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INTERBASIN GROUND-WATER FLOW IN SOUTHERN NEVADA

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A guidebook to the hydrogeology of the southern Amargosa Desert and adjacent areas in southern Nye County, Nevada and nearby California. Flow systems for Las Vegas and Pahrump Valleys and the Amargosa Desert and Nevada Test Site are described and compared. Focus is on the effects of interbasin flow on quality and quantity of water discharged in the Ash Meadows area.

INTERBASIN GROUND-WAT[ ]LOW IN SOUTHERN NEVADA
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INTERBASIN GROUND-WATER FLOW IN SOUTHERN NEVADA

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INTRODUCTION

Major springs in the Paleozoic carbonate rocks of eastern and south-central Nevada have a combined discharge in excess of 215,000 acre-feet per year (Maxey and Mifflin, 1966). Maximum discharge rates of 7,690 gpm are recorded, and of the 60 major springs, 40 exceed 1,000 gpm each. The springs are the most visible manifestation of interbasin flow, a phenomenon of great practical importance and scientific challenge. The purpose of this trip is to examine some of the evidence for interbasin flow in a part of southern Nevada, and to demonstrate the interaction of Tertiary and Quaternary valley fill structures and sediments on the hydraulic and chemical properties of ground water discharging from regional systems.

A brief field-trip guide is included as Appendix A at the rear of this volume.

The occurrence, movement, and chemistry of ground water is probably better understood within the geologic framework of southern Nevada than in any other part of the Great Basin. Regional hydrogeologic investigations in support of the U. S. Atomic Energy Commission Nevada Test Site operations, particularly from 1958 to 1966, have furnished a framework of understanding which has been amplified by research programs under the auspices of the Nevada Bureau of Mines and Geology, the U. S. Geological Survey, the Nevada State Engineers Office and the Desert Research Institute, and by numerous individuals.

Previous Investigations

The region being considered (see fig. 1) encompasses approximately 4,000 square miles, parts of which have been described by Cornwall (1972), Longwell and others (1965), Malmberg (1965, 1967), Maxey and Jameson (1948), Naff (1973) and Winograd and others (1971). Detailed studies of the hydrogeology of the Nevada Test Site were conducted by Blankennagel and Weir (1972), Johnson and Hibbard (1957), Winograd (1971a) and Winograd and others (1971). Summary accounts of the hydrology of the western part of the Test Site and the Amargosa Desert were published by Rush (1970), and Walker and Eakin (1963). Geological Society of America Memoir 110 (Eckel, ed., 1969) describes the hydrology and geology of the Nevada Test Site. Stratigraphic investigations of the sedimentary and volcanic rocks in the mountain blocks were conducted by Burchfiel (1964, 1965, 1966), Cornwall (1972), Cornwall and Kleinhampl (1964), Denny and Drewes (1965), and Naff (1973). The stratigraphy of the valley-fill deposits was described by Denny and Drewes (1965), Haynes (1967), Malmberg (1967), Maxey and Jameson (1948), and Naff (1973).

Well Numbering System

Wells, springs, and specific locations within or in the immediate vicinity of the Nevada Test Site are identified in terms of the 10,000-foot grid of the Nevada State Plane Coordinate System, central zone. The first two digits of the north coordinate and the first two digits of the east coordinate of this grid are used to identify the well.

In other areas, wells and springs are identified by section, township, and range of the U. S. Public Land Survey grid. In the part of the study area in Nevada, the townships are south of the Mount Diablo Base Line and the ranges are east of the Mount Diablo Meridian. California townships use the San Bernardino Base Line and all townships are "north," compared to "south" in Nevada. All ranges are located to the east of their respective meridians. Thus, a well in Nevada in the SW¼ sec. 9, T. 17 S., R. 50 E. is identified simply by 17/50 9c. The letters a, b, c, or d refer to the northeast, northwest, southwest, and southeast quarter sections, respectively. Double or triple letters that follow a section number identify a well site in a 40-acre or 10-acre tract, respectively.

Water Quality Data Collection and Analysis

The most recent data available were selected wherever possible in this report. About 70 percent of the analyses were collected in the period 1970-72, and the majority were obtained from two major sources, the U. S. Geological Survey and the U. S. Bureau of Reclamation. In addition, the Desert Research Institute, as part of a grant from the Office of Water Resources Research, Department of Interior, carried out an active sample collection and analysis program during the calendar years 1971 and 1972.

Rose and Piper diagrams were used by Schoff and Moore (1964), Winograd and others (1971), Winograd (1971a) and Naff (1973), for classifying the ground water at the Nevada Test Site and vicinity into five hydrochemical facies. In their scheme, waters were typed as to the dominant grouping of ionic species within either the cations or the anions, dominance being defined as a group consisting of at least 60 percent of the anions or cations present, in milliequivalents per million. If no grouping of anion or cation species is dominant, then that combination of ions is referred to as mixed. Because sodium, bicarbonate, and sulfate are usually dominant within their grouping, these groupings are referred to by the dominant ion name. Thus, water with a dominance of sodium plus potassium (alkali ions) and sulfate plus chloride would be referred to as a sodium sulfate type. This classification system and its

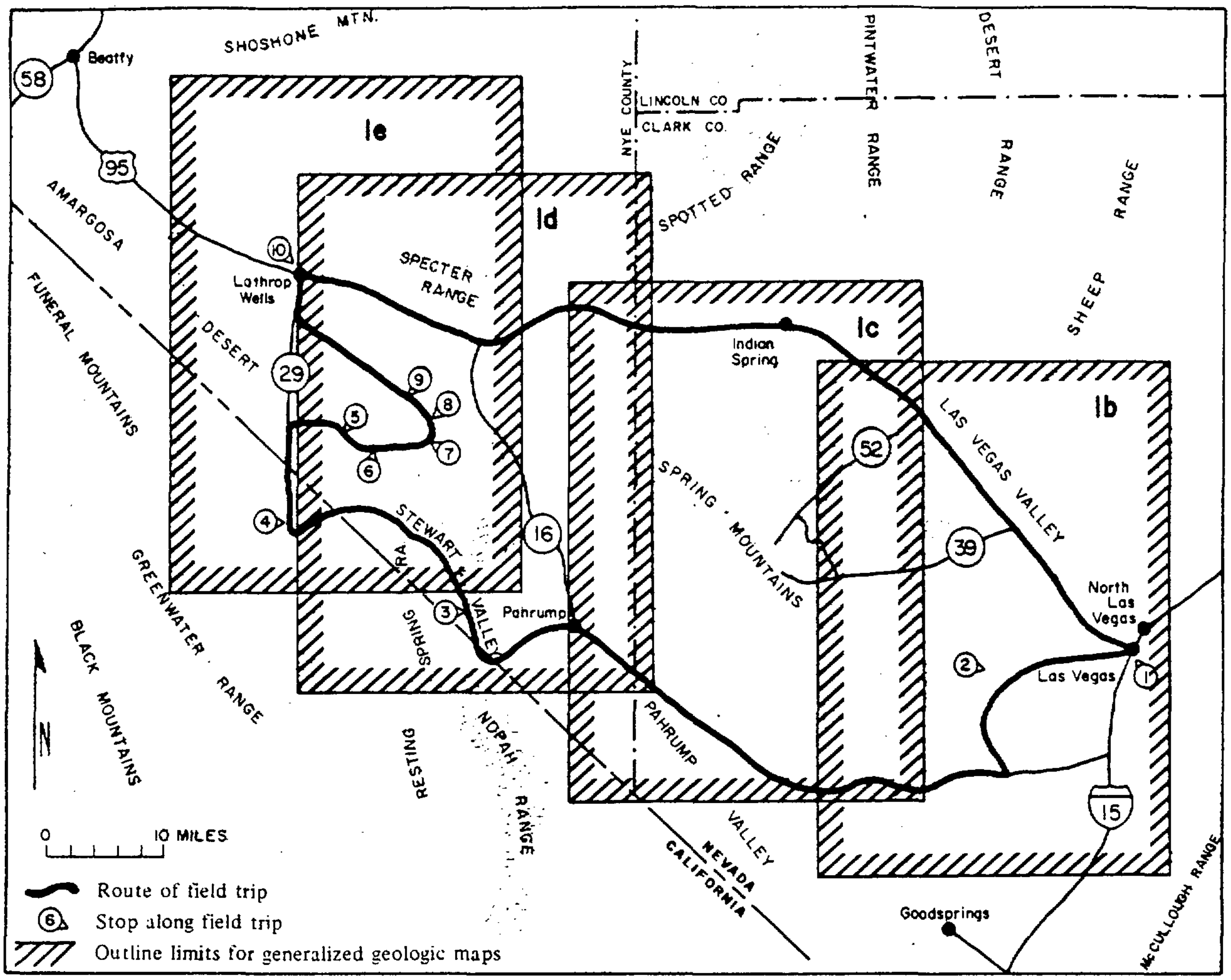


FIGURE 1a. Index map of southern Nevada showing field trip route and stops, and indicating areas of coverage of the generalized geologic maps, Fig. 1b, c, d, and e, on the following pages.

EXPLANATION FOR GENERALIZED GEOLOGIC MAPS

Quaternary rocks
Alluvium, fanglomerates, stream gravels, and playa lake deposits.

Tertiary rocks
Tuffaceous sedimentary rocks; rhyolitic to dacitic ash-fall and ash-flow tuffs; rhyolitic to latitic flows; some basalt flows and plugs. Mostly Miocene and Pliocene.

Mesozoic rocks
Includes limestone and marine clastic rocks of the Triassic Moenkopi Formation; non-marine clastic rocks of the Triassic Chinle Formation; and the Jurassic Aztec Sandstone.

Upper Paleozoic sedimentary rocks
Consists mostly of Mississippian to Permian limestone and dolomite, with minor interbedded marine clastic rocks, mostly Permian.

Precambrian and Lower Paleozoic sedimentary rocks
Includes Precambrian quartzite, sandstone, and shale in the northern Spring Mountains; Cambrian quartzite and sandstone; and Cambrian to Devonian limestone and dolomite with minor interbedded, dominantly fine-grained clastic rocks.

(4) **Stop along field trip**

Fault, *dashed where approximately located*

Thrust fault, *dashed where approximately located*

0 5 10 MILES

0 5 10 KILOMETERS

Geology adapted from Cornwall, 1972; and from Longwell and others, 1965.

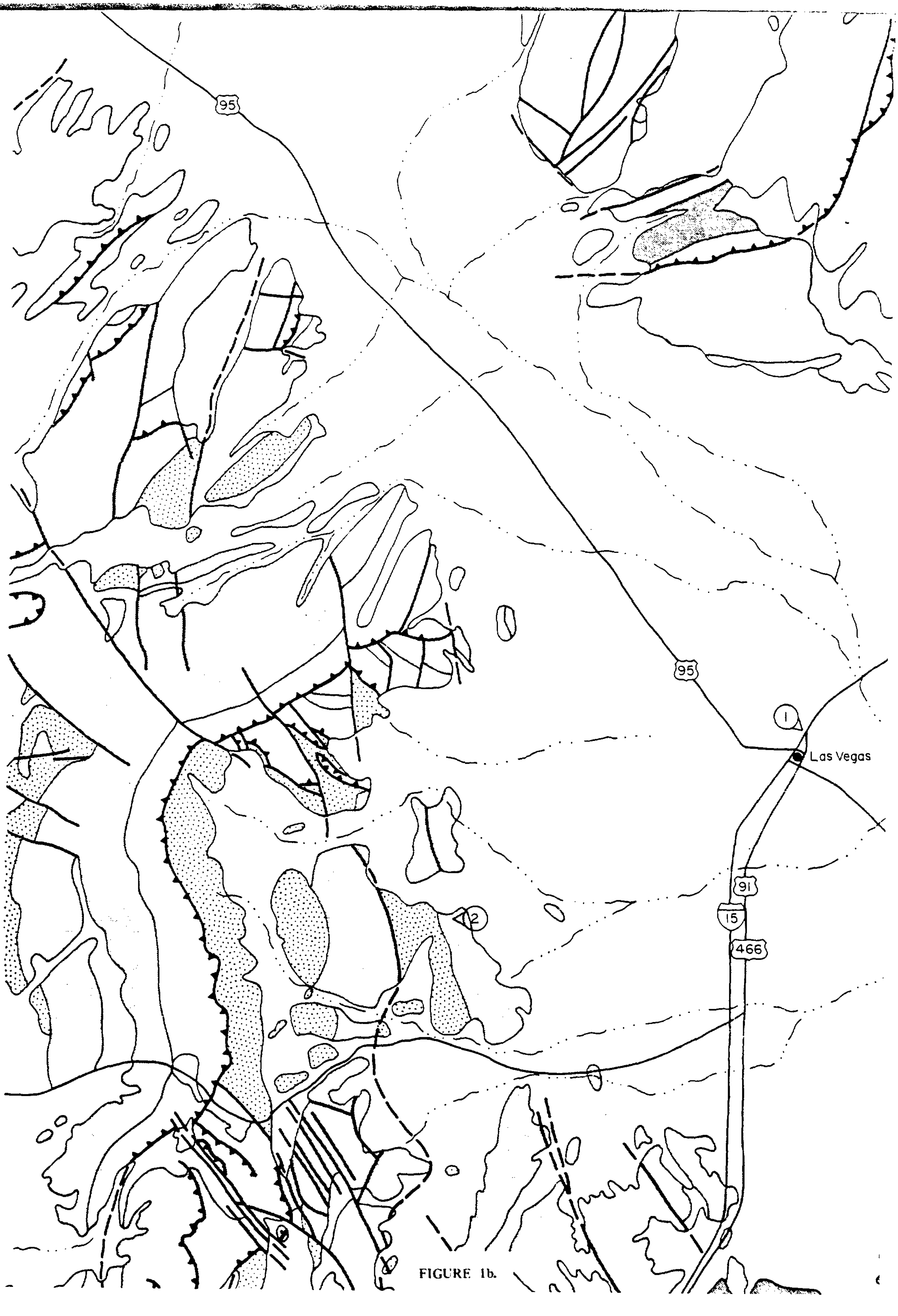
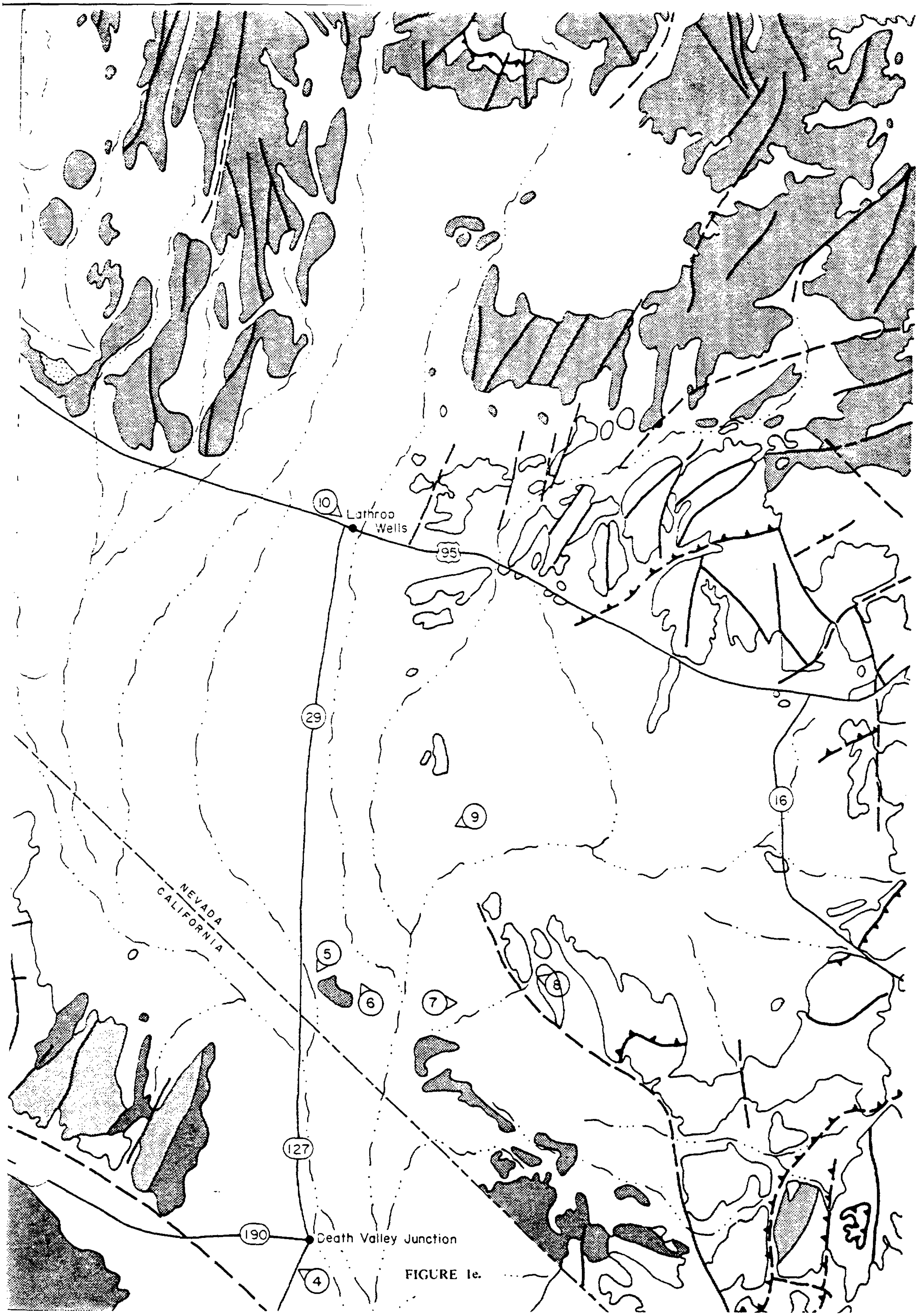


FIGURE 1b.

FIGURE 1c


Lathrop Wells
95
95
16
16
3
NEVADA
CALIFORNIA
52
Pahrump
127
Manse

FIGURE 1d.



10
Lathrop Wells
95
29
9
16
NEVADA
CALIFORNIA
5
6
7
8
127
190
Death Valley Junction
4

FIGURE 1e.

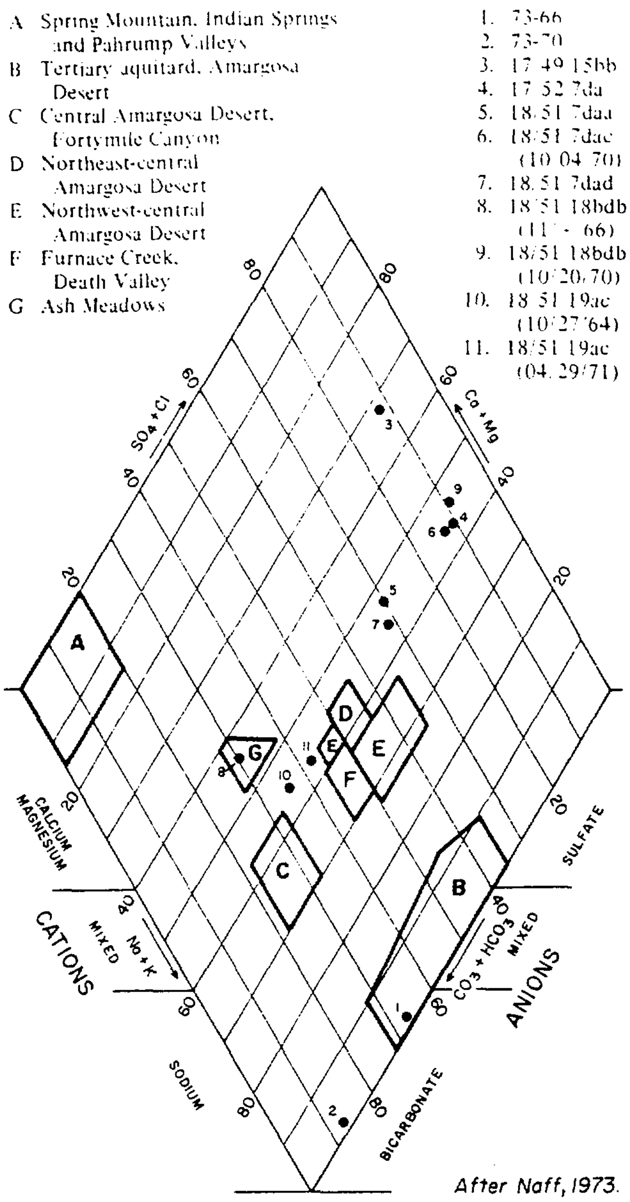


FIGURE 2. Piper diagram of ground water in the Amargosa Desert and vicinity.

application to ground water in the Amargosa Desert and vicinity is illustrated in figure 2.

Isopleth maps of summed ionic constituents and silica are used to show the distribution of waters within the Amargosa Desert, and Piper diagrams are used to portray the chemical evolution occurring due to travel along the flow path and due to mixing.

Geologic Setting

Las Vegas, Pahrump, and Indian Springs Valleys and the Amargosa Desert are bounded by mountain blocks consisting predominantly of complexly folded and faulted Paleozoic carbonate rocks. Some Tertiary volcanic rocks are present in the ranges bounding the Amargosa Desert. Crystalline and sedimentary rocks of Precambrian age occur on the eastern edge of Las Vegas and Stewart Valleys, and in the southeastern part of the Amargosa Desert. The valley fill in Las Vegas, Pahrump, and Indian Springs Valleys consists primarily of fine-grained Miocene and Pliocene sedimentary rocks of the Esmeralda(?) and Muddy Creek Formations which are incised and filled with Quaternary and Recent sands and gravels interbedded with playa and eolian sediments. The Amargosa Desert contains several thousand feet of highly deformed, indurated Tertiary clastic and limestone sedimentary rocks overlain by a thick sequence of tuffaceous playa lake sediments that include fluvial facies.

Paleozoic strata in the area of interest primarily represent carbonate sedimentation in a transgressive miogeosynclinal environment. Tectonic and epeirogenic pulses resulted in localized deposition of clastics. Mesozoic rocks are generally absent except for a few isolated intrusive masses, and for several isolated exposures of the Chinle and Moenkopi Formations and the Aztec (Navajo) Sandstone on the flanks of the Spring Mountains. Tertiary volcanic rocks erupted largely from calderas, are locally as much as 13,000 feet thick on the Nevada Test Site (Winograd and others, 1971) but are of little stratigraphic significance in the subject area. Tertiary and Quaternary detrital sequences, primarily alluvium, constitute the bulk of the valley fill.

The late Precambrian and Paleozoic sedimentary rocks, 30,000 to 40,000 feet thick, are genetically related to the formation of the Cordilleran miogeosyncline in eastern Nevada. Dominantly clastic sediments derived from metamorphic terrains to the east persisted until Early Cambrian time. The transition to carbonate sedimentation, the major depositional mode in the miogeosyncline throughout the remainder of the Paleozoic, is represented by the Carrara formation (Stewart, 1964; Roberts, 1964). The thickest sequence of post-Cambrian clastic rocks consists of the Ordovician Eureka Quartzite and the Devonian-Mississippian Eleana Formation. The Eureka Quartzite has a maximum thickness of 485 feet in the northeastern Amargosa Desert, and thins eastward (Burchfiel, 1964). The Eleana Formation, composed of 7,700 feet of clastic rocks at the Nevada Test Site, is represented by limestones further east, in the Spring Mountains to the south, and east of Ash Meadows (Johnson and Hibbard, 1957).

STRUCTURAL GEOLOGY

Two major periods of deformation have affected the region. Folding and thrust faulting of the late Precambrian and Paleozoic rocks occurred during the late Mesozoic-early Tertiary Laramide orogeny. Normal block faulting began in middle Cenozoic time and has continued into the Holocene. Strike-slip faults and shear zones were formed during both orogenies, and displacements of from 25 to 40 miles have been mapped along the Las Vegas Valley shear zone in Death Valley, the Amargosa Desert, the Nevada Test Site, and in Las Vegas Valley.

Late Mesozoic and early Tertiary deformation of the late Precambrian and Paleozoic miogeosynclinal rocks consisted of uplift, erosion, folding, and both thrust and strike-slip faulting. Normal block faulting occurred simultaneously with Miocene volcanism, and continued through the Quaternary, thereby further disrupting previously emplaced rock units, and causing formation of the horst and graben structure so typical of the Basin and Range province. By late Tertiary and Quaternary time the resulting valleys were filled with several thousand feet of alluvial materials; these have been subsequently extensively eroded.

Low Angle Reverse Faults

Thrust faults are the outstanding structural feature of the Spring Mountains and nearby ranges to the north (Longwell and others, 1965, pl. 4). Fleck (1970) recently reviewed the origin of these low-angle reverse faults, and has drawn the following conclusions concerning their character and origin: (1) Thrusting was preceded by folding, (2) Thrusting occurred on discrete surfaces which were not confined to incompetent units, (3) Fault breccia is minimal, generally occurring as a mylonized zone in the lower plate, and (4) Deep-seated crustal shortening is the thrusting mechanism. Fleck (1970) determined that this thrust faulting took place between approximately 75 and 90 m.y. ago, and that, in the northern Spring Mountains, a minimum of 15 miles of composite lateral shortening has occurred. Both the discrete nature of the fault plane and the relatively intact condition of the upper plate were considered to be indicative of high confining pressure.

Thrusts similar to those in the northern Spring Mountains have been described by Barnes and Poole (1968) in the Specter Range and at the Nevada Test Site. At the Nevada Test Site, these faults are described as essentially flat-lying, and are closely associated with folding, which preceded, accompanied, and followed thrusting. The major fault planes are often restricted to incompetent shales of the Carrara Formation, but in the Specter Range thrusting occurs in the form of a high-angle reverse fault that truncates the relatively competent Precambrian quartzites. This high-angle reverse fault probably represents an intermediate area between a deeper root zone and other flat-lying faults (Barnes and Poole, 1968).

Another distinct type of thrust fault was defined by Noble (1941) in the southern Black Mountains to the west (see fig. 1), where a flat-lying thrust plane, known as the Amargosa thrust, occurs between the later Precambrian sedimentary and earlier Precambrian metamorphic rocks. Rocks in the upper plate of this thrust are broken and sheared so extensively that Noble (1941) referred to them as the "Amargosa chaos." Some of the characteristics of this thrust are:

1. The chaos (upper plate) is composed of imbricated elongate blocks whose axes lie parallel to the Amargosa thrust.
2. The blocks have dimensions generally measured in hundreds of feet.
3. Blocks from widely separated stratigraphic horizons are often found in approximate juxtaposition.
4. Folding was not a common adjustment mechanism associated with thrusting.
5. Rupture appears to have occurred along incompetent units within the upper plate.
6. Faults between blocks in the chaos have not dislocated the lower plate; many were observed to meet this surface at an acute angle and to steepen upward as they diverge from it.
7. The upper plate (Amargosa chaos) generally consists of younger rocks than the lower plate.

The above characteristics were considered by Noble (1941) to be indicative of thrusting at shallow depths with correspondingly light overburdens. Noble (1941) considered that thrusting of this nature probably occurred in middle and late Tertiary time in the southern Black Mountains, but Drewes (1963) noted that older volcanics often intrude the thrust plane, and suggested that activity on the fault was limited to early and middle Tertiary time. This type of faulting, although with a less chaotic structure, is common in the Death Valley subsection of the Great Basin (Noble, 1941; Hunt and Mabey 1966).

In general, thrust faults common to the Amargosa Desert and vicinity can be classified into two general groups. In the older group the upper plates are generally composed of strata older than the lower plates, and are probably due to crustal shortening. The younger group are generally found to have a younger-over-older relationship, and are believed to be essentially detachment thrust faults (Hunt and Mabey, 1966).

Transcurrent Faults

Based on his analysis of the flexure of fold axes and thrust traces and directions of strike, and dip, Longwell (1960) proposed that a zone of extensive right-lateral displacement exists between the Spring Mountains and the ranges to the north (fig. 3). This large transcurrent fault was designated the "Las Vegas shear zone," but has been more recently referred to as the "Las Vegas Valley shear zone" by Longwell and others (1965) and Cornwall (1972). Lateral displacement in the vicinity of northern Las Vegas Valley is at least 25 miles, based upon the amount of offset on oroflexural trends north and south of the Las Vegas Valley shear zone. The oroflexural trends are probably the result of drag along the shear zone, which caused bending of pre-existing thrust plates, and of overturned folds (Albers, 1967; Fleck, 1970). Other estimates, derived from isopach and facies maps, indicate that up to 40 miles of right-lateral displacement in the same area is possible (Stewart and others, 1968).

In Mercury Valley, Burchfiel (1965) noted that most of the displacement along the fault was oroflexural, and by correlation of structures across the shear zone, he found that 24 miles of right-lateral offset is indicated. However, the high-angle reverse fault (Specter Range thrust) from which he obtained his correlation with thrust outliers in the Spotted Range, has been reinterpreted by Barnes and Poole (1968), who point out that the high-angle reverse fault is probably representative of an intermediate zone between a deeper root zone and the flat-lying outlier of the thrust in the Spotted Range. Thus, Burchfiel's (1965) estimate of right-laterial displacement in Mercury Valley may be exaggerated. Essentially continuous outcrops of Tertiary and Paleozoic rocks immediately north of the Specter Range indicate that little lateral crustal displacement has occurred in that area.

Noting that sedimentary units as young as Pliocene have been disturbed by the shear zone, Longwell concluded that the fault may have been active through much of the Tertiary, and both Ekren and others (1968), and Fleck (1970), consider that the movement is largely post-Oligocene. Burchfiel (1966) noted the presence of north- and northeast-striking oblique-slip faults which offset the basalt which caps Little Skull Mountain, east of Jackass Flats. Ekren and others (1968) have described a system of similar faults at the Nellis Air Force Bombing and Gunnery Range, several miles east of this location, which they consider to be a conjugate set related to the Las Vegas Valley shear zone. Because it is likely that the faults at Little Skull Mountain are of a similar origin, and because the basalt overlies the early Pliocene Timber Mountain Tuff, it is apparent that stresses related to the shear zone were active through the late Tertiary.

Atwater (1970) has concluded from magnetic anomaly data pertaining to the Pacific sea floor off the coast of California that right-lateral shear stresses should have begun in the Great Basin approximately 20 m.y. ago and have continued to the present. Because this time interval is approximately in agreement with the postulated duration of activity along the Las Vegas shear zone, subcrustal torsional stresses related to plate tectonics may be the mechanism of formation of the shear zone.

Hydrologic Significance of Geologic Structure

Regional movement of ground water is strongly influenced by the late Mesozoic-early Tertiary deformation of the late Precambrian and Paleozoic miogeosynclinal rocks, their subsequent erosion, and the faulting that took place during the late Cenozoic orogeny.

Deformation of the Tertiary rocks is highly variable. Simple tilting and block faulting occur in Las Vegas, Pahrump, and Indian Springs Valleys but in the Amargosa Desert, complex folding and faulting in the Tertiary strata influences the quality and movement of ground water.

Although thrust faults are the most spectacular tectonic feature in the region, their impact on ground water occurrence and movement at depth is little understood. Burchfiel (1964) and Secor (1962) maintain that such faults are decollement structures which flatten out with depth from initial dips of 35° to 50°. In contrast, Vincelette (1964) and Fleck (1970) present evidence that a steep dip is also present at depth.

Numerous normal faults, commonly with displacements of less than 500 feet but occasionally in the thousands of feet, are present in the region (Winograd, 1971a). In the Amargosa Desert, a north-south trending normal fault or fault zone in the Paleozoic carbonate rocks is believed to be responsible for the locus of springs in the Ash Meadows area. Normal faults, probably due to subsidence associated with differential compaction in the last several thousand years, are responsible for the locations of springs in Las Vegas Valley and probably in Pahrump Valley also.

REGIONAL HYDROGEOLOGY

Hydrostratigraphy

Table 1 summarizes the stratigraphic and hydrogeologic units present in the region bounded by the Nevada Test Site, Las Vegas Valley, and the California-Nevada boundary. The lower Paleozoic aquitard and the lower carbonate aquifer are generally well defined in this region, as are the extensive volcanic hydrostratigraphic units of the Nevada Test Site. Perhaps least known is the regional hydrologic significance of the deeply buried clastic rocks of the upper Paleozoic and Mesozoic.

Extensive outcrops of Mesozoic strata are limited to the Spring Mountains and to Frenchman Mountain on the east side of Las Vegas Valley. Three units, the Shinarump Conglomerate and the Moenkopi and Chinle Formations, are widespread throughout the southwest, and a fourth, the Aztec Sandstone, is believed to be correlative with the Navajo Sandstone of Utah and Arizona.

The Chinle and Moenkopi Formations are essentially impermeable, but they localize many small springs along contacts with other formations when other geologic and hydrologic conditions are favorable (Maxey and Jameson, 1948, p. 51). The Aztec Sandstone and Shinarump Conglomerate transmit small quantities of water. Although little is known of the subsurface extent of these Mesozoic units, they are not believed significant in the interbasin transfer of ground water. Their role, even in the hydrogeology of the Spring Mountains, is minor compared to that of the Paleozoic carbonate rocks.

Mesozoic hydrostratigraphic units within the vicinity of the Nevada Test Site are limited to a few isolated intrusive bodies which, for all practical purposes, are aquitards (Winograd and others, 1971). No attempt is made to distinguish them from Tertiary aquitards.

Certain late Tertiary welded tuffs at the Nevada Test Site are known aquifers (Winograd and others, 1971; Winograd, 1971b). These welded tuffs, part of the Paintbrush Tuff and Timber Mountain Tuff, are centered around the Timber Mountain caldera. As might be expected, welded tuffs cover extensive areas around Timber Mountain and thin irregularly away from the caldera (Lipman and Christiansen, 1964). Upon cooling, polygonal fractures formed in the more densely welded portions of each cooling unit. These primary fractures are the chief source of permeability and porosity of the welded tuffs (Winograd and others, 1971; Winograd, 1971b). Wells in one member of the Paintbrush Tuff beneath the western part of Jackass Flats indicate that these welded tuffs occasionally have transmissivities on the order of 100,000 gpd per foot or greater. It should be noted, however, that significantly lower transmissivities were obtained from the same formations in other areas (Winograd, 1971b). Further, Winograd (1971b) notes that older ash-flow tuffs below Pahute Mesa are considered aquitards, therefore it is not satisfactory to designate a formation as an aquifer simply because it is an ash-flow tuff.

TABLE 1. Stratigraphic and hydrogeologic

System	Series	Stratigraphic unit	Major lithology	Thickness (in feet)
Quaternary and Tertiary	Holocene Pliocene Pleistocene	Valley fill	*Alluvial fan, fluvial, fanglomerate, lakebed, mud flows, locally interbedded basalt flows*	2,000
	Pliocene (?)	Muddy Creek Formation	*Silt, clay, gravel*	2,000
	Oligocene Miocene Pliocene	Tuffs of the Nevada Test Site	*Basalt and rhyolite flows, ash falls*	
				2,500
				2,090
				1,000
				4,000
				1,100
Jurassic (?)		Aztec Sandstone	*Massive sandstone*	2,000
Triassic	Upper	Chinle Formation	*Shale and sandstone*	900
		Shinarump Conglomerate	*Sand and gravel conglomerate*	0-100
	Lower	Moenkopi Formation	*Shale, limestone, dolomite, sandstone*	900
Permian		Kaibab and Toroweap Fms.	*Two thick limestone units with weak shale, sandstone*	1,100
		Red beds	*Sandstone and shale*	300
Mississippian Pennsylvanian Permian		Bird Spring Formation (Spring Mountains only)	*Limestone with interbedded sandstone and dolomitic limestone*	2,500-7,000+
Mississippian	Upper-lower	Monte Christo Limestone (Spring Mountains only)	*Limestone with minor dolomite*	350-1,240
Devonian	Upper	Sultan Limestone (Spring Mountains only)	*Dolomite in lower part, limestone in upper part*	765-3,000
	Middle			
	Lower	Nevada Formation	*Dolomite*	〉1,525
Silurian	Upper	Undifferentiated	*Dolomite*	?
	Middle	Lone Mountain Dolomite	*Dolomite*	1,600
	Lower	Undifferentiated	*Dolomite*	?
Ordovician	Upper	Ely Springs Dolomite	*Dolomite*	305
	Middle	Eureka Quartzite	*Quartzite, minor limestone*	340
	?	Pogonip Group: Antelope Valley Ls.	*Limestone and silty limestone*	1,530
	Lower	Pogonip Group: Ninemile Formation	*Claystone and limestone interbedded*	335
		Pogonip Group: Goodwin Limestone ?	*Limestone*	〉900
Cambrian	Upper	Nopah Formation (Goodsprings Limestone in Spring Mts.)	*Dolomite, limestone*	1,070
			Limestone, dolomite	715
			Shale, minor limestone	225
	Middle	Bonanza King Fm. (Goodsprings Limestone in Spring Mts.) ?	*Limestone, dolomite*	4,600
		Carrara Formation	*Limestone predominant*	1,050
	Lower		*Siltstone predominant*	950
		Zabriske Quartzite	*Quartzite*	220
		Wood Canyon Formation	*Quartzite, siltstone, shale*	2,300
Precambrian		Stirling Quartzite	*Quartzite, siltstone*	3,400
		Johnnie Formation	*Quartzite, sandstone, siltstone*	3,200

[1] Modified after Cornwall, 1972; Longwell and others, 1965; Maxey and Jameson, 1948; Winograd and others, 1971.

units in southwestern Nevada.[1]

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Hydrogeologic unit	:teristics			
Valley fill aquifer and aquitard	*Transmissivity ... r ft. Interstitial permeability highly variable due to grain si... which ranges from clay to boulders; fracture permeability negligible except in indurated Tertiary clastics. Generally saturated except at the Nevada Test Site, where only the deepest parts of Yucca and Frenchman Flats are saturated.*			
	Porosity	Permeability	Transmissivity	Saturated
Lava flow aquifer	*Negligible*	*Fracture*	*500 - 10,000*	*Deep beneath Jackass Flats*
Welded tuff aquifer	*Negligible*	*Fracture*	*100 - 100,000*	*Deep beneath Yucca, Frenchman, Jackass Flats*
Bedded tuff aquifer	*Negligible*	*Fracture*	*200 - 1,000*	*Deep beneath Yucca, Frenchman, Jackass Flats*
Lava flow aquitard	*Negligible*	*Fracture*	*<500*	*Minor perched water*
Tuff aquitard	*Up to 40%*	*Negligible*	*100 - 200*	*Deep beneath Yucca, Frenchman, Jackass Flats*
Upper Paleozoic aquitard	*Very low transmissivity due to lithology and lack of secondary porosity and permeability; generally saturated; numerous local springs at the Aztec-Chinle contact.*			
Lower carbonate aquifer	*Secondary porosity and permeability due to fractures and solution; regional transmissivity due primarily to fractures; supplies major springs throughout eastern Nevada; transmissivity ranges from 1,000 to 1,000,000 gpd per ft.; saturated beneath most of eastern and southern Nevada.*			
Lower Paleozoic aquitard	*Complexly fractured but poorly permeable; accounts for no major springs; transmissivity is less than 1,000 gpd per ft.; essentially no interstitial porosity; fractures poorly connected; generally saturated.*			

At the Nevada Test Site, a series of early Tertiary zeolitized tuffs and tuffaceous sediments occur between the welded tuff aquifer (Paintbrush Tuff and Timber Mountain Tuff) and the carbonate aquifer. Tunnels, bore holes, electric logs, and well tests (Winograd and others, 1971) indicate that these formations were aquitards. In contrast to either the underlying carbonate aquifer or the overlying welded tuff aquifer, they are significantly less permeable, although their porosities may be several orders of magnitude greater than either of the aforementioned aquifers. Winograd and others (1971) attribute these aquifer characteristics to high clay and zeolite content of these beds, noting that slight interstitial permeability is their chief mechanism for transmission of ground water.

Within the Amargosa Desert, the previously described Tertiary sedimentary rocks probably form a similar aquitard beneath the Quaternary valley fill. That these sediments are also aquitards is indicated by their dominant clay lithology and by the effect they have upon ground-water flow. Two examples of the latter influence on flow can be examined in the southern Amargosa Desert. Grapevine Springs (19/50, 4 ba) is an elongate seep area at the erosional contact of early Pleistocene(?) gravels and Tertiary playa lake sediments, and occurs at an elevation considerably above the general water table in the area. As it is unlikely that the spring is receiving its recharge from any possible underlying carbonates, the only likely alternative is local recharge. The geological setting suggests that a local, semi-perched or perched flow system exists in the early Pleistocene(?) gravels. Such a system would require an aquitard beneath the gravels. A similar system can be seen at Navel Spring in Furnace Creek Canyon in Death Valley, at the contact of the Funeral Fanglomerate and the Furnace Creek Formation.

The second notable example of the influence of Tertiary playa-lake sediments on ground-water flow can be seen in the area of Clay Camp. Water table maps of the area show a slight horizontal gradient northwest of Clay Camp. South and southeast of Clay Camp the water table steepens abruptly, as if flow has intersected a barrier. The occurrence of Tertiary outcrops almost always coincides with this water table phenomenon, suggesting that the Tertiary sediments are less permeable than the overlapping younger sediments, and in terms of hydrostratigraphic units, the Tertiary and Quaternary valley fills are aquitard and aquifer, respectively.

The hydrostratigraphic units of the Nevada Test Site as defined by Winograd and others (1971) are not entirely applicable to the Amargosa Desert. The Devonian-Mississippian Eleana Formation, composed of 7,900 feet of argillite, quartzite, conglomerate, and limestone, comprises an upper clastic aquitard overlying the lower (Paleozoic) carbonate aquifer in the Nevada Test Site region. In the Amargosa Desert, the Eleana Formation is essentially absent (Naff, 1973), and confinement of ground-water within the Paleozoic strata is primarily a result of the overlying fine-grained Tertiary and Quaternary units which for the most part are poorly permeabile. Furthermore, in the Amargosa Desert other clastic Paleozoic units overlying the carbonates have average thicknesses of 100 to 200 feet and are usually completely displaced by vertical faults having greater stratigraphic offset (Naff, 1973), therefore their effectiveness as aquitards is typically only local (Winograd and others, 1971).

In particular, porosity and permeability in pre-Cenozoic rocks are probably related to the formation of open stress fractures, with some secondary solution in carbonate rocks (Winograd and others, 1971). The fractures are open to depths of 4,200 feet, and there is other evidence that ground-water circulation occurs to depths of 10,000 feet (Winograd, 1971a).

Ground-water Movement

Three types of ground-water movement are believed present in eastern and southern Nevada (Winograd, 1971a): 1) movement involving perched water, 2) intrabasin movement, and 3) interbasin movement. Only the latter two are considered in this report. Intrabasin basin movement within the subject area was defined by Winograd (1971a, p. 24) as that which occurs between the Cenozoic and Paleozoic aquifers and aquitards beneath a valley. In Pahrump, Las Vegas, and Indian Springs Valleys and in the Amargosa Desert, movement is upward, i.e. the Cenozoic aquifers receive discharge from the carbonate rocks. Conversely, in Yucca and Frenchman Flats intrabasin movement is downward into the carbonate rocks.

Interbasin movement involves the widespread lateral transfer of ground water within the carbonate rocks located at depth beneath the basins and in exposures in the flanking highlands. Such movement is fostered by the widespread occurrence of the carbonate rocks and their high transmissivities. Comparison of potential distribution in both the carbonate and Cenozoic aquifers, water chemistry, and disproportions in apparent catchment area versus spring discharge, provide additional evidence for the pattern of interbasin movement shown in figure 3.

Topographic and ground-water divides commonly do not coincide, therefore routine evaluation of static ground-water levels and basin water budgets can be misleading in regional flow system analysis. For this reason, hydrologic, geologic, geochemical, and isotopic methods are utilized. At best, ground-water movement can only be roughly defined in this geologic environment, which is markedly anisotropic in even a regional sense because of stratigraphic and structural variation, and for which sparse subsurface hydraulic data exist.

Las Vegas Valley

The hydrogeologic framework of Las Vegas Valley was first described by Maxey and Jameson (1948), and again by Malmberg (1965). Later studies which concentrated on particular aspects of the subject include Domenico and others (1964), Domenico and Mifflin (1965), Mindling (1971), and Käufmann (1971).

Terraces formed on cemented gravels are present as high as 9,000 feet above mean sea level in the Spring Mountains, indicating that at some time in the past this range, and probably others, were essentially covered by coarse debris.

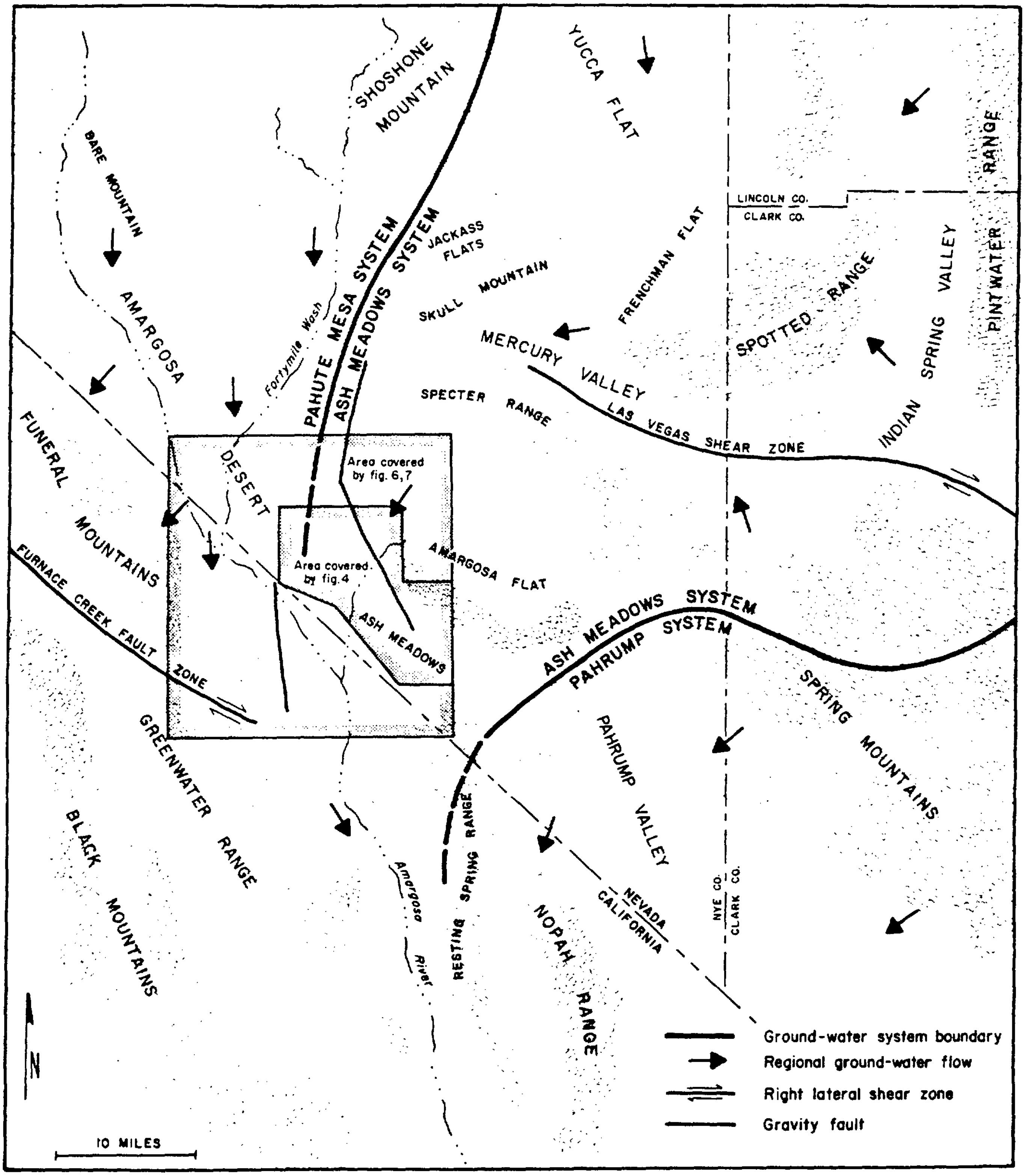


FIGURE 3. Index map of regional structural controls and directions of interbasin ground-water flow in the vicinity of the Amargosa Desert.

At present the fans extend 5 to 8 miles from the bedrock ranges and, at the distal ends, grade into the playa sediments in the central portion of the valley. Well records and outcrop evidence indicate that the upper parts of the alluvial fans consist mostly of extensive, thick, permeable lenses of coarse gravel with some sand and minor silt or clay. Farther down on the fans these lenses become thinner, more irregular, narrower, and discontinuous as they grade into thick deposits of silt and clay beneath the central parts of the valley.

The Muddy Creek Formation underlies most of Las Vegas Valley, cropping out on the southern and eastern sides of the Valley, and descending to depths of 700 feet or more in other places. These materials are finer grained, better sorted, and more evenly bedded than are the overlying sand and gravel units. In Paradise Valley, 5 to 10 miles southeast of Las Vegas, the Muddy Creek Formation is well exposed in Whitney Mesa and consists primarily of evenly bedded clayey silt with thin interbedded sand and gravel.

The facies changes briefly described above are commonly the loci of north-south trending gravity faults with displacements of as much as 150 feet. Scarps in the valley fill in the central, southern, northern, and western parts of Las Vegas Valley are a result of these faults. The faults are believed to be due to differential compaction of the valley fill with finer-grained beds compacting to a much greater degree than the coarser units to the west (Maxey and Jameson, 1948). Renewed, recent subsidence in Las Vegas Valley is concentrated around the zones of heaviest ground-water extraction. Such zones are characterized by recent non-differential settlement in excess of 3 feet, and by radially and tangentially oriented fissure patterns.

Based on various measurement methods, the natural water budget of Las Vegas Valley has been estimated to range from 22,000 to 35,000 acre-feet per year, with a mean of 25,000 acre-feet per year (Maxey and Jameson, 1948; Malmberg, 1965). Depending on climatic cycles in the recharge areas, the discrepancies in estimates may well reflect natural variations. Overdrafting of the ground-water reservoirs at a rate of 3 or 4 to 1 has taken place in recent years, and is evidenced by declining water levels in the deeper artesian aquifers. Augmentation of the insufficient ground-water supply with water imported from Lake Mead will either reduce or eliminate water supply problems, depending on the ultimate population of the valley. The combination of ground-water overdraft and surface water importation has created a hydraulic imbalance and changed the hydraulic and water quality equilibrium of the basin (Kaufmann, 1971; Kaufmann, Westphal, Maxey, in press). Under natural conditions outflow from the basin was by way of Las Vegas Wash, and consisted of flood water and approximately 200 acre-feet per year of ground water. At present, approximately 13,500 acre-feet per year of ground-water return flow surfaces and exits the valley as surface outflow (Kaufmann, 1971).

Pahrump Valley

The stratigraphy and structure of the valley fill in Pahrump Valley is very similar to that of Las Vegas Valley, but faulting in close proximity to the major springs is not evident from surficial expression or well log data despite the abrupt decrease in sediment grain size coincident with the locations of major springs. Bennetts Springs at the toe of the Pahrump Fan, and Manse Spring at the toe of the Manse Fan, may be fault related in that logs of wells drilled west of the springs and in the inter-fan areas revealed larger proportions of finer materials. Several small springs issue from the scarps that transect the valley fill in the southern part of Pahrump Valley.

Most of the deeper valley-fill sediments underlying the distal ends of the fans consist of silt and clay with occasional interbedded sand and gravel lenses. The deepest wells have been drilled in the vicinity of the springs, and are approximately 900 feet deep. They penetrate sediments that are possibly time equivalent with the Esmeralda and Muddy Creek Formations. The underlying bedrock has not been encountered.

Appraisals of the water supply of Pahrump Valley made by Maxey and Jameson (1948) and Malmberg (1967), indicate a water budget of 23,000 acre-feet per year. Heavy pumping of ground water for irrigation resulted in a 2 to 1 overdraft of alluvial aquifers which had discharged approximately 10,000 acre-feet per year under natural conditions. From 1916 to 1937 discharge was primarily by springs, but as more artesian and pumping wells were utilized, particularly since the mid 1940's, spring discharge initially declined and then stopped altogether.

Outflow from the basin is primarily to the southwest via the Paleozoic carbonate rocks. Although Maxey and Jameson (1948) originally regarded Pahrump Valley as an enclosed ground-water basin with no loss by underflow, later water budget and hydrochemical analyses by Malmberg (1967), Winograd and others (1971), Winograd (1971a), and Naff (1973) indicate that there is underflow to the Nopah and Resting Spring Ranges to the southwest. The amount of underflow was estimated at 2,000 acre-feet per year from the valley fill reservoir and 10,000 acre-feet per year from the lower Paleozoic carbonate rock reservoir.

Indian Springs Valley

This valley is similar to Las Vegas and Pahrump Valleys, and near-surface ground water is first encountered at depths of less than 100 feet in the less elevated portions of the Valley. The water is unconfined, and is recharged by infiltration of spring discharge. Confined aquifers have been penetrated by wells ranging in depth from 400 to 604 feet (Maxey and Jameson, 1948, p. 119).

Indian Springs discharge approximated 800 acre-feet per year for the period 1905 to 1942. From 1943 to 1945 discharge was increased to 1450 acre-feet per year through the use of wells.

From analysis of the catchment area elevation and acreage, Maxey and Jameson (1948, p. 119) estimated a recharge of 4,700 acre-feet per year, indicating that approximately 3,200 to 4,000 acre-feet per year leaves the basin either as underflow or evapotranspiration. Winograd and others (1971), using geologic, hydrologic, hydrochemical, and isotopic data, concluded that Indian Springs Valley is recharged from the Pintwater Range and, to a greater degree, from the Spring Mountains. Discharge not accounted for locally within the Valley represents recharge to the Ash Meadows regional ground-water system.

Amargosa Desert

The Amargosa Desert is a large basin encompassing approximately 600 square miles, and is surrounded by mountains composed of indurated rocks ranging from Precambrian to Tertiary in age. The valley fill consists of Tertiary and Quaternary alluvial fan and playa type deposits in various stages of deformation.

In a gross structural and stratigraphic sense, the Amargosa Desert is similar to many other basins in the southern Great Basin, but ground-water discharge within the basin is anomalously high, considering the elevation and area of the surrounding highlands. The intricacies and interrelations of physiography, geologic materials, structural deformation, and regional climatic conditions are such that the Amargosa Desert is a sink for three regional ground-water flow systems discharging about 23,500 acre-feet per year within the basin and 5,500 acre-feet as underflow to other areas.

Naff (1973) has delineated the systems within the southern portion of the Desert from analysis of geologic, hydrochemical, and ground-water potentials; flow systems elsewhere within the region have been delineated by Winograd and others (1971), Winograd (1971a), and Blankennagel and Weir (1972).

Early Tertiary Valley Fill The Titus Canyon Formation or its equivalent is a fluvial and lacustrine rock unit dated as possibly early Oligocene, and present on the southeast flank of the Funeral Mountains (Denny and Drewes, 1965; Naff, 1973). Members identified to date include a lower fanglomerate, lower conglomerate, upper limestone and shale, upper fanglomerate, and upper conglomerate. These units have a minimum aggregate thickness of 2,700 feet.

Late Tertiary Valley Fill The late Tertiary valley fill represents a thick sequence of playa lake sediments underlain by fanglomerates of the Titus Canyon Formation. The contact is considered conformable by Denny and Drewes (1965), but Naff (1973) concludes it is unconformable on the basis of variation in weathering, the difference in degree of induration of the playa lake sediments as compared to the underlying fanglomerate, and the sharp lithologic change.

The finer-grained playa lake clastics are generally tuffaceous and thinly bedded, and are characterized by variegated but light coloring and a high percentage of clay. Extreme lateral and vertical variation is common.

The southward dipping Tertiary valley fill in the southern part of the Amargosa Desert near Ash Meadows Ranch is characterized by siltstones, sandstones, zeolitized tuffs, and some limestone. Further north, in T. 18 S., R. 50 E., fanglomerates, silicified limestones, tuffaceous sandstones, shales, and claystone begin to appear in steeply dipping beds. Several breached, plunging anticlines are present in sec. 16 and in the SW ¼ sec. 5, T. 18 S., R. 50 E., and in the vicinity of the Tenneco processing plant in sec. 36, T. 17 S., R. 49 E.

The surficial structures indicate that north-south compressional stresses folded the Tertiary sedimentary rocks, and that subsequent east-west tensional stresses caused normal faults in the Cenozoic valley fill. The compressional stresses may have affected the Pleistocene valley fill as well, because the older Pleistocene sediments in the Clay Camp area also bear evidence of compressional disturbance.

The late Tertiary depositional environment was probably a playa lake, which as it filled with sediments, became a salt pan, and was eventually overrun by fluviatile deposits. Fans often appeared at the edge of the playa, resulting in tongues of fanglomerates at various levels in the finer-grained sediments. The tuffaceous character of the sediments indicates that volcanism occurred simultaneously in the area.

It is interesting to speculate on the source of water for the playa lake, as the algal limestone overlaps a breccia zone of a thrust plane below the Bonanza King Formation. This formation is a proven aquifer, and could account for springs discharging into the lake. The ability of such springs to maintain a playa lake would depend upon the rate of spring discharge, the evaporation potential, and the surface area of the lake, and it is quite possible that such a lake would be dry during the summer months, even though it had a constant inflow.

An early and middle Pliocene age was tentatively assigned to the playa lake sediments by Naff (1973). The conclusion is tentative because no identifiable fossils were found, and the correlation must be made on the basis of lithologic similarity and stratigraphic position with respect to similar formations of known age in surrounding areas.

In the Bullfrog quadrangle southwest of Beatty, Nev., Cornwall and Kleinhampl (1964) mapped tuffaceous clastic and carbonate sedimentary rocks as conformably overlying early Oligocene rocks of the Titus Canyon Formation. In the Daylight Pass area and northeast of the pass, these sedimentary rocks are interbedded with the Paintbrush Tuff (Cornwall and Kleinhampl, 1964), dated as late Miocene and early Pliocene in age (Kistler, 1968) by potassium-argon methods.

Southwest of Ash Meadows, Noble and Wright (1954) mapped late Tertiary sedimentary rocks in the northern Resting Springs Range of California as part of the Furnace Creek Formation, which formation has been dated as early and middle Pliocene by McAllister (1970) on the basis of diatoms. The Tertiary playa-lake sediments in the Amargosa Desert are quite similar to the description of the Furnace Creek Formation given by Drewes (1963) for the siltstone-shale and siltstone-limestone beds at the northern end of the Greenwater Range. Although shale and borate beds are not known to occur in the playa lake sediments at Ash Meadows, they are found in Tertiary sedimentary rocks of the Resting Springs Range near Shoshone, Calif. (Noble and Wright, 1954).

If the stratigraphic correlations discussed above are correct, the Tertiary sedimentary rocks at Ash Meadows are possibly either late Miocene or early Pliocene. Further, the Ash Meadows sedimentary rocks are very similar to early and middle Pliocene beds occurring in the Furnace Creek area of Death Valley. Therefore, Tertiary sedimentary rocks at Ash Meadows are possibly Furnace Creek Formation equivalents, and may also be equivalent to Tertiary sedimentary rocks interbedded with the Paintbrush Tuff.

Pleistocene Valley Fill The oldest Pleistocene valley fill is exposed in the vicinity of Clay Camp (18/49 1a). Pinkish gray, medium to thick bedded siltstones and claystones immediately overlie the Tertiary playa lake sediments, and are indicative of a low-energy, fluviatile environment. Some of the Pleistocene sediment consists of fuller's earth derived from Tertiary sedimentary rocks deposited in playa lakes.

Well logs in the area of Ash Meadows and Carson Slough show that the upper 300 feet of valley fill almost without exception is marl and clay. The outcrop and subsurface data indicate an extensive upper marl zone throughout the southeastern Amargosa Desert. Walker and Eakin (1963) indicate that this marl zone extends almost uniformly around Amargosa Flat up to an elevation of 2,400 feet.

The mineralogy of the silt fraction in the marls at Ash Meadows is similar to that of the phenocrysts of the late Tertiary tuff bordering the Amargosa Desert on the north. Lipman and Christiansen (1964) found that weathering of the glassy component of these tuffs results in the formation of montmorillonitic clays. Carbonic acid from meteoric waters may be the mechanism for the breakdown of the glassy fraction and for the formation of sodium bicarbonate ground water common to such terrains. Hoover (1968) noted the preferential exchange of hydrogen ions for sodium ions in volcanic glass.

Clay samples from the Pleistocene valley fill at Ash Meadows were identified by x-ray diffraction analysis as almost entirely dioctahedral montmorillonite.

At various localities throughout Ash Meadows, light colored vuggy limestones form protective caps on small mesas. The cap at Fairbanks Butte (16/50 27b) is probably the best example of these limestones. The base is rather marly and reminiscent of limestone beds lower in the section, but it grades upward into a clean, fine-grained white limestone comprising the bulk of its thickness. Flattened angular vugs, which appear to be columniated perpendicular to bedding, give the cap a distinctive appearance. The cap is massive and at least 20 feet thick at its southwest end, but thins to only a few feet at its northeast end.

An identical cap approximately 100 yards to the west, but at an elevation approximately 100 feet lower than the top of the Fairbanks Butte cap, is badly brecciated along fractures and joints, and from a maximum thickness of 10 to 15 feet along its easternmost edge it thins rapidly westward and northward. The similarity of the two caps suggests strongly that a north-northwest trending fault between them has downthrown the westernmost cap.

Environment of deposition. Evidence is lacking for a closed Pleistocene basin in the Amargosa Desert. If the basin had been closed during this epoch, the most likely location for a barrier causing complete closure would be at Eagle Mountain, to the South of Death Valley Junction, as this is the location of a natural restriction in the Amargosa River. However, if closure has ever existed at this point, severe tectonic tilting must have occurred since, because the area is generally at or below the mean elevation of the floor of the Amargosa Desert at Ash Meadows. Also, because nothing in the surficial sediments at Eagle Mountain is indicative of closure, it would be necessary for post-closure erosion to have removed all evidence of closure from the depositional record.

Northeast of Ash Meadows, extensive gypsum and clay beds are probably remnants of an ancestral playa in the Amargosa Flat area. It is likely, then, that local closure within the desert has occurred from time to time. Closure also may have existed at various times where gravity lows exist north and east of a gravity high which approximately parallels the Nevada-California boundary. The gravity high parallels a series of Tertiary outcrops which traverse the Amargosa Desert along the same trend. Gravity lows may be areas where locally closed basins existed in the Pleistocene epoch, but for which no surficial evidence is seen because of burial by later Pleistocene sediments. It should be remembered that the older Pleistocene sediments in the Clay Camp area are themselves tectonically disturbed, and that younger Pleistocene sediments overlap the Tertiary playa lake sediments with only minor indications of tectonic disturbance. Thus, these postulated basins may have been of an intermittent character, present only when tectonism could maintain an effective barrier in relationship to deposition of sediments in the basins.

The Pleistocene limestones and marls were probably formed as a result of discharge from the carbonate aquifer during that epoch, because the present discharge is saturated with respect to calcite, suggesting that chemically similar waters may have the source of the Pleistocene lithologies. The present discharge is also supersaturated with respect to atmospheric CO_2, thus allowing for a natural mechanism of precipitation. To illustrate the potential effect of saturation and supersaturation, car bodies placed in the reservoir southeast of Crystal Spring were covered with a coat of fine calcium carbonate within 6 months of the filling of the reservoir. However, it has also been observed that *chara*, growing in shallow pools in the area, will often be jacketed with a thin brittle coat of calcium carbonate. The interformational conglomerate and vuggy limestone facies of the limestone caps are also suggestive of a strong biological factor, because they could have formed as the result of precipitation on algal mats. A similar biological control is suggested for formation of lithoidal tufas at Mono Lake, Calif. (Scholl and Taft, 1964). Thus, both biological and thermodynamic factors may be responsible for the limestone and marl deposits at Ash Meadows.

The maximum elevation of these marls at Ash Meadows and around Amargosa Flat is approximately 2,400 feet. Because the carbonate aquifer underlies this entire area, the above elevation must represent the maximum potential obtained by ground water within the aquifer during the Pleistocene glacial stages. Waters warmed by their deep flow path probably discharged from springs and seeps over the entire land surface below the elevation of this maximum potential. These waters probably maintained tule-choked ponds and marshes in which marls and limestones were deposited, the calcite for these deposits being derived from ground water. Volcanic terrains to the north provided abundant debris, which was probably strained of its coarser component along the periphery of the marsh area as it was transported by surface waters toward the centers of the basins. Calcareous algal crusts closely associated with some springs may have accumulated locally, and later have been diagenetically altered. During interglacial periods, finer material was probably reworked and deposited, along with evaporites derived from ground-water discharge, in playas toward the center of the basins. Alluvial fans were actively growing on the mountain flanks away from the center of the basins, and the fan gravels would interfinger with marls in the vicinity of the zone of saturation.

Although the above description is schematic and therefore lacking detail, Naff (1973) regards it as approximately correct on a gross scale. It is certainly more applicable to the marls and clays than to the older Pleistocene valley fill in the Clay Camp area.

Hydrologic characteristics. In a bulk comparison with other strata, the Pleistocene valley fill can act either as an aquitard or aquifer. As previously noted, in contrast to the Tertiary playa lake sediments in the area of the Clay Camp, the Pleistocene valley fill is an aquifer. On the other hand, the opposite relationship is exhibited in comparison with the carbonate aquifer at Ash Meadows. Northeast of Ash Meadows, the piezometric surface in the carbonate aquifer slopes very gently toward Ash Meadows, the gradient averaging less than 1 foot per mile (fig. 4). At Ash Meadows, discharging springs indicate that the carbonate aquifer is in juxtaposition with less permeable sediments (Winograd, 1971a). These sediments consist, in large part, of the Quaternary valley fill. West of Ash Meadows, the water table in the Quaternary valley fill is essentially at the land surface, and slopes steeply away from the Paleozoic carbonate outcrops. The strongly contrasting gradients of the two surfaces are indicative of a large permeability contrast, and suggest that, in this instance, the Pleistocene valley fill is an aquitard.

Aquifers within the Pleistocene alluvial materials occur either as limestones several feet thick that have solution permeability, or as clean sand and gravel with high intergranular permeability. Specific capacities rarely exceed 5 gpm per foot of drawdown.

ASH MEADOWS GROUND-WATER FLOW SYSTEM

Recent investigations (Winograd, 1971a; Winograd and others, 1971) determined that the Ash Meadows regional ground-water flow system which discharges in the Amargosa Desert encompasses at least 4,500 square miles (fig. 3). Recharge may also occur as underflow from the White River ground-water basin located 90 miles to the northeast. The Pahute Mesa ground-water system, originating in the Nevada Test Site, enters the Amargosa Desert from the northwest. Discharge from the Amargosa Desert occurs primarily as evapotranspiration, with lesser amounts as underflow to Death Valley (5,000 acre-feet per year) and the Amargosa River to the south (500 acre-feet per year). There is possibly a third, smaller flow system that originates in the Timber Mountain-Buckboard Mesa area, and which enters from the north and discharges in the central part of the Amargosa Desert (Naff, 1973).

Recharge to the system occurs through the fractured Paleozoic carbonate rocks of the Sheep Range, northwestern Spring Mountains, and southern Pahranagat Range, with lesser amounts from the Pintwater, Desert, and Spotted Ranges (Winograd, 1971a, p. 77). Interbasin flow from Pahrump Valley is improbable because the lower clastic aquitard crops out nearly continuously between Pahrump and Stewart Valleys and the spring discharge area. In addition, the Montgomery thrust fault between Stewart Valley and the Johnnie mining district to the north further isolates the Paleozoic carbonates from the Cenozoic aquifers in Pahrump Valley. Head relations between Stewart and Pahrump Valleys and the Amargosa Desert also suggest a damming effect somewhere in between. (Winograd, 1971a, p. 76).

The Ash Meadows discharge area, located in the southeastern and east-central Amargosa Desert, is flanked on the east by an unnamed range of hills, an extension of the Resting Springs Range. The western edge of the discharge area is less distinct, and merges with Carson Slough. A large prominent normal fault, with a minimum displacement of several thousand feet in the vicinity of Big Spring at the southern end, extends approximately 5 miles north-northeast of Lathrop Wells. The fault places low-permeability Cenozoic deposits in juxtaposition with Paleozoic carbonate rocks.

The surface drainage area is a few hundred square miles (Loeltz, 1960), yet the springs discharge 17,000 acre-feet per year. Available data indicate that the springs are principal discharge lows for the Paleozoic carbonate aquifer which is recharged by precipitation in the Nevada Test Site, and by underflow from the White River ground-water system to the northeast (Winograd, 1971a).

Thirty springs are present in the discharge area, and extend for 10 miles along a N. 20° to 25° W. trending line. Twenty of the 30 are within a single mile-wide strip located away from the carbonate rocks to the east. Discharge is through Pleistocene(?) lake beds consisting of clay and marl and some thin gravel lenses.

Hydrochemical Evidence For Interbasin Flow

Nevada Test Site Region-Ash Meadows. The major regional aquifer is the thick section of Paleozoic carbonate rocks that is widely exposed in the mountain ranges to the east and northeast of the Amargosa Desert. Available data from these higher ranges indicate that ground water in these assumed source areas typically has a calcium-magnesium bicarbonate character, while discharge from the carbonate aquifer at Ash Meadows has a mixed bicarbonate character and a large sulfate component.

Evidence that the bulk of the water discharging at Ash Meadows originates in recharge areas composed of dolomitic strata can be obtained by comparing calcium percentages from various locations in aquifers in the region surrounding

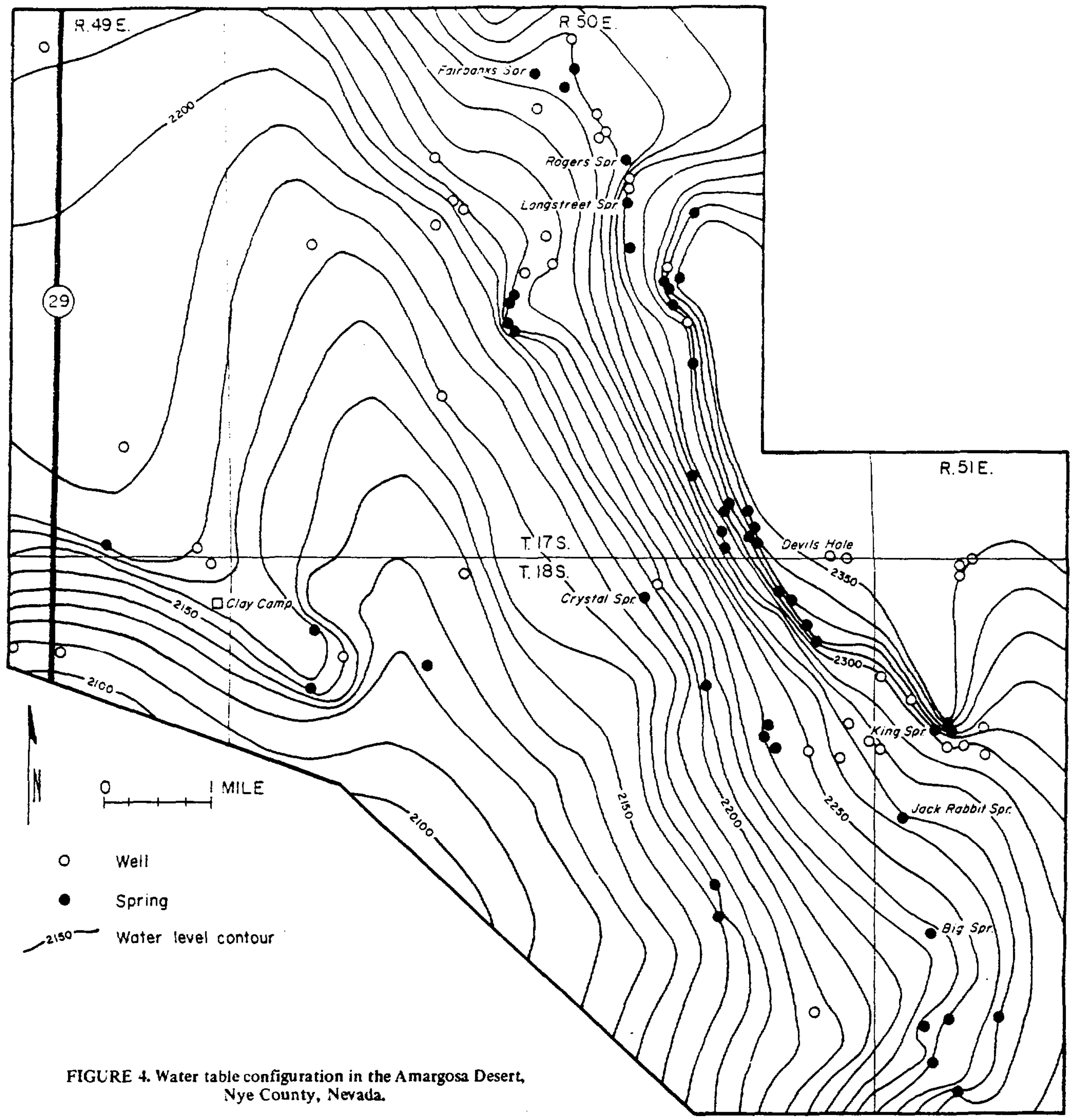
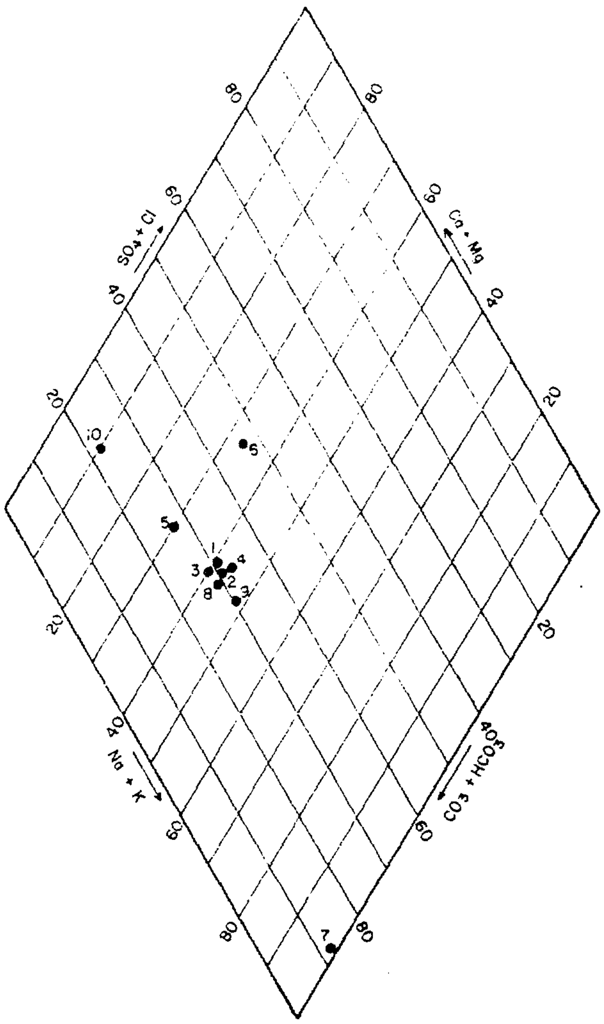


FIGURE 4. Water table configuration in the Amargosa Desert, Nye County, Nevada.

Ash Meadows. The Tertiary aquifer generally yields a calcium percentage on the order of 80 percent, while those from Ash Meadows are from wells and springs in the carbonate aquifer to the east of Ash Meadows, including the Spring Mountains area, and yield a percentage calcium of about 60 percent. Meisler and Becher (1967) note that springs from dolomite strata of Pennsylvania almost invariably yield a Ca^{++}:Mg^{++} ratio of one, or 50 percent calcium. Waters in the carbonate aquifer in the region to the east of Ash Meadows possess a calcium percentage that is indicative of a dolomitic limestone or mixed limestone and dolomite source area. For discharge at Ash Meadows, the fact that the percentage remains at this level either indicates that the greater bulk of the discharge in this area is derived from carbonate terrains, or that the percentage is coincidental.

Schoff and Moore (1964), and more recently Winograd (1971a), investigated the sources of sodium for waters having a sodium bicarbonate character in and around the Nevada Test Site. They concluded that the sodium was leached from glassy rhyolitic material in the alluvial and Tertiary aquifers and aquitards. Winograd (1971a) noted that ground water from rhyolitic terrains does not yield sufficient sodium to account for the entire sodium component in the underlying carbonate aquifer at the Nevada Test

	Location	Date	Summed Ionic Constituents
1.	17/50-36dc	01/22/53	559
2.	17/50-36dc	10/21/64	554
3.	17/50-36dc	03/30/67	555
4.	17/50-36dc	06/28/72	557
5.	16/53-4b	07/10/62	438
6.	73-70	04/25/62	578
7.	73-66	06/17/62	644
8.	16/51-27ba	02/ - /68	504
9.	75-73	05/10/62	600
10.	16/64-1aa	02/28/64	288



Points 1,2,3, and 4 from Devils Hole; 5 and 6 from carbonate aquifer southeast and northwest of Specter Range; 7 from Tertiary aquitard; 8 and 9 from carbonate aquifer, Amargosa and Frenchman Flats; 10 from carbonate aquifer between Indian Springs and Specter Range.

FIGURE 5. Piper diagram showing ground-water quality north of the Specter Range, Nevada.

Site, and suggested that the Tertiary aquitard may be the source of not only the sodium component, but also the sulfate component in the mixed bicarbonate facies. The Tertiary aquifer in this area is a complex of gypsiferous sedimentary units and sodium-rich zeolitized tuffs.

The almost complete absence of calcium and magnesium in the ground water of the Tertiary aquitard is attributed by Winograd (1971a) to cation exchange within the zeolitic and argillaceous units of the Tertiary aquitard. Whatever calcium or magnesium may enter the aquitard from above, or may be leached from gypsiferous units within the aquitard, is probably removed by cation exchange before leaving the aquitard. It is evident that if water of this chemical character were mixed with water from the carbonate aquifer, the calcium percentage in water from the carbonate aquifer would be little affected. Therefore, the source of the discharge at Ash Meadows is most likely recharge in the carbonate mountain ranges to the east and northeast of Ash Meadows. In the case of the Spring Mountains, only the northern portion is included.

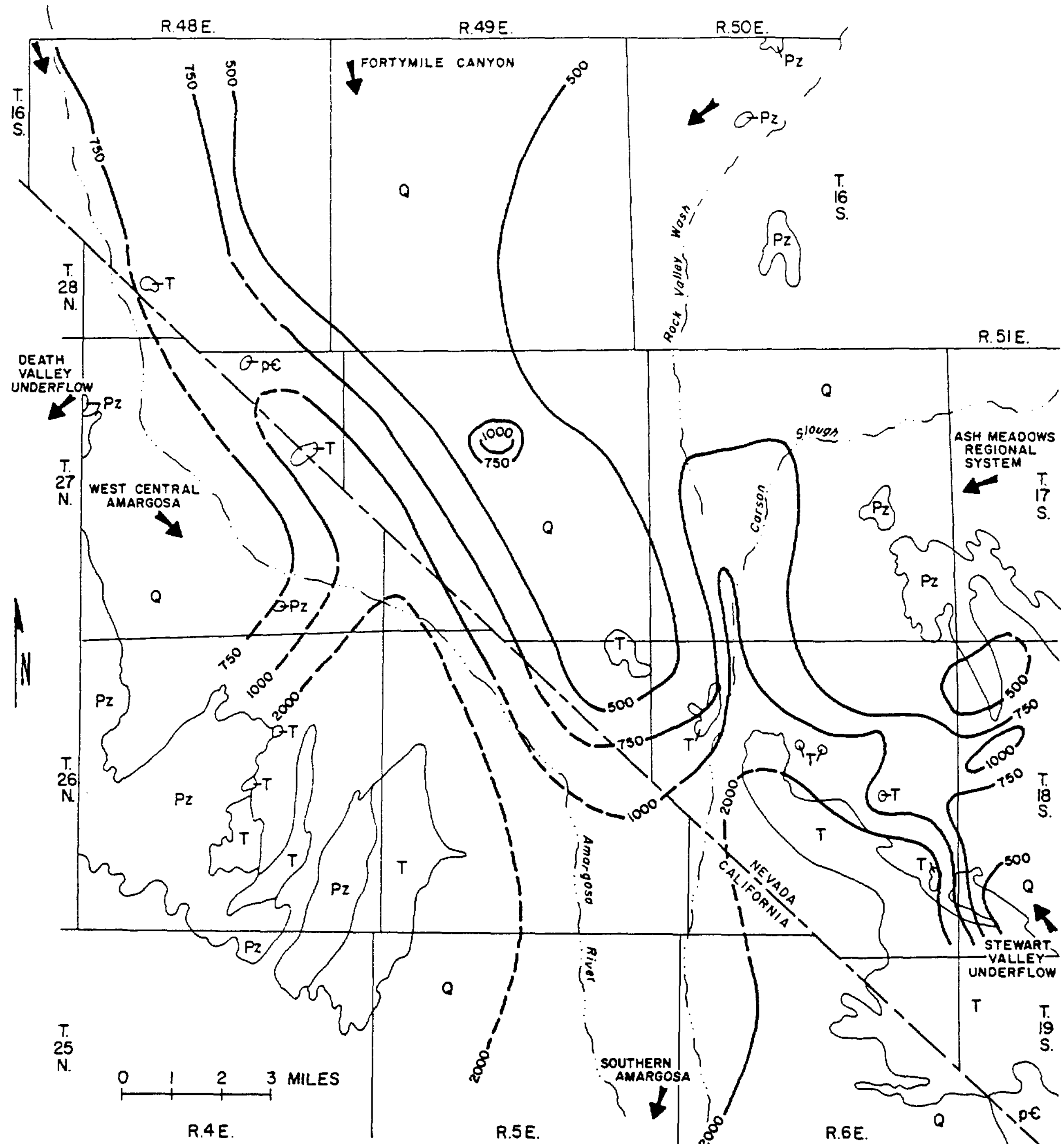
The strong possibility of movement of ground water in the carbonate aquifer from the Indian Spring area to Mercury Valley was noted by Schoff and Moore (1964). A likely end member of this movement in Mercury Valley is water from well 16/53-4b, which has greater summed ionic constituents than the water from Indian Spring Valley, and also larger sodium and sulfate components (fig. 5, analyses 5 and 10). This well is also located on the east flank of the aforementioned potentiometric trough in the carbonate aquifer north of the Specter Range. Well 73-70, which also penetrates the carbonate aquifer, is located on the west flank of the potentiometric trough. An analysis of water from well 73-70 (fig. 5, analysis 6) was used to represent flow from the west. Downward leakage through the Tertiary aquitard is represented by water from well 73-66 (fig. 5, analysis 7). These two analyses plus the Mercury Valley analysis, used to represent flow from the east, surround analyses for Devils Hole (fig. 5, analyses 1-4). Thus it is possible to mix these diverse waters (Piper, 1944) and to account for the chemical character of the discharge at Ash Meadows.

Figure 6 is an isopleth map of the summed ionic constituents, and shows an elongate lobe of high water quality entering the Amargosa Desert from the north. The lobe extends from where Fortymile Wash enters the Central Amargosa Desert west of Lathrop Wells to the area where the late Tertiary outcrops meet Carson Slough. Isopleth maps of silica (fig. 7) and sodium plus potassium show approximately the same pattern.

Within the Amargosa Desert topographic basin, the area receiving the preponderance of precipitation is that area tributary to the Fortymile Canyon drainage basin (Walker and Eakin, 1963). Schoff and Moore (1964), and later Winograd and others (1971), indicated the presence of a sodium bicarbonate water low in dissolved solids immediately north, west, and southwest of Lathrop Wells. The conclusion is that low dissolved solids in the ground water of this area and Western Jackass Flats reflect infiltration directly from the bed of Fortymile Wash.

The analysis of water from well 17/49-15bc in the central Amargosa Desert indicates the presence of a sodium bicarbonate water with low summed ionic constituents (230 ppm) 5 miles northeast of Ash Tree Spring. Figure 7 shows that a body of ground water of similar silica composition extends from this area into western Jackass Flats.

The sodium bicarbonate character of these waters is probably related to the weathering of glass which is the dominant component of tuffs in the Fortymile Canyon area.

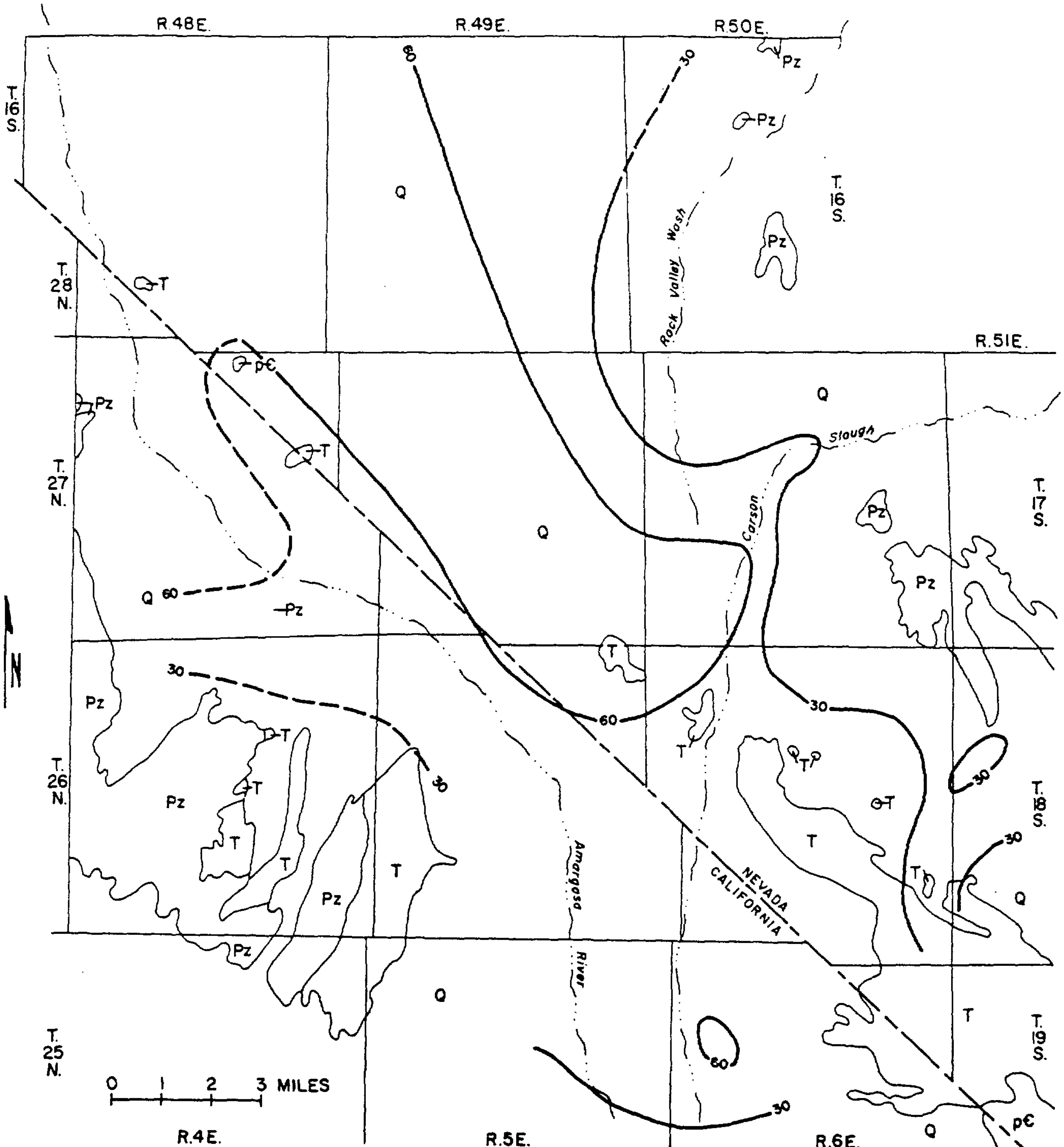


Q	Quaternary valley fill; marls, clays, sands, and gravels.
T	Tertiary rocks; predominantly tuffaceous sediments with lesser amounts of fanglomerate, fresh-water limestone, and tuff.
Pz	Paleozoic sedimentary rocks; predominantly massively bedded carbonates.
p€	Precambrian clastic rocks; predominantly orthoquartzite and argillite.

500 Isopleths of summed ionic constituents (numbers are ppm)
Dashed where control lacking

After Naff, 1973.

FIGURE 6. Distribution of total dissolved solids in ground water in the Amargosa Desert, Nevada-California.



Q	Quaternary valley fill; marls, clays, sands, and gravels.
T	Tertiary rocks; predominantly tuffaceous sediments with lesser amounts of fanglomerate, fresh-water limestone, and tuff.
Pz	Paleozoic sedimentary rocks; predominantly massively bedded carbonates.
p€	Precambrian clastic rocks; predominantly orthoquartzite and argillite.

30 Isopleths of silica concentrations (numbers are ppm)
Dashed where control lacking

After Naff, 1973.

FIGURE 7. Distribution of silica in ground water in the Amargosa Desert, Nevada-California.

The silica content of water in the central Amargosa Desert is greater than 60 ppm, and ranges up to 82 ppm. This probably represents an equilibrium condition with glass, either from epiclastic tuff in the alluvium or from ash-flow tuffs further north. Solution of glass may be associated with the release of calcium-magnesium and sulfate components to the ground water, and also may be related to the leaching of sodium and formation of montmorillonite during alteration of glassy tuffs.

The extreme southeastern end of the chemistry isopleth lobes are located in the Ash Tree Spring-Carson Slough area, an area of natural discharge. The maximum areal extent of the sink is outlined by the silica isopleth map (fig. 7). Silica concentration is probably at its maximum in the flow system, and, unlike dissolved solids and sodium plus potassium, will not increase further in the sink area.

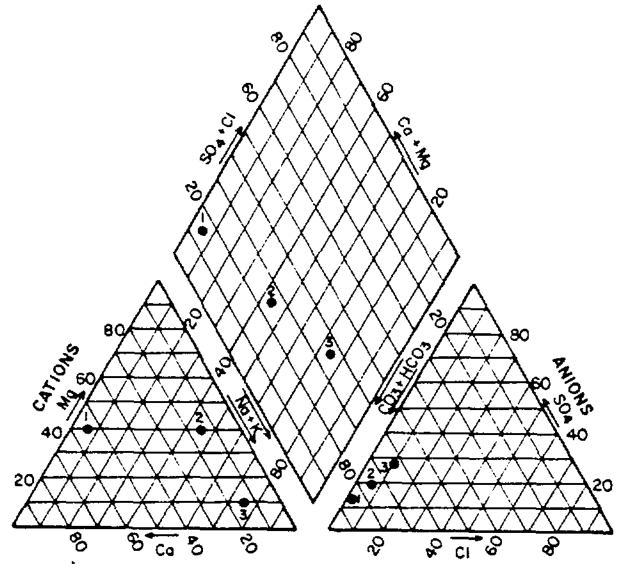
Pahrump and Stewart Valleys-Ash Meadows. Extensive outcrops of the clastic aquitard between Ash Meadows and Pahrump Valley inhibit flow in large quantities between the two valleys by way of the carbonate aquifer. Furthermore, waters in Pahrump Valley have a predominantly calcium-magnesium bicarbonate character, while those at Ash Meadows are mixed bicarbonate types (Winograd, 1971a).

The water quality of Manse Spring (20/54 3ad), a high yield spring located in Pahrump Valley, probably reflects closely the water quality in the carbonate aquifer in this area. Well 20/52 bdd is a small domestic well located in the alluvial aquifer in Stewart Valley south of the low topographic divide between this valley and Ash Meadows. This well is rather isolated from the large springs that comprise the main discharge area in Pahrump Valley, and is not located near any major orographic recharge area. The summed ionic constituents of the mixed bicarbonate water from the well and the calcium-magnesium bicarbonate water from Manse Spring are very nearly equal. If the analyses for these waters are plotted on a Piper diagram, the trilinear cation plot indicates that the magnesium percentage is approximately the same for both analyses, but that the well sample contains a higher percentage of sodium, and the spring analysis a higher percentage of calcium (fig. 8, analyses 1 and 2). This relationship of cations is indicative of exchange of sodium for calcium (Piper, 1944), and is compatible with the general exchange preference of clays (Back and Hanshaw, 1966).

The anion trilinear plot indicates a similar relationship, in which sulfate and chloride appear to be replacing bicarbonate. It would appear, then, that an almost perfect ion exchange occurs between ground water from the carbonate aquifer and clays in the alluvial aquifer of Stewart Valley. Because Paleozoic carbonates crop out near the Stewart Valley well, it is only necessary that the discharge at Manse Spring reflect the water quality in the carbonate aquifer in this area, and that the alluvial aquifer derive its water from this source, in order for the above ion-exchange mechanism to operate.

Piper-diagram plots of the analyses of water from Last Chance Spring, Manse Spring, and the Stewart Valley well, reveals that the former may be related to that of Stewart Valley (fig. 8, analysis 3). From the rhombic center of the Piper diagram, it is apparent that the plot of

	Location		Summed Ionic Constituents	Basin
1.	21/54	3ad	337	Pahrump Valley
2.	20/52	6dd	334	Stewart Valley
3.	18/51	30ac	434	Ash Meadows



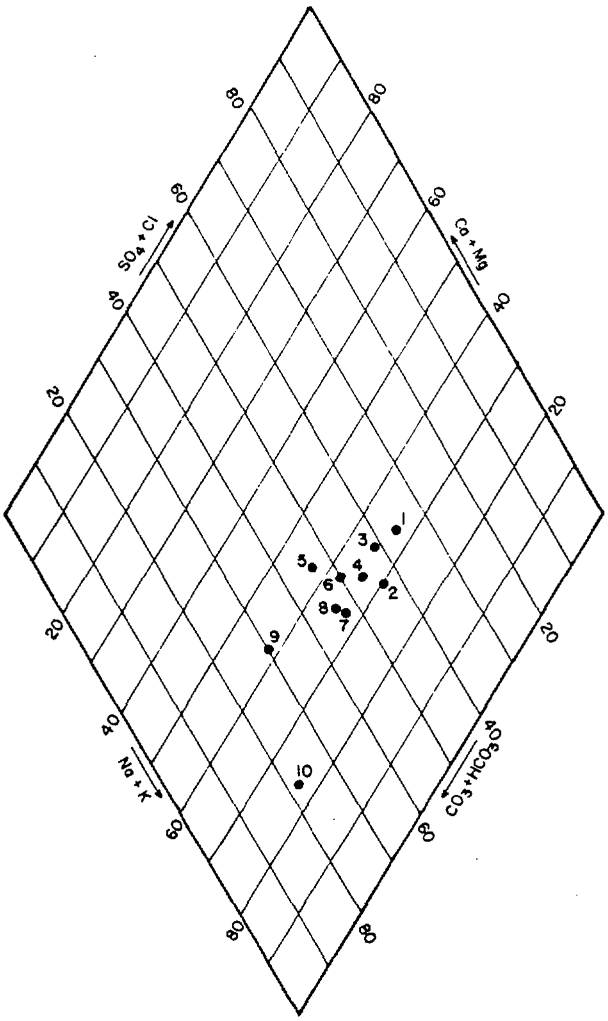
General Ion Exchange Preference
$Li^{+} < Na^{+} < H^{+} < K^{+} < Mg^{++} < Ca^{++} < Sr^{++} < Ba^{++}$

FIGURE 8. Piper diagram showing the chemical quality of underflow between Pahrump and Stewart Valleys and Ash Meadows.

the Last Chance Spring analysis is in a position to act as an end member of the two previous analyses, and it is suspected that a mechanism similar to that previously described also operates between Stewart Valley and Last Chance Spring in Ash Meadows. In the cation trilinear plot, it is apparent that the calcium content of the Stewart Valley samples and the Last Chance Spring samples are very nearly equal, but that sodium percentage is greater in the Last Chance Spring sample, and the magnesium percentage greater in the Stewart Valley sample. Provided that no readily exchangeable calcium is available between the two points, this relationship of cations is indicative of exchange of sodium for magnesium. Similarly, it also appears that some bicarbonate is being exchanged for sulfate and chloride. However, the true nature of any exchange phenomenon between these two points may be obscured by a 100 ppm increase in summed ionic constituents.

In summary, ground water discharging from the carbonate aquifer into the alluvial aquifer of Stewart Valley must pass through extensive clay deposits in and near the Stewart Valley playa. As the ground water flows through the clay units, first calcium then magnesium is exchanged for sodium, calcium being preferred over magnesium in cation exchange. If the water is not on a flow line which discharges in the Stewart Valley playa, then it may discharge from the valley via underflow through the low alluvial divide which separates Stewart Valley from Ash Meadows. Water leaving Stewart Valley and flowing through the

	Location		Summed Ionic Constituents	
1.	16/48	7ba	674	
2.	16/48	8ba	840	
3.	16/48	15ba	754	
4.	16/48	17ba	790	
5.	16/48	36dd	735	
6.	28N/1	36bd	771	
7.	27N/1	23ab	750	
8.	27N/1	25bb	734	
9.	27N/4	27bb	812	(8/18/62)
10.	27N/4	27bb	571	(6/24/71)



Points 6,7, and 8 are from Furnace Creek discharge area; other points are from west-central Amargosa Desert.

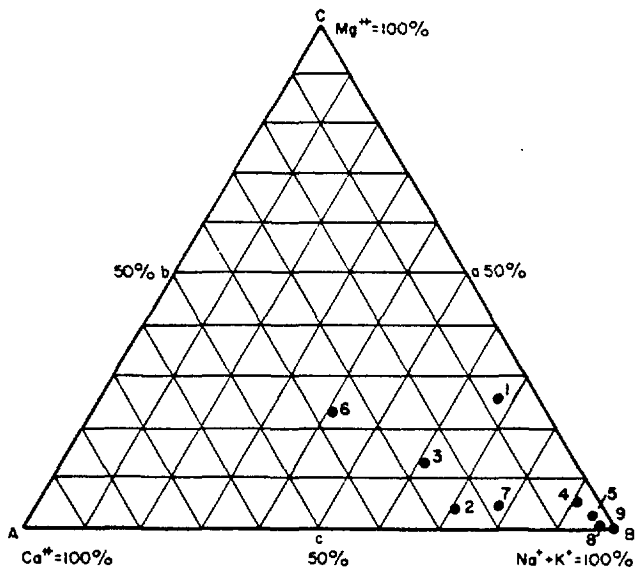
FIGURE 9. Piper diagram showing the quality of ground water in the west central part of Amargosa Desert and Death Valley.

alluvial aquifer toward Ash Meadows probably leaches some additional salts from the geologic materials in this area before discharging in the Last Chance Spring area.

Amargosa Desert-Death Valley The chemical similarity of waters from the northwestern and central parts of the Amargosa Desert, and from the large springs in the Furnace Creek area of Death Valley, has previously been noted by Winograd (1971a). The springs are in close proximity to, and probably discharge from, the Paleozoic carbonate rocks of the Funeral Mountains. The Piper diagram shown in figure 9 indicates a similar chemical character for water from wells in the northwest-central Amargosa Desert and from Nevares Spring (28N/1 36bd). Although discharges from Travertine Spring (27N/1 23ab) and Texas Spring (27N/1 25bb) are of slightly different character, their plotted points fall between analyses for the northwest-central Amargosa Desert and for west-central Amargosa Desert, as represented by water from well 27N/4 27bb. Therefore, mixing with waters farther south in the west-central Amargosa Desert could account for the quality of Texas and Travertine Springs in the Furnace Creek area. In addition to the above evidence, Nork (1971) noted a marked similarity in the deuterium and oxygen-18 isotope content of waters in the central Amargosa Desert and in the Furnace Creek discharge area of Death Valley.

Southern Amargosa Desert Ground water leaving the Amargosa Desert through the alluvium along the Amargosa River to the south undergoes a marked deterioration of water quality. This water, as represented by the municipal well at Death Valley Junction (25N/5 14ca), is high in sodium and very low in calcium plus magnesium (fig. 10). Waters in other areas of the Amargosa Desert to the north of Death Valley Junction contain considerably more calcium plus magnesium.

	Location		Summed Ionic Constituents	$Ca^{++}+Mg^{++}$ epm
1.	73 - 58		218	0.90
2.	16N/48	8ba	840	3.44
3.	16N/50	7ca	670	3.64
4.	17N/50	19aa	960	1.07
5.	17N/50	29ad	907	0.38
6.	17N/50	36dc	554	3.94
7.	24N/4	27bb	571	1.68
8.	25N/6	18aa	1302	0.51
9.	25N/6	20cc	3286	0.18



Points 4 and 5 from Carson Slough; 8 and 9 from Death Valley Junction; other points represent waters up gradient from natural sinks.

FIGURE 10. Trilinear diagram of ground-water quality in the southern part of the Amargosa Desert.

The trilinear cation plot of various flow systems discharging in the Amargosa Desert (fig. 10) demonstrates the removal of calcium and magnesium in the alluvial aquifer. An ion exchange process is indicated by the fact that at least 25 percent of the cations in the water from the flow systems are calcium plus magnesium, as compared to less than 10 percent in waters from wells in the sinks down gradient, from the major springs. It can also be seen that although the salt load does increase down gradient in the sinks, the actual calcium plus magnesium content of waters decrease. Thus, the decrease in the percentage of calcium plus magnesium is not due to an increase in the sodium component alone. In cation exchange between ground water and clayey sediments, there is selective enrichment of calcium compared to magnesium. Also contributory is the low percentage of calcium in water from the Carson Slough area. The net effect is that the flow systems have summed ionic constituents which vary between 218 and 840 ppm, and the calcium plus magnesium content ranges from 3.94 to 0.90 epm. Waters from the center of Carson Slough and from the Death Valley Junction area have summed ionic constituents which vary between 3,286 and 907 ppm, and the calcium plus magnesium content ranges from 1.07 to 0.18 epm.

At Death Valley Junction, a reversal of the trend toward a lower percentage of calcium is due not to an increase in calcium plus magnesium, but rather to a reversal of the proportions of calcium plus magnesium in the water. The maximum value for calcium in this area is 76 percent, or essentially that of water from the central Amargosa Desert.

SUMMARY

The discharge at Ash Meadows is derived from a regional flow system sustained by a recharge region to the east which includes the Sheep, Paharanagat, and Timpahute Ranges, part of the Spring Mountains, and a number of smaller ranges and valleys to the west which are largely composed of or underlain by Paleozoic carbonate rocks. This essentially continuous block of carbonate aquifer is bounded along its west side by extensive outcrops of the clastic aquitard west of Yucca and Frenchman Flats. Potentials in the carbonate aquifer immediately below and to the southwest of Yucca and Frenchman Flats indicate that a large potentiometric trough is centered under these valleys, and that flow within the trough is toward the Specter Range to the southeast of Frenchman Flat. The areal extent of the catchment basin of this regional flow system is a minimum of 4,500 square miles and the basin receives 570,000 acre-feet per year precipitation. Natural discharge at Ash Meadows therefore represented 3 percent of the total precipitation.

Spring discharge at Ash Meadows is the result of the juxtaposition of the carbonate aquifer and Tertiary and alluvial aquitards (Winograd, 1971a). In the spring discharge area, the carbonate aquifer consists of the Bonanza King Formation with a maximum stratigraphic thickness of 3,000 feet, while the Cenozoic valley fill to the west of the master fault at Ash Meadows is at least that thick (Healey and Miller, 1971, fig. 3). The master fault is probably responsible for the ultimate disposition of Cenozoic valley fill against the carbonate aquifer west of the Paleozoic outcrops, but it is not necessary that the actual contact be a fault plane, as Pleistocene deposition probably occurred concurrently with faulting and formation of a graben block beneath the Amargosa Desert. Thus, while faults displace the Pleistocene valley fill, and these displacements impede the westward flow of ground water within these sediments, the younger Pleistocene sediments are in depositional contact with the carbonate aquifer. Fault contact between the older Cenozoic valley fill and the carbonate aquifer may occur at depth below the Ash Meadows area.

Before pumping began in this area in 1968, the measured discharge from these springs amounted to 17,000 acre-feet per year (Walker and Eakin, 1963). As representative of discharge from the carbonate aquifer, the total spring flow is a minimum value, because discharge in the form of evapotranspiration also occurs in this area. However, it is difficult to separate that evapotranspiration which is directly related to the flow system from that which is generated by surface and near-surface flow from the springs.

The Spring Mountains and Pahrump Valley were considered the source area and flow path by several early investigators (Loeltz, 1960; Walker and Eakin, 1963; Hunt and Robinson, 1966). Considering the extensive outcrops of the clastic aquitard and the difference in chemical character of waters discharging from the carbonate aquifer in the two valleys, it is unlikely that significant interbasin flow occurs. Thus, although the potential in the carbonate aquifer of Pahrump Valley is greater than that at Ash Meadows, it is likely that the only underflow between the two valleys is through the alluvial aquifer, and the quantity of this underflow is very small.

The implication of the distribution of regional aquifer and aquitards, and of the location of the potentiometric trough in the carbonate aquifer north of the Specter Range, is that recharge to the carbonate aquifer in the highlands to the east probably moves westward through an essentially continuous block of carbonate aquifer, and eventually enters the potentiometric trough below Yucca and Frenchman Flats, where it is shunted through the Specter Range and discharges at Ash Meadows.

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APPENDIX A

Brief field-trip guide

Stop 1. Valley View Avenue near Fremont Street.

Background information related to this stop may be found on pages 7, and 12-14.

This is the West Charleston well field, an area (about ½ section) which has been the chief source of supply of ground water for Las Vegas Valley. The site of Big Spring was at the north end of the well field about one-fourth of a mile east of here. It supplied the city for many years, until pumping from wells reduced the head and the spring stopped flowing (about 1947). Note the scarp at this location, one of several scarps believed to be the result of differential compaction of the valley-fill materials. Another (possibly two?) such a scarp occurs west of here, and the largest scarp occurs a few miles to the east in the eastern part of Las Vegas and the western part of North Las Vegas. All of these scarps are aligned north-south and veer to the northeast of Las Vegas. Relationship to tectonic features in the bedrock has been searched for but none has ever been discovered. Since the scarps occur where the lithology changes from predominantly gravel and sand on the west to predominantly silt and clay on the east they are interpreted as differential compaction features. Evidence of subsidence as a result of withdrawal of ground water has been observed along most of the scarps. Cracking at the surface, vertical extrusion of well casings, displaced water mains, and displaced and distorted structures, all attest to such subsidence. Correlation between fluctuations in withdrawal of water and subsidence has been documented.

The Las Vegas Valley ground-water system roughly occupies the watershed area of Las Vegas Valley but may be connected hydraulically with systems contiguous to it, especially to the north (Ash Meadows system), and to the northeast (White River Valley system). Little is known of the deeper part of the system (below about 2,000 feet) since only a few oil, brine, and geothermal test wells have been drilled. The deepest reported test hole approximates 8,508 feet.

Stop 2. Red Rock Canyon area (about 12 miles west of Las Vegas on Charleston Boulevard extension).

Background information related to this stop may be found on pages 8 and 9.

The general stratigraphy and structure of the Las Vegas area may be observed from this location. Bedrock here consists of Permian Kaibab Limestone very close to the Permian-Triassic boundary. Looking westward the valley is cut into the Moenkopi Shale. The Shinarump Conglomerate forms the small dark hogback on the west side of the valley. It is overlain successively by the Chinle (purplish and red beds), the Kayenta, and the cliff-forming Aztec Sandstone. The Aztec, in turn, is overlain by Paleozoic limestones which were thrust over the Aztec in Laramide time (Keystone and Red Rock thrust faults). Breccia believed to be the sole of the thrust is draped over the Aztec and underlying rocks in a few places. The Keystone and related thrusts did not displace the crust as much on the southwest side of Las Vegas Valley as the Muddy Mountain and related faults did on the northeast side. This resulted in a shear zone now occupied by Las Vegas Valley. This shear zone extends under the Tertiary volcanic rocks of the River Mountains and McCullough Range to the south. It extends northward beyond Indian Springs, and is believed to be associated with the Walker Lane, possibly intersecting the latter.

From this stop the trip route proceeds westward into Pahrump Valley past Manse and Pahrump Springs, then into Stewart Valley.

Stop 3. Stewart Valley.

Background information related to this stop may be found on pages 9, 12, 14, and 22-23.

Here can be seen complexly folded and faulted early Paleozoic rocks in the Resting Springs Range.

Stop 4. Death Valley Junction.

Background information related to this stop may be found on pages 15, and 23-25.

Here we can discuss the general stratigraphic comparisons both in the bedrock and in the valley fill.

Stop 5. Clay Camp.

Background information related to this stop may be found on pages 12, and 15-17.

A short walk takes one into the abandoned clay pits (the clay mined here was used in filters) where structures and stratigraphy of the Tertiary and later valley fill may be seen. Near this point Ash Spring discharges water of very different quality from the water in the valley of the Amargosa River to the west or from that in Ash Meadows to the east. The flow system here exhibits a relatively high "ridge" with discharge points several feet higher than is discharged either to the east or the west. This ridge is obviously closely related to the complexly faulted and folded Tertiary valley fill in this area. The ground-water ridge is obviously accentuated by low water levels resulting from evapotranspiration of ground water to the east in Carson Slough.

Stop 6. East side of the Tertiary ridge.

Background information related to this stop may be found on pages 15-17.

Here can be seen additional structural features and lithology of the Tertiary valley fill.

Stop 7. Crystal Pool.

Background information related to this stop may be found on pages 8, 9, 12, and 17-18.

A typical large spring representing discharge from the Ash Meadows ground-water system.

Stop 8. Devil's Hole.

Background information related to this stop may be found on pages 8, 9, and 17-18.

This location demonstrates the role of reservoir mechanics in relation to the problem of preserving an endangered species, the Desert Pupfish.

Stop 9. Fairbanks Butte.

Background information related to this stop may be found on pages 15-17.

Normal faulting of the calcareous tufa is well displayed here, along with outcrops of the tufa-capped marls.

Stop 10. Lathrop Wells.

Background information related to this stop may be found on pages 8-9, 14, and 19-22.

Return to Las Vegas by way of Indian Springs.