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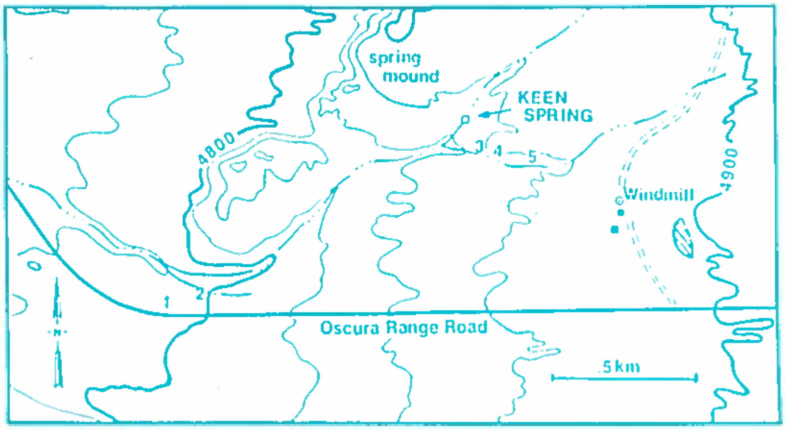

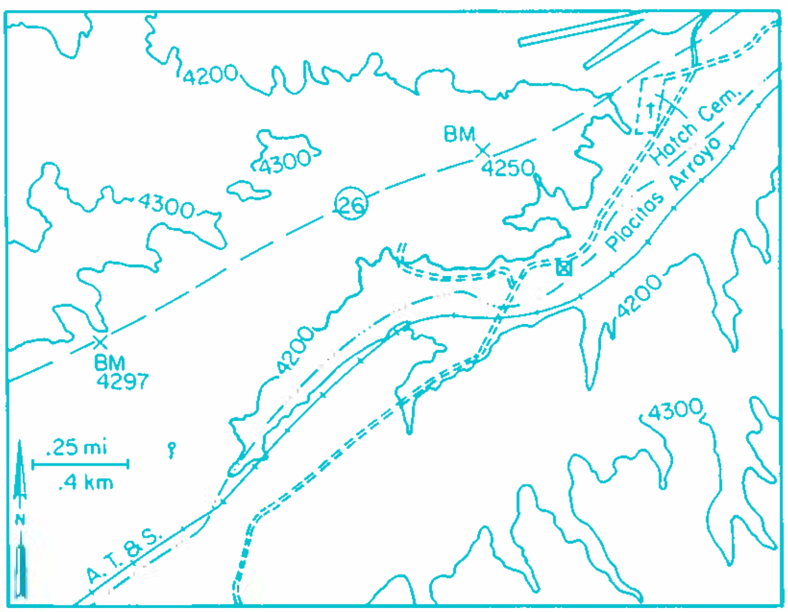

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COVER—See Figs. 1 and 5 (pp. 14, 16) for explanation.

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Fossil molluscan faunas from four spring-related deposits in the northern Chihuahuan Desert, southern New Mexico and westernmost Texas

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Abstract

Fossil molluscs from four spring-related deposits in the northern Chihuahuan Desert were examined and identified. The fossil assemblages are interpreted as being late Pleistocene—early Holocene in age. Approximately 52 species were recovered. Current distribution and habitat preferences of molluscan species in the southwestern United States were used to make inferences concerning paleohabitats and past biogeographical patterns. All the fossil faunas studied are richer in species than extant faunas occupying the same areas today. Many of the fossil species are currently restricted to higher elevations and/or more northern latitudes in the Southwest, and some species, common as fossils, are rare in the southwestern fauna today. Shifts in geographic ranges and local extinctions seemingly have been influenced by climatic changes since the early Holocene.

Introduction

According to Brune (1975: 25), "Thousands of small springs [in Texas] have dried up, and the larger springs have generally suffered a decrease in flow." Depleted springs may leave depositional evidence of their former existence and these spring deposits may contain fossils that provide a unique record of paleohabitats. Since little attention has been given to these windows on the past, investigation of faunal occurrences at spring sites seemed especially appropriate.

The purposes of this study are to document and interpret the occurrence of fossil molluscan faunas from spring-related deposits at four localities in the northern Chihuahuan Desert. These localities are described in the succeeding section.

All localities are situated in the Lower Sonoran Life Zone (Bailey, 1913) of the Chihuahuan Desert, which extends from northern Mexico into Trans-Pecos Texas and southern New Mexico. In characterizing the Chihuahuan Desert, Johnston (1977: 339) wrote: "The unifying and widespread vegetational matrix is the microphyllous desert scrub dominated by *Larrea tridentata* or creosote bush." Kuchler (1964) noted that the semiarid climate supports vegetation consisting of shrubs, dwarf shrubs, and grasses.

The value of fossil molluscs for paleohabitat reconstruction is well established (Taylor, 1960, 1965; Evans, 1972; Jaehnig, 1971; Miller, 1978). However, little work of this kind has been done concerning molluscs from Quaternary spring deposits in the Chihuahuan Desert, as noted by Metcalf (1977: 64).

The following three criteria, as described by Taylor (1960, 1965), are used for paleoecologic interpretation of the fossil assemblages: (1) ecologic tolerances of individual species, (2) comparison with the extant fauna from the same area, and (3) comparison with similar living faunas. The limitations of using molluscs for paleohabitat reconstruction have been summarized by Miller (1978), who noted that problems include unstable taxonomy, difficulties in identifying fossil shells, insufficient ecological and distributional information about modern molluscs, and possible evolutionary changes influencing ecological tolerances.

Frye and Leonard (1967: 431-433) suggested that terrestrial gastropods with "specific ecological requirements" and aquatic molluscs requiring permanent, lotic water are most useful for interpreting paleoecology because they are sensitive to their immediate environment. Faunal analyses in this study focus on such species. All species treated herein are still extant. Inferences drawn from published analyses of habitats and distribution of living populations are utilized in the reconstruction of paleohabitats and the discussion of paleobiogeographical patterns.

Acknowledgments

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Descriptions of localities

Localities are identified hereafter by the letter and numerical designations indicated. The Nash Draw localities are designated by the letter "L" for nearby Livingston Ridge. Informally, sites will be referred to as the Placitas Arroyo, Keen Spring, Nash Draw, and Naegele Springs sites.

Placitas Arroyo (P)

New Mexico, Dona Ana County, NE 1/4 NE 1/4 NW 1/4 sec. 19, T19S, R3W; Placitas Arroyo ca 3.2 km southwest of Hatch, 32° 38' 52" N, 107° 11' 20" W (Figs. 1, 2, 3).

P-1: Far west end of outcrop.
P-2: 5 m west of east end of exposure in sediments weathering light gray.
P-3: Far east end of outcrop in sediments weathering light gray.

Keen Springs (K)

New Mexico, Lincoln County, Keen Spring area ca 3.25 km west of Oscura, north of Oscura Base Camp Road on Helms Ranch (Figs. 5, 6).

K-1: 0.25 km east and slightly north of center of sec. 34, T9S, R8E; 33° 29' 02" N, 106° 05' 37" W; north side of Oscura Base Camp Road along shallow (incipient) arroyo located 38 m northwest of beginning of curve to north.
K-2: SE 1/4 NE 1/4 sec. 34, T9S, R8E; 33° 29' 04" N, 106° 05' 33" W; in arroyo banks ca 70 m north of above road and ca 160 m east of beginning of its curve to north.
K-3: NW 1/4 NW 1/4 sec. 35, T9S, R8E; 33° 29' 16" N, 106° 05' 07" W; composite collection in light-gray sediments from north bank of reentrant arroyo, ca 75 m southeast of arroyo fork.
K-4: Same as K-3, but in east wall of reentrant arroyo in light-gray sediments.
K-5: NW 1/4 NW 1/4 sec. 35, T9S, R8E; 33° 29' 14" N, 106° 05' 01" W; north wall of arroyo 190 m southeast of arroyo fork in light-gray sediments.

Nash Draw (L)

New Mexico, Eddy County, ca 0.8 km west of east wall of Nash Draw—a large collapse-sink feature (Figs. 8, 9, 10).

L-1: Near center of sec. 15, T22S, R30E; 32° 23' 58" N, 103° 52' W; arroyo walls 0.2 km north of east-west road shown on Nash Draw northeast 7 1/2' quadrangle.
L-2: SW 1/4 sec. 15, T22S, R30E; 32° 23' 18" N, 103° 52' 17" W; 0.75 km southwest of abandoned drill pad in arroyo walls, east of north-south road not shown on above quadrangle.

Naegele Springs (N)

Texas, Presidio County, Naegele Springs area, 8.5 km north-northwest of Ruidoso (Fig. 12).

N-1: 30° 02' 05" N, 104° 39' 28" W; banks along north-east margin of marshy meadow, ca 90 m above mouth of northwest-flowing springbrook.
N-2: 30° 02' 02" N, 104° 39' 24" W; dissected arroyo banks (southeast bank) ca 60 m above mouth of above springbrook, in peaty deposits.
N-3: 30° 02' 09" N, 104° 39' 01" W; south bank of arroyo between ranchhouse and main springs in lower 1.2 m of exposure.

Materials and methods

Bulk sediment samples were collected from each locality and washed through a U.S. Standard Sieve no. 30, which has mesh openings of 0.595 mm. After skimming off floating shells, the matrix residue was dried before sorting out the remaining shells. Hand-picking of larger specimens from the outcrop also was utilized. Shells were identified and housed in the Invertebrate Collection of the Laboratory for Environmental Biology at the University of Texas at El Paso. Sediment color was determined using the Rock-Color Chart of the Geological Society of America, Rock-Color Chart Committee.

Annotated list of species

Some 52 species (the category Succineidae likely comprises more than one species) of fossil molluscs identified from the four sites are listed in Table 1 and discussed in this section in systematic order.

Localities utilized in Table 1 and in this section are those listed above. The distributional data given stress modern occurrences in New Mexico and Texas. Distribution for species in New Mexico was derived primarily from collections of the Laboratory for Environmental Biology at The University of Texas at El Paso. Texas distributions were obtained mainly from Cheatum and Fullington (1973), Fullington (1978), and Fullington and Pratt (1974). Unless otherwise indicated, distributional information for Arizona was derived from Bequaert and Miller (1973). Habitat preferences and additional comments also are included.

Where catalog numbers of specimens in museums are used, abbreviations employed are as follows: UTEP, University of Texas at El Paso; ANSP, Academy of Natural Sciences of Philadelphia; USNM, U.S. National Museum of Natural History; UMMZ, University of Michigan Museum of Zoology.

Phylum MOLLUSCA
Class BIVALVIA
Order HETERODONTA
Family SPHAERIIDAE

SPHAERIUM STRIATINUM (Lamarck, 1818)

Locality P-1.

This fingernail clam is extant in northern New Mexico (UTEP 256, 1104, 1929) and in the panhandle and southern portions of Texas (Heard, 1963: 106). It has been found, as a fossil, in Cochise County, Arizona, in banks of the San Pedro River near Palominas (UTEP 6325). According to Hibbard and Taylor (1960: 76) *S. striatinum* requires permanent water with some current action. Herrington (1962: 28) stated "I have never found it in ponds, swamps or anywhere in stagnant water. . . ."

PISIDIUM CASERTANUM (Poli, 1791) Localities K-1, 2, 3, 5, L-2, N-3, P-1, 2, 3.

This sphaeriid is widespread in Arizona, New Mexico, and Trans-Pecos Texas. A highly adaptable species, *P. casertanum* inhabits lentic or lotic water and can withstand desiccation. The thin-shelled forms

TABLE 1—Numbers of specimens of molluscs collected from 13 localities in the northern Chihuahuan Desert. Specific location of each collection is listed in the text. Asterisk indicates bivalves for which numbers of valves recovered are indicated.

Molluscan species	**Placitas Arroyo**			**Keen Spring**					**Nash Draw**		**Naegele Springs**		
	P–1	P–2	P–3	K–1	K–2	K–3	K–4	K–5	L–1	L–2	N–1	N–2	N–3
*Sphaerium striatinum**	4												
*Pisidium casertanum**	20	48	1320	158	8	23		3		1			3
*Pisidium compressum**	5								1				
*Pisidium contortum**				1									
*Pisidium ventricosum**				2									
*Pisidium insigne**	5					6							1
Valvata humeralis	1		1										
Fontelicella sp.			1								852	207	20
Carychium exiguum		4	5		1	1							
Lymnaea caperata				48		8			35	7			
Lymnaea palustris		14	135	35									
Bakerilymnaea cubensis											4	2	
Fossaria modicella		19	260	18				17	2				
Fossaria parva	5	1	70	166	5	67			8	2			
Ferrissia californica			9										1
Planorbella tenuis				1									
Planorbella trivolvis													2
Gyraulus crista	1			2									
Gyraulus circumstriatus	7			36	9	7							
Gyraulus parvus	21	4	1	178	4	6		16					
Physa virgata	1	51	168	90		26				109	2	44	2
Vertigo berryi				18		1		7					
Vertigo cf. *elatior*						2							
Vertigo milium				1	11	1		7		8			
Vertigo ovata			21	1	20	25		2	16	4	12	6	2
Vertigo cf. *ventricosa*						1							
Vertigo sp.				1		26							
Gastrocopta armifera	2	1	3										
Gastrocopta cristata	17	70	118	2		54	3	3	172	33	52	4	3
Gastrocopta pellucida	1	3	5				2		1	99	3	3	29
Gastrocopta pentodon	1	14	64		15	65		4	6	14			
Gastrocopta pilsbryana						1							
Gastrocopta procera						3							
Pupilla blandii	16	2		51		4	3	4	296	230			
Pupilla muscorum	6			40	25	10		7					
Pupilla sonorana								1					
Pupoides albilabris	9	10	9	4		4				5			3
Pupoides hordaceus	4	2	3			5							
Pupillid apices		34	61	101		9	5					6	19
Vallonia cyclophorella	1			46	16	8	2	35	90				
Vallonia gracilicosta	7	1	2	9		11	2	3		25			
Vallonia parvula										21			
Vallonia perspectiva	1			1		12							
Vallonia sp. (immature)				14		2	6	67	3				
Succinea luteola											6	12	
Oxyloma sp.	12		27										
Succineids, spp. indet.	37	55	417	149	8	201	5	140	23	17	32	90	3
Discus cronkhitei	6												
Helicodiscus singleyanus	4	17	3			2					12	3	1
Hawaiia minuscula	17	79	100			41				28			15
Nesovitrea hammonis						1							
Zonitoides arboreus	3	4	4										
Deroceras laeve		2	5	1		67	5	56			2	2	29
Ashmunella rhyssa							3						
Thysanophora hornii											1		2
Total number of species (excluding *Vertigo* sp., *Vallonia* spp., and pupillid apices)	27	20	24	24	11	29	8	15	11	14	11	10	15

(described more fully hereafter) from Placitas Arroyo probably indicate, as did such specimens reported by Hibbard and Taylor (1960: 77), "ponds, swamps, lagoons, bog ponds, and similar quiet water bodies" as possible habitats. The dark staining of these shells also suggests deposition in humic material.

PISIDIUM COMPRESSUM Prime, 1852

Localities L-1, P-1.

In New Mexico *P. compressum* occurs above 2,130 m in Rio Arriba and San Miguel Counties (UTEP 280, 3093). Heard (1963: 113) reported it from the Texas counties of Comal, Dallas, Kaufman, and Val Verde. According to Hibbard and Taylor (1960: 78), "This species inhabits only perennial water bodies with some current action, such as lakes, rivers, and creeks; it is never found in ponds, swamps, lagoons, or bogs."

PISIDIUM CONTORTUM Prime, 1854

Locality K-1.

D. W. Taylor (pers. comm.) has found living *P. contortum* in northern New Mexico. It also occurs in the White Mountains of Arizona. Herrington (1962: 46) described the habitat of this species as "Large ponds, bog ponds, lakes, creeks, and rivers. Seems to prefer shallow water. . . ."

PISIDIUM VENTRICOSUM Prime, 1851

Locality K-1.

In New Mexico and the Texas Panhandle *P. ventricosum* occurs as a fossil, and D. W. Taylor (pers. comm.) has observed it extant at several localities in north-central New Mexico. Clarke (1973: 203) collected *P. ventricosum* from lakes, ponds, rivers, and streams.

PISIDIUM INSIGNE Gabb, 1868

Localities K-3, N-3, P-1.

This minute clam is widespread in the Southwest. According to Herrington (1962: 43) *P. insigne* is found "Mostly in creeks in low spots, i.e., slow-moving creeks or spring creeks." It is found living in the outflow of springs at Naegele Springs, Presidio County, Texas.

Class GASTROPODA
Subclass PROSOBRANCHIA
Order MESOGASTROPODA
Family VALVATIDAE

VALVATA HUMERALIS Say,

1829 Localities P-1, 3.

In Arizona *V. humeralis* has been recorded living in Apache County (Bequaert and Miller, 1973: 213; UTEP 8263). Although it was reported from Bernalillo (Pilsbry and Ferriss, 1909: 104) and Valencia Counties in New Mexico (Pilsbry, 1906: 130), there are no records of living specimens in the state in more recent years.

Family HYDROBIIDAE

FONTELICELLA sp.

Localities N-1, 2, 3, P-3.

D. W. Taylor identified these specimens as belonging to the genus *Fontelicella* as defined by Gregg and Taylor (1965: 103-110). Species were not determined. The specimens from Naegele Springs, where both living and fossil specimens were found, likely pertain to an unnamed species. Species of this genus are associated with the outflow of springs.

Subclass PULMONATA Order BASOMMATOPHORA Family ELLOBIIDAE

CARYCHIUM EXIGUUM (Say, 1822)

Localities K-2, 3, P-2, 3.

This snail is rare in the Southwest. Living specimens (UTEP 419) have been taken along the Tularosa River, Otero County, New Mexico, at 2,040 m, and it is abundant as a fossil at lower elevations in the same valley. Specimens are found in moist to wet areas, such as stream floodplains and marshes. Hibbard and Taylor (1960: 84) noted that "In northern Nebraska *C. exiguum* was found among wet leaves in seepage areas and beside a spring-fed brook."

Family LYMNAEIDAE

LYMNAEA (STAGNICOLA) CAPERATA (Say, 1829)

Localities K-1, 3, L-1, 2.

Extant populations of L. *caperata* have been reported from northern Arizona (Bequaert and Miller, 1973: 197) and New Mexico (D. W. Taylor, pers. comm.), where it seems rare. It appears to be a species that has suffered great restriction of range in the Southwest since the Pleistocene. L. *caperata* inhabits temporary ponds and streams and can withstand desiccation. According to Baker (1928: 263), "this species seems to almost invariably occupy intermittent streams or small pools, ponds and ditches which dry up in the summer."

LYMNAEA (STAGNICOLA) PALUSTRIS (Muller, 1774)

Localities K-1, P-2, 3.

In New Mexico *L. palustris* has been found in McKinley and Rio Arriba Counties at elevations above 2,130 m (UTEP 3090, 8007). In Texas and southern New Mexico it occurs only as a fossil. Baker (1911: 311) observed that this species "Inhabits both clear and stagnant water, but prefers a habitat in which the water is not in motion."

BAKERILYMNAEA CUBENSIS (Pfeiffer, 1839)

Localities N-1, 2.

This species has usually been reported as *Lymnaea bulimoides techella* Haldeman. It was found to be the most common living lymnaeid in the Rio Grande Valley of southern New Mexico by Metcalf (1967: 35-36), who observed that it can withstand extended periods of desiccation.

FOSSARIA MODICELLA (Say, 1825)

Localities K-1, 5, L-1, P-2, 3.

F. modicella is common in northern New Mexico and rarer to the south. Fullington (1978: 133) reported it, as *F. obrussa* (Say), in central Texas. *F. modicella* inhabits small, shallow bodies of water and, according to Baker (1928: 290), prefers "a mud flat or a strip of muddy beach which is kept rather moist." The nomenclature of the group is in need of revision.

FOSSARIA PARVA (Lea, 1841)

Localities K-1, 2, 3, L-1, 2, P-1, 2, 3.

In southern New Mexico this small lymnaeid occurs along the Rio Grande and Pecos River Valleys. Fullington (1978: 135) reported it, as *Lymnaea dalli,* from numerous counties in Texas. Baker (1911: 247) observed that "*Parva* is to be searched for in wet, marshy places, generally out of the water, on sticks, stones or muddy flats." In western Montana, Russell (1967: 54) found this species "in seepage areas or roadside ditches where there is a minimum of water."

Family ANCYLIDAE

FERRISSIA CALIFORNICA (Rowell, 1863)

Localities N-3, P-3.

Metcalf (1967: 37) reported this species, as *Ferrissia fragilis* (Tryon, 1863), in the drainage of the Rio Grande in New Mexico. We have taken it also in the Pecos River drainage below Blue Spring in Eddy County, New Mexico (UTEP 8883). In Texas, Clapp (1913: 77) recorded it, as *Gundlachia hjalmarsoni,* in the Rio Grande drainage, and we have taken it in the Rio Grande in Presidio County, Texas, not far from Naegele Spring (UTEP 5864, 5881, 5887). According to Basch (1963: 428) this species inhabits "small bodies of standing water, often temporary, and usually stagnant."

Family PLANORBIDAE

PLANORBELLA (PIEROSOMA) TENUIS (Dunker, 1850)

Locality K-1.

This aquatic snail occurs in Arizona, New Mexico, and Trans-Pecos Texas (Bequaert and Miller, 1973: 208). Fullington (1978: 197-198) reported it, as *H. foveale* (Menke, 1830), as far east in Texas as Tarrant and McLennan Counties. *Planorbella tenuis* inhabits lentic water with thick vegetation and tolerates seasonal desiccation.

PLANORBELLA (PIEROSOMA) TRIVOLVIS (Say, 1817)

Locality N-3.

This aquatic snail occurs in Colfax (UTEP 6146) and Roosevelt (Sublette and Sublette, 1967) Counties in New Mexico, and is widespread in Texas (Fullington, 1978: 204). Baker (1928: 332) noted that "Typical *trivolvis* is always an inhabitant of quiet, more or less stagnant water." According to experiments conducted by Cheatum (1934: 393-394), this species can survive prolonged desiccation by burrowing into mud.

GYRAULUS (ARMIGER) CRISTA (Linnaeus, 1758)

Localities K-1, P-1.

This species has usually been reported as *Armiger crista.* Only fossil specimens of this snail are found in Texas, Arizona (Bequaert and Miller, 1973: 210-211), and New Mexico (UTEP 4635, 5106). *Gyraulus crista* inhabits lentic waters with thick vegetation. It can tolerate "seasonally dry bog lakes," according to LaRocque (1968: 496-497).

GYRAULUS (TORQUIS) CIRCUMSTRIATUS (Tryon, 1866)

Localities K-1, 2, 3, P-1.

This species is rare in New Mexico and occurs only as a fossil in Texas. Hibbard and Taylor (1960: 97) noted that *G. circumstriatus* "is characteristic of small, seasonal water bodies, such as woods pools, marshes, ponds on flood plains, or prairie ponds."

GYRAULUS PARVUS (Say, 1817)

Localities K-1, 2, 3, 5, P-1, 2, 3.

This species occurs sporadically in western Texas (Cheatum et al., 1972: 7). UTEP collections contain fresh specimens from Colfax, Union, Lincoln, Eddy, Grant, and Hidalgo Counties, New Mexico. Schultz and Cheatum (1970: 848) noted that *G. parvus* "thrives in lush vegetation zones of small bodies of water, sluggish streams and marshes."

Family PHYSIDAE

PHYSA VIRGATA Gould, 1855

Localities K-1, 3, L-2, N-1, 2, 3, P-1, 2, 3.

This is a common and widespread species in the Southwest. It tolerates a broad range of aquatic habitats.

Order STYLOMMATOPHORA
Family VERTIGINIDAE

VERTIGO BERRYI Pilsbry, 1919
(Fig. 13/5)

Localities K-1, 3, 5.

Extant only in California and Baja California (Bequaert and Miller, 1973: 189), this gastropod occurs as a fossil in southeastern Arizona (UTEP 932, 1999) and has been taken in the following counties in New Mexico: Valencia (UTEP 8255), Lincoln (UTEP 7852, 7903, 7830, 7742), Sierra (UTEP 544, 7106), Dona Ana (UTEP 584), and Otero (UTEP 7218). In the Southwest this species seems to have been associated with springs, judging by assemblages reported at the localities listed above.

VERTIGO cf. ELATIOR Sterki, 1894
(Fig. 13/3)

Locality K-3.

Bequaert and Miller (1973: 189) reported *V. elatior* as a Pleistocene fossil in Arizona. In New Mexico fresh shells have been found in the Oscura Mountains, Socorro County (ca 32 km northwest of Keen Spring) by Pilsbry (1948: 956), and in the Sacramento Mountains, Otero County, at ca 2,470 m (UTEP 4024). Fossil specimens have been found in San Miguel (UTEP 3032), Lincoln (UTEP 7904), and Roosevelt (Leonard and Frye, 1975: 18) Counties in New Mexico. Franzen and Leonard (1947: 357) noted that "*Vertigo elatior* prefers a cool humid climate characteristic of northern United States or mountainous areas of southern states."

VERTIGO MILIUM (Gould, 1840)
(Fig. 13/1)

Localities K-1, 2, 3, 5, L-2.

In Arizona this species has been reported from two localities in Cochise County at elevations of 1,830 and

2,290 m (Bequaert and Miller, 1973: 182). It is living in east-central Texas (Bequaert and Miller, 1973: 94) and possibly in the Guadalupe Mountains (Fullington, 1979: 106). *Vertigo milium* is known only as a fossil in New Mexico, where, to our knowledge, it has not been reported previously. In addition to the sites reported in this study, fossil specimens of this snail have been found in alluvial sediments along the Black River, Eddy County (UTEP 7299). This snail inhabits damp areas near water.

VERTIGO OVATA (Say, 1822)
(Fig. 13/4)

Localities K-1, 2, 3, 5, L-1, 2, N-1, 2, 3, P-3.

This gastropod is rare in Arizona and New Mexico. We have collected it in a damp area bordering the outflow from Blue Spring, Eddy County, New Mexico (UTEP 8879). Cheatum and Fullington (1973:32) noted that *Vertigo ovata* is "The most wide-spread species of the genus *Vertigo* in Texas for both Recent and Pleistocene," and that it is "Usually associated with considerable moisture; under humus, rocks, logs, near springs, creeks and marshy areas." This snail inhabits damp or marshy areas and, according to Bequaert and Miller (1973: 93), "*ovata* often lives in muddy litter and on damp logs or semiaquatic plants, close to the water's edge of ponds and shallow creeks." This aptly characterizes its habitat at the Blue Spring locality.

VERTIGO cf. VENTRICOSA (Morse, 1865)
(Fig. 13/2)

Locality K-3.

Although a common Pleistocene fossil in Arizona (Bequaert and Miller, 1973: 189), *V. ventricosa* remains extant only at Sylvania Spring, Huachuca Mountains, at 1,875 m (J. I. Mead, pers. comm.). Specimens from the Keen Spring locality comprise the first report of this species in New Mexico. This snail inhabits wet areas, such as margins of ponds, streams, and marshes, according to Oughton (1948: 95).

Family PUPILLIDAE

GASTROCOPTA ARMIFERA (Say, 1821) Localities P-1, 2, 3.

In Arizona this species is found only as a fossil (Bequaert and Miller, 1973: 172). It is a common fossil at some localities in eastern New Mexico. Over 200 specimens were found at one archaeological site along the Pecos River north of Santa Rosa, Guadalupe County, New Mexico (UTEP 7105). In New Mexico it presently seems to be of restricted occurrence. In the southern part of the state it has been collected in the Sacramento Mountains at 2,195 to 2,470 m. In northeastern New Mexico it occurs along floodplains of streams draining the eastern Sangre de Cristo Mountains and the Mesa de Maya (ANSP 79647; UTEP 8311). In the Southwest living specimens of this snail are rare, while fossil occurrences are frequent. Fullington (1979: 104) concluded that "Evidence indicates that this species is losing ground in the West."

GASTROCOPTA CRISTATA (Pilsbry and Vanatta, 1900) Localities K-1, 3, 4, 5, L-1, 2, N-1, 2, 3, P-1, 2, 3.

In southern Arizona this species occurs in the Lower and Upper Sonoran Life Zones at elevations from 760 to 1,370 m (Bequaert and Miller, 1973: 169). It is found in New Mexico below 1,730 m, and in the western two-thirds of Texas (Cheatum and Fullington, 1973: 14; fig. 4). In the arid Southwest it seems to occur in habitats that are at least seasonally damp, such as floodplains, riparian woodlands, and cienegas and urban lawns. This species is discussed further under the account of *Gastrocopta procera*.

GASTROCOPTA PELLUCIDA HORDEACELLA (Pilsbry, 1890) Localities K-4, L-1, 2, N-1, 2, 3, P-1, 2, 3.

In the Southwest this is a species of the Lower and Upper Sonoran Life Zones. It is common in leaf litter under shrubs along floodplains and in lower canyons in mountainous areas. Metcalf (1967: 41) reported it in El Paso County, Texas, "under the dead, leafy caudices of sotol and *Yucca elata* along the faces of the scarps of the Valley-border, and in foothills of the Franklin Mountains."

GASTROCOPTA PENTODON (Say, 1821)
(Fig. 13/6-10)

Localities K-2, 3, 5, L-1, 2, P-1, 2, 3.

In New Mexico *G. pentodon* is found living at higher elevations in Union (UTEP 1089, 8379), Mora (UTEP 8376), Eddy (UTEP 146, 155, 884), Lincoln (UTEP 4140), Colfax (UTEP 8364), and Grant (USNM 152369) Counties.

In this study *G. pentodon* (Say, 1821) is interpreted to include *G. tappaniana* (Adams, 1842). The perplexing relationship of these forms has been discussed in detail by Vanatta and Pilsbry (1906: 121-128) and Sterki (1906: 134). These authors concluded that each form is a distinct species. An excellent summary of the complex situation involving these taxa is presented by Bequaert and Miller (1973: 88-89), who stated:

> . . . it is impossible to recognize consistently two biological species. So-called *pentodon* and *tappaniana* are extremes of a continuum, with intermediate variants which obviously interbreed freely with the extremes. While it is easy to refer single shells or small lots to one or the other, large populations usually contain shells that must be placed arbitrarily. At any rate, within the Southwest there is no evidence of either the more slender *pentodon* or more obese *tappaniana* predominating in any section of the territory, so that there is no justification for treating them as geographical subspecies. All named forms are individual variants of a single species. . . .

Fig. 13 shows a series of *G. pentodon* from locality K3, which illustrates a continuum between the two extreme forms, like that described by Bequaert and Miller.

Ecological differences of these two forms have been reported by Sterki (1906: 134), Baker (1939: 100-101), and others. The form *tappaniana* is usually found in "low, damp places" while *pentodon* is common in drier, open areas according to these authors.

Following the reasoning of Bequaert and Miller, perhaps the two forms are ecophenotypes, responding, in expression of their shell morphology, to local environmental conditions. Reporting only *G. tappaniana* from Kansas, Franzen and Leonard (1947: 336) observed great variability in shell size and shape, and concluded that "The variables are phenotypic and not characteristic of the shells of any certain part of the state nor of any one or [sic] several fossil faunules."

GASTROCOPTA PILSBRYANA (Sterki, 1890) Locality K-3.

G. pilsbryana is widespread in the mountains of Arizona from 1,220 to 3,050 m and in New Mexico at elevations above 1,830 m. In the Organ Mountains, Dona Ana County, New Mexico, Metcalf (1984, table 1) found it occurring from 1,920 to 2,500 m. It occurs in the Guadalupe Mountains in Texas at elevations over 1,980 m according to Fullington (1979: 105), who noted that "At present, the Guadalupe Mountains are the easternmost limit for this western mountain-dwelling species." The species inhabits montane forests and wooded canyons.

GASTROCOPTA PROCERA (Gould, 1840) Locality K-3.

According to Bequaert and Miller (1973: 90) no fossil specimens of *G. procera* have been found in Arizona and occurrence of this species in the central part of the state is due to introductions by man. The westernmost fossil occurrences seem to be in Socorro and Dona Ana Counties along the Rio Grande Valley in New Mexico at ca 107° west longitude (UTEP 4542, 7153). Living populations exist in northeastern New Mexico and in the Sacramento-Guadalupe Mountains at 2,130 to 2,440 m (Metcalf, 1970: 42). Fossil specimens have been found on the Rio Grande floodplain as low as 1,200 m (UTEP 7153). This species is widespread from central Texas eastward (Cheatum and Fullington, 1973: 19) and in the Texas Panhandle. In the Great Plains *G. procera* is a species characteristic of grasslands, but in central New Mexico it presently occurs only in montane areas both in open, grassy meadows and on wooded slopes.

Shells of *G. procera* and *G. cristata* are morphologically similar. In New Mexico the two species have been found together only as fossils, with only five such occurrences known (*procera* listed first): Dona Ana County at 1,250 m (UTEP 901, 898) and at 1,200 m (UTEP 7153, 7154), Socorro County at 1,730 m (UTEP 4542, 4543), Lincoln County at 1,480 m (UTEP 7884, 7878), and Eddy County at 1,730 m (UTEP 7292, 7291). In New Mexico *G. procera* does not presently exist at these low elevations, in contrast to *G. cristata.*

PUPILLA BLANDII Morse, 1865
(Fig. 14/10)
Localities K-1, 3, 4, 5, L-1, 2, P-1, 2.

In New Mexico *P. blandii* occurs in montane forests, descending as low as 1,980 m in wooded canyons. In northeastern New Mexico it is also found in grasslands, especially along creeks and cienegas (UTEP 745, 1927). It is found in mountains in Culberson and Jeff Davis Counties in Texas (Cheatum and Fullington, 1973: 23).

PUPILLA MUSCORUM (Linnaeus, 1758)
Localities K-1, 2, 3, 5, P-1.

In New Mexico specimens of *P. muscorum* have been found in the following counties: Grant (ANSP 89640), Socorro (ANSP 83038), Torrance (UMMZ 109928, UTEP 8330), Lincoln (UTEP 1261, ANSP 78721), Santa Fe (UMMZ 109826), Taos (ANSP 73592), Union (UTEP 1088, 1092, 1097, 8381), Colfax (UTEP 8362), and Otero (UTEP 1745). Although this species usually is found at higher elevations in New Mexico, it also occurs rarely in more arid habitats. Pilsbry (1948: 935) reported it (as the subspecies *xerobia)* "from an arid sandstone butte near Duran, New Mexico." It seems to have been much more widespread in the Southwest in the later Pleistocene.

PUPILLA SONORANA (Sterki, 1899)
(Fig. 14/9)
Locality K-5.

This species is restricted to forests and canyons of mountains of south-central New Mexico at elevations above 1,860 m. In the Organ Mountains Metcalf found it occurring between 1,920 and 2,500 m. It occurs in the Guadalupe Mountains, Texas, above 1,920 m, according to Fullington (1979: 106). *P. sonorana* is found living on both sides of the Tularosa Valley in the Sierra Blanca-Sacramento Mountains complex on the east and in the Organ Mountains and on Salinas Peak (UTEP 3196) on the west. The occurrence at K-5 is the first record of *P. sonorana* in the basin between these mountains. Fullington (1979: 106) and Bequaert and Miller (1973: 59) stated that *P. sonorana* may not be specifically distinct from P. *blandii.* However, the two species can be clearly distinguished by the crescent-shaped parietal tooth of *P. sonorana* and other features (see Fig. 14/9).

PUPOIDES ALBILABRIS (Adams, 1841) Localities K-1, 3, L-2, N-3, P-1, 2, 3.

This species is widespread at low elevations throughout Arizona, New Mexico, and Texas. It is tolerant of a variety of habitats and can withstand high temperatures and desiccation (Leonard and Frye, 1962: 26). In southern New Mexico specimens are found along river valleys and piedmont alluvial plains.

PUPOIDES HORDACEUS (Gabb, 1866) Localities K-3, P-1, 2, 3.

This species occurs in northern Arizona and New Mexico. In New Mexico it has been taken living as far south as near Corona, Torrance County, at ca 1,950 m (UTEP 2315). In western Texas it is found only as a fossil (Cheatum and Fullington, 1973: 29). An arid Upper Sonoran habitat seems to be the preference of this species (Bequaert and Miller, 1973: 177).

Family VALLONIIDAE

VALLONIA CYCLOPHORELLA (Sterki, 1892) Localities K-1, 2, 3, 4, 5, L-1, P-1.

In New Mexico this species occurs as low as 1,950 m in wooded canyons and up to 3,255 m in montane forests. According to Fullington and Pratt (1974: 28) distribution in Texas is limited to "Relict colonies in sheltered canyons along the eastern escarpment ('caprock') of the High Plains." Although *V. cyclophorella* usually occurs in montane forests in the Southwest, it also inhabits grasslands. Hoff (1962: 57) noted that this species "is associated with a variety of plant communities, some of which are characterized at least seasonally by a moisture deficit."

VALLONIA GRACILICOSTA Reinhardt, 1883

Localities K-1, 3, 4, 5, L-2, P-1, 2, 3.

Although this snail is widespread in New Mexico at ca 1,220 to 2,865 m, only fossil specimens are recorded from Arizona (Bequaert and Miller, 1973: 192). In Texas it is extant in the panhandle (UTEP 812, 840, 8420) and on Guadalupe Peak, Culberson County, at 2,290 m (Fullington, 1979: 107). Specimens are found in cienegas on floodplains, riparian forests, and mountain canyons in the Southwest.

VALLONIA PARVULA Sterki, 1893

Locality L-2.

In New Mexico *V. parvula* is known, living, from Union, Mora, and Quay Counties, and as a fossil from San Miguel County. An isolated population occurs along the eastern side of the Sacramento Mountains in Chaves County (UTEP 4373). It is common in the Texas and Oklahoma Panhandles (UTEP collections) and eastward. Inhabiting the Upper Sonoran Life Zone in New Mexico, this species is associated with canyons and bluffs where it occurs in leaf litter under shrubs. In Chaves County it occurs at the base of bluffs on the edge of the Peñasco River floodplain. Apparently this eastern gastropod migrated westward into the eastern part of New Mexico in the Pleistocene, and remains living only in the northeastern part of the state and (as a relict) in Chaves County. Fossil specimens at Nash Draw may give evidence of such a migration occurring, as they do, between present eastern and western populations.

VALLONIA PERSPECTIVA Sterki, 1893

Localities K-1, 3, P-1.

This species is common in mountain ranges of southern New Mexico at elevations of 1,450 to 2,830 m, inhabiting the Upper Sonoran and Transition Life Zones. Specimens have been found in scrub-oak leaf litter, associated with dead *Agave* in the Chisos Mountains (Fullington and Pratt, 1974: 29), in rhyolitic talus (Metcalf and Johnson, 1971: 90), in valley walls above a cienega (UTEP 4184), and on floodplains of small mountain streams (UTEP 5072).

Family SUCCINEIDAE

SUCCINEA LUTEOLA Gould, 1848
(Fig. 14/8)

Localities N-1, 2.

This species is widespread in Texas and present in southern New Mexico. In the Mesilla Valley of southern New Mexico *S. luteola* may be found just above the water line in irrigation ditches during the irrigation season.

OXYLOMA Sp.
(Fig. 14/7)

Localities P-1, 3.

Snails of this genus are extinct in Arizona in the view of Bequaert and Miller (1973: 155). A fossil of scattered occurrence in New Mexico, *Oxyloma* remains extant in the Tularosa River Valley, Otero County. Members of this genus are typically found on wet ground and on vegetation in marshes, floodplains, and along ponds (Franzen, 1964: 74). Along the Tularosa River specimens are usually found on watercress or along banks close to water.

SUCCINEIDAE (SUCCINEA and/or *CATINELLA,* spp. indet.)

Present at all localities.

Snails of these genera are widespread in Arizona, New Mexico, and Texas. Ecological information is generally unavailable for fossil specimens of these genera since soft anatomy is necessary for species identification. *Succinea luteola* (above) is an exception as it has a more distinctive shell.

Family ENDODONTIDAE

DISCUS CRONKHITEI (Newcomb, 1865)

Locality P-1.

This snail is common in southern New Mexico above 2,290 m, and occurs in wooded canyons down to ca 1,770 m. In Texas it is found only in the Guadalupe Mountains at elevations above 1,980 m according to Fullington (1979: 100). It occurs widely in Arizona over a broad range of elevations. Dillon (1980: 204) found that vegetation cover and substrate, not elevation, affected its distribution in Arch Canyon, Organ Pipe Cactus National Monument, Pima County, Arizona. At low elevations, 880 to 900 m, all specimens occurred in densely vegetated areas (R. T. Dillon, Jr., in litt., 3 September 1980).

HELICODISCUS SINGLEYANUS (Pilsbry, 1890)
(Fig. 14/2, 5)

Localities K-3, N-1, 2, 3, P-1, 2, 3.

UTEP collections contain specimens of this snail from the following counties in New Mexico: Grant, Doña Ana, Otero, Mora, San Miguel, and Chaves. It also occurs in Trans-Pecos Texas. This gastropod is tolerant of diverse habitats, being found in both mesic and arid situations.

Family ZONITIDAE

HAWAIIA MINUSCULA (Binney, 1840)
(Fig. 14/1, 4)

Localities K-3, L-2, N-3, P-1, 2, 3.

This gastropod is common in western Texas and at lower and higher elevations in both Arizona and New Mexico. This eurytopic species is found on flood-plains in mesic, forested montane habitats, and even in relatively xeric habitats in low mountains and foothills. In the Organ Mountains of Dona Ana County, New Mexico, it was taken from 1,615 to 2,285 m (Metcalf, 1984, table 1).

NESOVITREA HAMMONIS ELECTRINA (Gould, 1841)

Locality K-3.

This species is an inhabitant of montane forests in the Southwest at this time. It occurs in northern New Mexico at elevations above 2,130 m. The southernmost record in New Mexico is 16 km east of Mogollon, Catron County (UTEP 1128). Fossils such as the ones at Keen Spring clearly indicate altitudinal and latitudinal extensions (downward and southward) in the Pleistocene.

ZONITOIDES ARBOREUS (Say, 1816)

Localities P-1, 2, 3.

Typically associated with trees, *Z. arboreus* occurs in montane forests of the Southwest. In New Mexico it descends along forested canyons to approximately 1,980 m. It is restricted to mountains in western Texas.

Family LIMACIDAE

DEROCERAS LAEVE (Muller, 1774)

Localities K-1, 3, 4, 5, N-1, 2, 3, P-2, 3.

In the Southwest this slug is restricted to wet or damp habitats, as along springs, marshes, floodplains, or in urban areas.

Family POLYGYRIDAE

ASHMUNELLA RHYSSA ALTISSIMA (Cockerell, 1898) (Fig. 14/3, 6)

Locality K-4.

A. rhyssa presently occurs only in the Sierra Blanca—Sacramento Mountains complex (Stern, 1973: 41); the closely related species *A. salinasensis* Vagvolgyi, 1974, occurs on Salinas Peak. These mountains flank the Tularosa Basin on the east and west, respectively. The nominal subspecies *A. r. rhyssa* (Dail) occurs as a fossil in the southern Guadalupe Mountains in Texas (Metcalf and Fullington, 1976: 51) and along the Black River, Eddy County, New Mexico, at only 960 m elevation (UTEP 8207). *A. rhyssa* primarily inhabits montane forests, but may extend as low as 1,830 m along sparsely wooded canyons where it is restricted mainly to accumulations of talus. This is the first report of *A. r. altissima* (a subspecies of the Sierra Blanca and Nogal Peak areas) in the Tularosa Valley between the mountains noted above. The occurrence of this species at Keen Spring and at Black River is evidence (not previously suspected) of former, more widespread occurrences at lower elevations.

Family SAGDIDAE

THYSANOPHORA HORNII (Gabb, 1866)

Localities N-1, 3.

This species is found in southern New Mexico at elevations of 1,220 to 2,130 m (Metcalf, 1970: 44), and occurs also in western Texas. It is especially tolerant of arid conditions. Bequaert and Miller (1973: 56) noted that "It is most prevalent in bajadas and canyons of the Lower Sonoran Life-Zone."

The habitat characterizations given above allow recognition of three broad categories indicated in Table 2. These characterizations are further utilized in faunal analyses attempted in the next section.

TABLE 2— Characterization, by habitat, of species of molluscs collected during this study.

Aquatic	
Sphaerium striatinum	*Bakerilymnaea cubensis*
Pisidium casertanum	*Fossaria modicella*
Pisidium compressum	*Fossaria parva*
Pisidium contortum	*Ferrissia californica*
Pisidium ventricosum	*Planorbella tenuis*
Pisidium insigne	*Planorbella trivolvis*
Valvata humeralis	*Gyraulus crista*
Fontelicella sp.	*Gyraulus circumstriatus*
Lymnaea caperata	*Gyraulus parvus*
Lymnaea palustris	*Physa virgata*
Paludal	
Carychium exiguum	*Vertigo* cf. *ventricosa*
Vertigo cf. *elatior*	*Oxyloma* sp.
Vertigo milium	*Deroceras laeve*
Vertigo ovata	
Terrestrial	
Vertigo berryi	*Vallonia gracilicosta*
Gastrocopta armifera	*Vallonia parvula*
Gastrocopta cristata	*Vallonia perspectiva*
Gastrocopta pellucida	*Succinea luteola*
Gastrocopta pentodon	Succineids, spp. indet.
Gastrocopta pilsbryana	*Helicodiscus singleyanus*
Gastrocopta procera	*Discus cronkhitei*
Pupilla blandii	*Hawaiia minuscula*
Pupilla muscorum	*Nesovitrea hammonis*
Pupilla sonorana	*Zonitoides arboreus*
Pupoides albilabris	*Ashmunella rhyssa*
Pupoides hordaceus	*Thysanophora hornii*
Vallonia cyclophorella	

Discussion

Placitas Arroyo site, Dona Ana County, New Mexico

General description

The exposure studied along Placitas Arroyo is in NE 1/4 NE 1/4 NW 1/4 sec. 19, T19S, R3W, ca 3.2 km southwest of Hatch, Dona Ana County, New Mexico (Figs. 1, 2). Elevation is ca 1,270 m. It is located in the Lower Sonoran Life Zone (Bailey, 1913: 14); vegetation is dominated by mesquite *(Prosopis glandulosa)* and creosote bush *(Larrea tridentata).* Placitas Arroyo is situated in the southern part of the Palomas Valley, which is bounded by the Caballo Mountains on the east and Sierra de Las Uvas on the south. The arroyo cuts through the Camp Rice and underlying Rincon Valley Formations. Seager, Hawley, and Clemons (1971: 14) named the Rincon Valley Formation, noting that it "is a sequence of pale red gypsiferous siltstone, claystone, and mudstone." This formation consists of closed-basin deposits laid down during the late Miocene to Pliocene according to these authors (p. 18). Sediments of the Camp Rice Formation form the up-

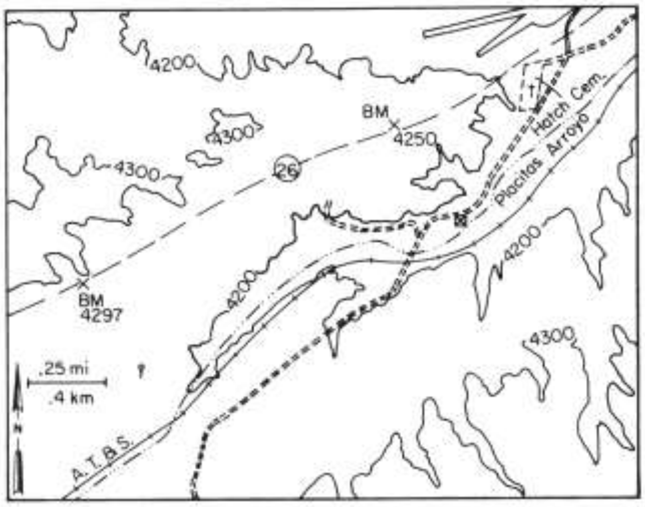

FIGURE 1—Map of Placitas Arroyo with collection site indicated by **X**. Elevations are designated in feet. A.T.&.S. = Atchison, Topeka, and Santa Fe Railroad; Cem. = Cemetery. Modified from U.S. Geological Survey map of 7½′ Hatch quadrangle, Doña Ana County, New Mexico.

FIGURE 2—Aerial photograph of Placitas Arroyo with collection site indicated by **X**.

per part of the canyon walls flanking Placitas Arroyo and date from late Pliocene(?) to middle Pleistocene (Seager et al., 1975: 21). Upon completion of basin filling, as represented by the Camp Rice Formation, the present Rio Grande Valley system developed through repeated episodes of valley cutting and filling by the Rio Grande and its tributaries (Seager and Hawley, 1973: 20).

Faunal occurrences and analyses

Deposits of the later valley fill that are exposed along Placitas Arroyo were examined. Collections were made at three locations along a 30 m (east—west oriented) section of the northwestern bank of the arroyo (Fig. 3), which varies from 3 to 4 m in height. As indicated in Fig. 4, fossil molluscs were found in units 1 and 2 of the western locality (P-1), and in unit 3 of the central (P-2) and eastern (P-3) localities. Many shells have a well-preserved periostracum and numerous sphaeriid clams have valves still joined. Both of these features indicate in-situ deposition of molluscs.

The grayish-pink (5 R 8/2) sediments of unit 1 are indurated sands and silts with limonitic staining. This staining indicates deposition in the presence of water according to Twenhofel (1950: 421), who noted that "Deposits of iron-bearing minerals have been formed under conditions of a wide range of environments that include those of weathering, seeps, springs, swamps, streams, lakes, lagoons, and the sea."

Unit 2 consists of coarser gravels with slightly indurated sands. The massive silts of unit 3 show humic staining on exposed surfaces. The non-indurated sediments of unit 3 are pale yellowish brown (10 YR 6/2) and are overlain by a thin, non-indurated stratum of gravels and sand (unit 4). The uppermost unit (unit 5) consists of grayish-orange—pink (5 YR 7/2), non-indurated, massive silts. These deposits could be interpreted as representing an upward fining of sediments deposited by a meandering stream or a braided-stream system. A fluvial origin seems probable because of the size of the clasts. This interpretation is supported by the paleoenvironmental analysis of the fauna.

The molluscs present in units 1 and 2 of the western locality (P-1) are predominately terrestrial (Tables 1, 3). In New Mexico the terrestrial species *Pupilla blandii, P. muscorum, Discus cronkhitei,* and *Zonitoides arboreus* are presently found together in montane forests. The latter two species seem especially dependent upon presence of leaf litter of trees. The fingernail clams *Sphaerium striatinum* and *Pisidium compressum* also occur in these units. Their presence indicates permanent water with current action according to interpretations by Hibbard and Taylor (1960: 76, 78). This assemblage suggests the former presence of a stream and riparian forest at locality P-1.

The younger, unindurated sediments (unit 3) at the

TABLE 3—Percentages of molluscan species having aquatic, paludal, and terrestrial habitat preferences, and total number of specimens present in fossil assemblages at Placitas Arroyo, Doña Ana County, New Mexico. Habitats are allocated as in Table 2. At localities P–2 and P–3 collections were taken at 50 cm intervals as described in the text.

	P–1	P–2					P–3			
	Total	Base	50 cm	100 cm	150 cm	Total	30 cm	80 cm	130 cm	Total
Aquatic	26.9	20.5	7.5	25.7	34.7	27.5	61.8	61.6	85.3	62.8
Paludal	6.1	2.6	5.7	0	0.9	1.4	3.8	2.1	0	2.7
Terrestrial	67.0	76.9	86.8	74.3	64.4	71.1	34.4	36.2	14.7	34.4
Total specimens	197	39	53	101	219	412	867	1,189	102	2,158

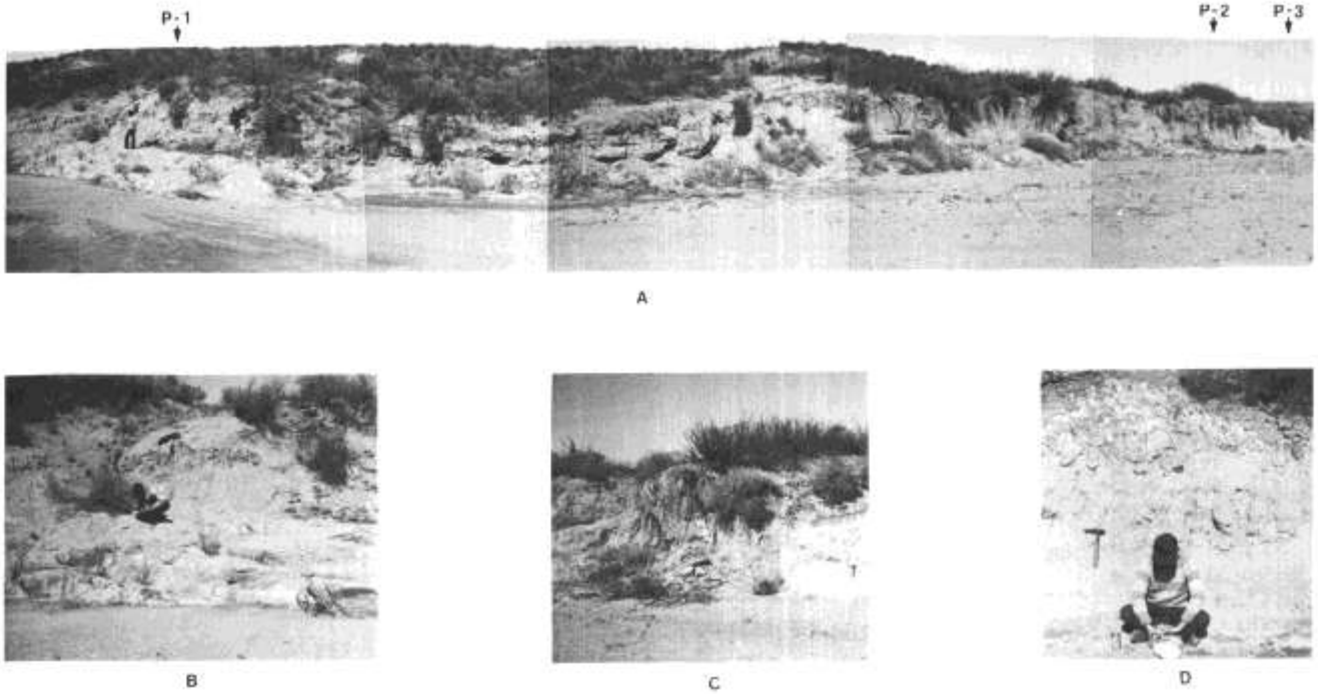

FIGURE 3—Placitas Arroyo site, Doña Ana County, New Mexico: **A,** general view north, with collection localities indicated; **B,** locality P–1, fossiliferous sediments of unit 1 are being examined; **C,** locality P–2, fossiliferous sediments of unit 3 are above debris; **D,** locality P–3, fossiliferous sediments of unit 3 are indicated at top of pick.

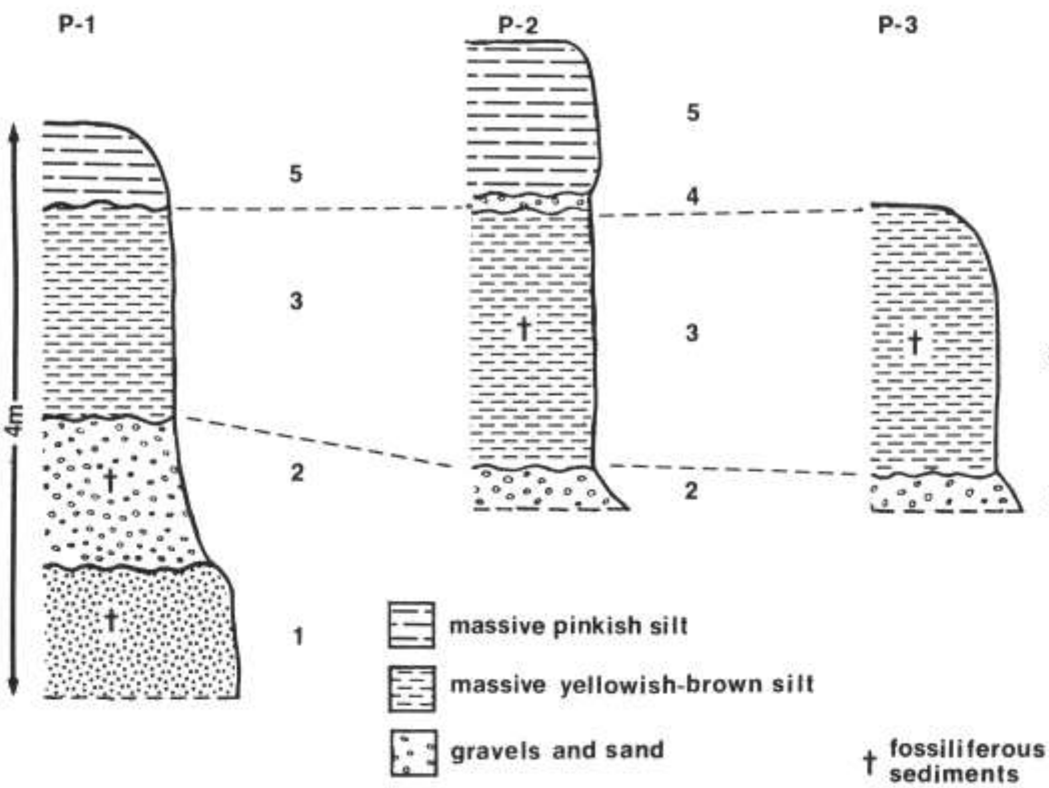

FIGURE 4—Placitas Arroyo site stratigraphy. Units 1 through 5 are discussed in text.

central and eastern localities (P-2 and P-3) overlie the deposits at P-1 (units 1 and 2) discussed above. The relative abundance of aquatic species increases at the central and eastern localities (Tables 1, 3). The great abundance of aquatic species and the presence of *Fontelicella* and of ostracodes suggest the existence of a spring during this time near locality P-3. Ponding of spring outflow would have produced suitable habitats in the form of pools and marshes for other molluscs reported at both P-2 and P-3.

Specimens of sphaeriids with thin shells are evidence of such ponding. According to Hibbard and Taylor (1960: 77) thin-shelled forms of *P. casertanum* inhabit lentic waters, such as ponds and marshes. These valves are dark brown, indicating deposition in humic material. Paludal species *(Carychium exiguum, Vertigo* sp., *Oxyloma* sp., and *Deroceras laeve)* also could have inhabited the edges of these marshes. The presence of *Zonitoides arboreus* would again suggest the occurrence of trees and associated leaf litter.

Ascending vertically in the section, collections at both P-2 and P-3 (Table 3) reflect an increase of aquatic species and a decrease of terrestrial and paludal snails. Such vertical faunal changes may indicate either a deterioration of suitable habitats for terrestrial and paludal species or alterations in drainage patterns and springbrook course.

Age of sediments

Neither pollen (Stephen A. Hall, in litt., 31 January 1980) nor vertebrate fossils were found in any of the Placitas Arroyo sediments to facilitate dating. The pinkish deposits of unit 5 are similar in lithology and stratigraphic position to the Fillmore alluvium that is common in the Rio Grande Valley. Radiocarbon dates ranging from 200 to 5,000 years B.P. for Fillmore alluvium have been recorded by Metcalf (1969: 159), who also reported a "B-2 alluvium" underlying Fill-more alluvium (ca 16 km northwest of Placitas Arroyo), which has yielded a radiocarbon date (charcoal) of 9,360 ± 150 years B.P. (p. 160). Having nine terrestrial species in common, the molluscan fauna found in unit 3 is similar to that of the B-2 alluvium; its deposition could have occurred near the Pleistocene—Holocene boundary. Because of their induration and lower stratigraphic position, sediments of unit 1 (P-1) are thought likely to be late Pleistocene in age.

Keen Spring site, Lincoln County, New Mexico

General description

Keen Spring, Lincoln County, New Mexico, is located 32 km southwest of Carrizozo, New Mexico. Localities K-1 and K-2 are in NE 1/4 sec. 34, T9S, R8E; localities K-3, K-4, and K-5 are in NW 1/4 NW 1/4 sec. 35, T9S, R8E (Fig. 5). Collections were made at elevations of 1,455 to 1,486 m.

Dominant vegetation at Keen Spring includes creosote bush *(Larrea tridentata),* mesquite *(Prosopis glandulosa),* saltbush *(Atriplex canescens),* grasses *(Sporobolus* sp.), and composites. Salt cedar *(Tamarix* sp.) and loco weed *(Astragalus* sp.) grow along the arroyo bottom. Vegetation on a spring mound (Fig. 5), 200 m north-

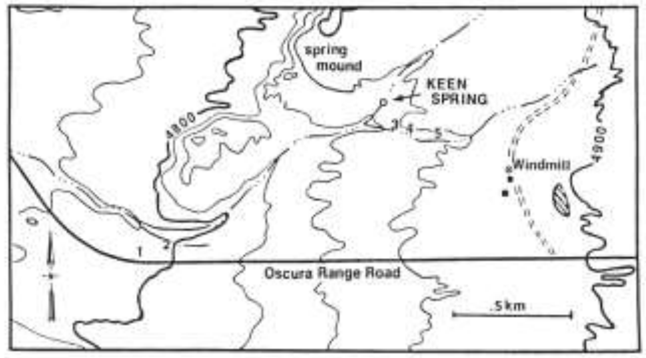

FIGURE 5—Map of Keen Spring area with collection localities numbered. Only seepage areas remain at spring location; flowing water is indicated by solid line above "2." Elevations are designated in feet. Modified from U.S. Geological Survey map of 7½' Oscura quadrangle, Lincoln County, New Mexico.

west of the seepage area, is primarily *Coldenia hispidissima* and snakeweed *(Xanthocephalum* sp.).

The Keen Spring site is situated in the northern part of the Tularosa Basin in the Basin and Range physiographic province. This basin lies between the Sierra Blanca—Sacramento Mountains complex on the east and the Organ—San Andres—Oscura chains on the west. In reference to such intermontane basins Kottlowski et al. (1965: 291) noted that "Most of these basins have been constantly filling since their formation as grabens in late Pliocene—early Pleistocene time."

Faunal occurrences and analyses

Assemblages were collected at five localities (Figs. 5, 6) in the Keen Spring area. Collections from locality K-1 were made in pale-orange (10 YR 7/2) silt exposed along a small rill north of Oscura Range Road. The preponderance of the aquatic species (Tables 1, 4) *Pisidium contortum, Lymnaea palustris, Fossaria modicella, Gyraulus* spp., and *Planorbella tenuis* indicates existence of shallow, lentic water here. An adjacent marshy area with grassy margins would have provided a suitable habitat for the associated paludal and terrestrial species.

Specimens from locality K-2 were collected in arroyo banks 120 m northeast of K-1. Here the fossiliferous silts grade from yellowish gray (5 Y 8/1) to very pale orange (10 YR 8/2) above and are overlain by pale-yellowish-brown (10 YR 6/2) fine sand and silt similar to the Fillmore alluvium mentioned previously.

The fauna at K-2 contains predominately terrestrial species (Tables 1, 4). *Pupilla muscorum* and *Vallonia cyclophorella,* the dominant species, usually occur in montane forests in the Southwest. *Vertigo ovata, V. milium,* and *Carychium exiguum* are paludal species requiring a damp habitat. The majority of the aquatic species present prefer sluggish waters. The assemblage could have existed near the edge of a marsh as proposed for locality K-1.

Localities K-3, K-4, and K-5 are all along the north bank (or along reentrants of the bank) of an arroyo leading east from the arroyo fork southwest of Keen Spring as shown in Fig. 5. A Fillmore-type alluvium (Gile et al., 1981: 45) caps the opposite, south wall of

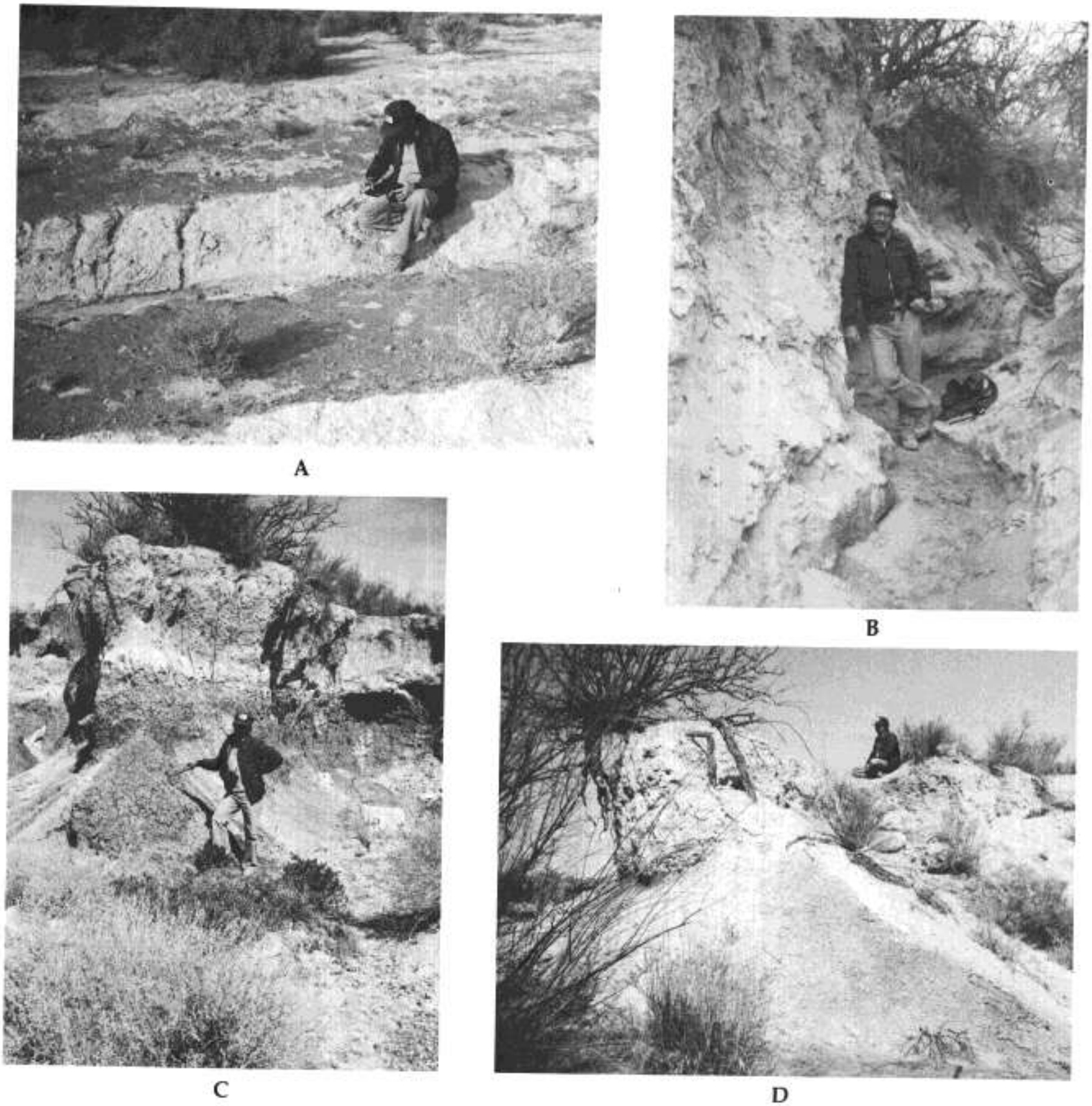

FIGURE 6—Keen Spring site, Lincoln County, New Mexico: **A**, view towards north at locality K–1, fossiliferous sediments being collected in shallow rill; **B**, view towards east at locality K–2, person leaning on light fossiliferous sediments of unit 2; **C**, view of north arroyo wall at locality K–3 (east section), fossil molluscs are present in and above light-colored band of sediments (unit 2); **D**, view towards northwest at locality K–4, person resting on fossiliferous sediments of unit 3.

TABLE 4—Percentages of molluscan species having aquatic, paludal, and terrestrial habitat preferences, and total numbers of specimens present in fossil assemblages at Keen Spring, Nash Draw, and Naegele Springs sites. Habitats are allocated as in Table 2. Percentages for K–3 and N–1 represent composites of more than one unit.

	Keen Spring					Nash Draw		Naegele Springs		
	K–1	K–2	K–3	K–4	K–5	L–1	L–2	N–1	N–2	N–3
Aquatic	59.9	18.6	18.8	0	9.4	7.0	19.7	87.7	66.8	20.3
Paludal	0.4	27.1	17.9	13.9	17.5	2.5	2.0	1.4	2.1	23.3
Terrestrial	39.8	54.2	63.3	86.1	73.0	90.5	78.3	10.8	31.1	56.4
Total specimens	1,094	118	686	36	371	653	603	978	379	133

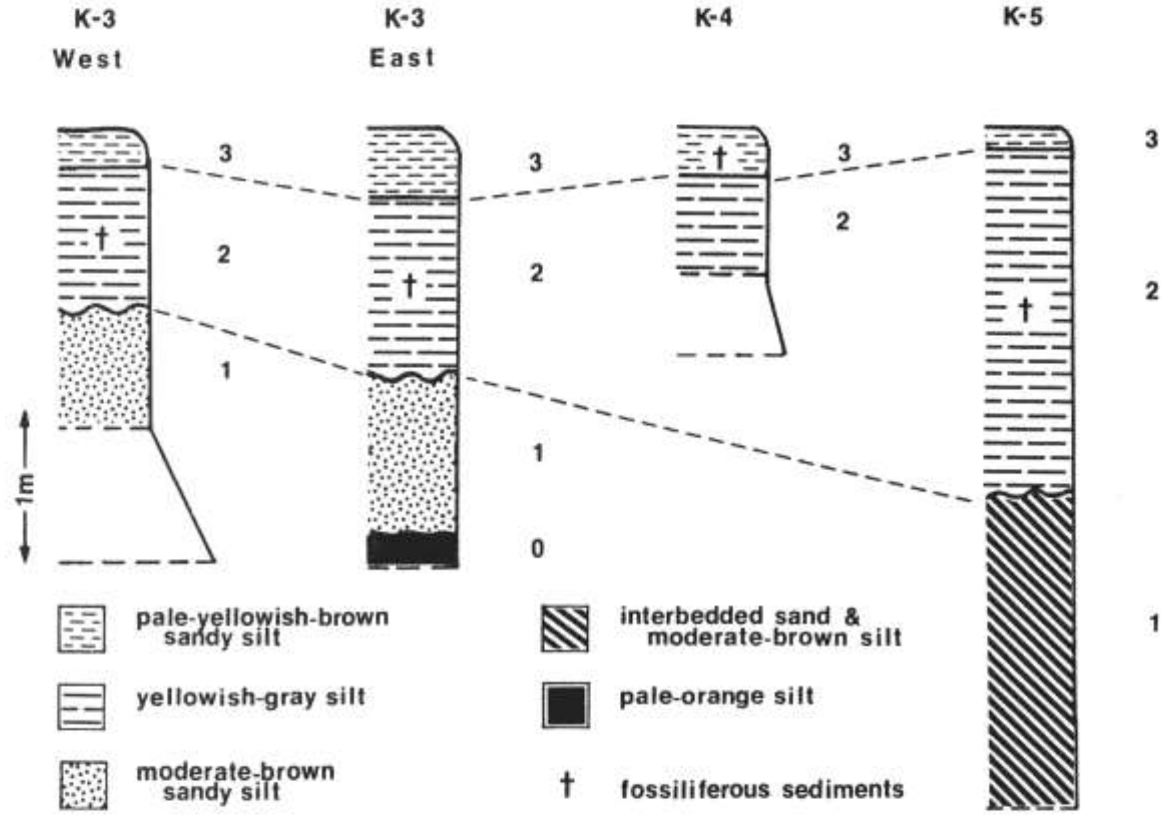

FIGURE 7—Keen Spring site stratigraphy. Units 0 through 3 are discussed in text.

the arroyo, but is not present at localities K-3, K-4, and K-5.

The composite collection at locality K-3 was taken along 150 m of the north bank of a reentrant arroyo 76 m east of the arroyo fork noted above. Two vertical sections, 15 m apart, illustrate the facies present at this locality (K-3 West and K-3 East in Fig. 7). Unit 1 in both exposures is moderately brown (5 YR 4/4) silt and fine sand, and is overlain unconformably by unit 2. The fossiliferous silts of unit 2 are yellowish gray (5 Y 8/1). Unit 3 is a pale-yellowish-brown (10 YR 6/2) sandy silt. Both units 1 and 2 contain pyrolusite (MnO_2) and limonitic staining, suggesting the presence of water during the time of deposition according to Twenhofel (1950: 450). The east exposure at locality K-3 reveals a lower unit (0) of very pale-orange (10 YR 8/2) silt lying unconformably under unit 1.

The upper 0.75 m of unit 2 at locality K-3 yielded a diverse, predominately terrestrial assemblage (Tables 1, 4). Aquatic species represented could have inhabited lentic waters, perhaps with thick vegetation, and could have tolerated seasonal desiccation. Paludal species, including *Vertigo* spp. and *Carychium exiguum*, are numerous. Although many of the terrestrial species are extant only in montane forests of the Southwest, some could have inhabited grasslands. A cienega wherein rushes and sedges graded peripherally to tall grasses could have supplied suitable habitats for all species.

At locality K-4, immediately east of locality K-3, only units 2 and 3 are visible above debris. Unit 2 is a yellowish-gray (5 Y 8/1) silt. In overlying unit 3 fossil molluscs were found in pale-yellowish-brown (10 YR 6/2) sandy silt (Tables 1, 4). No aquatics were collected here; however, the slug *Deroceras laeve* would have required a mesic habitat.

The occurrence of *Ashmunella rhyssa altissima* at locality K-4 is the first record of this species in the Tularosa Valley, although *A. rhyssa* and its close relative, A. *salinasensis*, have been reported living at higher elevations in, respectively, the Sierra Blanca–Sacramento Mountains complex and Salinas Peak, flanking both sides of the valley (Stern, 1973: 4; Vagvolgyi, 1974: 154)—see species accounts above.

Collections at locality K-5 were made along 50 m of the north arroyo wall 190 m east of the arroyo fork southwest of the Keen Spring site (Fig. 5). The arroyo wall is ca 4.4 m in height; sediments in the lower 2 m of unit 1 are composed of interbedded fine sand and moderately brown (5 YR 4/4) silt, unconformable to the overlying sediments. Fossiliferous silts of unit 2 are yellowish gray (5 Y 8/1), and unit 3 is a paleyellowish-brown (10 YR 6/2) sandy silt. Molluscs recovered at locality K-5 (Tables 1, 4) are predominately terrestrial species *(Pupilla blandii*, *Vallonia cyclophorella*, and *V. gracilicosta)* which could have inhabited either grasslands or cienegas. Aquatic species could have existed in shallow, lentic water which, marginally, also could have provided a damp habitat for the *Vertigo* species present. *Pupilla sonorana* inhabits montane forests on both sides of the Tularosa Valley, This is the first record of it, fossil or living, in the basin between these mountains.

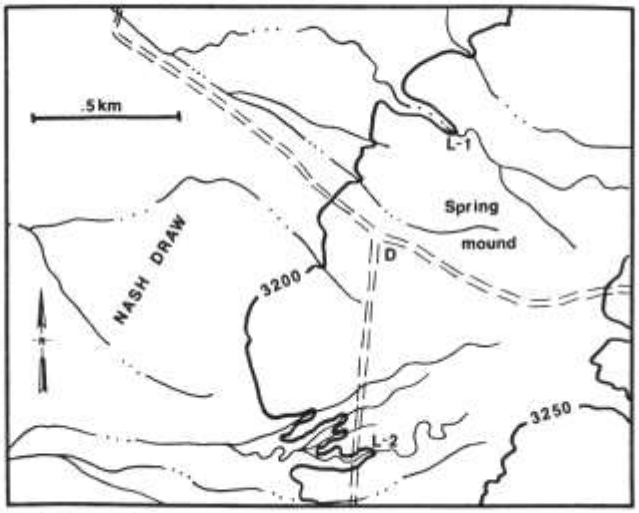

FIGURE 8—Map of Nash Draw with collection localities numbered. D = Drill pad. Elevations are designated in feet. Modified from U.S. Geological Survey map of 7½' Nash Draw NE quadrangle, Eddy County, New Mexico.

FIGURE 9—Aerial photograph of Nash Draw with collection localities numbered. Lower slopes of the scarp of Livingston Ridge, which borders Nash Draw on the east, can be noted to the right. Road leading southward from D, shown in Fig. 8, does not appear in this photograph.

Age of sediments

Near localities **K-1** and K-2 proboscidean remains were found in fossiliferous sediments like those examined in this study (R. H. Weber, in litt., 3 April 1981). This occurrence and the composition of the faunas indicate that the deposits were laid down during the Pleistocene. Occurrence of the strata immediately below Holocene sediments argues for a late Pleistocene (late Wisconsinan) age, as does lack of significant induration and calichification of the sediments.

Nash Draw site, Eddy County, New Mexico

General description

The Nash Draw site is 54 km east of Carlsbad, Eddy County, New Mexico. Locality L-1 is in center sec. 15, T22S, R30E; locality L-2 is in SW¼ sec. 15, T22S, R30E (Figs. 8, 9). Elevation at both localities is ca 975 m. Nash Draw is located in the Lower Sonoran Life Zone; vegetation is dominated by mesquite *(Prosopis glandulosa)* and creosote bush *(Larrea tridentata).* Vegetation in the arroyos includes dock *(Rumex* sp.), grasses *(Aristida* spp.), *Coldenia hispidissima,* **and** snakeweed *(Xanthocephalum* sp.). An extensive spring mound southeast of L-1 (Fig. 8) has a flora that is strikingly different from that of the surrounding area. Creosote bush is very sparse and mesquite is absent on the spring mound deposits. Vegetation is mainly muhly grass *(Muhlenbergia pungens), Croton* sp., *Coldenia hispidissima,* and *Xanthocephalum* sp.

Situated in the northern Delaware Basin, Nash Draw is located between Livingston Ridge (whence the designation "L" used herein) to the east and Quahada Ridge to the west. According to Vine (1963: B38) the draw is "an undrained physiographic depression" resulting from solution of underlying massive halite and gypsum deposits of Permian age.

In the area of study the depression is partially filled with alluvial deposits of sand and silt. Vine (1963: B35) noted that this alluvium "is locally derived material deposited by sheet wash on the slopes of depressions and by intermittent streams that discharge their load into the depressions as alluvial fans during rare periods of flash flooding." Arroyos such as those at localities L-1 and L-2 (Figs. 8, 9) have cut through these deposits, exposing the fossiliferous sediments analyzed in this study.

Faunal occurrences and analyses

Collection L-1 was taken along a 46-m, east—west oriented outcrop of an arroyo bank (Fig. 10A). Three sections, L-1 west, central, and east, are shown in Fig. 11. At the eastern end of the exposure, unit 1 is a pinkish-gray (5 YR 8/1) gypsiferous silt (Fig. 11). At L-1 east, fossil molluscs were collected in the lower 0.3 m of unit 2, which is composed of light-brown (5 YR 5/6) fine sand with some silt. Unit 3, white (N 9) silt with minute gypsum crystals, is overlain by moderately reddish-brown (10 R 4/6), fine to very fine sands of unit 4.

Units 2 and 3 are not exposed 15 m to the west at L-1 west, where unit 4 directly overlies fossiliferous unit 1 (Fig. 11). This facies change may represent lateral migration of arroyo deposition.

The molluscan fauna at L-1 (all sites) is predominately terrestrial (Tables 1, 4). The most numerous species at this locality, *Pupilla blandii,* is presently found mainly in montane forests in New Mexico, but also occurs along creeks and cienegas in the northeastern part of the state. The occurrence of the clam *Pisidium compressum* indicates the presence of perennial water with current action. A springbrook, perhaps originating near the spring mound 250 m to the southeast and lined by grassy banks (Fig. 8), could have created suitable habitats for all species recovered.

Sediments at locality L-2 are exposed in a deeply entrenched, steep-sided arroyo (Fig. 10B). Mollusc shells and vertebrate bones were collected at locality

A

B

FIGURE 10—Nash Draw site, Eddy County, New Mexico: **A**, view of northwest arroyo wall at locality L–1 (west exposure), fossils were collected in lower bench of light-colored sediments (unit 1) upon which man is standing; **B**, view of northwest arroyo wall at locality L–2, person rests upon light-colored fossiliferous sediments of unit 1.

L-2 from unit 1 (Fig. 11), which consists of pinkish-gray (5 YR 8/1) silt with some limonitic staining. Unit 2 is grayish-orange—pink (5 YR 7/2) gypsiferous silt and is overlain by reddish-brown, fine to very fine sands of unit 3.

At this locality molluscs are predominately terrestrial (Tables 1, 4), and all the aquatic species present *(Pisidium casertanum, Lymnaea caperata, Fossaria parva,* and *Physa virgata)* can tolerate a habitat of standing water and periods of desiccation. Both aquatic and paludal species could have existed on the edge of a cienega; surrounding grasslands would have provided suitable habitats for the pupillid gastropods and the vertebrate fauna noted below.

Age of sediments

Bones of *Camelops* sp. and *Equus* cf. *niobrarensis* Hay, 1913, were found in the fossiliferous deposits at locality L-2 (George Bachman, in litt., 24 July 1980). Although radiocarbon dates on the Nash Draw specimens are inconclusive, presence of these vertebrate remains and stratigraphic position of the strata strongly indicate deposition during the Pleistocene, most likely the late Wisconsinan.

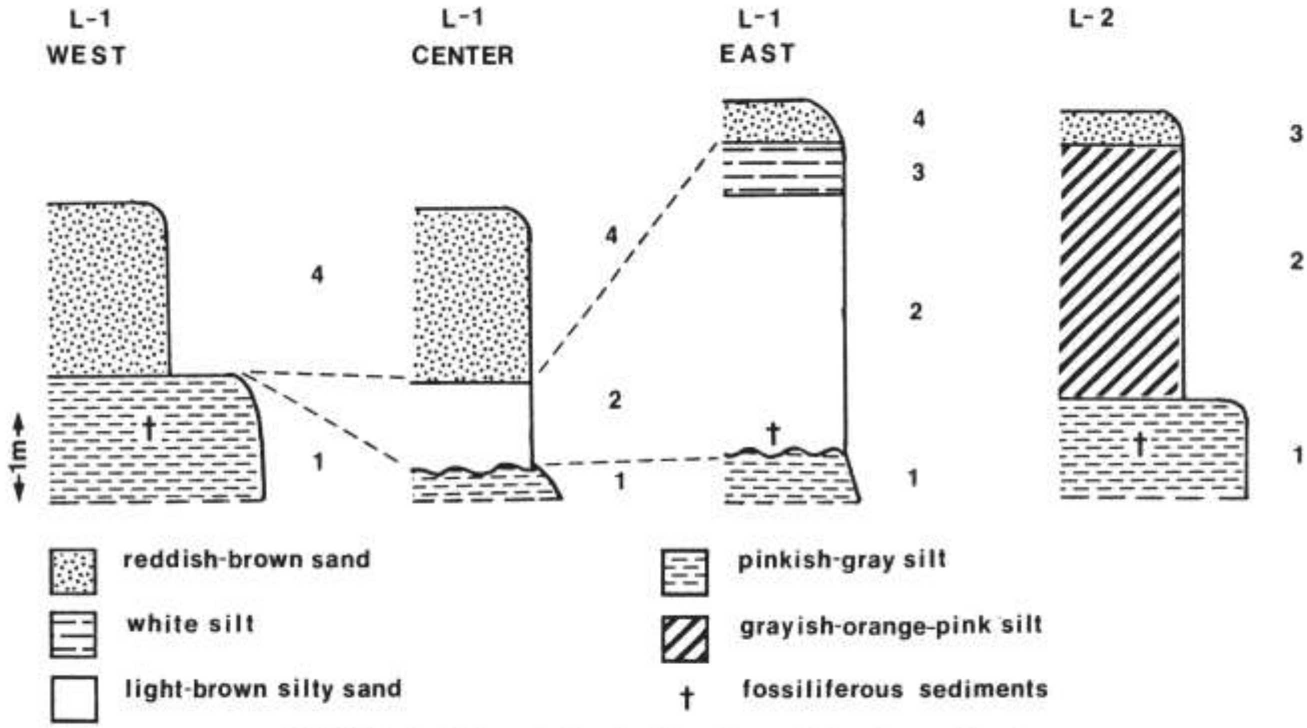

FIGURE 11—Nash Draw stratigraphy. Units 1 through 4 are discussed in text.

Naegele Springs, Presidio County, Texas

General description

Naegele Springs, Presidio County, Texas, is located ca 64 km northwest of the town of Presidio and 8.5 km northwest of the village of Ruidosa (Fig. 12). Collections were made in two arroyos (northeast and southeast) at elevations of 926 to 945 m. Springs in each arroyo produce springbrooks and marshy areas (Fig. 12).

Xeric vegetation predominates in the study area and includes creosote bush *(Larrea tridentata),* mesquite *(Prosopis glandulosa),* prickly pear *(Opuntia* sp.), and catclaw *(Acacia constricta).* Meadow vegetation includes salt cedar *(Tamarix* sp.), seepwillow *(Baccharis sp.),* willow *(Salix* sp.), desert tobacco *(Nicotiana trigonophylla),* rushes *(Juncus* sp.), and sedges *(Carex* sp.). Watercress *(Rorippa nasturtium-aquaticum)* grows in the outflow of the springs; cottonwoods *(Populus fremontii)* surround the area of the main spring (Fig. 12).

The Naegele Springs area is located in the northern part of the Presidio Bolson in the Basin and Range physiographic province. This part of the bolson is bordered on the west by the Sierra de Ventana (in Mexico) and on the east by the Sierra Vieja and the Chinati Mountains.

Basin-center deposits in the northern Presidio Bolson are primarily mudstone and sandstone according to Groat (1972: 16, 24), who suggested that "the bolson was the site of a dry lake throughout much of its history, perhaps with a more permanent spring-fed body of water existing in the Ruidosa area." Presidio Bolson deposits probably accumulated during the same period as other basin filling along the Rio Grande (Miocene through early Pleistocene; Groat, 1972: 25).

The basin fill consists mainly of fluvial deposits from aggrading streams and sheet floods as described by Dickerson (1966: 35), who classified sediments in the vicinity of Naegele Springs as "sandstone facies" consisting of sandstone and siltstone. The Rio Grande and its tributaries have since excavated the basin fill. Such downcutting has produced exposures along Naegele Creek, discussed herein, that reveal an abundant molluscan fauna in younger deposits.

Faunal occurrences and analyses

Collection N-1 was made along a 32-m outcrop of the north bank of the southeast arroyo which borders a wet meadow (Fig. 12). The lowest unit consists of olive-gray (5 Y 4/1) silt; it is overlain by a unit that consists predominantly of dark, humic materials, which is in turn overlain unconformably by a unit of paleyellowish-brown (10 YR 6/2) silt similar to the Fillmore

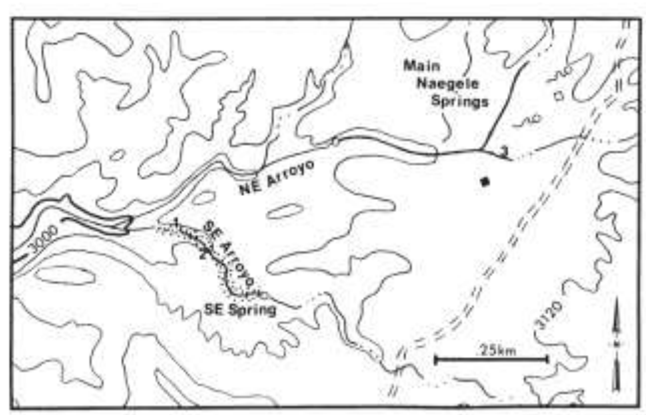

FIGURE 12—Map of Naegele Springs area with collection localities numbered. Dotted area indicates a wet meadow. Elevations are designated in feet. Modified from U.S. Geological Survey map of 7½' Pueblo Nuevo quadrangle, Presidio County, Texas.

alluvium discussed previously. The lower two units are fossiliferous. The molluscs present are predominantly aquatic (units combined in Tables 1, 4).

The outcrop at locality N-2, 90 m to the southeast, is similar to that at N-1 except here the humic sediments are more than a meter thick and contain some peaty materials, indicating marsh deposits. These sediments overlie cemented rubble deposits similar to the early (Tertiary or early Quaternary) basin fill. Fossils of the hydrobiid snail genus *Fontelicella* are abundant at both localities and suggest former existence of a nearby spring and springbrook, as at the present time. A spring (SE spring in Fig. 12) and a wet meadow are located 120 m southeast of the fossiliferous deposits. *Pisidium casertanum, Fontelicella sp., Physa virgata,* and ostracodes were found living in the outflow. This spring is probably the descendant of a more extensive spring (or complex of springs) responsible for the deposits discussed above.

Collections at locality N-3, near the main springs (Fig. 12), were made in a lower unit of the exposure, which consists of silt that grades from light olive gray (5 Y 5/2) to pale yellowish brown (10 YR 6/2). Above these sediments are alternating silt and gravel lenses in which cementation increases upward, culminating in a "caprock" surface. Molluscs in the fossiliferous sediments of the lower unit, indicated in Tables 1 and 4, are predominantly terrestrial and paludal species. *Ferrissia californica* and *Planorbella trivolvis* prefer stagnant water, while *Pisidium insigne* and *Fontelicella* sp. inhabit springs. The assemblage (see Tables 1, 4) suggests former presence of a spring nearby and an associated marshy area.

Age of sediments

Since the sediments at localities N-1 and N-2 are not indurated and are overlain by a Fillmore-type alluvium, the deposits and faunas probably were laid down no earlier than early Holocene. According to Gile, Hawley, and Grossman (1981, tables 21, 27) carbonate horizons such as the caprock at locality N-3 occur on surfaces no younger than late Pleistocene. Perhaps the underlying deposits at this locality are also of late Pleistocene age. The presence of spring-associated species at N-3, as discussed above, suggests that springs have long been present in this area.

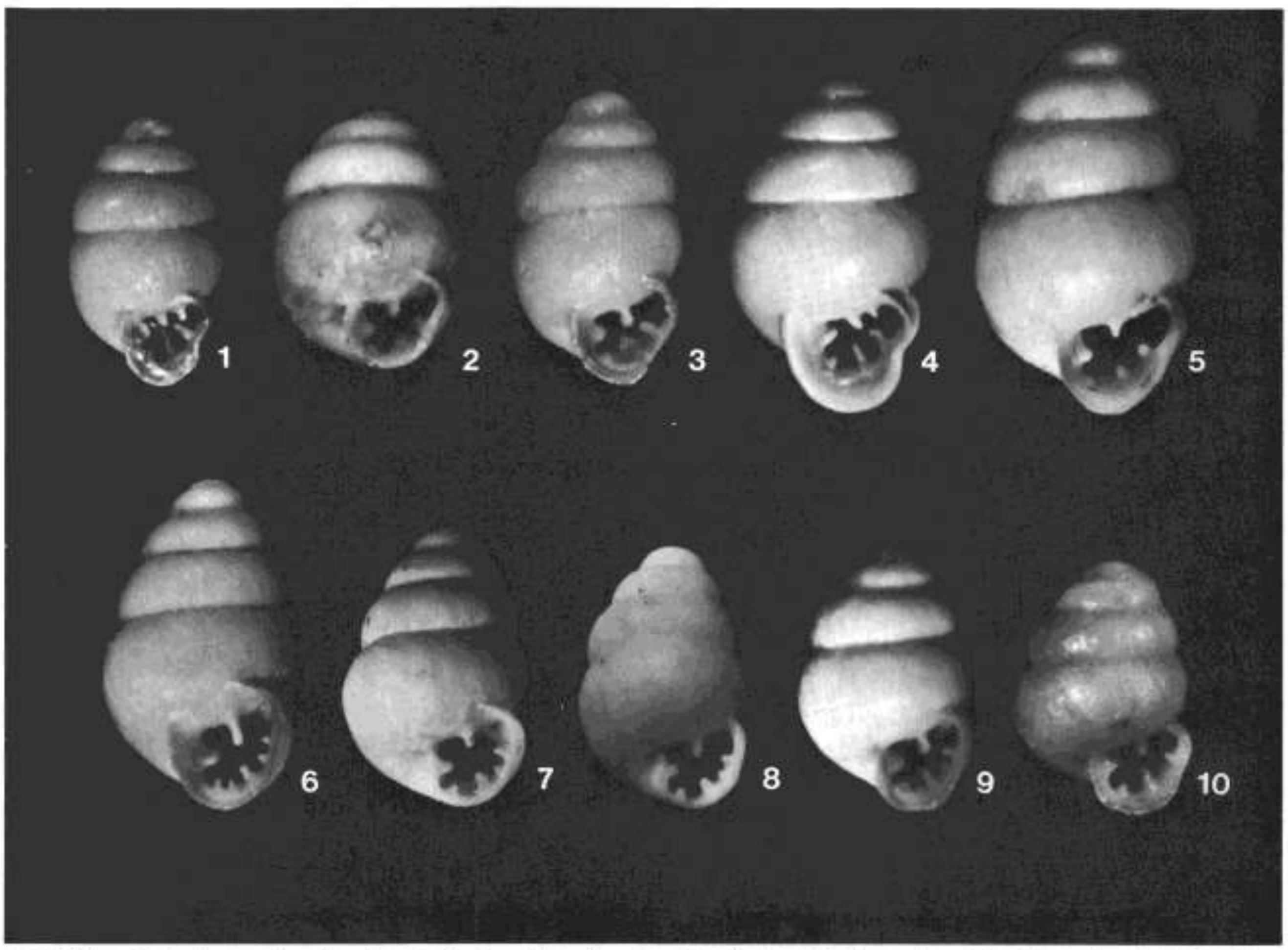

FIGURE 13—Photomicrographs of mollusc shells found in sediments of study sites: **1,** *Vertigo milium* (Gould) from locality K–2 at Keen Spring (height = 1.6 mm); **2,** *Vertigo* cf. *ventricosa* (Morse) from locality K–3 at Keen Spring (height = 1.8 mm); **3,** *Vertigo* cf. *elatior* Sterki from locality K–3 at Keen Spring (height = 2.0 mm); **4,** *Vertigo ovata* (Say) from locality N–1 at Naegele Springs (height = 2.0 mm); **5,** *Vertigo berryi* Pilsbry from locality K–1 at Keen Spring (height = 2.6 mm); **6** through **10,** *Gastrocopta pentodon* (Say) from locality K–3 at Keen Spring (height = 2.2, 1.8, 1.7, 1.6, and 1.4 mm, respectively).

Conclusions

Several generalizations may be derived from analyses of the fossil assemblages discussed above. First, the fossil faunas studied are much more diverse than those existing in the same areas today. No living molluscs were found at the Placitas Arroyo and Keen Spring sites. Succineids occurred at the Nash Draw site. It is likely that a few other xeric-adapted species are to be found in the environs of the localities. The aquatic species *Pisidium casertanum, P. insigne, Fontelicella* sp., and *Physa virgata* were recovered from the outflow of Naegele Springs. Nonetheless, these living faunas are much less diverse than the fossil ones. We know of no place where faunas with the species composition of the fossil assemblages currently exist.

Secondly, numerous species found in the fossil assemblages require a cooler and more humid environment than is currently available at these elevations and, therefore, their extant populations are restricted to higher elevations and/or more northern latitudes in the Southwest. Metcalf (1970: 46) suggested that such species *(Gastrocopta armifera, Pupilla blandii, Pupoides hordaceus, Vallonia cyclophorella,* and *V. gracilicosta)* migrated "southward in connection with an extension of piedmont grasslands rather than (or in addition to) migrating downward from nearby mountain ranges." Presence of *Pupilla blandii, Vallonia cyclophorella,* and *V. gracilicosta* at the Nash Draw site, far from present populations of these species, indicates a lengthy migration at lower elevations, from some source, be it montane or northern.

Other species now living in more northern or montane habitats in the region treated here include: *Sphaerium striatinum, Pisidium contortum, P. ventricosum, Valvata humeralis, Carychium exiguum, Lymnaea palustris, Vallonia perspectiva, Gastrocopta pilsbryana, Pupilla muscorum, P. sonorana, Nesovitrea hammonis electrina, Discus cronkhitei, Zonitoides arboreus, Gastrocopta pentodon,* and *G. procera.* The latter two species are of restricted occurrence in the Southwest and are seemingly invaders from the east. *Gastrocopta procera* apparently migrated only as far as western New Mexico, as this species does not occur as a fossil in Arizona

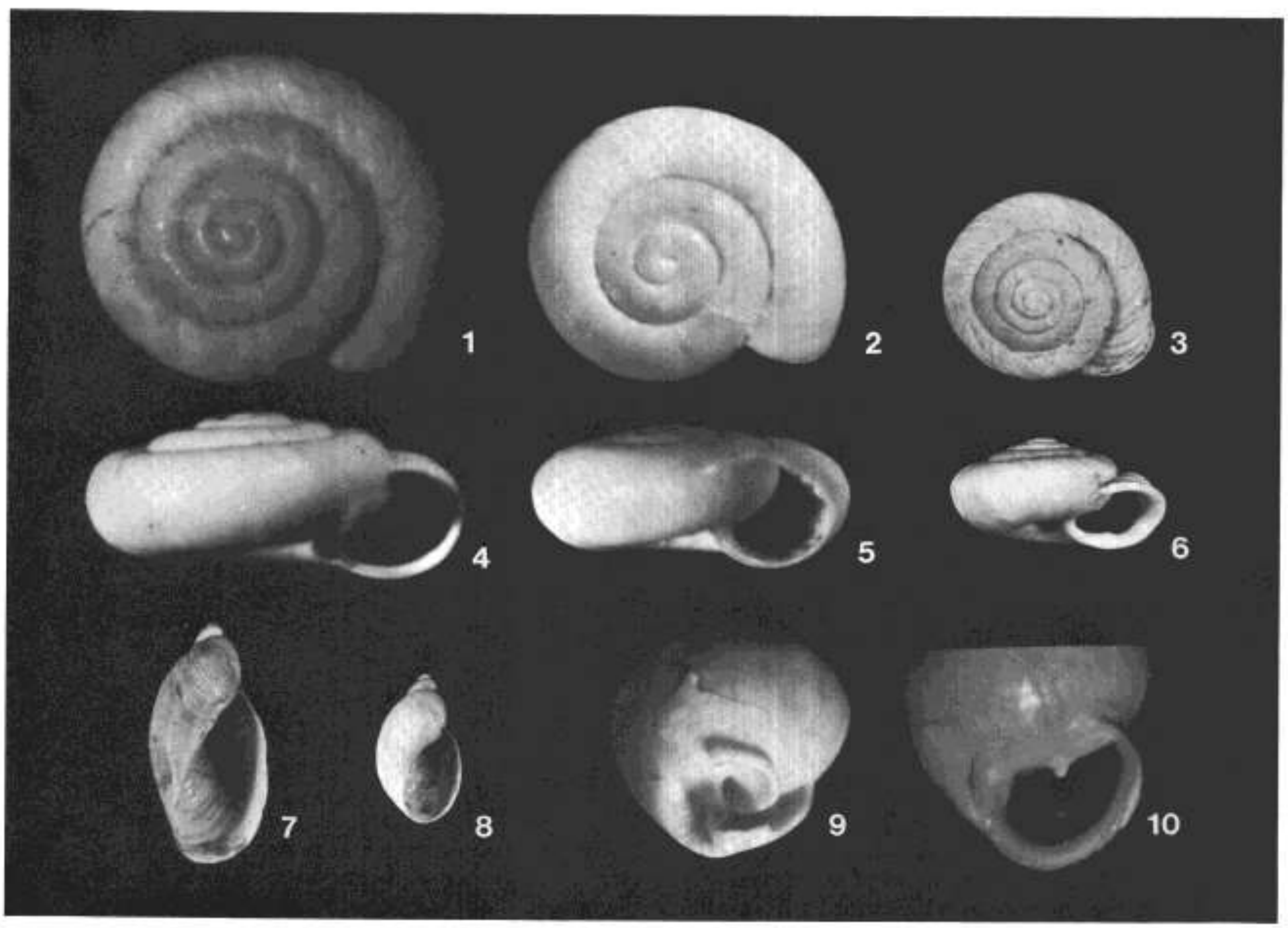

FIGURE 14–Photomicrographs of mollusc shells found in sediments of study sites: **1, 4,** *Hawaiia minuscula* (Binney) from locality N–3 at Naegele Springs (diameter = 2.3 mm); **2, 5,** *Helicodiscus singleyanus* (Pilsbry) from locality N–1 at Naegele Springs (diameter = 2.1 mm); **3, 6,** *Ashmunella rhyssa altissima* (Cockerell) from locality K–3 at Keen Spring (diameter = 15.0 mm); **7,** *Oxyloma* sp. from locality P–1 at Placitas Arroyo (height = 15.0 mm); **8,** *Succinea luteola* Gould from locality N–2 at Naegele Springs (height = 9.0 mm); **9,** *Pupilla sonorana* (Sterki) from locality K–5 at Keen Spring (aperture width = 0.9 mm); **10,** *Pupilla blandii* Morse from locality L–2 at Nash Draw (aperture width = 0.8 mm).

(Bequaert and Miller, 1973: 90). ***Vallonia parvula*** also invaded westward into New Mexico, where it is known to be living only in Chaves County and in northeastern parts of the state. Fossil specimens at Nash Draw are evidence of this posited former migration. The southwestern species, ***Pupilla sonorana*** and ***Ashmunella rhyssa,*** now restricted to montane habitats in New Mexico, must have occurred at lower elevations in the past, as indicated by fossil specimens found at the Keen Spring site.

Finally, several species are common as fossils, but are uncommon in the southwestern fauna today. Species of molluscs the populations of which are judged to be declining in the Southwest are ***Pisidium ventricosum, Lymnaea caperata, L. palustris, Vertigo elatior, V. ovata, V. ventricosa, Gastrocopta armifera,*** and ***G. procera.*** Species exhibiting significant geographic displacement from present ranges are ***Vertigo berryi*** (restricted to California and Baja California), ***Gyraulus crista,*** and ***G. circumstriatus*** (living only north of Arizona and New Mexico according to Taylor, 1954: 8, 1960: 58), ***Pisidium contortum*** (found in the White Mountains of Arizona by D. W. Taylor, his pers. comm.), ***Valvata humeralis*** (extant in northern Arizona), and ***Lymnaea palustris*** (living in northern New Mexico).

Although all species of molluscs examined in this study are still extant, shifts in geographic ranges have occurred. Since effective precipitation and temperature extremes influence the distribution of modern molluscs (Miller, 1978: 28), development in the Holocene of a more arid climate with greater seasonal temperature variations must have contributed to distributional changes and local extinctions of molluscs in the Southwest. Faunas closely associated with springs, such as the ones treated herein, surely were especially vulnerable to a Holocene climate exhibiting increased aridity. Thus, for all the "paleosprings" treated, local extinction is the rule. Even at Naegele Springs, where springs still persist, the fauna is not as rich today.

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Selected conversion factors*

TO CONVERT	MULTIPLY BY	TO OBTAIN
Length		
inches, in	2.540	centimeters, cm
feet, ft	3.048×10^{-1}	meters, m
yards, yds	9.144×10^{-1}	m
statute miles, mi	1.609	kilometers, km
fathoms	1.829	m
angstroms, Å	1.0×10^{-8}	cm
Å	1.0×10^{-4}	micrometers, µm
Area		
in^2	6.452	cm^2
ft^2	9.29×10^{-2}	m^2
yds^2	8.361×10^{-1}	m^2
mi^2	2.590	km^2
acres	4.047×10^{3}	m^2
acres	4.047×10^{-1}	hectares, ha
Volume (wet and dry)		
in^3	1.639×10^{1}	cm^3
ft^3	2.832×10^{-2}	m^3
yds^3	7.646×10^{-1}	m^3
fluid ounces	2.957×10^{-2}	liters, l *or* L
quarts	9.463×10^{-1}	l
U.S. gallons, gal	3.785	l
U.S. gal	3.785×10^{-3}	m^3
acre-ft	1.234×10^{3}	m^3
barrels (oil), bbl	1.589×10^{-1}	m^3
Weight, mass		
ounces avoirdupois, avdp	2.8349×10^{1}	grams, gr
troy ounces, oz	3.1103×10^{1}	gr
pounds, lb	4.536×10^{-1}	kilograms, kg
long tons	1.016	metric tons, mt
short tons	9.078×10^{-1}	mt
oz mt^{-1}	3.43×10^{1}	parts per million, ppm
Velocity		
ft sec^{-1} (= ft/sec)	3.048×10^{-1}	m sec^{-1} (= m/sec)
mi hr^{-1}	1.6093	km hr^{-1}
mi hr^{-1}	4.470×10^{-1}	m sec^{-1}

TO CONVERT	MULTIPLY BY	TO OBTAIN
Pressure, stress		
lb in^{-2} (= lb/in^2), psi	7.03×10^{-2}	kg cm^{-2} (= kg/cm^2)
lb in^{-2}	6.804×10^{-2}	atmospheres, atm
lb in^{-2}	6.895×10^{3}	newtons (N)/m^2, N m^{-2}
atm	1.0333	kg cm^{-2}
atm	7.6×10^{2}	mm of Hg (at 0° C)
inches of Hg (at 0° C)	3.453×10^{-2}	kg cm^{-2}
bars, b	1.020	kg cm^{-2}
b	1.0×10^{6}	dynes cm^{-2}
b	9.869×10^{-1}	atm
b	1.0×10^{-1}	megapascals, MPa
Density		
lb in^{-3} (= lb/in^3)	2.768×10^{1}	gr cm^{-3} (= gr/cm^3)
Viscosity		
poises	1.0	gr cm^{-1} sec^{-1} *or* dynes cm^{-2}
Discharge		
U.S. gal min^{-1}, gpm	6.308×10^{-2}	l sec^{-1}
gpm	6.308×10^{-5}	m^3 sec^{-1}
ft^3 sec^{-1}	2.832×10^{-2}	m^3 sec^{-1}
Hydraulic conductivity		
U.S. gal day^{-1} ft^{-2}	4.720×10^{-7}	m sec^{-1}
Permeability		
darcies	9.870×10^{-13}	m^2
Transmissivity		
U.S. gal day^{-1} ft^{-1}	1.438×10^{-7}	m^2 sec^{-1}
U.S. gal min^{-1} ft^{-1}	2.072×10^{-1}	l sec^{-1} m^{-1}
Magnetic field intensity		
gausses	1.0×10^{5}	gammas
Energy, heat		
British thermal units, BTU	2.52×10^{-1}	calories, cal
BTU	1.0758×10^{2}	kilogram-meters, kgm
BTU lb^{-1}	5.56×10^{-1}	cal kg^{-1}
Temperature		
°C + 273	1.0	°K (Kelvin)
°C + 17.78	1.8	°F (Fahrenheit)
°F − 32	5/9	°C (Celsius)

Divide by the factor number to reverse conversions.
Exponents: for example 4.047×10^{3} (see acres) = 4,047; 9.29×10^{-2} (see ft^2) = 0.0929.

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