U.S.DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

GEOLOGY AND AQUIFER SYSTEM OF THE COYOTE SPRING VALLEY AREA, SOUTHEASTERN NEVADA

By

Dwight L. Schmidt

and

Gary L. Dixon

Open-File Report 95-579

Prepared in cooperation with Las Vegas Valley Water District

This report is preliminary and has not been edited for conformance with U.S. Geological Survey stratigraphic nomenclature

Denver, Colorado
1995

CONTENTS

ILLUSTRATIONS

GEOLOGY AND AQUIFER SYSTEM OF THE COYOTE SPRING VALLEY AREA, SOUTHEASTERN NEVADA

ABSTRACT

Most of the water in the lower part of the large White River drainage system of central-eastern and southeastern Nevada flows underground as ground water through a thick Paleozoic carbonate-rock section that constitutes the White River ground-water flow system. The ground water in the Coyote Spring Valley area is herein called the Coyote Spring Valley aquifer system, at the southeastern lower part and terminus of the White River ground-water flow system. A large amount of the flow (36,000 acre-feet/yr) discharges at Muddy River springs at the head of the Muddy River, which has perennial flow downstream from the springs in an arid terrane where surface flow is not common. Within the Coyote Spring Valley area, upstream of the springs, the only surface drainage consists of infrequent floodwater derived locally. The Paleozoic carbonate rocks in the area constitute a potentially single, thick aquifer that is stratigraphically more than 4,500 m thick. Lower Cambrian to Precambrian clastic rocks constitute a lower confining layer to the Paleozoic carbonate-rock section, and the top of the aquifer is closed only by the broad, extensional basins where as much as several thousand meters of upper Tertiary basin fill make an upper confining layer. The basin fill consists of a deformed (synextensional), thick Horse Spring Formation and an overlying little deformed (post-extensional), moderately thick Muddy Creek Formation. The Horse Spring Formation of middle Miocene age, as exposed, consists of silty conglomerate and limestone whereas the Muddy Creek Formation of late Miocene age consists of clayey and silty lake beds. The lower, older, Horse Springs part of the upper confining layer, however, has leaked in places because the formation is well consolidated, deformed, and, in places, well fractured.

Porosity and permeability within the carbonate-rock aquifer are controlled by fracture networks imposed by extensional deformation that has continued since early Miocene time (since less than 20 Ma); primary porosity and late Tertiary solutional permeability are negligible. Extensional fracturing culminated about 16-15 Ma during the maximum displacement of the ranges and basins (basin-range faulting), when rapid erosion of the elevated ranges resulted in rapid filling of the extended and depressed basins. Relative extensional quiescence after about 12 Ma resulted in continued but slow basin filling by lake deposits of the Muddy Creek Formation.

By the time of the early establishment of the basin-range topography, that is, about 16-15 Ma, the White River ground-water flow system was already well established. Since this was established, spring discharge has been in the same general area, between the middle part of Coyote Spring Valley (Starvation Flat) and the Muddy River springs (Moapa area). This timing is demonstrated by large to small deposits of spring carbonate as spring-carbonate veins, spring-carbonate mounds, and spring-carbonate beds in the basin-fill deposits of the Horse Spring and Muddy Creek formations. These spring-carbonate deposits record a full history (more than 20 m.y.) of deep ground-water movement through the area. During the Pliocene and Pleistocene, after basin filling ended when the Colorado River was integrated through the Lake Mead area (about 5 Ma), the Muddy River springs became essentially the sole discharge point of the Coyote Spring Valley aquifer system because the springs area had become the tectonic and topographic low point of the aquifer system.

INTRODUCTION

The Coyote Spring Valley area in southeastern Nevada (fig. 1) was selected to study the geology above a large downstream segment of the large White River ground-water flow system of central-eastern and southeastern Nevada. The White River ground-water flow system approximately coincides with the White River drainage basin (Mifflin, 1968; Eakin, 1966). Eakin (1964) estimated that 35,000 acre-feet (43×10^6 m^3) of deep ground-water flows beneath Coyote Spring Valley in contrast to only 2,600 acre-feet (3.2×10^6 m^3) of surface-precipitation recharge within the valley drainage area. East of Coyote Spring Valley, at Muddy River springs, however, about 36,000 acre-feet (44.4×10^6 m^3) of the aquifer water is discharged in springs and pumped wells. Our study searched for geologic clues, both present and past, that might bear on the nature and specific location of a large aquifer within the lower part of the White River ground-water flow system in the deep carbonate rocks beneath the study area in and around Coyote Spring Valley and Muddy River springs.

Coyote Spring Valley is part of the Basin and Range Province and is a north-trending valley, 65 km long, located between the Sheep and Las Vegas Ranges on the west and the Arrow Canyon Range and Meadow Valley Mountains on the east. The Valley at the north end of the Arrow Canyon Range is located 72 km north-northeast of Las Vegas.

The ephemeral surface drainage in Coyote Spring Valley is that of the White River drainage system, which heads 300 km north in the vicinity of Ely, Nevada, where ranges having large areas and peaks above 2,440 m and 2,740 m provide an initial large recharge to the ground-water system. The ephemeral streams of Pahranagat Wash, the name of the downstream part of the White River through Coyote Spring Valley, and Kane Springs Wash drain into Coyote Spring Valley (fig. 1). Pahranagat Wash flows southeastward out of Coyote Spring Valley across the northern end of the western part of the Arrow Canyon Range at an altitude of 650 m, through Table Mountain basin, and through the precipitous Arrow Canyon in the eastern part of the Arrow Canyon Range to Muddy River springs at about 545 m (fig. 1). Muddy River springs is an informal name applied to about a dozen springs at the head of the Muddy River; the springs include Warm Spring and Muddy Spring as shown on the Overton 100,000-scale topographic base of figures 2 and 3. The discharge at Muddy River springs forms the perennial Muddy River at the head of the upper Moapa Valley. Eighteen kilometers downstream from the springs, the perennial Meadow Valley Wash joins the Muddy River at about 450 m altitude at Glendale (fig. 3). Their combined surface flow provides abundant irrigation water for the highly productive 27-km-long lower Moapa Valley to the southeast. The Muddy River discharges into Overton Arm of Lake Mead at about 400 m altitude.

The Coyote Spring Valley and nearby areas (fig. 2) encompasses more than a 30-minute area, consisting mostly of the western part of the Overton 1:100,000-scale quadrangle, but includes parts of the mutually adjoining 1:100,000-scale quadrangles of Clover Mountains to the north, Pahranagat Range to the northwest, and Indian Springs to the west. The geologic map of figure 2 is compiled from the geologic maps of Clark County (Longwell and others, 1965) and Lincoln County (Tschanz and Pampeyan, 1970) with some modification of the Tertiary rocks of Lincoln County according to Ekren and others (1977). The geology at 1:250,000 scale in these reports was digitized and computer enlarged to 1:100,000 scale with some loss of line accuracy and detail. The geology is superposed on the 1:100,000-scale topography by matching latitude-longitude coordinates without any attempt to rectify geologic contacts and topographic contours. Field work for this report was done between May and July 1985. Some mapping of upper Cenozoic deposits during the 1985 field season has been sketched on the topographic base of the Overton 1:1,000,000-scale quadrangle as figure 3 in order to portray critical information. The geologic study reported herein is preliminary and integrates coordinated water-resource and geophysical studies; all the studies are intended to determine the potential water resource of the deep, Paleozoic carbonate-rock reservoir in southeastern Nevada. This report was written during the winter of 1985-1986, but has been modified in order to update the contents (see for example, Schmidt, 1994).

Acknowledgments

We acknowledge the informative hydrologic discussions with W.D. Nicols, J.O. Nowlin, J.R. Harrill and M.D. Dettinger, USGS, Carson City, Nevada, on the overall deep-aquifer problems of southern Nevada. Michael Dettinger was particularly helpful with specific geologic and hydrologic problems in the Coyote Spring Valley area, as were M.O. Mifflin, Desert Research Institute, Las Vegas, and A.M. Preissler and R.W. Plume, USGS, Carson City. Parts of the geophysical studies have been indirectly integrated into our report and we appreciate the communications and discussions with H.R. Blank, gravity and magnetics, D.L. Sawatzky, remote sensing-linear features, J.S. Duval, radiometrics, all of USGS, Denver, and D.H. Schaefer, gravity and shallow seismic refraction, USGS, Carson City. V.A. Frizzell, and E.H. Pampeyan, USGS, Menlo Park, were helpful with geologic information. We give special thanks to R.J. Ross for detailed discussions and field trips on the Paleozoic rocks and to R.L. Langenheim for unpublished detailed geologic maps of parts of the 15-minute Arrow Canyon quadrangle. Many discussions with H.R. Blank, W.B. Myers, and J.W. Whitney have sharpened our focus on structural and geomorphic details of the Basin and Range region of southeastern Nevada and specifically within the Coyote Spring Valley area. The manuscript was reviewed by P.D. Rowley.

STRATIGRAPHY

The ranges of the Coyote Spring Valley area consist of Paleozoic sedimentary rocks that are transitional between a thin shelf facies to the east and southeast and a thick miogeosynclinal facies to the west and northwest. Complete exposed sections of Ordovician to Lower Permian rocks total about 3,125 m (fig. 4). Beneath this section is an estimated 1,500 m of Cambrian rocks, only partly exposed. Above the Lower Permian rocks are incompletely exposed Permian and Triassic sedimentary rocks that in southeastern Lincoln County (fig. 2, northeast corner of map) have a thickness in excess of 3,000 m (fig. 5; Tschanz and Pampeyan, 1970, p. 61-64). Late Proterozoic sedimentary rocks, the Noonday Dolomite, Johnnie Formation, and Stirling Quartzite, and the Proterozoic-Cambrian Wood Canyon Formation, aggregate more than 3,000 m of section in western Clark County and may have thinner correlative parts in the subsurface beneath the Coyote Spring Valley area. However, on the cross section of this report (fig. 16), these units are sketched in as a full 3,000 m of section overlying older Precambrian igneous and metamorphic rocks, which in turn constitute the nonexposed magnetic and gravity basement inferred from the geophysical interpretation (H.R. Blank, written commun., 1985).

The composite stratigraphic column and cross section (figs. 4 and 16) are centered on the Arrow Canyon Range, which is a relatively stable block between compressional thrust structures both east and west of the Range within the map area and between much more extended ranges outside of the map area. In fact, the Cambrian to Permian section exposed in the northern half of the Arrow Canyon Range is one of the least deformed and most continuous Paleozoic sections in southeastern Nevada. The composite stratigraphic column (fig. 5) for Lincoln County (Tschanz and Pampeyan, 1970) shows a more inclusive section, including Precambrian and Mesozoic rocks that might be expected in the subsurface in the vicinity of the Arrow Canyon Range. The brief discussion of these rocks is chiefly based on Langenheim and others (1962) and the Clark County and Lincoln County geologic reports (Longwell and others, 1965; Tschanz and Pampeyan, 1970) and will be restricted for the most part to the exposed rocks in the Arrow Canyon Range.

The Cenozoic stratigraphy consists of upper Tertiary volcanic rocks, upper Tertiary semiconsolidated basin-fill deposits, and Pliocene and Quaternary alluvial deposits. The basin-fill deposits in the Coyote Spring Valley area for the most part act as confining layers to the Coyote Spring Valley aquifer system, and thick basin-fill clays play an especially important role as impervious barriers to recharge and discharge of the aquifer system.

Pre-Jurassic Rocks

Cambrian rocks

Upper Cambrian carbonate rocks of the Nopah Formation are exposed in the eastern and western parts of the Arrow Canyon Range and in the southwestern part of the Meadow Valley Mountains (fig. 2). The Nopah consists of cherty dolomite and limestone. About 60 m of section is exposed, but the base is not exposed. For the cross section (fig. 16) through the Arrow Canyon Range, a thickness of 1,525 m of Cambrian rocks is interpolated from measured sections of 915 m at Frenchman Mountain to the south and 2,750 m in the Desert Range to the west.

For evaluation of aquifer characteristics, the Cambrian section in the Arrow Canyon Range is divided into an Upper Cambrian carbonate section and a Lower Cambrian clastic section, (fig. 16), wherein the carbonate rocks are potentially permeable (aquifer rocks) and the clastic rocks are potentially not permeable (confining rocks). The upper carbonate section presumably consists of the Nopah and Bonanza King formations separated by a thin Dundenberg Shale. The rock composition of the lower clastic section, whether similar to that of the Desert Range or to that of Frenchman Mountain, is more difficult to determine, but measured sections from both of these ranges contain dominantly quartzite and shale, and we presume that the nonexposed lower Cambrian rocks of the Arrow Canyon Range are similarly confining to ground-water flow.

Ordovician rocks

Ordovician carbonate rocks and quartzite are widely distributed in the Sheep Range, Arrow Canyon Range, Meadow Valley Mountains, and western Delamar Mountains of the map area. In the Arrow Canyon Range, the Lower and Middle Ordovician Pogonip Group consists of about 1,000 m of cherty and noncherty dolomite of the Goodwin Limestone and 420 m of cherty limestone and limestone of the Antelope Valley Formation. The Middle Ordovician Eureka Quartzite consists of 41 m of resistant and especially clean orthoquartzite. The Middle(?) and Upper Ordovician Ely Springs Dolomite is 140 m thick. Disconformities bound the bottom and top of the Eureka Quartzite.

Silurian rocks

The Silurian Laketown Dolomite is exposed in the Arrow Canyon Range, Meadow Valley Mountains, and western Delamar Mountains. In the Arrow Canyon Range and southern Meadow Valley Mountains, the gray fossiliferous dolomite ranges in thickness from 67 to 101 m. This variation is attributed to erosion prior to Devonian deposition (Langenheim and others, 1962).

Devonian rocks

The undivided Devonian rocks in the Arrow Canyon Range, aggregating 600 m thick, are named the Sultan Limestone on the Clark County map using the formational designation from the Goodsprings District of southern Clark County. On figure 2, we use the Sultan Limestone, but on the cross section of figure 16, we use the more detailed formational designations of Langenheim and others (1962). Langenheim and others (1962) retained only the Crystal Pass Limestone Member (raised to formational rank) of the Sultan and locally named the Piute, Moapa, and Arrow Canyon Formations below the Crystal Pass.

In Lincoln County, the Devonian rocks are subdivided, from base to top, into the Sevy Dolomite, Simonson Dolomite, and Guilmette Formation; these units can be correlated as well with rocks in the Arrow Canyon Range (Tschanz and Pampeyan, 1970). The Piute Formation, 100 m thick, is dolomite and its lower part correlates with the Lower Devonian Sevy and its upper part, including the uppermost, region-wide *stringocephalus* zone, correlates in part with the Middle Devonian Simonson Dolomite. The Moapa Formation, 90 m thick, is dolomite and limestone and includes the yellow weathering zone that correlates with the lower yellow member of the Middle and Upper Devonian Guilmette Formation. The thick, medium- to dark-gray Arrow Canyon Formation, 325 m thick, consists of limestone with interbedded thin layers of rusty-brown quartzite and gray dolomite and correlates with the upper part of the Guilmette Formation. The white-weathering, homogeneous Crystal Pass Limestone (formation), 85 m thick, does not correlate with the uppermost Guilmette.

The Upper Devonian-Lower Mississippian Pilot Shale as shown on the Lincoln County geologic map is not present in the Arrow Canyon Range; it is exposed in the northern part of the Meadow Valley Mountains (Pampeyan, 1989).

Mississippian rocks

Gray to black, fine- to coarse-grained, crinoidal limestone and cherty limestone of the Upper and Lower Mississippian Monte Cristo Group are about 450 m thick in the Arrow Canyon Range, Meadow Valley Mountains, and Las Vegas Range. The Group is divided in ascending order into the Dawn, Anchor, Bullion, and Yellowpine Limestones as in the Goodsprings District, except a fifth subunit, the Arrowhead Limestone of the Goodsprings District is absent in the Coyote Spring Valley area. The Dawn Limestone at the base of the Monte Cristo Group is a uniform, thick-bedded, black, medium-grained, crinoidal limestone that ranges from 46 to 60 m thick.

Much of the Anchor Limestone is thin-bedded, dark-brown weathering, cherty limestone, in parts of which discontinuous tabular thin beds of chert constitute 50 to 70 percent of the limestone. The abundance and form of the chert varies within the section from especially abundant thin-bedded chert in the lower part to much less abundant lenticular and nodular chert in the dark, well-bedded, gray limestone in the upper part. The formation ranges from 203 to 246 m thick.

The Bullion Limestone is massive, thick-bedded, fine- to medium-grained, gray, crinoidal limestone variably containing sparse to locally abundant nodules and lenses and locally tabular interbeds of brown weathering chert. In Arrow Canyon the lower part of the formation contains abundant thin-bedded chert and the upper part contains only small amounts of chert. The formation ranges from 110 to 155 m thick. The Yellowpine Limestone is a thick-bedded, medium-grained, dark-gray weathering limestone that ranges from 27 to 30 m thick in the Arrow Canyon Range.

The Battleship Wash Formation of Late Mississippian age at Arrow Canyon overlies the Monte Cristo Group, is about 24 m thick, and consists of fine- to medium-grained, gray limestone in 1- to 2-m-thick beds. A basal interbedded sandy limestone and sandstone forms a possible disconformity with the underlying Yellowpine Limestone (Langenheim and others, 1962, p. 603; Webster and others, 1984, p. 53).

The overlying Indian Springs Formation, also of Late Mississippian age, at Arrow Canyon, is about 70 m thick and consists of a lower unit of reddish-brown weathering fissile shale and thin interbeds of calcareous quartz sandstone. It is equivalent to a thin part of the Chainman Shale and Scotty Wash Quartzite, which at Kane Springs Wash are 285 m and 35 m thick, respectively (Duley, 1957, p. 19-25). The Chainman Shale at Kane Spring Wash consists of a lower unit of red-brown and purple weathering siltstone containing thin interbeds of limestone, sandstone, and quartzite and an upper unit of fissile black shale that weathers red and brown and contains thin interbeds of red-brown calcareous sandstone and quartzite. The Scotty Wash Quartzite at Kane Springs Wash consists of reddish-brown weathering, interbedded, massive quartzite and calcareous, quartzose sandstone containing several thin crinoidal limestone beds.

Mississippian-Pennsylvanian-Permian rocks

The Bird Spring Formation, ranging from latest Mississippian through Pennsylvanian and well into Early Permian age, is widely distributed in the eastern Meadow Valley Mountains, central and southern Arrow Canyon Range, and the eastern Las Vegas Range. Only the lowest 15 to 18 m of the formation is Mississippian age (Webster and others, 1984). The upper part of the formation is everywhere covered by Cenozoic deposits; the exposed part of the formation west of Muddy River springs is about 935 m thick. The Bird Spring Formation consists predominantly of thick- and thin-bedded limestone containing abundant chert and minor calcareous shale and sandstone in alternations that in places suggest cyclical deposition. The upper 160 m of the exposed part of the formation is white-weathering, thick-bedded limestone and dolomite that is relatively chert free.

The Mississippian-Pennsylvanian-Permian strata above the Monte Cristo Group have been variably subdivided and named in the Arrow Canyon Range and southern Meadow Valley Mountains. Langenheim and others (1962) raised the rank of the entire section to the Bird Spring Group, but in a later paper (Webster and others, 1984), Langenheim and his co-authors retained the formational and restricted status of the Bird Spring Formation and separated out the Battleship Wash and Indian Springs Formations. We prefer the latter to emphasize the lithologic similarity of the Indian Springs Formation with the Chainman Shale and Scotty Wash as defined at Kane Springs Wash (Duley, 1957) and farther north in order to emphasize their low permeability to ground-water flow.

Permian and Triassic rocks

Permian red beds and undivided Toroweap Formation-Kaibab Limestone and the Triassic Moenkopi and Chinle formations are exposed in a few scattered areas and isolated outcrops in the structural basin of Meadow Valley Wash (fig. 2). The Lower Permian red beds are correlative to some part of the descending sequence, Coconino Sandstone, Hemit Shale, Esplanade Sandstone, and Supai Formation in southwestern Utah and northwestern Arizona. The red beds are about 550 m thick in the Meadow Valley Wash area. A resistant lower unit, 185 m thick, consists of varicolored, thick-bedded, very fine- and fine-grained sandstone and quartzite containing a few thin silty and calcareous beds. A less resistant upper unit, 370 m thick, consists of brick-red, yellow, red-brown, and light-gray, very fine- to coarse-grained sandstone containing a few interbeds of gypsiferous limestone and shale.

The Lower Permian Toroweap Formation-Kaibab Limestone, undivided, is partly exposed at Rox (near the eastern edge of fig. 2). In the Mormon Mountains, the combined unit is 70 to 140 m thick. In the eastern Meadow Valley Mountains, the Toroweap Formation consists of a lower, 30-m-thick, resistant unit of gray to brownish- or reddish-gray limestone containing alternations of cherty and noncherty layers, all overlain by an upper, 12-to-24-m thick, less-resistant unit of gray to pink, thin-bedded shaley limestone containing several thick

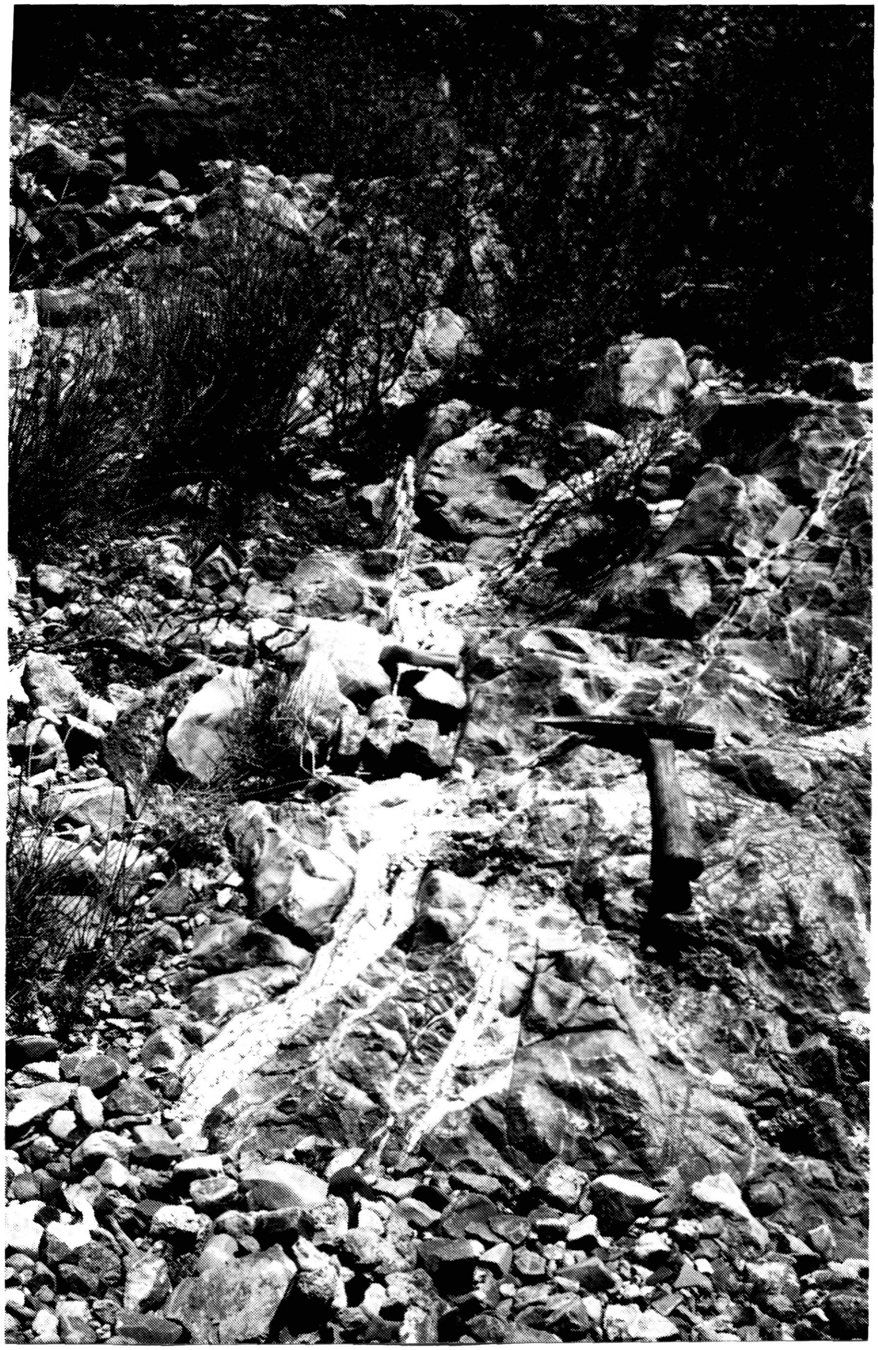


Figure 10.—Spring-carbonate veins, north-striking and as wide as 10 cm, that consist of laminated, coarsely crystalline, white calcite that fill fractures in Permian Bird Spring Formation (limestone) in the Bunker Hills, eastern Meadow Valley Mountains. Veins probably are of middle Miocene age.

The younger volcanic rocks in the map area are probably middle Miocene age and overlie the older volcanic rocks with angular unconformity. They are exposed in a succession of ash-flow and bedded tuffs that are reddish-brown and yellowish-brown to buff and cream colored and are about 90 m thick along the southeastern side of Kane Springs Wash (Cook, 1965; Scott and others, 1995). Ekren and others (1977) and Cook (1965) correlated these volcanic rocks with the Kane Wash Tuff originating from the Kane Springs Wash caldera complex in the Delamar Mountains just north of the map area. The principal outflow tuffs of the Kane Wash Tuff range from 15 to 14 Ma (Novak, 1984; Scott and others, 1995).

The middle Miocene Horse Springs Formation consists of limestone and silty conglomerate deposits that filled the basins of the Coyote Spring Valley area during active tectonic extension. The limestone is exposed best along the range front of the Arrow Canyon Range south of Muddy River springs, where it is in part strongly faulted and tilted. The silty conglomerate is more widely exposed, as detrital silty conglomerate, silty sandstone, and sandy to conglomeratic siltstone (fig. 8) found mostly north of State Highway 168. Large thick deposits of this coarse, poorly-sorted, rapidly-deposited, matrix-supported, conglomerate are thoroughly cemented by calcium carbonate where well exposed in the dissected drainages of Wildcat, Dead Man, and McKay Washes. In Meadow Valley Wash north of Farrier, the thickly bedded, carbonate-cemented, silty conglomerate (not well depicted on fig. 3) is seen in nearly vertical walls as much as 60 m high or in steep valley sides exposing more than 120 m of silty conglomerate. In places, a large percentage of the clasts in the conglomerate are Tertiary volcanic rocks, but elsewhere (generally close to the range), the clasts are chiefly Paleozoic carbonate rocks. A few boulders locally may be more than one-meter across. The silty conglomerate facies represents a rapid aggradational deposit containing detritus shed locally from uplifting ranges during basin-range extension.

The Tertiary basalt in the northeastern corner of the map area mostly overlies the younger volcanic rocks, but one 52-m-thick lava flow lies between the older and younger volcanic rock units (Cook, 1965). The basalt is a gray to black, olivine flow rock and in most sections is less than 30 m thick. In Lincoln County, some basalt is as young as 8.5 Ma.

The upper Miocene Muddy Creek Formation consists of lacustrine deposits that filled the basins of Coyote Spring Valley area after tectonic extension had essentially ceased (fig. 3). The lacustrine facies consists of red, greenish-gray, buff, and white claystone, siltstone, and fine sandstone commonly in massive thick beds or in cyclic beds of thick- to thin-bedded and laminated sediments. A few thin, silty to clayey, silicic, tuffaceous beds can be identified. In different places, white tabular beds of freshwater limestone form a small part of the exposed lake deposits. Individual tabular limestone beds are one to several meters thick and pinch out in distances of 1 to 2 km. Carbonate casts and molds of plant debris and algae are preserved in some of these beds. The lacustrine clastic beds, for several to many meters above and below the limestone layers, are commonly highly calcareous (marl). Abundant disseminations of gypsum are widespread, but thin beds of gypsum are rare and only associated with the white limestone and marl.

In places along the range fronts, the flat-lying lake beds of clay and silt are in contact with steep-sloping Paleozoic bedrock, indicating a former shoreline in steep topography. Commonly within a few meters of this contact, the lake beds contain only a few intertonguing beds of coarse talus or slope debris. In the few places where tongues of angular stream-worked detritus are found near bedrock contacts, the coarse local debris only extends several tens of meters into the lake deposit.

The thickness of the lacustrine facies of the Muddy Creek Formation in the map area varies with the underlying tectonic relief. In many places within the area, 60 to 150 m of discontinuous exposure of lake beds can be seen from valley bottom to the highest lake-bed remnant exposed on the slopes of the adjacent range. Overall, about 275 m of thickness can be estimated from discontinuous exposures of Muddy Creek Formation as measured from the Muddy River channel at Moapa, just off the east edge of the map area, to highest exposures beneath Mormon Mesa east of Farrier. Between Moapa and the upper reaches of Battleship Wash, we estimate about 255 m of discontinuous exposure. At the northern end of the Arrow Canyon Range, as much as 140 m of nearly continuous exposure can be estimated. If the entire Coyote Spring Valley map area is considered, as much as 350 m of erosional relief on the Muddy Creek Formation can be estimated from Glendale to the high exposures in Coyote Spring Valley. These thickness estimations are calculated simply from differences in altitude measured on topographic maps; they do not consider depositional slope or compaction, nor possible low-angle regional tilting or more localized faulting nor extensive and complete erosion of the top of the Muddy Creek Formation. It is possible, but not likely, that the lake in the Moapa area and the lake in the Coyote Spring Valley may not have been connected. However, as a first approximation, corrections for faulting and tilting are probably small. Likewise, the highest exposures of the Muddy Creek lake beds on the slopes of the ranges may not be deeply eroded below the original top of the formation, and the altitudes of these exposures do suggest that the two lakes were connected, at least during most of Muddy Creek time.

The subsurface thickness of the Muddy Creek Formation is more difficult to estimate. A well near the county line in Coyote Spring Valley, 6 km north-northwest of the northern end of the Arrow Canyon Range but west of the center of the valley, contains a reported thickness of 250 m of Muddy Creek Formation overlying Paleozoic carbonate rock; considering the altitude of the Muddy Creek outcrops on the adjacent valley side, we estimate a total thickness of 300 m for Muddy Creek Formation. About 430 m of basin fill in the center of Coyote Spring Valley, 8 km south-southwest of the northern end of the Arrow Canyon Range, was estimated from a seismic reflection study (Anderson and Jenkins, 1970, p. 13); when combined with high valley-side exposures of lake beds, we estimate a total thickness of 530 m.

In upper Moapa Valley, the subsurface thickness of the Muddy Creek Formation may be between 150 and 460 m, estimated by extrapolations from known thicknesses to across the about 12-km width of the basin between Muddy River springs and Glendale. The Permian Bird Spring Formation dips gently under Muddy Creek lake beds at Muddy River springs, whereas complexly deformed Permian and Mesozoic rocks and Tertiary Horse Spring Formation underlie the lake beds near Glendale. To the north, the approximate base of the Muddy Creek is exposed in Farrier Canyon, about 3 km north of Farrier. Thick spring-carbonate beds exposed in the Muddy Creek Formation at White Narrows suggest a relatively thin deposit here because ground water (the source of the limestone beds) of any age rarely discharges through thick clay deposits. In summary, a total thickness of the Muddy Creek Formation in Coyote Spring Valley may be estimated at about 600 m and in the upper Moapa Valley (near Moapa) at about 450 to 750 m.

The age of the Muddy Creek Formation in the Coyote Spring Valley area is broadly restricted by map units below and above to late Miocene. The Muddy Creek in many places in the area overlies an ash-flow tuff of probable Kane Wash Tuff of about 14 Ma, for example on McKay Wash, north of Highway 168; the Tuff is far below the nonexposed top of the Horse Spring Formation, so that the base of the Muddy Creek has to be considerably younger. The Muddy Creek Formation is everywhere cut by pediments at least as old as late Pliocene and in Meadow Valley Wash is overlain by aggradational gravel of early Pliocene age. Just east of the map area, the formation is overlain by the Mormon Mesa carbonate soil that is probably of earliest Pliocene age.

The glass in two thin beds of silicic volcanic tuff in the Muddy Creek lake beds at Table Mountain has been dated by the K-Ar method at 7.2 ± 0.2 and 5.9 ± 0.3 Ma (Metcalf, 1982, p. 106). In the same study, however, broad ranges of K-Ar ages on Muddy Creek ashes outside the Coyote Spring Valley area do not assure confidence in the ages at Table Mountain.

In the Muddy Mountains southeast of the Coyote Spring Valley map area, the Muddy Creek Formation is underlain by a "red sandstone" having fission-track ages of 11.9 to 10.0 Ma; we consider the red sandstone to be basal Muddy Creek and, therefore, 12 Ma is a reasonable age for the base of the Muddy Creek. Elsewhere the Muddy Creek contains intercalated basalt lava flows dated at 11.3 and 8 Ma. Near Hoover Dam, Muddy Creek lake beds are overlain by the Fortification Basalt Member, whose youngest K-Ar age is 5.9 Ma (Bohannon, 1983); this basalt is at or near the top of the Muddy Creek (but is older than the draining of the lake by an earliest Colorado River). The Hualapai Limestone Member, which is considerably thicker than 240 m, constitutes a large part, including the top, of the Muddy Creek Formation in the axial zone of the Colorado River basin at and near the Grand Wash Cliffs (Blair and Armstrong, 1979). An air-fall tuff, 36 m above a local base of the member, gives a K-Ar age of 8.7 ± 2.2 Ma and a basalt flow locally beneath the Hualapai gives a K-Ar age of 10.9 Ma (Blair and others, 1977). The top of the Hualapai represents the end of Muddy Creek deposition and the beginning of through flowage of the ancestral Colorado River, which is suggested to be as late as 6 Ma by Lucchitta (1972, 1979).

Tentatively, we estimate the age of the Muddy Creek Formation to range from 12 to 5 Ma, about the same age (13 to 5 Ma) suggested by Anderson and Lancy (1975) for the interval between maximum basin-range development in southern Nevada and integration of the Colorado River system.

Pliocene and Quaternary alluvial deposits

The Coyote Spring Valley area was deeply dissected and eroded following integration and entrenchment of the Colorado River during Pliocene and Quaternary time. Meadow Valley Wash established a consequent course across the depositional lake beds of the Muddy Creek Formation. Muddy River (including Pahranagat Wash in Coyote Spring Valley) likewise was consequent across the top of the Muddy Creek lake beds but was probably superposed across the Paleozoic limestone ridge of the Arrow Canyon Range at Arrow Canyon; its position at Arrow Canyon may have been controlled chiefly by large, carbonate-spring-water discharges at Table Mountain and at Muddy River springs. Most likely, since the end of Muddy Creek lake time, the ridge at Arrow Canyon has been elevated about 60 to 120 m relative to Coyote Spring Valley in order for an ancestral Pahranagat Wash to entrench across the Arrow Canyon ridge.

Most of the erosion of as much as 150 m of Muddy Creek lake beds has been accomplished by sidestream pedimentation, the process which controls the specific lateral location of any given mainstream within its valley. The Pliocene-Quaternary deposits are divided into old alluvium in terraces and dissected high pediments, young alluvium in stream channels, and eolian sand (figs. 2 and 3). L.R. Gardner (1968, 1972a) has mapped in more detail the Quaternary deposits east of the Arrow Canyon Range in the southeastern corner of figures 2 and 3. Old alluvium is abundantly and widely distributed throughout the Coyote Spring Valley area chiefly as thin pediment gravels that cover broad areas of the piedmont slope between the bedrock outcrops and the center of valley (or basin) mainstream. These pediment gravels are degradational deposits locally derived from the nearby, upslope ranges. A widely varied, gravel-clast size depends on the erosional character of the upstream bedrock and on the size of the individual upstream drainages. Only locally, a few small gravel deposits may be interpreted as aggradational fill and fan deposits that are controlled by Pliocene faults and climatic fluctuations. The old piedmont pediments are graded to old gravel terraces along the mainstreams, mostly along relatively narrow axial zones of the various basins or valleys.

These terrace gravels are coarser and better sorted than the sidestream pediment gravels, and their flatter gradient surfaces are conspicuously well preserved by old soils.

Old alluvium has a well-developed carbonate soil and desert-varnished cobble pavement developed on its surface, and the oldest, extensive, pediments and terraces are preserved beneath thick, resistant soils. Most of the old gravels also are in part cemented by shallow ground-water calcium carbonate, especially at their base where underlain by relatively impervious bedrock or lake-clay deposits. The old alluvium ranges from early Pliocene to middle Pleistocene age; the oldest high-altitude remnant gravels are as old as the Mormon Mesa surface (Machette, 1985), earliest Pliocene.

Eolian sand-dune deposits are shown in the northeastern corner of the map area and along Pahranagat Wash west of Meadow Valley Mountains on the Lincoln County geologic map (Tschanz and Pampeyan, 1970). Eolian sand and silt is transported across, and deposited on, the broad basin surfaces, but it is washed and reworked by surface water and does not conspicuously accumulate, except locally.

Young alluvium of Holocene to middle Pleistocene age constitutes the sand, gravel, and silt deposits in narrow, incised, stream channels and on at least three consistent, conspicuous, inset terraces. The young alluvium includes that of the narrow valley floors of the basin mainstreams as well as the dissection channels below the old pediments. Aggradational silt is commonly interbedded with the terrace gravels and is widely preserved on the mainstream valley floor; these aggradational deposits are associated with cyclical pluvial climates of the middle and late Pleistocene.

SPRINGS AND SPRING-CARBONATE DEPOSITS

Modern springs

A large part of the 36,000 acre-feet/year, that is, perhaps one-third of the estimated discharge of the presumed White River ground-water flow system, discharges at Muddy River springs. Muddy River springs consists of 12 springs (total discharge includes some pumped wells) that are mostly at an altitude of about 550 m but that range from just above 530 to about 555 m (fig. 3). A small amount of water also discharges ephemerally at Hogan Spring at an altitude of about 522 m, 9.5 km south-southeast of Muddy Spring. A much smaller discharge issues ephemerally from springs at an altitude of 670 to 695 m, 7 km north of Muddy Spring. The only other nearby spring is in Farrier canyon on Meadow Valley Wash; it discharges at an altitude of about 555 m, about 15 km north-northeast of Muddy Spring. Other springs, all ephemeral, in the Coyote Spring Valley area are Coyote Spring, opposite the mouth of Kane Springs Wash, and five springs adjacent to Kane Springs Wash.

Muddy River springs are at the head of the broad, vegetated Moapa Valley. The Muddy River here flows in a mature flat-bottomed valley about 2 km wide that is cut chiefly in weakly unconsolidated rocks of the Muddy Creek Formation. Reconstruction of high, dissected, carbonate-soil-crusted pediments north and south of Muddy River springs suggests that the Muddy River has incised more than 50 m since about middle Pliocene time.

The Muddy River springs are at their present location because this local area provides the lowest-altitude discharge point in the region. This discharge altitude was tectonically and erosionally produced; farther eastward, lateral flow of ground water was and is entirely restricted by the basin-fill confining layer consisting of the Muddy Creek and Horse Spring formations beneath the Upper Moapa Valley. From Coyote Spring Valley, the water level of the aquifer slopes gently east from about 557 m altitude at the Ertec well no. 5, about 554 m (precise level uncertain) at Ertec well no. 6, to about 552 m at the Muddy River springs.

These levels suggest a low gradient of 0.36 to 0.26 m/km along the intervening distance of 28 km. Two high-level springs at Muddy River springs are at 555 m altitude and may require the nearby water level to be even above 555 m, in which situation the water-level gradient may be as low as 0.087 m/km.

Spring-carbonate deposits

General statement

Upper Cenozoic spring-carbonate deposits demonstrate that large springs of carbonate water have been active at times throughout the Coyote Spring Valley area since and during the deposition of the Horse Spring Formation. These deposits include erosionally exhumed spring mounds, spring-carbonate veins and pipes, and tabular carbonate beds, all of which are well exposed in the Muddy Creek lacustrine deposits and in the Horse Spring limestone and conglomerate deposits. Some of these spring-carbonate deposits are depicted in figure 3. Through various arguments presented below, we suggest that all these deposits are associated with discharge of deep bicarbonate-ion water that presumably was ancestral to the modern White River ground-water flow system. This ground-water flow was in a bedrock configuration and beneath a surface topography that was similar to that of today since the culmination of extensional deformation during Horse Spring time (about 16-15 Ma). Some of these spring deposits are at least as young as late Pleistocene and some are at least as old as the early part of the Horse Spring Formation (about 20 Ma). The largest volume and number of the spring-carbonate deposits of all ages are concentrated in a wide zone along the present-day course of the Pahranagat Wash-Muddy River, which suggests a connection between ground-water and surface-water flow over time. It can be easily argued that this drainage line is consequent to the principal pathway of the White River ground-water flow system.

Spring-carbonate mounds

Six exhumed spring-carbonate mounds, rising slightly above the surrounding broad piedmont surface, form small resistant hills (fig. 7) between 5 and 6.5 km west of Ute (southeast corner of fig. 3) at altitudes between 650 and 700 m (fig. 3). These small mounds consist of a thin remnant caprock of resistant limestone (travertine) that overlies nonresistant lacustrine clay and silt beds of the Muddy Creek Formation. The limestone is part of the Muddy Creek Formation. The caprock is the thickest and most resistant part of an exhumed spring-carbonate deposit at a spring source or discharge point within the Muddy Creek lake. When initially discovered, these mounds were thought to be subaerial Pleistocene spring mounds deposited on an erosional surface cut on the Muddy Creek Formation. Subsequent field study, however, proved that the mounds are part of the Muddy Creek Formation because (1) no to-be-expected, calcic soil was developed beneath any of the limestone caps; (2) the mound shape is accentuated by present-day erosion, during which the carbonate bed breaks and slumps as the underlying, nonresistant clays are eroded; and (3) nearby noneroded spring-carbonate beds in the Muddy Creek Formation actually can be traced back to a source mound. A spring-carbonate mound of any late Cenozoic age in the Coyote Spring Valley area represents a discharge point of regional, bicarbonate ground water.

The small, circular, spring-mound remnant shown in figures 7 and 3 (southeastern mound) is 1.5 m thick by 25 m in diameter and has a conspicuous bread-crust structure that developed as the limestone capping slightly collapsed above the eroding underlying, soft clay and silt of the Muddy Creek Formation (fig. 7). The northeastern mound is about 3.5 m thick and at least 100 m across and has a well exposed cross section where the adjacent wash has dissected the mound. It, however, has a much more extensive carbonate apron that extends out more than 0.5 km from the spring source as an interbed within Muddy Creek lake beds but which is largely covered by surface debris and sparsely exposed. The other two exhumed mounds are close together and adjacent to outcrop of the Permian Bird Spring Formation. They are oblong in shape, are much larger (30 m wide by 100 m long), rise about 13 m above the adjacent pediment, and have a remnant spring-carbonate cap about 4 m thick.

In general, the mounds consist of a vaguely layered, massive and dense upper carbonate part that is underlain by a soft, highly porous, thinly layered lower marly part. Both parts contain carbonate molds and casts of formerly abundant plant stems and roots and algal mats, but these are especially well developed in the lower part. Smooth-faced pipes and veins were formed by spring-water flowage and were entirely or partly filled by laminated crystalline calcite. Bulbous or mammillary semi-spheres—spherical, open-space growths—were formed of concentrically laminated calcite. A local faint- to light-red, iron-oxide coloration on primary bedding and fracture planes is also characteristic. Significantly, several large, laminated spring-carbonate veins as wide as 50 cm in greenish-gray silty clay lake beds beneath both of the western mounds are the feeders for the overlying, exhumed carbonate mounds.

The four exhumed spring-carbonate mounds near Ute are within a late Tertiary fracture and fault zone cutting the highest pediment (Pliocene) in the Ute area (fig. 3). One fault of this zone cuts the high pediment surface adjacent to the northeastern spring mound and displaces nearby Muddy Creek lake beds about one meter. Such fracturing and faulting near a spring source is one bit of evidence favoring an association of fracturing and spring discharge.

The age of all four mounds near Ute is that of the Muddy Creek Formation (12 to 5 Ma). The two eastern mounds are surrounded by Pliocene pediments wherein the small but resistant, exhumed carbonate beds prevented destruction by pedimentation.

Spring-carbonate veins and pipes

Veins and less abundant pipes, both containing laminated carbonate deposits (calcite), are locally abundant in the Coyote Spring Valley area. The veins were emplaced in fractures and faults of late Tertiary and Quaternary age. Large concentrations of veins are associated with parts of some fracture-fault zones. The veins are partly or entirely filled with laminated, coarsely crystalline calcite that precipitated from warm, bicarbonate-bearing ground water on the basis that the character of the carbonate deposit is always similar and in many places can be associated with the near-surface, spring discharge of ground water. Other examples of coarsely crystalline calcite veins and fractures are of different character principally in that they are nonlaminated; these veins are found only to cut Paleozoic basement rocks and are assumed to be older and formed in a deeper environment than did the spring-carbonate veins. The spring-carbonate veins and pipes are found in Paleozoic basement rocks, the Horse Spring Formation, the Muddy Creek Formation, and alluvial deposits as young as the Pliocene, carbonate-soil-covered pediment gravels.

An excellent example of a spring-carbonate plumbing system containing abundant spring-carbonate veins and pipes is in the deeply incised canyon and adjacent pediment just east of Starvation Flat on Wildcat Wash, 1.8 km north of the junction between the abandoned US 93 and State Highway 168. The latest faulting here is early Pliocene (see Structural Geology chapter) based on the age of faulted aggradational gravel that contains spring carbonate-lined pipes as much as 20 cm in diameter and that contains sparse laminated spring-carbonate veins. In the adjacent incised canyon of Wildcat Wash, many more faults and spring-carbonate veins cut Paleozoic carbonate rocks and synextensional basin-fill deposits consisting of coarse, silty conglomerate of the Horse Spring Formation (fig. 8). Abundant laminated, coarse-crystalline carbonate filled or partly filled veins and pipes as wide as 15 cm cut the conglomerate. Some vugs and holes (ojos) in the conglomerate are lined with coarse calcite crystals as long as 2.5 cm inch that grew into open spaces.

Spring-carbonate veins and pipes are abundant in the intensely north-south faulted and altered Ordovician limestone walls of the incised Wildcat Canyon (fig. 9). The veins and pipes are as wide as 60 cm and are filled or partially filled by layers or laminae of coarsely crystalline white calcite; some layers in both the veins and pipes consist of coarse calcite crystals as long as 8 cm that grew perpendicular to the vein or pipe walls. These veins and pipes in the Horse Spring conglomerate and Ordovician limestone are probably slightly younger than the top of the Muddy Creek Formation (about 5 Ma), but minor reactivated faulting on the range-front fault of the Meadow Valley Mountains produced small spring-carbonate pipes as young as middle Pliocene age.

Other examples of spring-carbonate veins and pipes are exposed along the eastern side of the Meadow Valley Mountains, 4, 6, and 20 km north of Muddy Spring, where the veins and pipes are locally in upper Paleozoic carbonate rocks (Bird Spring Formation; fig. 10) near the range front and the contact with the basin-fill deposits.

The spring-carbonate veins and pipes, 20 km north of Muddy Spring, are in the high foothills of the Bunker Hills on the eastern slope of the Meadow Valley Mountains, 4 to 5 km (fig. 11) west of Rox. The veins fill en echelon fractures in zones extending from the bottom of the modern washes to the high peaks, a vertical distance of about 300 m. The veins may be as wide as several meters and spaced tens to several hundreds of meters apart.

Characteristic white, laminated, coarsely crystalline carbonate fills or nearly fills the veins in the Bunker Hills. The large, total amount of calcite in these veins implies a very large, long-term flow of carbonate spring water that could not have flowed in the present-day elevated topography. The laminated carbonate in the veins and pipes have characteristics of late Miocene veins and pipes and probably were active during late synextensional time (late Horse Spring Formation, 15 to 12 Ma). The uplifted bedrock exposed in the Bunker Hills formerly had access to an ancestral White River, carbonate-rock aquifer system. The Bunker Hills have been elevated at least 300 m since the culmination of extension at about 15 Ma.

Red water-course rock

Red-colored joints, faults, fractures, zones of open-work breccia, and irregular zones of closely fractured carbonate bedrock are locally distributed throughout the Coyote Spring Valley area. Commonly the open spaces in these fractured rocks are partly filled with a red carbonate silt, that is, a microbreccia or gouge derived from the nearby faulted wall rock. The reddening of these fractured rocks is caused by oxidation of iron impurities within the limestone or dolomite rocks. The microbreccia is commonly intensely reddened owing to the oxidation of sparse iron impurities within the innumerable fine particles. These reddened rocks or rock zones are herein called *red water-course rock*, and they imply the passage of large volumes of warm, oxidizing ground water. This ground water is probably similar to the warm, bicarbonate ground water discharging at Muddy River springs today. This modern ground water of the White River flow system is known to be oxidizing and, so too, it is assumed that the ancient ground waters of the ancestral White River flow system were oxidizing.

When large volumes of even slightly oxidizing ground water react with iron-bearing mineral impurities within carbonate bedrock, the iron may be oxidized red and cause the reddening of the carbonate rock described above. Because the oxygen content of the ground water is low (a few mg/l), because the iron-mineral impurity in limestone and dolomite is commonly low, and because the reactivity between the iron and oxygen is probably slow, very large volumes of ground water are needed to redden the carbonate wall rock. This further implies that only the highly permeable parts of the carbonate bedrock that conduct large volumes of ground water will be reddened and become *red water-course rock*.

Evidence does not exist for an alternative proposal that the red material consists of reddened clay minerals dissolved from the carbonate rock and concentrated as films on fracture walls or as fillings in fractures and open-work breccia in the carbonate rock. In fact, solution features in the carbonate bedrock of the area are nonexistent or exceedingly minor; solution does not contribute to rock porosity in the Coyote Spring Valley area.

A good example of red water-course rock is a small red canyon cut in the Bird Springs Formation near its contact with the Muddy Creek lake beds, 6.4 km north of Muddy River springs. The red canyon is eroded along a north-striking fault zone about 30 m wide and 300 m long as exposed. This reddened zone contains large lenses of reddened fault breccia and gouge of tectonic origin (fig. 12) and contains many open-work fractures indicative of high permeability and of the former flow of large volumes of ground water. Spring-carbonate veins and pipes are abundant in and around the red canyon site.

Tabular spring-carbonate beds

Tabular beds of white limestone of lacustrine origin are locally abundant in the Coyote Spring Valley area within the Horse Spring Formation, Muddy Creek Formation, and deposits younger than the Muddy Creek. These beds range from one to tens of meters thick and in carbonate-rock sections as thick as 75 m (fig. 13). Interbeds of lacustrine clay, silt, and volcanic ash are highly calcareous, commonly gypsiferous, and are white or cream colored because of their large component of disseminated calcite. Below these carbonate sections commonly are red-brown clay and silt beds, as for example those that characterize the Muddy Creek Formation. Traced laterally, the thickness of individual carbonate beds tapers to zero over distances from a few hundred meters to several kilometers, and individual successions of carbonate beds intertongue and pinch out over similar or somewhat longer distances. Individual beds and successions of carbonate beds grade laterally into the red-brown lake beds. Some carbonate beds are massive and dense on field examination, and under the mask of the white weathered carbonate do not reveal internal sedimentary structures. These dense limestone beds grade vertically and laterally into white, powdery weathered, gypsiferous, calcareous-rich clay, and silt beds and eventually grade into red beds. The vertical change may be abrupt across centimeters or gradational over meters or tens of meters, but most generally the more gradual gradations relate to thick individual beds or thick successions of carbonate beds; that is, more gradation relates directly to more total carbonate content in any one bed or succession.

In many places, the thickest part of any one carbonate deposit can be assessed to be a spring-water discharge point, and we conclude that most or all the upper Tertiary carbonate deposits in the Coyote Spring Valley area have a bicarbonate ground-water source. Furthermore, we suggest that most of or all this spring discharge is from the regional ground water (White River flow system) because the commonly large volumes of carbonate precipitate require a voluminous ground-water source. Therefore, the distribution of the carbonate deposits shows the distribution of carbonate aquifer discharge during late Tertiary time and the volume of carbonate at any one locality is proportional to the volume and length of time of bicarbonate ground-water discharge.

The spring sources are areas tens of meters to 100 m across that show various criteria indicative of spring deposition, namely: (1) wavy, laminated, dense carbonate layers alternate with porous, open-space layers—these characteristics seem directly related to prolific plant and algal-mat growth; (2) some porous layers, one to many centimeters thick, contain abundant casts and molds of plant fragments and roots and in places delicate thin-walled, soda-straw-size tubelets; (3) carbonate pipes and short veins filled with laminated crystalline carbonate cut the tabular carbonate beds; (4) bulbous or mammillary growths of laminated carbonate, as large as 15 cm in diameter, occupy space in some open-space fractures and veins; and (5) sparse amounts of red iron oxide redden some parting planes and fracture surfaces or more rarely coat the interlaminae surfaces of veins. Most of these criteria are indicative of spring discharge of super-saturated bicarbonate ground water. The really tabular carbonate beds indicate spring discharge in a shallow lake environment. These criteria are identical to those present in the exhumed spring-carbonate mounds in the Ute area, as described above. This similarity affirms the identity of the small Ute mounds as the discharge points for the spring-carbonate beds, where most commonly only the thicker, more resistant source-mound part is preserved or exposed.

Criterion no. 3 listed above contains additional evidence for a spring source. Where the carbonate pipes and veins have open interiors commonly 1 to 30 cm across or wide, the walls are smooth-faced and composed of fine-grained crystalline calcite; this calcite suggests slow accumulation from rapidly flowing, warm ground water. On the other hand, the open-space growth of radial, coarse calcite crystals on walls of the pipes and veins suggests accumulation from slow flowing or even nearly stagnant ground water. The coarse crystal layers consist of parallel crystals as long as 4 cm that grew perpendicular to the pipe or vein wall and are sparsely interspersed between the more characteristic and abundant, finer-grained, but still coarse-grained, laminar carbonate filling.

A good example of a spring source for the carbonate beds in the slightly-younger-than Muddy Creek lake beds is at Hogan Spring, where a deformed (attitude of N. 65° E., 11° SE.) tabular carbonate bed is about 2 m thick and has most of the spring-center criteria listed above. One bed contains an open, laminated-carbonate-lined distributary canal about 0.6 m wide, 0.25 m deep, and exposed for a length of 30 m. The canal and its walls contain numerous, smooth-faced, laminated-carbonate-lined secondary distributary pipes, as much as 15 cm in diameter; laminated-carbonate spherical growths, as much as 13 cm in diameter; algal mat structures; and abundant casts and molds of plant fragments and roots (fig. 15). Other similar distributary canals are associated with other tabular carbonate beds at other levels in this thick carbonate-bed succession. The ancestral ground-water feeder for these canals are a zone of faults slightly younger than the top of the Muddy Creek Formation (about 5 Ma).

At White Narrows (downstream from Muddy River springs; fig. 3), many thick-layered, tabular carbonate beds are exposed in a succession thicker than 40 m that has an eroded top and a base below river level. Some carbonate beds show many of the above spring-source criteria. The succession of beds is deformed to an attitude of N. 15° W., 10° SW. and the west side of the large outcrop is a large north-striking fault that juxtaposes the red lake beds of the Muddy Creek Formation against the full thickness of the exposed carbonate section. Parallel fractures to this fault were the ground-water conduits for deposition of the carbonate beds.

Another excellent example of spring-source carbonate beds is on Wildcat Wash, north and south of the junction of abandoned US 93 and Highway 168, where across an area of about 1 km west-northwest by 3 km north-northeast, a succession of tabular carbonate beds more than 60 m thick pinches out, intertongues with, and grades into a comparable thickness of pale-red lake beds. This carbonate section in Wildcat canyon unconformably overlies fractured and carbonate veined, Horse Spring conglomerate above the well-exposed plumbing system of spring-water flow pipes and spring-carbonate veins in highly fractured and faulted limestone of the Ordovician Pogonip Group.

The largest volume and thickest section of tabular spring-carbonate beds is in the Muddy Creek Formation, centered at Table Mountain, where the exposed section is 75 m thick (fig. 13) but where the spring source has not been directly identified. The spring source most likely is in or near the highly deformed Mississippian limestone in the westernmost part of Arrow Canyon.

Cementation occurs beneath the surface, generally near the base of the clastic bed above an impervious layer where shallow ephemeral ground water transports in solution the carbonate cementing agent. The carbonate cement is most commonly very fine-grained calcite that suggests cool, ambient-temperature precipitation. Possible sources of the carbonate in these shallow aquifers are: (1) shallow ground water locally derived from upstream Paleozoic carbonate bedrock, (2) authigenic carbonate from clasts of Paleozoic limestone and dolomite within the sand and gravel deposit, (3) pedogenic carbonate carried down through the vadose zone by rainwater (here the ultimate source may be eolian carbonate silt and bicarbonate ions in raindrops), or (4) bicarbonate-ion ground water that leaked up into the shallow aquifer from the deep, warm carbonate-rock regional aquifer (White River aquifer system). A combination of all or some of these sources may be involved in the cementation of any one deposit. The first three sources are probably more significant in the Coyote Spring Valley area during wetter-than-present (pluvial) climatic times, whereas the deep aquifer source (no. 4) is probably most significant near and downstream from discharges of the regional ground water.

In addition to these Pliocene and Pleistocene calcretes, by far the largest carbonate-cemented calcrete deposit in the Coyote Spring Valley area in terms of areal extent, thickness, and overall volume of carbonate cement is the carbonate-cemented, silty conglomerate of the Horse Spring Formation. The Horse Spring Formation is well exposed in near-vertical, 90-m-high cliffs and in sections more than 120 m thick at Hoya in Meadow Valley Wash. The conglomerate beds are exposed southward along the Wash to south of Farrier canyon and westward to Wildcat Wash near the west range front of the Meadow Valley Mountains. In places throughout this large area, the Kane Wash tuff (15 to 14 Ma) is interlayered in the conglomerate. In places where some spring-carbonate veins cut the Horse Spring conglomerate, coarsely crystalline white carbonate also cements the gravel clasts; this cement grades away from the vein area into aphanitic carbonate cement and farther away into normal diagenetic cement. The coarsely crystalline cement was precipitated directly from warm, deep ground water and presumably much of the aphanitic carbonate cement was precipitated from the same, but diffused and cooled, deep ground water. It is reasonable to assume that large amounts of deep-aquifer carbonate contributed to the cementation of large parts of the Horse Spring gravels and that, once consolidated, the conglomerate was extensionally fractured such that spring-carbonate veins could be emplaced—all during late Horse Spring time (20 to 12 Ma). Most of the carbonate may have come from the White River aquifer, as did the carbonate in the line of abundant carbonate veins and pipes presently discontinuously exposed and uplifted high above the Horse Spring depositional basin for 18 km along the eastern Meadow Valley Mountains, from north of Muddy River springs to the Bunker Hills.

Carbonate soil

Carbonate soil is pedogenic, secondary carbonate abundantly accumulated in a K-horizon in place of the calcic B-horizon of less arid soils (Gile and others, 1965, 1966; Machette, 1982; Bachman and Machette, 1977). Detailed study of the carbonate abundance in these calcic-rich soils indicate Pleistocene and Pliocene age estimates of the underlying deposits (see above references). A useable detailed calibration study has not been done in the study area, even though an original test using carbonate abundance in carbonate soils to determine age was done at Overton, about 30 km downstream (southeast) of Muddy River springs (Gardner, 1972b). However, approximate estimates of early, middle, or late Pleistocene ages of carbonate soils are made in this report based on personal experience with, and observation of, carbonate soils that have been dated elsewhere (Machette, 1982).

The distinction between a soil carbonate and a spring-carbonate bed or mound (and also, an eroded calcrete deposit) is critical to the evaluation of the spring-carbonate deposits in the Coyote Spring Valley area; this distinction can be complicated by increasing age and burial of both types of deposits. Criteria for the detailed identification and classification of calcic soils can be found in Gile and Grossman (1979) and Bachman and Machette (1977). Suffice here to indicate that the distinction of spring- and soil-carbonate in our reconnaissance study was not a problem.

STRUCTURAL GEOLOGY

Introduction

The structural features of the Coyote Spring Valley area were formed during two episodes of deformation, first, during the late Mesozoic to early Tertiary compressional Sevier orogeny, and second, during the Miocene to Holocene extensional basin-range tectonism. Structures older than the late Mesozoic have not been found, but several significant erosional disconformities in the Cambrian to Triassic sedimentary record and less obvious changes in rates of sedimentation suggest that mild to moderate vertical epeirogenic processes had been active in the region. Except where noted, most of the compressional and extensional structures depicted on figure 2 and the discussion herein are from the Clark County and Lincoln County geologic reports (Longwell and others, 1965; Tschanz and Pampeyan, 1970; Ekren and others, 1977); more recent interpretations are taken chiefly from Wernicke and others (1984).

Sevier orogeny

The Coyote Spring Valley area is entirely within the northeast-trending Sevier orogenic belt, more generally named the Mesozoic foreland thrust belt, that includes Lincoln and Clark counties. Sevier compressional transport was directed toward the east and southeast. The map area is approximately bounded by the Gass Peak thrust fault in the Las Vegas Range on the west and by the Glendale-Mormon thrust faults located just off the map area on the southeast and east. The Dry Lake thrust fault (R.L. Langenheim, Jr., written commun., 1985) divides the Arrow Canyon Range. The Gass Peak thrust abruptly places Late Proterozoic Stirling Quartzite over Permian-Pennsylvanian Bird Spring Formation, which is moderately overturned in the lower plate near the thrust and openly folded farther east of the thrust. The Dry Lake thrust in Cambrian and Ordovician carbonate rocks is a thrust-broken, overturned anticline (nappe) in which Ordovician, Silurian, and Devonian rocks are sharply overturned in the lower plate near the thrust and in which Mississippian, Pennsylvanian, and Permian rocks are steeply tilted to openly folded farther east of the thrust (fig. 16).

Broad, open synclines, complimentary to the thrusts, lie west of the Gass Peak thrust in the Sheep Range and west of the thrusted anticline of the Dry Lake thrust in the Arrow Canyon Range. Small-displacement thrusts and overturned folds further deform parts of the Bird Spring Formation in the northeastern Las Vegas Range. In the eastern Meadow Valley Mountains, the clastic rocks of the Triassic Moenkopi and Chinle formations were openly folded during the Sevier orogeny.

Horizontal displacement on the Gass Peak thrust may exceed 30 km and it stratigraphically ramps across 5,900 m of section (Wernicke and others, 1984, p. 482). Horizontal displacement on the Dry Lake thrust is much smaller insofar as parts of the fold geometry of the early-formed nappe structure can be reconstructed in the 640 m of section involved in the thrust.

The age of Sevier thrusting in southern Nevada ranges from Late Triassic (>200 Ma) to Late Cretaceous (95 Ma) (Wernicke and others, 1984). The area east of the Gass Peak thrust in the Coyote Spring Valley area is part of the Keystone-Mormon Mountains thrust plate, which was deformed during the Keystone-Muddy Mountains-Glendale thrusting about or somewhat older than 95 Ma. The Gass Peak thrust, correlated with the Wheeler Pass thrust of the Spring Mountains, is of Early Cretaceous to Late Triassic age.

Basin-range structure

Regional extension

The Coyote Spring Valley area has a characteristic basin-range topography formed during late Tertiary extensional tectonism in southern Nevada (Wernicke and others, 1984). Horizontal extension on a mid-crustal, low-angle detachment fault caused the brittle upper crust to break along large high-angle faults and to form the characteristic north-trending ranges and basins. Differential horizontal extension between major areas or regions of detachment caused vertical, transverse shear zones (transform faults, strike-slip displacement) to form between these areas of relative differential movement. The Coyote Spring Valley area is located between two such transform systems, the northwest-striking, right-lateral, Las Vegas Valley shear zone to the south and the northeast-striking, left-lateral, Pahranagat shear system to the north. The latter system includes the strike-slip zones of Kane Springs Wash and of Maynard Lake, which together bound the Delamar Mountains. The components of strain on these two shear zones suggest overall east-west extension within the intervening wedge-shaped region, and the large north-striking range-front normal faults of the Arrow Canyon Range and Meadow Valley Mountains are in accord with this movement.

Proposed wide zones of extensional deformation in the Mormon Mountains and Muddy Mountains to the east and in the western Sheep Range to the west suggest that the Las Vegas Range, Arrow Canyon Range, and Meadow Valley Mountains form a comparatively stable intervening terrane in the intervening area (Wernicke and others, 1984, p. 489). This stable terrane, stable relative to the much more extended (100 percent?) Mormon Mountains and Sheep Range, accounts for the relatively simpler extensional structures and less disrupted stratigraphy in at least parts of the Las Vegas Range, Arrow Canyon Range, and Meadow Valley Mountains. The age of culmination of extensional tectonism in the region around the Coyote Spring Valley area is about 16 to 15 Ma (Schmidt, 1988; R.G. Warren and D.A. Sawyer, written commun., 1991).

The few Quaternary faults and fractures (2-0 Ma) in alluvial deposits younger than the Muddy Creek Formation, and the small, localized deformation (about 5 Ma) of the Muddy Creek lake beds in the Coyote Spring Valley area suggests that regional extension has been slight since Horse Spring (synextensional) time (about 12 Ma).

High-angle normal faults

High-angle normal faults account for all the extension in the exposed parts of the ranges of the Coyote Spring Valley area. The large range-front fault on the western side of the Arrow Canyon Range displaced the range front stratigraphically up about 1,200 m along the line of cross section (fig. 16). Several normal faults in the central part of the range increase this stratigraphic displacement another 450 m. The combined calculated vertical displacement across the entire vertical normal fault zone is 1,600 m. Most of the range-front strata dip 20 to 30 degrees east, but most of this dip can be accounted for on the eastern limb of a large, broad, open anticline that is complimentary to the broad, open Arrow Canyon syncline west of the overturned and thrusted anticline of the Dry Lake thrust. That is, much of this dip is accounted for by Sevier folding. If 10 degrees is assumed to be late Tertiary extensional rotation on the range-front fault, then the rotated Arrow Canyon block would be 6.5 to 8 km wide and the rotational extension would be only about 3 percent, which seems small. In general, the concept of a Las Vegas Range-Arrow Canyon Range-Meadow Valley Mountains stable terrane allows only for differential horizontal movement on a mid-crustal, low-angle detachment fault.

The cross section of figure 16 does not show the abundant narrow blocks and slivers, as wide as 100 m, that step down the steep Arrow Canyon range front. These common step faults do not appreciably affect the overall geometry of the range-front faults, as shown in figure 16.

Examination of Landsat images of the Coyote Spring Valley area suggests that the Arrow Canyon range front in map view consists of a series of en echelon (curvilinear in plan view), range-front faults about 4 to 5 km long. These curvilinear faults suggest that the range front deformed on deep-seated, high-angle listric faults. Examination of the whole Coyote Spring Valley area further suggests that en echelon segments of the other ranges are rotated on curvilinear faults in map view and suggests that they too are rotational, deep, steeply dipping, high-angle, listric faults.

A secondary set of high-angle to vertical normal faults and fractures strike obliquely, from N. 60° W. to N. 60° E., across the north-trending ranges. These oblique fractures have zones of brecciation and breccia filling of less than a meter to many meters wide depending on the amount of displacement on the fault and the physical character of the wall rock. This displacement ranges from less than one meter to many meters per fault, and many oblique faults may have a strike-slip component. Porous, open-work breccia fills many of these faults and fractures, and in some places, open fractures are filled with laminated spring-carbonate veins and show other evidence of the former flow of deep ground water. For example, such spring-carbonate-filled fractures are well exposed on the uplifted east slope of the Bunker Hills, west of Rox.

Strike-slip faults

Components of strike-slip displacement on some of the high-angle normal faults within the Coyote Spring Valley area are significant, but too few reliable measurements have been made to estimate the collective effect. Strike-slip movement might be expected on some of the oblique-to-range-front faults. Some strike-slip movement might be expected as well on other north-striking, high-angle faults. An unusual observation of strike-slip movement in the Bunker Hills west of Rox at the Texaco well site was on a single highly polished fault plane having an attitude of N. 10° E., 80° NW. and having striations plunging 5° N.; this single plane, however, is only part of a wide zone of gouge in which a large vertical displacement has taken place.

Deformation of the Muddy Creek Formation

The Muddy Creek Formation is deformed where Pliocene and Pleistocene faults transect the formation (fig. 17). Syndepositional deformation has not been observed. The lack of internal deformation within the Muddy Creek Formation supports the supposition that Muddy Creek lake basins represent a tectonically quiet time following rapid middle Miocene extension (Horse Spring time). A small amount of extensional deformation might not be easily recognized in the soft lake beds but some such slight deformation might be suggested by the abundant spring-carbonate deposits in parts of the Muddy Creek; the ground-water conduits for these deposits required at least some minimal, continued fracturing.

Cursory observation of the Muddy Creek lake beds in the Coyote Spring Valley area, such as viewed from the roads through the area, suggests that the Muddy Creek is flat lying; reconnaissance evaluation, however, is difficult because most of the erosional slopes of lake-bed exposures are covered by a thin, pink, gypsiferous clay crust (wash coat) that commonly masks the underlying bedding. Detailed examination of exposed Muddy Creek lake beds, however, shows that about 5 percent of the formation is deformed in many small rotated blocks having bedding dips that range from slight to rarely as much as 35 degrees. These blocks are bounded by small normal faults of highly variable dips, which range from vertical to 45 degrees, and strikes. The deformed Muddy Creek is commonly aligned in zones of through-going, north-striking faults exposed for as long as 6 km and from a few tens of meters to 1 km wide. In a few places where these fault zones cross Pliocene piedmont surfaces, they are represented by surface fractures and fault scarps as high as 3.5 m. Because few of the faults displacing the Muddy Creek lake bed also displace the younger, Pliocene piedmont surfaces, most of the Muddy Creek faulting must be early or even earliest Pliocene age.

The principal exposed areas of the restricted deformation of lake beds in the Coyote Spring Valley area (fig. 3) are at: Hogan Spring, where bedding dips are as much as 25 degrees and fault-plane dips are as low as 45 degrees (figs. 17 and 18); White Narrows, where bedding dips are as much as 10 degrees and fault-plane dips are nearly vertical; Table Mountain, 1 km south of the mouth of Wildcat Wash, where bedding dips are as much as 32 degrees and fault-plane dips are as low as 80 degrees; Wildcat Wash, north of Highway 168, where bedding dips are as much as 33 degrees and fault-plane dips are as low as 65 degrees; Double Canyon, where bedding dips are as much as 7 degrees and fault-plane dips are as low as 80 degrees; Starvation Flat, 0.5 km northeast of Ertec well no. 5, where bedding dips are as much as 15 degrees and fault-plane dips are as low as 65 degrees (fig. 19); Starvation Flat, 2 km northwest of Ertec well no. 5, where bedding dips are as much as 16 degrees; and Starvation Flat, 3 km southwest of Ertec well no. 5, where bedding dips are as much as 35 degrees.

Pliocene-Pleistocene fractures and faults

North-striking fracture alinements and fault scarps are visible on a few Pliocene-Pleistocene piedmont slopes in the Coyote Spring Valley area. This fracturing is younger than the stable pediments of Pliocene age that deeply erode the Muddy Creek lake beds to nearly their modern configuration; this faulting is about middle Pliocene or younger in age. Only in one place is fracturing seen to slightly displace alluvium of late Pleistocene age. Oblique fractures cutting piedmont alluvium as yet have not been seen. Three noteworthy late-faulting localities (fig. 3) are: (1) west of Ute, (2) between Hogan Spring and Byron (a railroad stop about 3 km south of Hogan Spring), and (3) the eastern part of Starvation Flat. The few most conspicuous alinements are fault scarps, 1 to 6 m high, that displace soil-carbonate-crusted pediment gravel of Pliocene age. Most north-trending alinements without observed displacement are much easier seen on aerial photographs than on the pediment surface itself, but some of these fractures without exposed scarps have been traced to the banks of incised washes, where displacements of 1 or 2 m can be observed. Reconnaissance observation and mapping of these fractures and faults is greatly aided by broad, nondissected areas of old (Pliocene) pediments. In all the areas, Pliocene to Pleistocene fracturing is associated with still older deformation and with spring-carbonate deposits in post-Muddy Creek, Pliocene lake beds.

The fractures and faults in the west-of-Ute location form two sets, each about 3 km wide and about 11 km long, but some fractures and faults have been observed to extend at least another 8 km to the south across Interstate Highway 15. These fracture sets were mapped by Ealey (1966), whose geologic map has been used with slight modification on figure 3. The eastern set is more conspicuous, and actual scarps can be seen readily. Actual displacements can be measured on some of the faults, especially in the southern part of the Ute area. Some fault pairs on the pediment surface make small graben structures, 1 to 6 m deep, 90 to 200 m wide, and 300 to 900 m long (Ealey, 1966), and suggest that extension is involved. Adjacent to the northeastern spring-carbonate mound (fig. 3), the Muddy Creek lake beds are displaced about one meter and on the opposite bank of the adjacent wash, the soil-carbonate crust on the pediment is likewise displaced about 1 m. The youngest age of the faulting in the Ute area is much younger than the Pliocene age of the high pediment, the age of which is estimated from the thick carbonate soil developed on its gravel deposit. A few fractures cross young, lower inset terraces, and at one place Holocene(?) gravel may be disturbed.

Along the Byron-Hogan Spring fault zone, a distinct 3.5-m-high fault scarp extends for about 1.6 km along the old pediment surface (fig. 20) to where the pediment is destroyed by deep dissection of the underlying Muddy Creek lake beds. Many more and larger, older faults in the same fault zone are exposed below the pediment in the dissected area, where white spring-carbonate lake beds of early Pliocene age are juxtaposed against red clayey beds of the Muddy Creek Formation. The fault scarp, down to the east, on the pediment is well preserved by the resistant, about-one-meter-thick, weathered and eroded, carbonate soil that forms the top of the pediment. The latest movement on the fault is younger than the carbonate-soil crust, but because the gentle sloping fill beneath the fault has only a weak carbonate soil, the faulting may be of Pleistocene age. In places the scarp branches into two smaller fault scarps, and at one place an opposing fault forms a shallow graben.

At the Starvation Flat locality, the fractures cutting the high piedmont alluvial surface are not as well exposed as at the eastern localities. However, an excellent example of a Pliocene-Pleistocene fault juxtaposes Pliocene gravel against the Muddy Creek lake beds at a highway borrow pit 1.4 km north of the junction of abandoned US 93 and State Highway 168. The down-to-west normal fault has an attitude of N. 5° E., 65° W. and has a displacement much greater than the 2.5-m-deep pit. The down-dropped western side of the fault is filled with erosional debris from the eastern side of the scarp, and the faulted outcrop has been regraded to the surface of the high Pliocene pediment. The carbonate soils on the pediment, the fill below the fault scarp, and the regraded gravel are not well preserved at the fault, so that any Pleistocene displacement has not been determined.

HYDROGEOLOGIC DISCUSSION

Stratigraphic aquifer and confining-layer rocks

The deep White River ground-water flow system as defined by Mifflin (1968; see also Eakin, 1966) underlies the entire Coyote Spring Valley area. Below we examine the Paleozoic stratigraphic column looking for specific formations through which significant quantities of ground water might be transmitted. The low gradient of the top of the static water level of the aquifer system between the Ertec well no. 5 in Starvation Flat and Muddy River springs is 0.2 to 0.4 m/km (1 to 2 feet per mile), if the direct distance more or less beneath Highway 168 is assumed. Along this possible pathway, the ground water transects complexly faulted Ordovician to Permian carbonate rocks and at depth probably transects Upper Cambrian limestone and dolomite as well. This low gradient through these deformed rocks suggests that aquifer permeability is (1) independent of any one set of formations of the post-Middle Cambrian Paleozoic rocks and (2) dependent on the complex fault network that extensionally deforms these rocks. Therefore, throughout the Coyote Spring Valley area, the Paleozoic section, consisting of about 4,600 m of predominantly carbonate rock, must be considered a potential aquifer. This aquifer system receives most of the ground water entering the Coyote Spring Valley area from the north, from the White River ground-water flow system. We herein refer to this segment of the flow system as the Coyote Spring Valley aquifer system.

The low-gradient Ash Meadows aquifer system of Nye County is analogous to the Coyote Spring Valley aquifer system. The Ash Meadows system is sharply channeled and bounded between large structural blocks and stratigraphic layers that are either confining layers or aquifers to ground-water flow. Three confining layers are defined by Winograd and Thordarson (1975). They are the Cambrian and Late Proterozoic clastic rocks, Upper Devonian and Mississippian clastic rocks, and thick sections of Tertiary volcanic rocks. The three rock stratigraphic layers are defined by these authors as the lower, middle, and upper confining layers. By analogy in the Coyote Spring Valley area, the middle confining layer is mostly missing or very thin and is represented instead by Upper Devonian and Mississippian carbonate rocks except in the northernmost Meadow Valley Mountains, where the Upper Mississippian Chainman Shale thickens to nearly 300 m (Duley, 1957). Accordingly, the entire Paleozoic section exposed in the Arrow Canyon Range and all that is exposed in the Meadow Valley Mountains, except in the northern part, is a potential carbonate-rock aquifer, herein called the Coyote Spring Valley aquifer.

A lower, clastic confining layer of Late Proterozoic and Lower Cambrian clastic rocks everywhere makes the deep base of the Coyote Spring Valley aquifer system and must exist beneath the Coyote Spring Valley area. In the area, the regional north and south plunge of the Paleozoic rocks brings this lower confining layer near the surface in the central Arrow Canyon Range at about latitude 36°39' N., both along the western range front and in the interior along the Dry Lake thrust (figs. 2 and 16). At both places the Cambrian Nopah Formation is exposed at the surface, which suggests that the Lower Cambrian clastic rock may be about 1,000 m or more below the exposed Noah. Likewise, at both places, ground-water flow must be somewhat restricted, but by no means is flowage blocked. Radially out from both these places, the Paleozoic carbonate section is thick, so that the two local shallowings of the Precambrian-Cambrian confining layer along latitude 36°39' N. can hardly seriously effect the flow of ground water through the Arrow Canyon Range.

An upper confining layer of Tertiary volcanic rocks does not exist in the Arrow Canyon Range nor in the Meadow Valley Mountains except in the northern part of the Meadow Valley Mountains (northeast corner of fig. 2). Likewise, few volcanic rocks underlie the basin fill in Coyote Spring Valley area except to the north, so that a volcanic upper confining layer does not exist in the study area. Instead, a basin-fill confining layer is an important uppermost impervious unit especially in the basin east of the Arrow Canyon Range. This confining layer consists of thick lake-bed clays and silts of the Muddy Creek Formation and probably most of the thick section of well indurated silty conglomerate of the Horse Spring Formation below the Muddy Creek. The lake-bed clays make an excellent and impervious layer that is not easily made transmissive by faulting and fracturing. The basin-fill confines the Coyote Spring Valley aquifer system below Coyote Spring Valley and causes the ground water to flow deep enough to be heated to about 32°C. Continued eastward flowage of this ground water through the Arrow Canyon Range and Meadow Valley Mountains is then laterally blocked by the deep basin-fill confining layer in the Upper Moapa Valley on the east side of the Arrow Canyon Range, where, instead of being diverted deep beneath the basin fill, the warm ground water discharges at Muddy River springs.

The alteration effects of magmatic intrusion beneath the Kane Springs wash caldera complex (in Kane Spring Wash adjacent to the northern border of fig. 3; Ekren and others, 1977) may have sufficiently altered and sealed a very large volume of the underlying carbonate-rock aquifer system to effectively keep the White River flow system to the west of the central Delamar Mountains and northern Meadow Valley Mountains, that is, well west of the Kane Springs Wash caldera complex.

Rock fracture and permeability

Primary matrix permeability is low in Paleozoic carbonate rocks that are extensively and well exposed in little weathered outcrops, such as in Arrow Canyon and many other small canyons on the steep range fronts of the Arrow Canyon Range and Meadow Valley Mountains. Where observed, secondary permeability related to compressional structures of the Sevier orogeny is also low, in that highly sheared rocks of both major and minor compressional structures invariably are well reconsolidated and self-cemented and show little or no evidence of former ground-water flowage. Even the highly brittle Devonian and Ordovician quartzite beds, where faulted, contain a well graded breccia that is well recemented by its own silica gouge. We conclude that the Paleozoic rocks of the Coyote Spring Valley aquifer have little or no primary matrix permeability and little or no secondary permeability caused by Sevier compressional shear. A.M. Preissler (written commun., 1985) concluded the same from his field study of the permeability and porosity of these rocks.

High permeability in the Coyote Spring Valley aquifer system must be caused entirely by late Tertiary extensional fracturing and faulting. In recent years, specialists in the study of fractured rocks have emphasized the importance of fracturing in producing secondary permeability (for example, Mandelbrot, 1982; Long and Witherspoon, 1985) and more specifically fracturing in extensional terranes (for example, Barton, 1985). Montezar and Wilson (1985) at Yucca Mountain, southern Nevada, have shown that "measured fracture-network permeabilities in some areas are six to seven orders of magnitude greater than rock matrix permeabilities" (Barton, 1985). For the same general area, "hydraulic conductivities of fractured densely welded ash-flow tuff in the saturated zone are three to eight orders of magnitude greater than matrix hydraulic conductivities of the same rock" (Winograd and Thordarson, 1975; see also Scott and others, 1983).

For good permeability, fracture networks in Paleozoic carbonate rocks must contain abundant open fractures that are interconnected. Once formed and filled with water, the ground water establishes a specific flow regime through the fracture network depending on the distribution and openness of fractures. At the earliest stage of establishing flow after a fracturing event, the ground-water flow may actually transport and deposit locally some fine breccia and in effect clean the flow path and locally improve the flow rate. On the other hand, we find that ground-water solution along the flow path is not evident and, thus, flow enhancement through dissolution of carbonate bedrock is not likely. In contrast to fractured Paleozoic carbonate rocks, fractured Paleozoic clastic rocks generally preserve little or no open-work-fracture permeability, so that fractured clastic rocks have low permeability. Extensional fracturing of shale and quartzite commonly produces highly comminuted and well graded breccia that tends to readily consolidate into a self-sealed, deformed rock. Therefore, for the most part, these clastic rocks, even when fractured, remain confining layers, such as the lower clastic confining layer of the Coyote Spring Valley area. However, the thin quartzite beds of Devonian and Ordovician age in the Paleozoic carbonate rock aquifer of the Coyote Spring Valley area, even though clastic stratigraphic units are too thin to cause effective layer confinement within the Coyote Spring Valley aquifer.

Spring-carbonate deposits and recurrent fracturing

Saturated bicarbonate ground water flowing beneath a discharge point in a regional aquifer may precipitate carbonate in veins and pipes within the fractured rock, so that the overall system tends to self-seal itself. For continued flow, either new fractures must be continually opened or old fractures must be continually widened. The recurrent fracturing and widening process is well represented by the multiple cyclical laminations seen as distinct to subtle variation in color and crystal size of the carbonate precipitated in the veins and pipes below regional spring discharge sites.

In the Coyote Spring Valley area, springs and spring-carbonate deposits that formed during deposition of the Horse Spring and Muddy Creek formations and during the subsequent 5 m.y. to the present day, are closely associated with late Cenozoic fractures and faults. Continuous faulting and spring-carbonate deposition at any one site throughout the 20 m.y. existence of the Coyote Spring Valley aquifer system is not to be expected. Rather, springs and spring-carbonate deposition moved from one favorable site to another as zones of faulting and fracturing changed position or as erosion or faulting lowered the discharge altitude of one site in contrast to another. Even though evidence for an association and timing of spring discharge and faulting at any one site is rarely well preserved, the association when examined throughout the Coyote Spring Valley area is positive and convincing.

Present-day Hogan Spring, which lacks visible, modern spring-carbonate deposits, is a minute remnant of a mighty system of spring discharge that once deposited tens-of-meters of carbonate rock and white marly sediments for more than 10 km (one huge spring-carbonate mound) along the wide, north-striking fault zone along which faulting deformed the underlying red beds of the Muddy Creek Formation. Penecontemporaneous fracturing and tabular carbonate-bed deposition slightly younger than the Muddy Creek Formation can be inferred in this Hogan Spring zone, where a vertical succession of spring-water distributary canals required renewed nearby fracturing of each successive carbonate bed as the carbonate-bed succession itself thickened upward (fig. 15). This Hogan Spring zone of faulting and spring-carbonate deposition signifies the end of relative deformational quiescence during Muddy Creek time and identifies a brief time of renewed extensional faulting (a last gasp). The very different sediment products of the Horse Spring Formation and Muddy Creek Formation must indicate relative fault quiescence during Muddy Creek time relative to excessive faulting during Horse Spring time.

The time interval (about 4 m.y.) since the Hogan Spring faulting has been one of post-extensional stability, during which basin-range faulting has been slight and erosion of the little consolidated Muddy Creek lake beds has been extensive, but during which time the Coyote Spring Valley aquifer system has continued to discharge at favorable topographic, structural, and stratigraphic sites. In the region, the Colorado River first began to flow through the Lake Mead area about 5 m.y. ago and since then the tributaries to the Colorado River within the Great Basin have become extensively integrated, deeply incised, and deeply dissected into the soft upper Tertiary basin fill (Horse Spring and Muddy Creek formations). In the Coyote Spring Valley area, the Muddy Creek depositional basin was integrated to the Colorado River system and the basin-fill deposits have been dissected and eroded; in places more than 150 meters of Muddy Creek lake beds have been removed by processes of bad-land erosion and pedimentation.

The abundant spring-carbonate veins and pipes in limestone in the Bird Spring Formation on the eastern slope of the Bunker Hills indicate abundant aquifer paleo-discharge along this range-front fault zone during Horse Spring time. These veins and pipes are exposed because the Bunker Hills have been uplifted more than 300 m since Horse Spring time. Additional localized paleo-discharge is recorded southward, extending to Muddy River springs along this same range-front fault zone, where uplifted and erosionally exposed spring-carbonate veins and pipes are somewhat less abundant but also probably of Horse Spring age. Several conspicuous, red water-course rock zones in north-striking fault zones in the Bird Spring Formation formed along former ground-water channels that were beneath the shallow zone of spring-carbonate-veins below discharging paleosprings active during Horse Spring time.

Muddy River springs, the present-day discharge site of the Coyote Spring Valley aquifer system, lies across the trend of the east range-front fault zone of the Arrow Canyon Range and the Meadow Valley Mountains. The springs are relatively young, younger than the Muddy Creek Formation, and probably not older than middle Pliocene. The adjacent Muddy Creek lake beds contain few spring-carbonate beds, which signifies that little spring discharge occurred during Muddy Creek time in the eastern half of the Arrow Canyon Range. The Muddy River springs are ideally located for major aquifer discharge: the springs are at an erosional topographic low point along a major north-striking range-front fault zone, where at least the upper part of the flow of the Coyote Spring Valley aquifer in the Bird Spring Formation is blocked by a thick basin fill of the Horse Spring and Muddy Creek formations.

REFERENCES

Anderson, R.E., and Jenkins, E.C., 1970, Geologic studies in Dry Lake Valley and Hidden Valley, southern Nevada: U.S. Geological Survey Report USGS-47455 (NTS-176), (Revision 1) prepared for the Nevada Operations Office, U.S. Atomic Energy Commission, 35 p.

Anderson, R.E., and Laney, R.L., 1975, The influence of late Cenozoic stratigraphy on distribution of impoundment-related seismicity at Lake Mead, Nevada-Arizona: U.S. Geological Survey Open-File Report 77-794, 162 p.

Bachman, G.O., and Machette, M.N., 1977, Calcic soils and calcretes in the Southwestern United States: U.S. Geological Survey Open-file Report 77-794, 162 p.

Barton, C.C., 1985, Fractal geometry of two-dimensional fracture networks at Yucca Mountain, southwest Nevada, *in* Stephannson, Ove, ed., Fundamentals of rock joints: Bjorkliden, Sweden, Proceedings of International Symposium on fundamentals of rock joints (Sept. 15-20, 1985), Centek, Publishers, Lulea, Sweden, p. 77-84.

Best, M.G., Christiansen, E.H., and Blank, R.H., Jr., 1989a, Oligocene caldera complex and calc-alkaline tuffs and lavas of the Indian Peak volcanic field, Nevada and Utah: Geological Society of America Bulletin, v. 101, p. 1076-1090.

Best, M.G., Christiansen, E.H., Deino, A.L., Grommé, C.S., McKee, E.H., and Noble, D.C., 1989b, Eocene through Miocene volcanism in the Great Basin of the Western United States: New Mexico Bureau of Mines Memoir 47, p. 91-133.

Blair, W.N., and Armstrong, A.K., 1979, Hualapai limestone of the Muddy Creek Formation: the youngest deposit predating the Grand Canyon, southeastern Nevada and northwestern Arizona: U.S. Geological Survey Professional Paper 1111, 14 p.

Blair, W.N., McKee, E.H., and Armstrong, A.K., 1977, Age and environment of deposition of the Hualapai Limestone member of the Muddy Creek Formation [abs.]: Geological Society of America Abstract with Programs, v. 9, no. 4, p. 390-391.

Bohannon, R.G., 1983, Geologic map, tectonic map and structure sections of the Muddy and northern Black Mountains, Clark County, Nevada: U.S. Geological Survey Miscellaneous Investigations Series Map I-1406, scale 1:62,500.

Cook, E.F., 1965, Stratigraphy of Tertiary volcanic rocks in eastern Nevada: Nevada Bureau of Mines Report 11, 61 p.

Duley, D.E., 1957, Mississippian stratigraphy of the Meadow Valley and Arrow Canyon Ranges, southeastern Nevada: University of California at Berkeley, unpublished M.A. thesis, 99 p.

Eakin, T.E., 1964, Ground-water appraisal of Coyote Spring and Kane Spring Valleys and Muddy River Springs area, Lincoln and Clark Counties, Nevada: Nevada Department of Conservation and Natural Resources, Ground-Water Resources—Reconnaissance Series Report 25, 40 p.

______1966, A regional interbasin ground-water system in the White River area, southeastern Nevada: Water Resources Research, v. 2, no. 2, p. 251-271.

Ealey, P.J., 1966, Vegetative alignments and their geologic implications, Arrow Canyon Range, Clark County, Nevada: Urbana, Illinois, University of Illinois, unpublished M.S. thesis, 68 p.

Ekren, E.B., Orkild, P.P., Sargent, K.A., and Dixon, G.L., 1977, Geologic map of Tertiary rocks, Lincoln County, Nevada: U.S. Geological Survey Miscellaneous Investigations Series Map I-1041, scale 1:250,000.

Gardner, L.R., 1968, The Quaternary Geology of the Moapa Valley, Clark County, Nevada: University Park, Pennsylvania, Ph.D. dissertation, The Pennsylvania State University, 162 p., scale 1:41,600.

Gardner, L.R., 1972a, Pediments and terraces along the Moapa Valley, Clark County, Nevada: Geological Society of America Bulletin, v. 83, p. 3479-3486.

______1972b, Origin of the Mormon Mesa caliche, Clark County, Nevada: Geological Society of America Bulletin, v. 83, p. 142-156.

Gile, L.H., and Grossman, R.B., 1979, The desert project soil monograph—soils and landscapes of a desert region astride the Rio Grande Valley near Las Cruces, New Mexico: U.S. Soil Conservation Service, 984 p.
Gile, L.H., Peterson, F.F., and Grossman, R.B., 1965, The K-horizon—A master soil horizon of carbonate accumulation: Soil Science, v. 99, no. 2, p. 74-82.
______1966, Morphology and genetic sequences of carbonate accumulation in desert soils: Soil Science, v. 101, no. 5, p. 347-360.
Langenheim, R.L., Jr., Carss, B.W., Kennerly, J.B., McKutcheon, V.A., Waines, R.H., 1962, Paleozoic section in Arrow Canyon Range, Clark County, Nevada: American Association of Petroleum Geologists, v. 46, no. 5, p. 592-609.
Long, J.C.S., and Witherspoon, P.A., 1985. The relationship of degree of interconnection to permeability in fracture networks: Journal of Geophysical Research, v. 90, no. B7, p. 3087-3089.
Longwell, C.R., Pampeyan, E.H., and Bowyer, Ben, 1965, Geology and mineral deposits of Clark County, Nevada: Nevada Bureau of Mines Bulletin, v. 62, 218 p., scale 1:250,000.
Lucchitta, Ivo, 1972, Early history of the Colorado River in the Basin and Range province: Geological Society of America Bulletin, v. 83, no. 7, p. 1933-1947.
______1979, Late Cenozoic uplift of the southwestern Colorado Plateau and adjacent lower Colorado River region: Tectonophysics, v. 61, p. 63-95.
Machette, M.N., 1982, Guidebook to the late Cenozoic geology of the Beaver basin, south-central Utah: U.S. Geological Survey Open-File Report 82-850, 42 p.
______1985, Calcic soils of the southwestern United States: Geological Society of America Special Paper 203, p. 1-21.
Mandelbrot, B.B., 1982, The fractal geometry of nature: W.H. Freeman and Co., San Francisco, 460 p.
Mann, A.W., and Horwitz, R.C., 1979, Groundwater calcrete deposits in Australia—some observations from Western Australia: Journal of Geological Society of Australia, v. 26, p. 293-303.
McBeth, Jr., P.E., 1986, Hydrogeologic significance of Landsat Thematic Mapper lineation analyses in the Great Basin: unpublished M.S. thesis, University of Nevada, Reno, 100 p.
Metcalf, L.A., 1982, Tephrostratigraphy and potassium-argon age determinations of seven volcanic ash layers in the Muddy Creek Formation of southern Nevada: Nevada, Desert Research Institute Publication No. 45 23, 187 p. (U.S. Department of Energy, Nevada Operations Office, report DOE/DP/10162-23).
Mifflin, M.D., 1968, Delineation of ground-water flow systems in Nevada: University of Nevada, Desert Research Institute Technical Report, Series H-W, v. 4, 111 p.
Montezar, Parviz, and Wilson, W.E., 1985, Conceptual hydrologic model of flow in the unsaturated zone, Yucca Mountain, Nevada: U.S. Geological Survey Water Resources Investigation Report 84-4345, 55 p.
Novak, S.W., 1984, History of the rhyolitic Kane Springs Wash Volcanic Center, Nevada: Journal of Geophysical Research, v. 89, no. B10, p. 8603-8615.
Pampeyan, E.H., 1989, Geologic Map of the Meadow Valley Mountains, Lincoln and Clark Counties, Nevada; U.S. Geological Survey Miscellaneous Investigations Series, Map I-2173, scale 1:50,000.
Rowley, P.D., Nealey, L.D., Unruh, D.M., Snee, L.W., Mehnert, H.H., Anderson, R.E., and Grommé, C.S., 1995, Stratigraphy of Miocene ash-flow tuffs in and near the Caliente caldera complex, southeastern Nevada and southwestern Utah, *in* Scott, R.B., and Swadley, W C, eds., Geologic studies in the Basin and Range to Colorado Plateau transition, Arizona, Nevada, and Utah: U.S. Geological Survey Bulletin 2056-C.

Schmidt, D.L., 1988, The Black Hills basin, *in* Guth, P.L., Schmidt, D.L., Deibert, Jack, and Yount, J.C., 1988, Tertiary extensional basins of northwestern Clark County, Nevada, p. 239-253; *in* Weide, D.L., and Faber, M.L., eds., 1988, This extended land: Geological Society of America Field Trip Guidebook; Las Vegas, University of Nevada Printing Services, 330 p.

______1994, Preliminary geologic map of the Farrier quadrangle, Clark and Lincoln Counties, Nevada: U.S. Geological Survey Open-File Report 94-625, scale 1:24,000.

Scott, R.B., Grommé, C.S., Best, M.G., Rosenbaum, J.G., and Hudson, M.R., 1995, Stratigraphic relationships of Tertiary volcanic rocks in central Lincoln County, southeastern Nevada; *in* Scott, R.B., and Swadley, W C, eds., Geologic studies in the Basin and Range-Colorado Plateau transition in southeastern Nevada, southwestern Utah, and northwestern Arizona, 1992: U.S. Geological Survey Bulletin 2056-A.

Scott, R.B., Spengler, R.W., Diehl, Sharon, Lappin, A.R., and Chornack, M.P., 1983, Geologic character of tuffs in the unsaturated zone at Yucca Mountain, southern Nevada, *in* J.W. Mercer, P.S.C. Rao, and I.W. Marine, eds., Role of the unsaturated zone in radioactive and hazardous waste disposal: Ann Arbor, Ann Arbor Science, p. 289-335.

Tschanz, C.M., and Pampeyan, E.H., 1970, Geology and mineral deposits of Lincoln County, Nevada: Nevada Bureau of Mines Bulletin, v. 73, 187 p., scale 1:250,000.

Webster, G.D., Mackenzie, Gordon, Jr., Langenheim, R.L., and Henry, T.W., 1984, The Mississippian-Pennsylvanian boundary in the eastern Great Basin (Field Trip 1), *in* Lintz, Joseph, Jr., Western Geological Excursions, v. 1, Geological Society of America: Reno, University of Nevada, MacKay School of Mines, p. 1-86.

Wernicke, Brian, Guth, P.L., and Axen, G.J., 1984, Tertiary extensional tectonics in the Sevier Belt of southern Nevada (Field Trip 19), *in* Lintz, Joseph, Jr., Western Geological Excursions, v. 4, Geological Society of America: Reno, University of Nevada, MacKay School of Mines, p. 473-510.

Winograd, I.J., and Thordarson, William, 1975, Hydrogeologic and hydrochemical framework, south-central Great Basin, Nevada-California, with special reference to the Nevada Test Site: U.S. Geological Survey Professional Paper 712-C, 126 p.

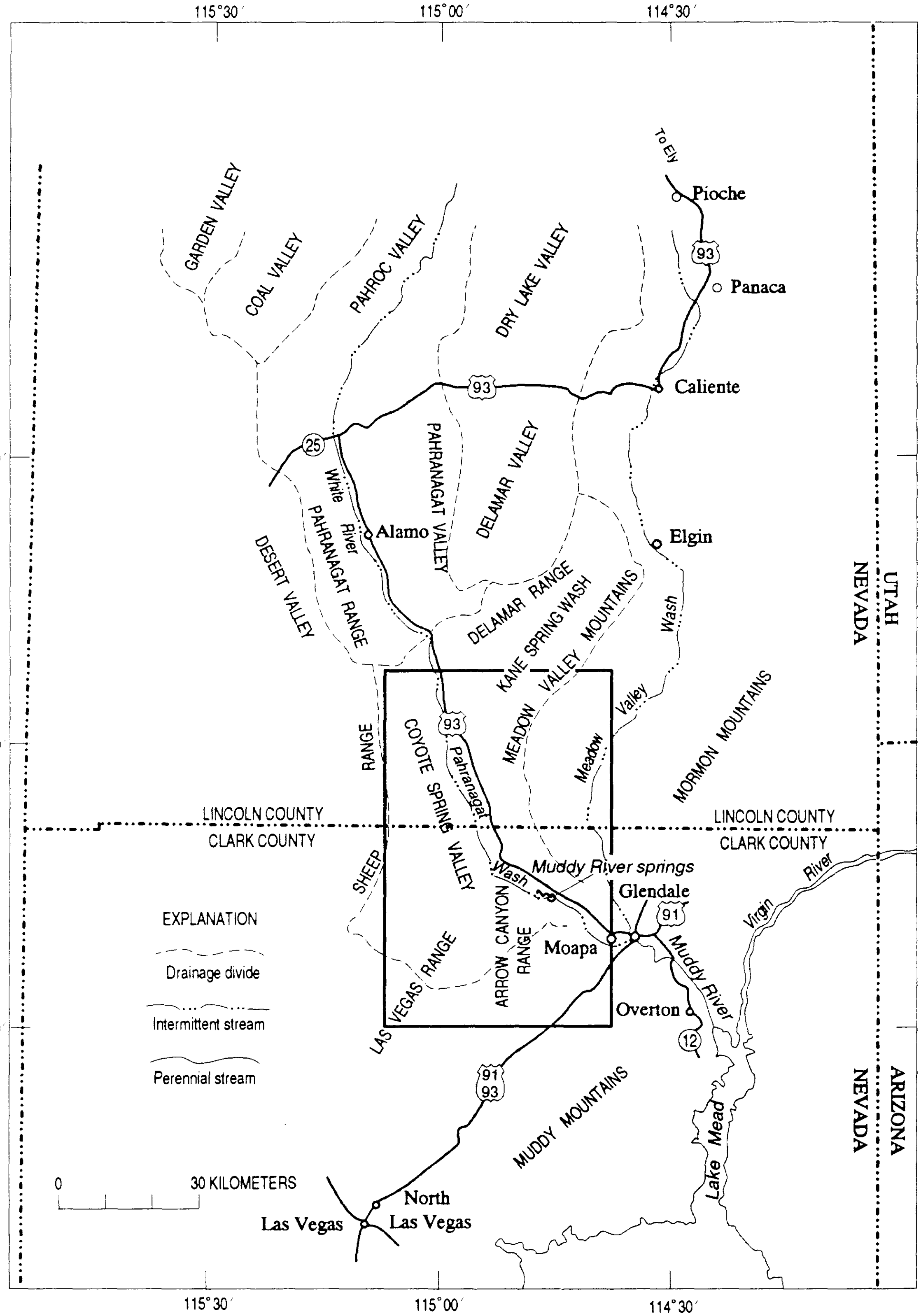


Figure 1.—Index map of part of southeastern Nevada showing outline of the Coyote Spring Valley area of figure 3. Modified from Eakin (1964).

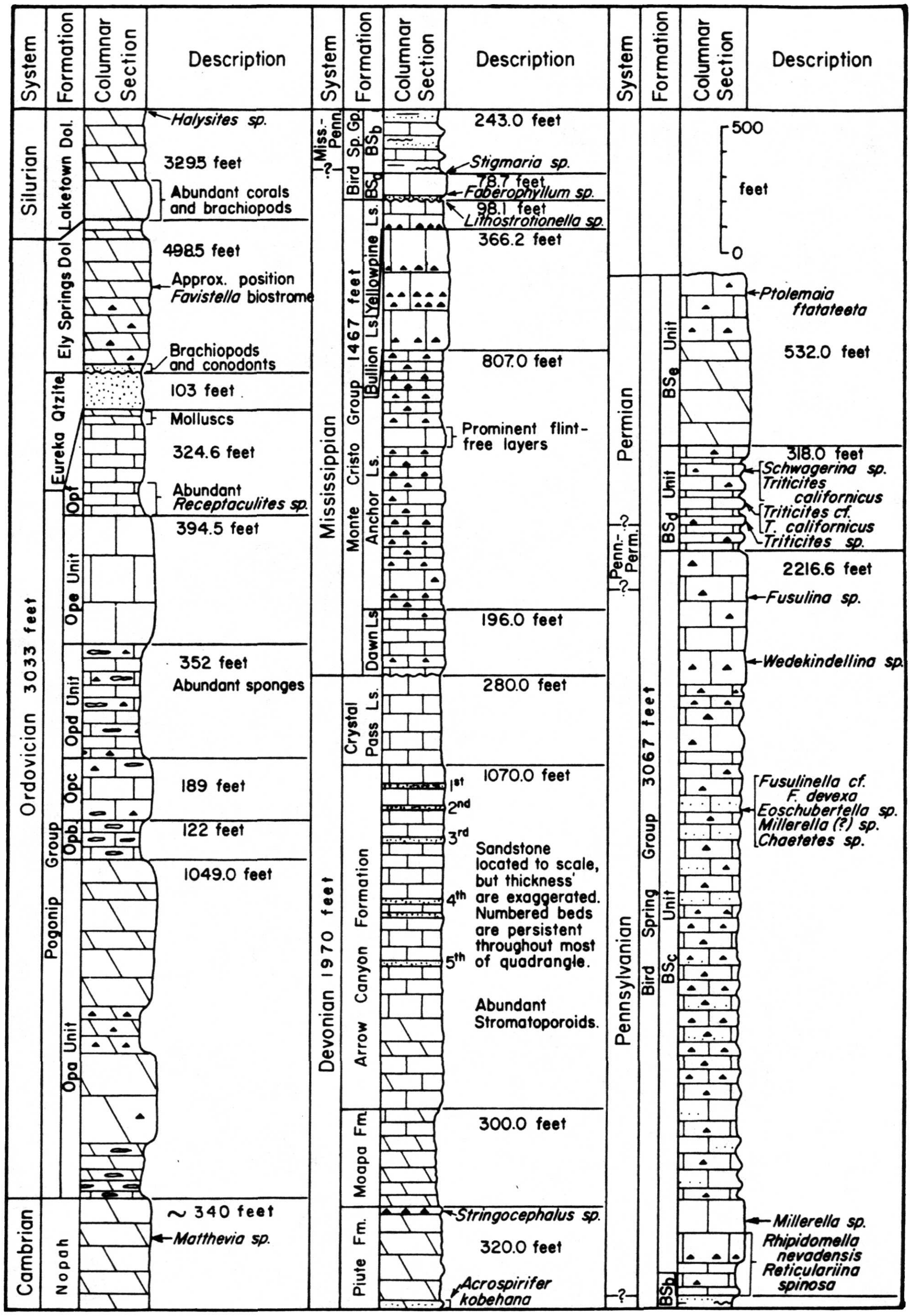


Figure 4.—Composite stratigraphic column of uppermost Permian through Cambrian rocks in the Arrow Canyon Range, Clark County, Nevada (from fig. 4 in Langenheim and others, 1962).

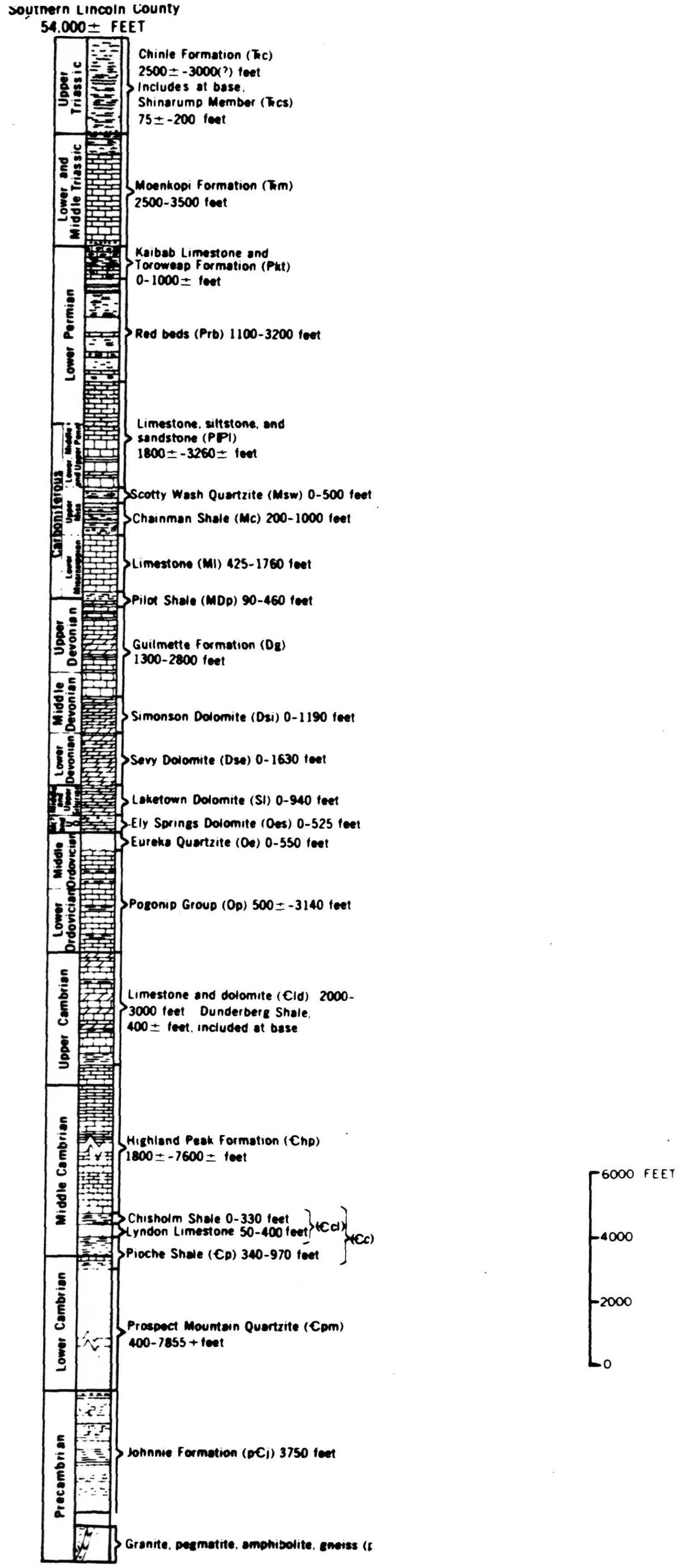


Figure 5.—Composite stratigraphic column of Triassic and older rocks in southern Lincoln County, Nevada (from fig. 2 in Tschanz and Pampeyan, 1970).

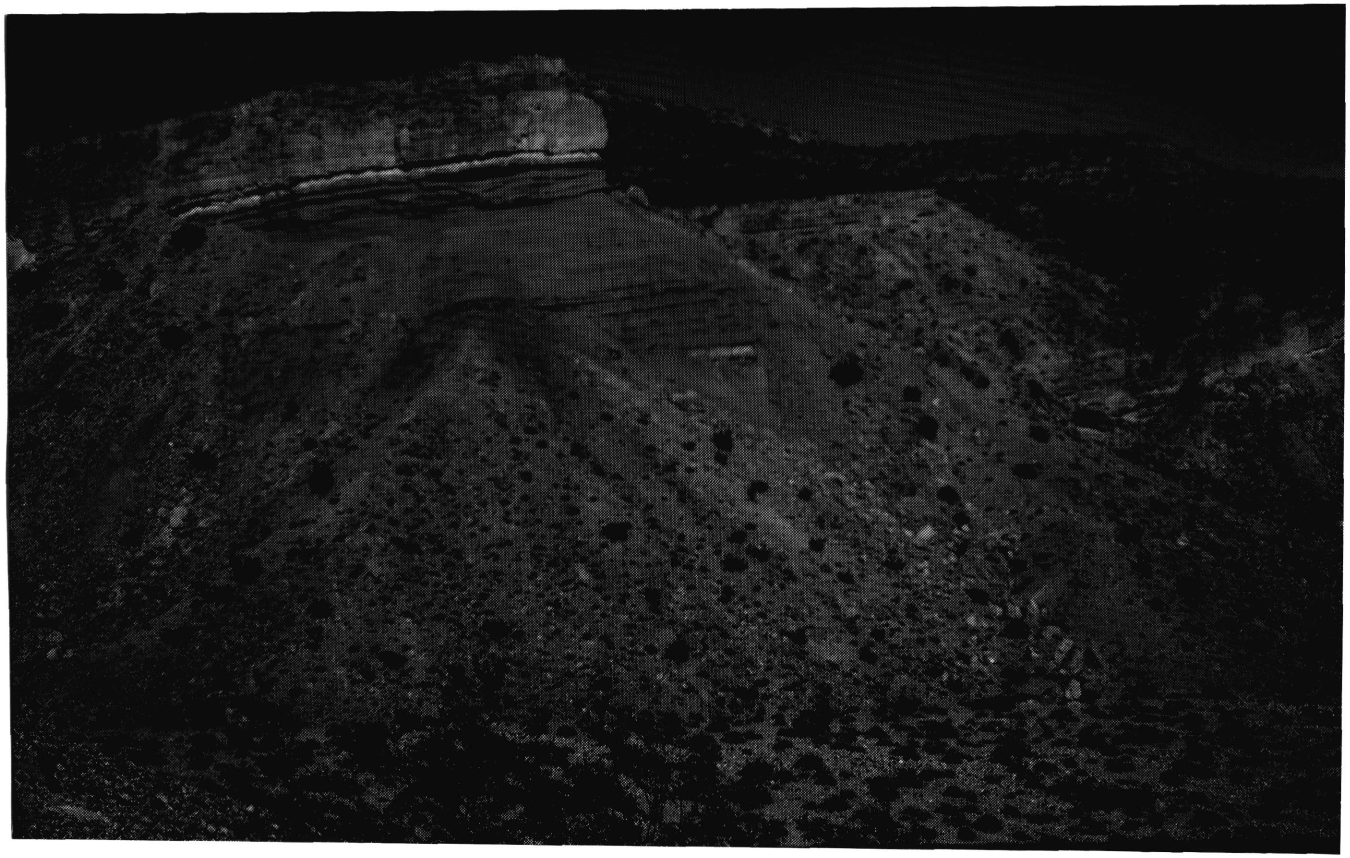


Figure 6.—Tan carbonate-cemented sand and gravel, 5 m thick, of Pliocene aggradational gravel (below skyline) overlying red lacustrine clay, silt, and fine sand of the Muddy Creek Formation, which dips gently to the north. View looking east, Starvation Flat, Coyote Spring Valley.

Figure 7.—Exhumed spring-carbonate mound in red clayey sediments of the Muddy Creek Formation; resistant upper travertine (limestone) is 1.5 m thick and contains abundant carbonate casts and molds of plant stems and roots. Mound shape is accentuated by erosion of underlying clays and by collapse of the capping travertine. Lag pavement in foreground consists entirely of fragments of underlying, thick, Pliocene carbonate soil, which developed on Pliocene pediment gravel. Mound is not underlain by pediment gravel. Mound represents a small, regional ground-water discharge point during latest Miocene time in the southeastern part of the Ute area (fig. 3).

Figure 8.—Spring-carbonate veins as much as 15 cm wide in carbonate-cemented, coarse silty conglomerate of the Horse Spring Formation in Wildcat Wash, 1.2 km north of State Highway 168. Veins consist of laminations of coarsely crystalline white calcite.

Figure 9.—Spring-water conduits or pipes, lined with thin layers of coarsely crystalline, white calcite, are exposed by deep dissection in Ordovician Pogonip limestone in Wildcat Wash, 1.8 km north of State Highway 168. Upper conduit is about 0.3 m wide. Both conduits are probably of late Miocene age and are tectonic cavities developed along small low-angle normal faults dipping about 15° to the right. View looking north.

Figure 11.—Many spring-carbonate veins, mostly north-striking ($\pm$ 20°) and as wide as 0.5 m, on the south-facing slope of Bunker Hills, eastern Meadow Valley Mountains, west of Rox (see fig. 10 for details of one vein). Veins represent the substructure of a large spring-discharge system that was active and subsequently uplifted and exposed during middle Miocene extensional deformation of the Bunker Hills.

Figure 12.—Open, spring-water conduit about 2.5 cm wide and partly filled or lined with laminated calcite that follows a late fracture in limestone breccia developed slightly earlier (middle Miocene?) during extensional deformation of limestone of the Permian Bird Spring Formation. Red-colored limestone breccia was a red water-course rock that conducted ground water at a deeper level than the calcite-lined fracture; red color of breccia is caused by alteration and oxidation of sparse, disseminated iron-bearing minerals in the limestone regional ground water; the fine particles of the limestone gouge of the breccia matrix are especially intensely reddened. Hammerhead is 0.3 m long. Location is 7 km north of Muddy River springs.

Figure 13.—Resistant rimrock, about 11 m thick, of brown-weathering, tabular, spring-carbonate beds that are interbedded with less-resistant, white, gypsiferous, calcareous, clay and silt (marl) lake beds of the upper Miocene Muddy Creek Formation; exposed section is about 60 m thick. The gypsum and calcite are precipitated from regional ground water discharged from extensionally deformed Mississippian limestone at the mouth of Arrow Canyon about 2 km to the southeast, behind the camera. View is to the west, toward Table Mountain in the middle ground.

Figure 14.—Exhumed, spring-water, open distributary canal, 0.6 m wide by 0.3 m high (only half of canal is preserved in view), that has a left wall or levee of laminated calcite about 0.25 m thick. Wall and floor of canal are lined with spheres of laminated spring carbonate, 10 to 20 cm diameter. In places, many calcite casts and molds of plant roots and stems (not visible) indicate a former, abundant plant growth in the warm spring-water canal. Canal was self-constructed by carbonate precipitate from spring water discharged through slightly older, underlying spring-carbonate beds; eventually the carbonate precipitate developed into a tabular, spring-carbonate bed. A few other examples of well preserved distributary canals are exposed in the area near Hogan Spring. These lower Pliocene, tabular spring-carbonate beds directly overlie, and are slightly younger than, the Muddy Creek Formation. Hammerhead is 0.3 m long.

Figure 15.—Bulbous chert concretion, 1 m long and left of hammer, within a one-meter-thick, tabular, spring-carbonate bed in the Muddy Creek Formation in Table Mountain basin, 2 km southeast of the mouth of Wildcat Wash. This rare silica-bearing carbonate bed can be traced about 700 m west to a probable spring source. White, gypsiferous, highly calcareous clay and silt (marl) beds lie above and below the concretion bed.

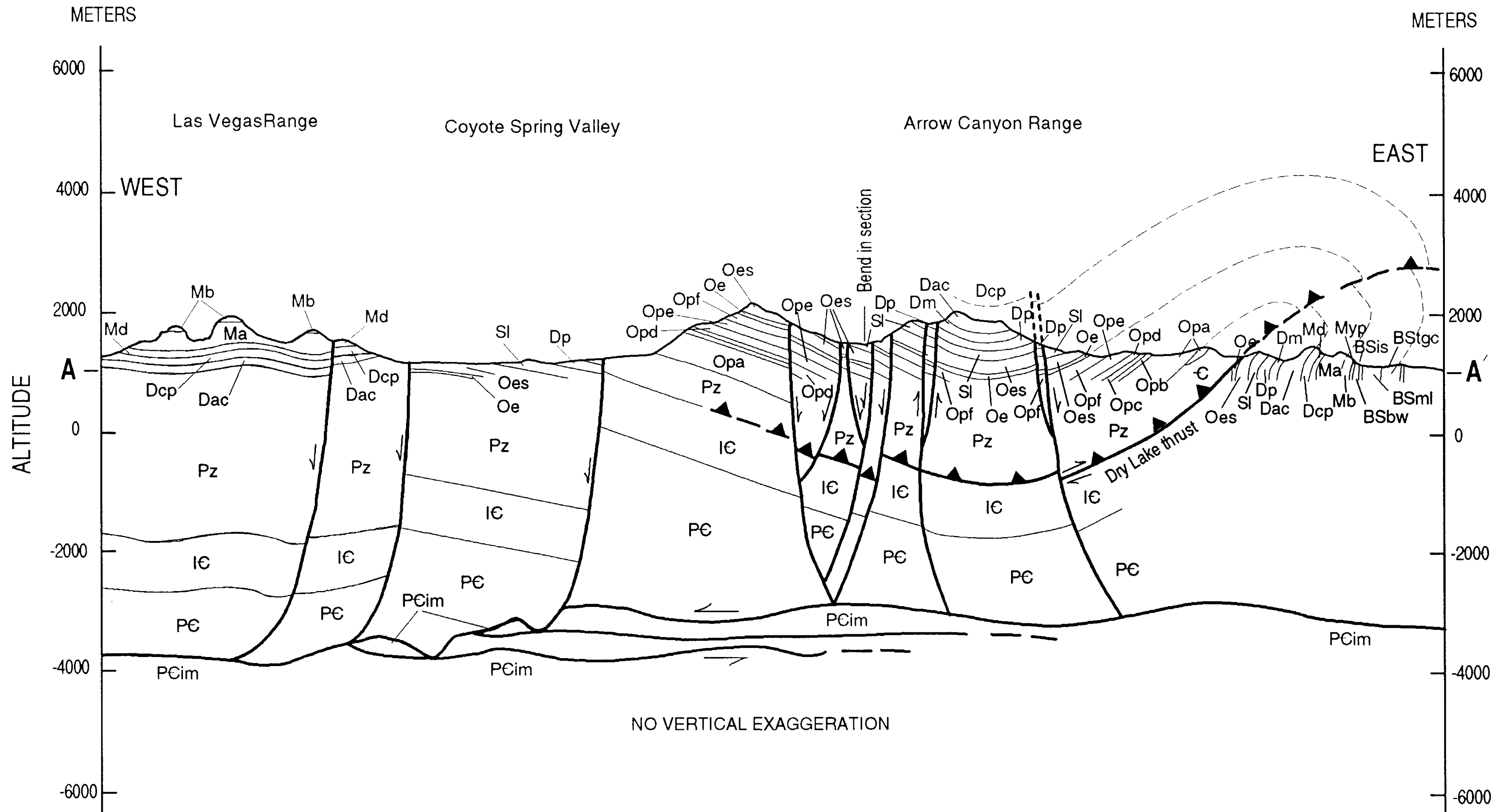


Figure 16.—Cross section through the Arrow Canyon Range and eastern Las Vegas Range (fig. 2). Rock symbols are as on figure 4, except: Pz, inferred Paleozoic carbonate section below about 1,000 m altitude above sea level; Uє, inferred upper Cambrian carbonate section; lє, inferred Lower Cambrian clastic section; Pє, inferred uppermost Precambrian clastic rocks; Pєim, inferred Precambrian igneous and metamorphic rocks involved in proposed detachment fault at depth of about 4 km (inference based on geophysical data by H.R. Blank, written commun., 1985). Cross section from surface to about 1,000 m altitude is from R.L. Langenheim (written commun., 1985) based on his detailed mapping of the Arrow Canyon quadrangle (15-minute sheet).

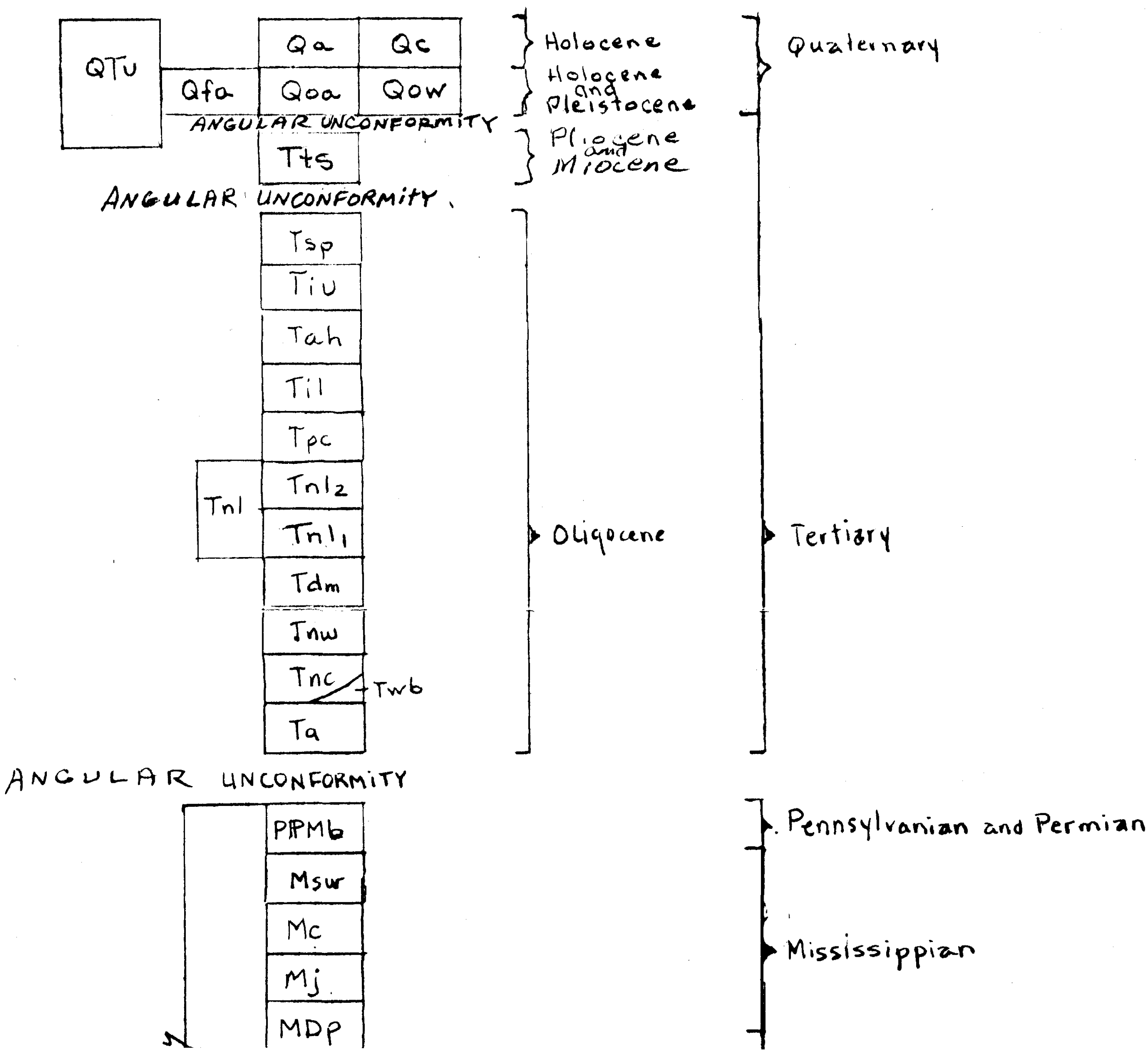
Figure 17.—Tilted lake beds overlying the Muddy Creek Formation beneath a Pliocene pediment near Hogan Spring. Lake beds consist of white, gypsiferous, calcareous clay and silt (marl). Dissection scarp is about 17 m high.

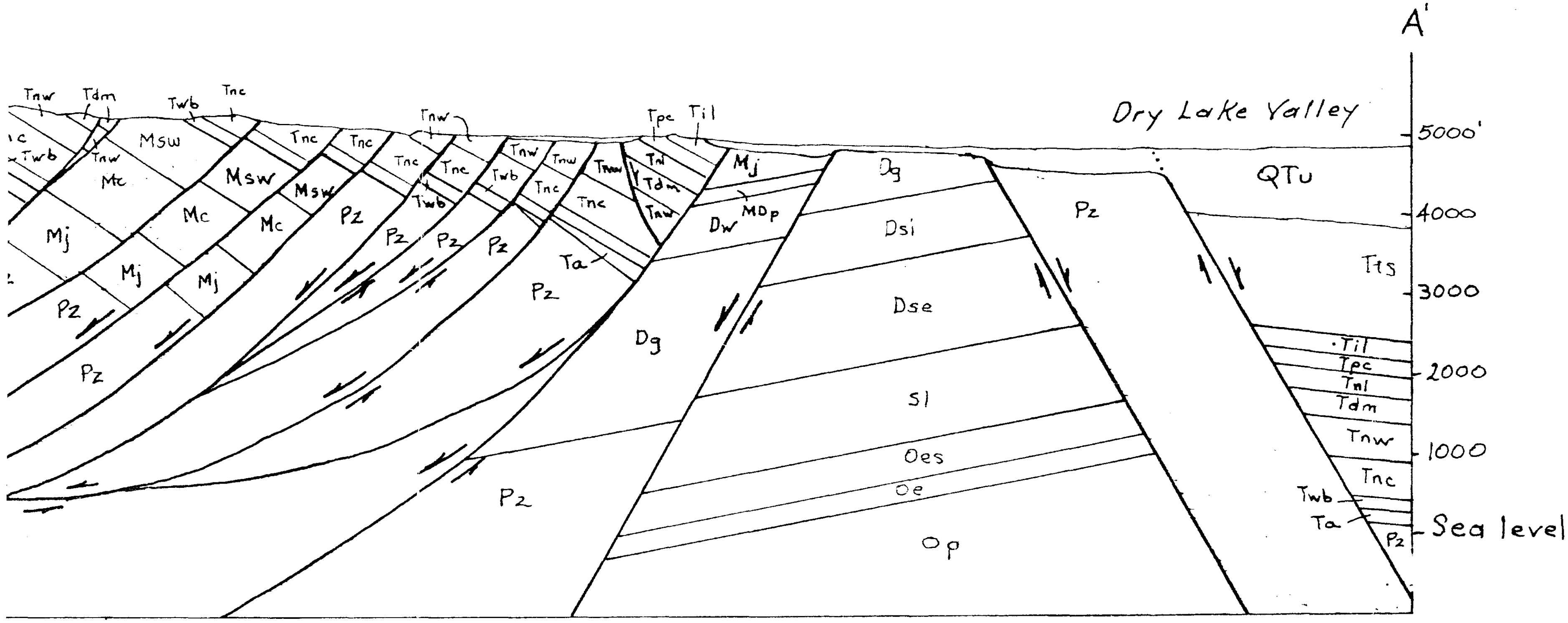
Figure 18.—North-striking normal fault (left foreground) dips 60° W. (left) and drops white calcareous (spring-carbonate) lake beds (left), which are slightly younger than the Muddy Creek Formation, against red clayey lake beds of the Muddy Creek Formation near Hogan Spring. This fault, which is slightly younger than the age of the top of the Muddy Creek, caused mostly gentle tilting of the Muddy Creek lake beds in some places. An eroded, Pliocene, carbonate soil on a pediment gravel, 1.7 m thick, caps the butte above and to the left of the fault. The high stream-cut scarp in the middle ground exposes gently east-tilted (to right) Muddy Creek lake beds. View is to the north, from 0.8 km south-southeast of Hogan Spring.

Figure 19.—Normal fault, attitude N. 21° E., 64° SE., that drops tan, carbonate-cemented aggradational sand and gravel (on left), down about 15 m against red clay, silt, and fine-sand lake beds of the Muddy Creek Formation; line shows trace of fault on hill slope. The sand and gravel unit is slightly younger than the Muddy Creek Formation. Cliff on right skyline is the same carbonate-cemented sand and gravel as forms the down-dropped block of the fault in the left foreground. View looks south-southwest from the east side of Starvation Flat.

Figure 20.—North-striking Byron fault (center of photo, to right of vehicle) that displaces a carbonate-soil cap to a middle Pliocene pediment gravel down 3.5 m to the east (right). Fault strikes north away from viewer and may be traced for 1.6 km to the badlands topography of Hogan Spring, which is cut below the pediment surface and where the same fault system is seen in figures 17 and 18. In comparison to the fault in the figure, early Pliocene displacement of the Muddy Creek Formation is tens of meters on many faults. Southeastern part of the Arrow Canyon Range is on the skyline.

CORRELATION OF MAP UNITS
Coyote Spring Quadrangle




A'
Dry Lake Valley
5000'
4000
3000
2000
1000
Sea level
QTu
Tts
Til
Tpc
Tnl
Tdm
Tnw
Tnc
Twb
Ta
Pz
Dg
Dsi
Dse
Sl
Oes
Oe
Op
Dw
MDp
Mj
Msw
Mc
Tnc
Tnw
Twb
Tdm
Tpc
Til