study area.

The conglomerate of the Winsor Member exposed at Shepard Point, west of the study area, is probably too fine grained to be the source pebbles in the pipes. The Cedar Mountain Formation and the Dakota Formation both are known to contain suitable pebble conglomerates, but the Cedar Mountain Formation is not preserved in the study area. It could have been present at the time of pipe formation, however, and subsequently removed before deposition of the Dakota Formation.

Breccia and conglomerates occur in the base and interior of pipe 47, an otherwise "typical" sandstone pipe, and also in the basal part of dike 49, but not in the upper parts. These occurrences suggest that the conglomerate came from below.

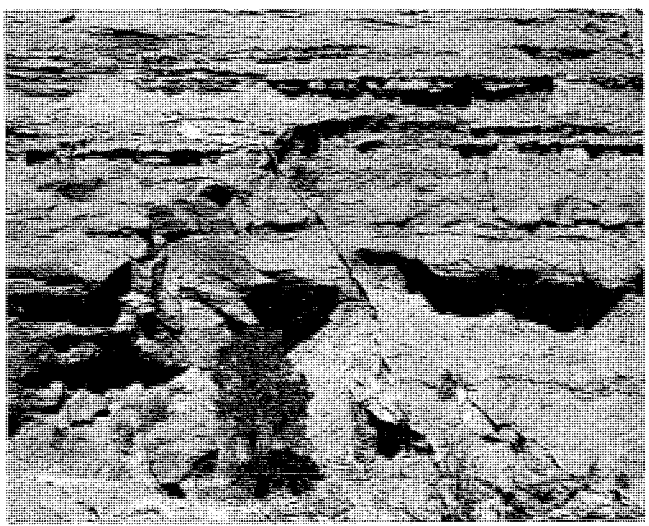

FIGURE 29.–Convergence of dikes between pipes 10 and 11. One dike flattens on silty bed in upper half of photograph. Dip of dike is 53° east.

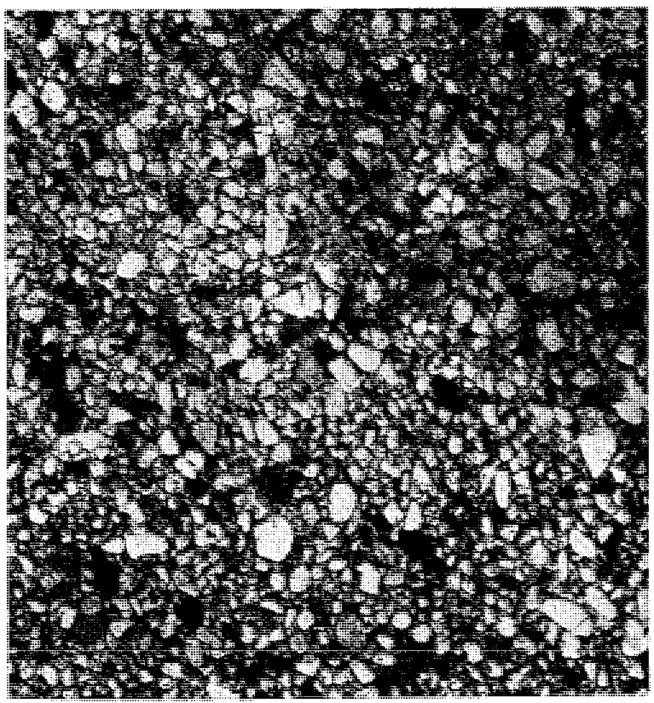

FIGURE 30.–Photomicrograph of thin section of thin dike from between pipes 10 and 11. White is quartzite; black is chert, clay, or organic debris.

The light greenish gray color of the pipes suggests alteration of the predominantly red country rock or that it may have been the original color of the emplaced sand. Grayish green sand could have come from either the Paria River Member of the Carmel Formation and beds below that or from beds above the Gunsight Butte Member such as the Henrieville or the Dakota Formation. Bleaching country rock fractures associated with the pipes and dikes does occur, whatever the source of the sand. Bleaching also shows as greenish gray rinds of incorporated sandstone blocks of country rock, bleaching beyond the sharp fracture edges of the pipes, and as an altered green rind of some of the reddish brown chert pebbles. Because bleaching has occurred, any of the sandstone units in the stratigraphic sequence of the study area could be potential source beds for the fine-grained fraction of the filling. Such bleaching could have been caused by hydrothermal activity, oxygen-starved water, organic-rich water, or gypsiferous water. The mineral assemblage in the pipes and their matrix does not indicate hydrothermal activity. Organic content of the pipes is not excessive, although many do have preserved fine wood debris. Gypsiferous beds of the underlying Wiggler Wash and Paria River Members of the Carmel Formation are thought to be the source of the gypsiferous and calcareous parts of the rocks and could have produced the bleaching solutions.

Interpretation

Theories of formation of pipes and dikes, in general, are divisible into the collapse-feature theories, with filling coming from above, or pressure-feature theories, with materials derived from below.

Composition is the main evidence in favor of a collapse origin for the pipes and dikes. The silicified wood from pipe 11 and conglomerate are suggestive of fill from beds above. No good source for the pebbles or silicified wood can be positively identified from underlying units although local sources of both are possible. Stratification within a few pipes is also suggestive of sequential fill from above, although stratification could also result from settling of a turbated mass undergoing dewatering or loss of fluidity.

Evidence against collapse and filling from above is found in the dikes. Conglomerate-filled dikes are good evidence against collapse. The pebbles would have had to be worked downward 160 or 175 m to be found in the lowest part of the deepest conglomerate-bearing pipe (figs. 2, 5) if conglomerate came from the Dakota or the Cedar Mountain Formation. The conglomerate must also have then been injected into even the thin dikes. Furthermore, structures like pebbly material surrounding bleached sandstone blocks, dikes, and faint concentric layering near the borders indicate flow.

Flowage of pipe filling has been described in the collapse features of Temple Mountain, Utah, area, where sandstone dikes up to 5 cm wide and 6 m long have been mapped (Keys and White 1955). The Temple Mountain collapse is 600 m wide and 150 m long. Rocks inside the mass dropped as much as 100 m to produce the weight for flow at the bottom. Flow of fragmental materials has also been described in diatremes of the Hopi Buttes Field, Arizona (Hack 1942).

Diatremes offer features of both pressure-related systems and collapse systems. For example, dikes are connected with the diatremes of Hopi Buttes, Shiprock, Agathle's Needle, and other related features in the Colorado Plateau. Blocks of country rock are often incorporated in the diatreme breccia. Rocks surrounding the diatremes are often undisturbed (Hack 1942). Diatremes do not necessarily imply close proximity to major igneous activity. Some occur as far away as 32 km from the nearest volcanic cenrer. Kodachrome Basin is within rhat radius of Tertiary basic volcanic rocks.

Diatremes are usually associated with basic volcanic sources but do not necessarily contain volcanic debris. However, most do contain a mixture of country rock and juvenile magmatic material (Gabelman 1957). The upper part of a diatreme is made of collapsed wall rocks and fill from above. Lower parts are usually basic igneous pyroclastic fragments, country rocks, and stringers or veinlets of basalt. The deepest part may contain upper mantle rocks and mineral such as ecologite, peridotite, garnet, olivine, and pyroxene (Hack 1942).

Diatremes are possible, though unlikely, origins for the pipes and dikes of Kodachrome Basin. These pipes and dikes have an apparent stratigraphic control which would not be consistent with diatremes. Abundant basic igneous rocks, either pyroclastic or plutonic, are lacking. Also lacking are the carbonate veins, widespread hydration, and low-temperature alteration of minerals characteristic of diatremes.

Collapse-plug pipes and cryptovolcanic structures are somewhat similar to diatremes. Collapse-plug pipes are near-surface expressions of diatremes (Gabelman 1957). They are common elsewhere in the Colorado Plateau. Violent escape of igneous-derived gas could produce an empty hole, to be filled from above. The filling of a hole at least 175 m deep and 7.6 m in diameter resulting in the composition and structures found in the pipes and dikes of Kodachrome Basin does not seem likely. If material collapsed into the pipes from the walls there should be a gradually changing sequence of rocks above that stratigraphic level. Filling would also leave no avenue for pebbles to work down.

Volcanic hot springs and geysers generally occur in close proximity to areas of intensive igneous activity. The Kodachrome Basin area shows no evidence of hot-spring or geyser activity. The sandstone country rocks are porous and would make poor host rocks for pressures requisite to geyser activity. There is limited evidence of hydrothermal alteration and no geyserite or tufa in the pipes or dikes.

Cold-water springs are a possible mode of origin for the pipes and dikes. The greatest evidence for cold-water springs is one of the pipes at Shepard Point. The tall, thin plug with a bulbous top (much like a diapir) suggests water or fluids moving through the section. Rocks from a similar structure nearby were thin-sectioned and show the mixed, churned, and unsorted nature of the filling of the sandstone pipes and dikes. This structure at Shepard Point has not been bleached but lies entirely in the reddish interbedded mudstone and sandstone section of the Winsor Member. The fact that it was not bleached is another evidence, aside from its apparent self-containment in outcrop, that it did not originate in the still lower gypsiferous units. The gypsiferous Paria River and Wiggler Wash Members of the Carmel lie below and above the Winsor Member, respectively.

Limited water for cold springs could come from the diagenetic change of gypsum to anhydrite, but more likely sources are an artesian system or compaction and lithification of underlying shale or mudstone. Earthquakes could trigger liquefaction and springs as well (Swenson 1959, Reimnitz and Marshall 1965).

Injection of sand is a fairly common origin for sandstone dikes. Injection of pipes in the Moreno Shale of California is thought to be related to differential lithification. Clay dewaters, compacts, and becomes lithified, but sand must be cemented to become lithified. Under stress, with possibly a tremor to trigger it, water-saturated sand could liquefy and be injected into overlying units (Smyers and Peterson 1971). In most situations injected material is lithologically indistinguishable from the beds from which it came, except for the possible addition of inclusions of country rock. In Colorado, sand was injected downward into fissures in granite (Vintanage 1954). The pipes and dikes of the Kodachrome Basin area were probably not injected from sandstone units above into the Gunsight Butte, Wiggler Wash, and Winsor beds. Distance is one problem, and control and driving mechanism are others.

Parker (1933) described upward injection of sand into pipes and dikes. He described mechanical stoping of blocks of country rock and incorporation of these into the intruding sands, vertical banding or sheeting near the walls, horizontal jointing or pseudostratification perpendicular to the axes of the pipes, and near-vertical grooves on the walls of the pipes. All these features are found in one or more of the pipes of Kodachrome Basin.

The principal differences between the pipes and dikes described by Parker and these Utah examples are the unsorted sizes of sand grains without secondary enlargement, conglomerate-breccia, fossil wood fragments, zonation, bleaching, and gradational wall edge.

The differences are mostly compositional and suggest that the two may be genetically related. Difference could be attributed to location and source beds, except for the unsorted grain sizes and the progressively increasing upward average grain size with the different types of pipe. The great variations in sand size suggest the involvement of several different sources or of a highly unsorted unit. The structures at Shepard Point suggest the Kodachrome area structures could be due to a more fluid, perhaps a cold-spring-initiated, system. Progressively increasing average grain size shows a progression or a changing system rather than quick liquefaction and emplacement like that of the New Mexico pipe and dikes described by Parker (1933). Progression of grain size is expected in injected sandstone pipes because water and small particles continue to flow beyond where sand loses its ability to flow (Swarbrick 1968).

The most critical objection to a theory of pipe material coming from below is the lack of a known source for the conglomerate pebbles. However, this objection is not insurmountable. There are stratigraphic units from which the conglomerate could have come, although they are not positively identifiable from this study, such as the top of the main Navajo Sandstone, the top of Thousand Pockets Tongue of the Navajo Sandstone, or the Winsor Member of the Carmel Formation.

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