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A NEW *PYRGULOPSIS* (GASTROPODA: HYDROBIIDAE) FROM SOUTHEASTERN CALIFORNIA, WITH A MODEL FOR HISTORICAL DEVELOPMENT OF THE DEATH VALLEY HYDROGRAPHIC SYSTEM

Robert Hershler and William L. Pratt

Abstract.—*Pyrgulopsis giulianii,* new species, from a few, mid-elevation streams in southern Sierra Nevada (Indian Wells and Kern River Valleys), is described and new records for three other local congeners also are given. Details of shell form and penial morphology distinguish the new snail from related forms found in Owens Valley. Zoogeographic patterns of Death Valley System *Pyrgulopsis* support the hypothesis that a highly integrated pluvial drainage was present in the region, and also suggest that the system had various historic connections (possibly non-contemporaneous with the above) to adjacent areas. A model of drainage evolution of the Death Valley System is presented, based on distributional data of hydrobiids and other organisms of perennial waters.

This is the third and final paper in a series on systematics of springsnails (Gastropoda: Hydrobiidae) from Death Valley System, southeastern California and southwestern Nevada. Earlier contributions dealt with fauna from the Ash Meadows spring oasis in Amargosa Desert (Hershler & Sada 1987), and Owens and Amargosa Basins (exclusive of above, Hershler 1989). Results of survey of remaining portions of the system and adjacent areas are summarized herein, including description of a new *Pyrgulopsis* and new records for three other congeners. A model for historical development of drainage in the Death Valley System is presented, largely based on zoogeography of resident *Pyrgulopsis.*

Materials and Methods

Localities visited during this portion of the survey are listed in Appendix 1, and consisted of low- to mid-elevation springs and perennial streams. Fuller treatments of taxa (other than the new species) are in Hershler (1989) and Hershler & Sada (1987). Shell morphometric methodology is that of Hershler (1989). Dots on distribution maps represent one or several closely spaced localities. Repositories of material examined are indicated in the text as follows: LACM—Los Angeles County Museum of Natural History; SBMNH—Santa Barbara Museum of Natural History; UNLVM—University of Nevada at Las Vegas Museum of Natural History; USNM—National Museum of Natural History; WBM—Walter Miller personal collection.

Systematics

Family Hydrobiidae Troschel, 1857
Genus *Pyrgulopsis* Call & Pilsbry, 1886
Pyrgulopsis giulianii, new species
Southern Sierra Nevada springsnail
Figs. 1–4

Pyrgulopsis cf. *stearnsiana.*—Hershler, 1989:194 (Sage, Sand Canyons; figs. 37–40).

Material examined.—California. Kern County: Stream in Sage Canyon, USNM 853520, 857975; Stream in Sand Canyon, USNM 860444 (holotype), 853519 (para-

Table 1. Shell parameters for *Pyrgulopsis giulianii.* UNSM catalog number and number of specimens (in parentheses) are given beneath locality name. WH = number of whorls, SH = shell height, SW = shell width, LBW = length of body whorl, WBW = width of body whorl, AL = aperture length, AW = aperture width, W = whorl expansion rate, D = distance of generating curve from coiling axis, T = translation rate, SA = aperture shape.

Parameter	Locality			
	Sand Canyon 853519 (10)	Sage Canyon 853520 (15)	Ninemile Canyon 860446 (6)	Cow Canyon 860448 (8)
WH mean	4.13	4.15	4.25	4.44
SD	0.13	0.16	0.27	0.18
range	4.00–4.25	4.00–4.50	4.00–4.50	4.00–4.50
SH	2.43 (mm)	2.58	3.33	3.16
	0.19	0.14	0.41	0.15
	2.06–2.74	2.39–2.87	2.82–3.99	3.01–3.48
SW	1.68	1.67	2.26	2.17
	0.11	0.13	0.25	0.12
	1.45–1.81	1.52–2.04	2.26–2.60	1.98–2.37
LBW	1.90	1.99	2.55	2.38
	0.16	0.11	0.23	0.10
	1.61–2.13	1.83–2.22	2.27–2.78	2.24–2.49
WBW	1.43	1.48	1.82	1.77
	0.08	0.08	0.18	0.08
	1.27–1.53	1.37–1.61	1.56–2.08	1.65–1.89
AL	1.21	1.18	1.59	1.55
	0.11	0.08	0.13	0.07
	1.03–1.36	1.06–1.39	1.41–1.76	1.35–1.55
AW	0.97	0.96	1.31	1.21
	0.07	0.05	0.13	0.06
	0.88–1.06	0.88–1.13	1.16–1.49	1.08–1.26
W	1.95	1.99	1.88	1.65
	0.15	0.24	0.18	0.19
	1.69–2.23	1.59–1.89	1.61–2.14	1.45–2.03
D	0.60	0.62	0.58	0.56
	0.04	0.06	0.04	0.03
	0.54–0.68	0.51–0.74	0.50–0.62	0.51–0.61
T	4.90	6.29	4.84	4.65
	0.47	0.47	0.91	0.51
	4.27–5.65	4.32–8.61	3.84–5.96	4.04–5.31
SA	1.25	1.23	1.22	1.21
	0.06	0.06	0.04	0.06
	1.14–1.36	1.13–1.34	1.19–1.29	1.15–1.30

types), 857974, SBMNH 35140 (paratypes); Stream in Sand Canyon, 3.7 km up canyon from US 6, WBM 4230, 4387; Small streamlet, S Fork Short Canyon, USNM 860445; Stream in Ninemile Canyon, USNM 860446; Stream in Grapevine Canyon, USNM 860447; Stream in Grapevine Canyon, 7.2 km up canyon from US 6, WBM 4229, 4360; Stream in Cow Canyon, USNM 860448.

Diagnosis.—A small- to moderate-sized species with ovate conic shell. Penis small relative to head/foot; penial lobe reduced, filament elongate relative to remaining penis. Penial glandular ridges 1–4; ventral ridge sometimes borne on low swelling.

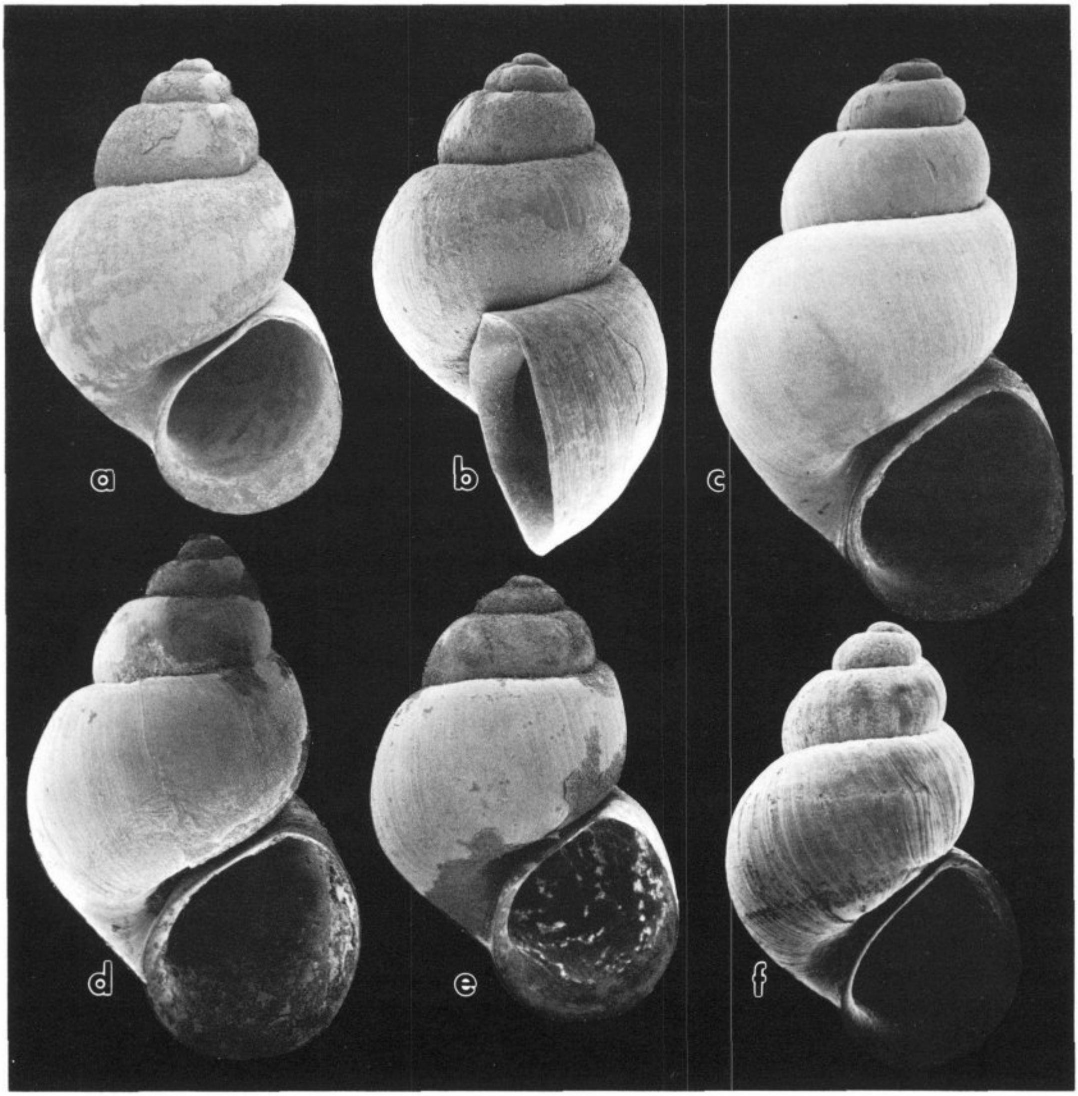

Fig. 1. Scanning electron micrographs of shells of *Pyrgulopsis giulianii,* new species: a, b, USNM 860444, holotype (standard and side views); c, USNM 860447; d, USNM 860446; e, USNM 860448; f, USNM 860445. The holotype is 2.75 mm tall (other micrographs are printed at the same scale).

Description.—Shell morphometric data are in Table 1. Shell (Fig. 1) 2.0–4.0 mm high, height/width, 130–170%. Apex protruding (Fig. 2e). Whorls, 4.0–4.5, slightly to moderately convex, with indented sutures and slight sub-sutural shoulders. Aperture ovate, angled above, about half as tall as body whorl. Inner lip straighter than outer, slightly to moderately thickened and reflected, adnate to small portion of or slightly separated from body whorl. Outer lip thin; apertural plane slightly tilted relative to coiling axis. Umbilicus slit-like to moderately open. Shell surface usually encrusted with brown-black deposits.

Operculum (Fig. 2f) paucispiral, with eccentric nucleus; whorls, 3–4. Opercular surface attached to foot bearing elongate (ca.

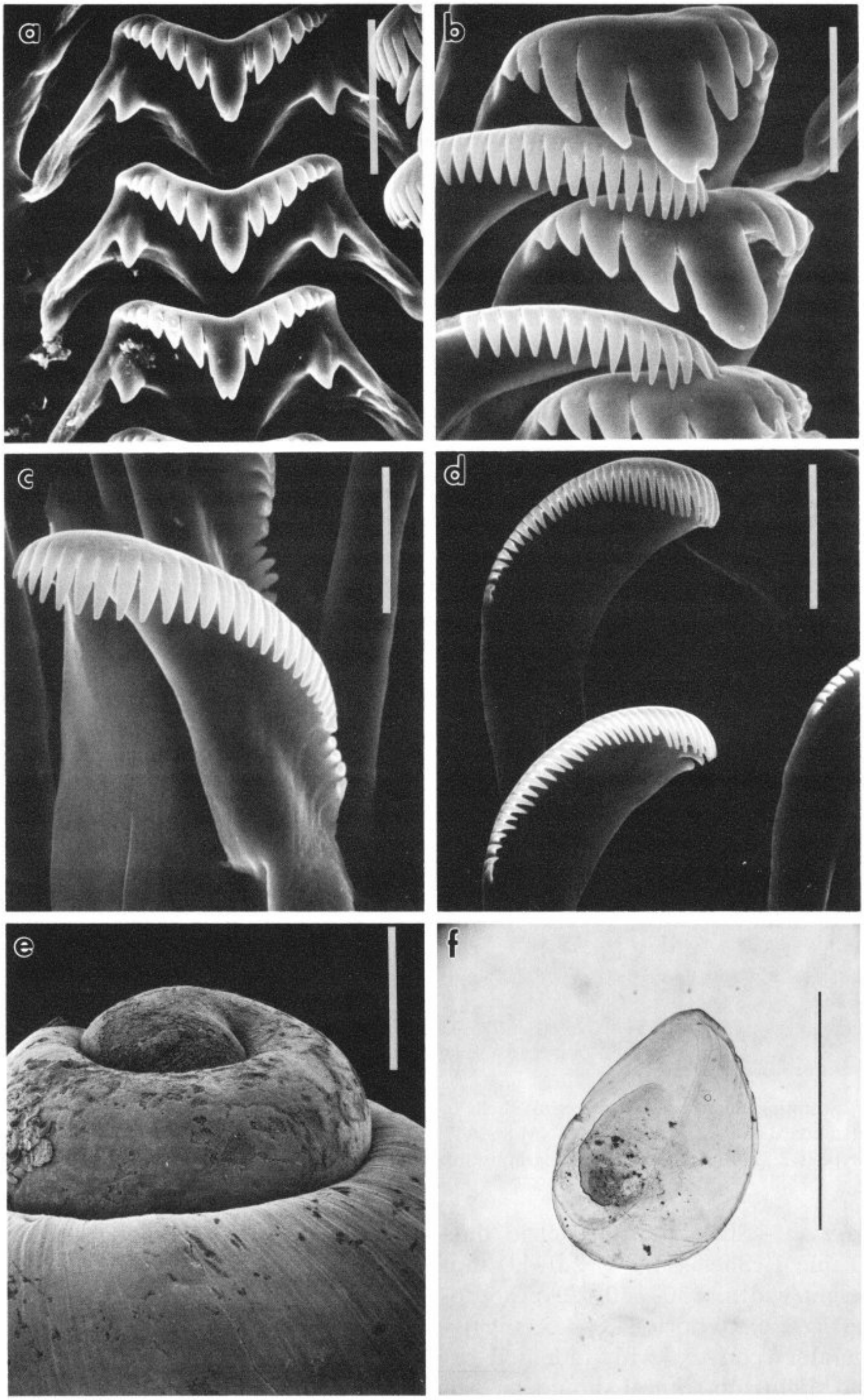

Fig. 2. *Pyrgulopsis giulianii*: a–d, Radula, USNM 860448 (a, Centrals, bar = 12.0 μm; b, Laterals and inner marginals, bar = 8.6 μm; c, Inner marginal, bar = 7.5 μm; d, Outer marginals, bar = 8.6 μm); e, Shell apex (bar = 136 μm), USNM 860447; f, Dorsal view of operculum showing thickened callus (bar = 1.0 mm), USNM 853519.

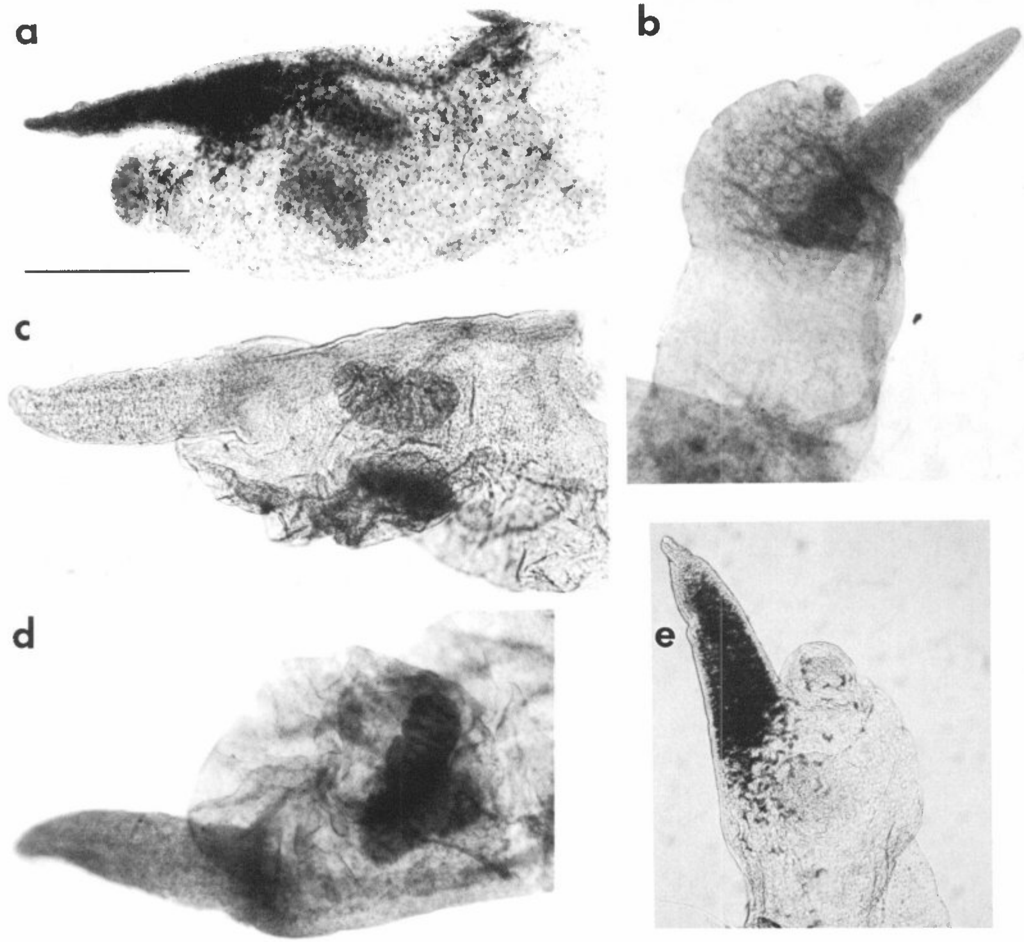

Fig. 3. Penes (whole mounts) of *P. giulianii*: a–c, Dorsal aspects; d, e, Ventral (a, e, USNM 857974, bar = 0.25 mm [others to scale]; b–d, WBM 4229). Note stained glandular ridges (both dorsal and ventral examples visible) and black subepithelial pigment (mostly in penial filaments).

50% of operculum length), gently curved, thickened, non-calcareous, amber callus (similar to those described for congeners by Taylor 1987). Dark, grey-black epithelial pigment on most of snout (except distal tip), proximal portion of cephalic tentacles, along anterior and posterior edges of sides of head/foot, and part or all of operculigerous lobe. Pigment on central portions of sides of neck absent to dark (dense subepithelial pigment cluster present in area).

Ctenidial filaments, ca. 20. Osphradium ca. 25% of ctenidium length. Style sac and remaining stomach ca. equal in length. Small caecal chamber present. Radular (Fig. 2a–d) formula: 5(6)-1-5(6), 2(3,4)-1-3(4,5), 23-29, 23-35 (from two populations). Central tooth broadly trapezoidal; basal cusps short, triangular; basal process moderately excavated. Penis (Fig. 3) rarely protruding beyond edge of mantle collar, usually of stunted appearance, relatively flat (apart from ventral swelling), longer than wide. Filament slender, sub-equal to remaining penis length. Reduced lobe short relative to filament length. Tip of lobe usually ornamented with small glandular ridge; somewhat larger, single ridges on dorsal penial surface

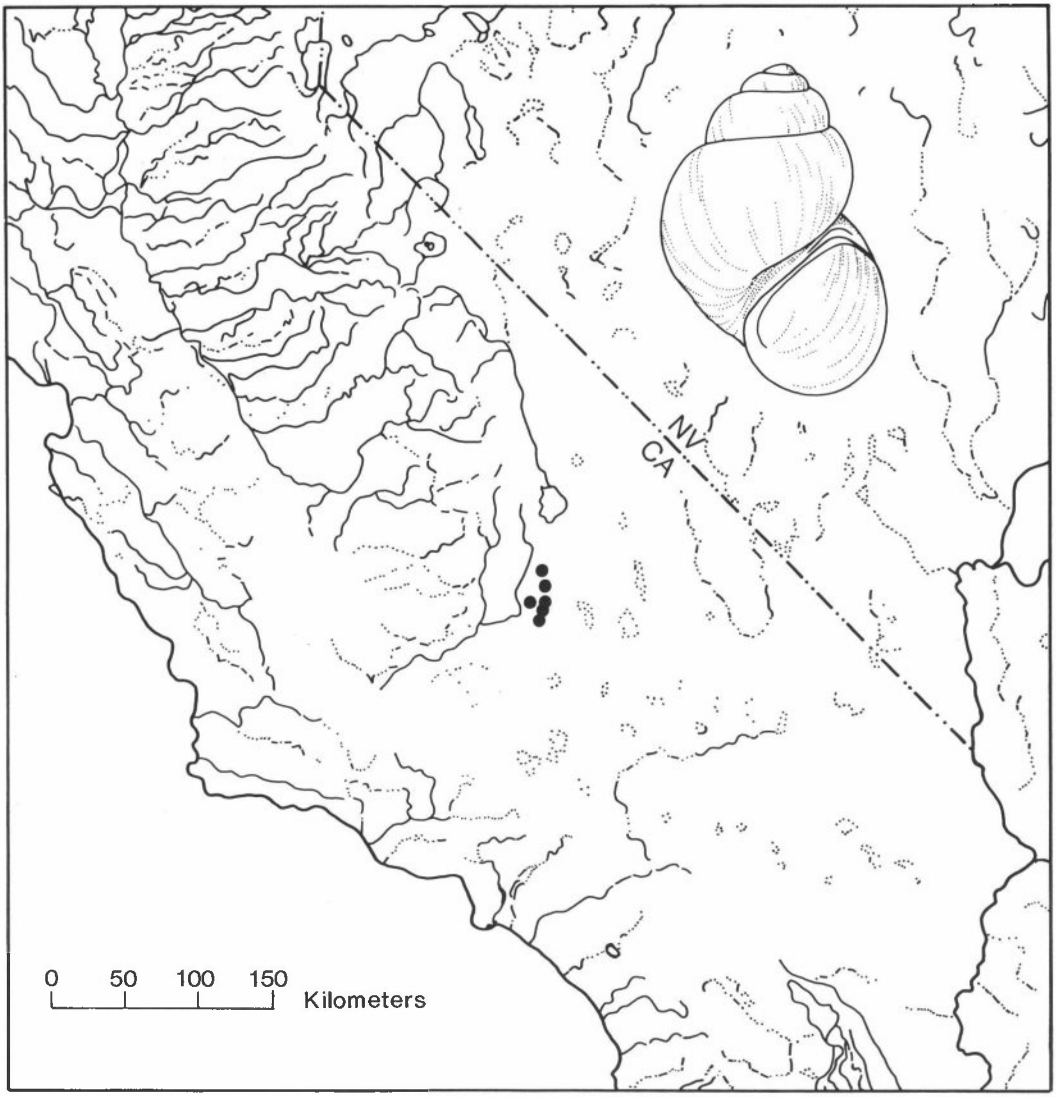

Fig. 4. Distribution of *P. giulianii.*

at central position ca. halfway between base of penis and base of filament, on ventral surface near (sometimes on) inner edge. A single specimen (from Cow Canyon) had a small fourth ridge located on dorsal surface between ridge on lobe and central dorsal ridge. Filament with dark sub-epithelial pigment streak; pigment granules also scattered throughout small area surrounding base of filament. Albumen gland sub-equal to capsule gland. Seminal receptacle small, positioned anterior to bursa copulatrix. Bursa copulatrix small relative to capsule gland, positioned partly posterior to gland.

Type locality.—A moderate-sized stream in floor of Sand Canyon, Kern County (center of section 7, T 25S, R 38E; ca. 1068 m elevation) (Hershler 1989:fig. 8d). Snails common in shallow water (<0.5 m), on watercress.

Distribution and habitat.—Known from six small- to moderate-sized streams in southern Sierra Nevada, of which five are in western Indian Wells Valley and one is in adjacent Kern River Valley (Fig. 4).

Etymology.—Named after Derham Giuliani, an avid student and indefatiguable collector of Great Basin biota, who discovered a number of new localities of *Pyrgulopsis* in Owens Valley area.

Remarks.—Hershler (1989) tentatively assigned this snail to *P. stearnsiana* (Pilsbry) based on similarity of shell, but later comparison with near-topotypical, preserved material of the latter revealed striking differences in their penes and indicated separate species status for the populations in southern Sierra Nevada. *Pyrgulopsis giulianii* is distinguished from close allies found in Owens Valley (to the north) by its combination of large size, moderately elongate shell, and small penis with small lobe and very reduced ventral swelling.

Pyrgulopsis micrococcus (Pilsbry, 1893)
Fig. 5

Amnicola micrococcus Pilsbry *in* Stearns, 1893:277 (Small spring in Oasis Valley, Nevada; fig. 1).

Pyrgulopsis micrococcus.—Hershler & Sada, 1987:788 (numerous localities, mostly in Ash Meadows; figs. 8a, 9–16).

Pyrgulopsis micrococcus.—Hershler, 1989: 182 (numerous localities; figs. 17c, d, 20–25).

Paludestrina stearnsiana.—Berry, 1909:78 (Rill near mouth of Mill Creek Canyon).

Amnicola stearnsiana.—Berry, 1948:59 (Mill Creek Canyon).

Paludestrina longinqua.—Hannibal, 1912: 34 (Spring branch, mouth of Mill Canon, fide Berry 1909).

Hydrobia sp.—Taylor, 1954:69 (Old Woman Springs, Inyo Co.).

Material examined.—California. San Bernardino County: Mohave River at Barstow, USNM 713484; Old Woman Springs, 20.8 km SE of Lucerne Valley, LACM 106639, 107741; USNM 526395; Cushenbury Springs, 16 km SE of Lucerne Valley, LACM 106640, 106660, 106661, WBM 4270, USNM 860449; Box S Spring, 2.6 km SE of Lucerne Valley, LACM 106641; Box Spring (probably same as above), WBM 4266; Broadbent Spring, 10.2 km ESE of Lucerne Valley, LACM 106639, WBM 4264; Bear Lake, USNM 175096; Roadside spring between N shore highway and Big Bear Lake at point 1.2 km E of road which crosses lake, WBM 4274; Spring-fed pond between N shorc road and Big Bear Lake, at point 1.6 km W of road which crosses lake, WBM 4276; Spring zone SW of Big Bear Ranger Station, USNM 860450; Spring, S side of CA Highway 18, N side Big Bear Lake, LACM 106644; Rill near mouth of Mill Creek Canyon, LACM 106646, 106647; Small stream, Mill Creek Canyon, SE of CA Highway 38, 0.34 km NE of Power House Canyon Bridge, LACM 106645; Mill Creek at Thurman Flats Picnic Area, USNM 860451; Spring 4.5 km up Mill Creek Rd. from junction with Yucaipa Rd., WBM 4263. Nevada. Clark County: Cold Creek, UNLVM 3212; Willow Creek, UNLVM 3451.

Diagnosis.—A small-sized species, with globose to ovate-conic shell. Penis with moderate-sized lobe; distal edge of lobe usually ornamented with small glandular ridge.

Remarks.—This snail is very similar, even in general form of penis and disposition of glandular ridge, to *P. stearnsiana* (Pilsbry), which occurs in Central California, "from Sonoma County to Monterey County along the coast and inland in the foothills of the Sierra Nevada" (Taylor 1981:152). The sole reliable distinguishing feature appears to be the larger and longer penial lobe of *P. micrococcus,* but study of additional material of *P. stearnsiana* will be necessary to determine generality of this difference.

Populations in San Bernardino Mountains are separated from remaining range of *P. micrococcus* to the north by poorly watered (and apparently snailless) Mohave Desert (but note that an old collection was taken from an intermediate locale at Barstow). Populations in the headwaters of the Willow Creek drainage (which enters Indian Springs Valley) on the northeast slope of Spring Range are apparently relicts from pre-Wisconsin time, since the snail is absent from well-studied (26 samples) late Wisconsin sediments from the valley floor at the mouth of Willow Creek (Quade & Pratt 1989).

Pyrgulopsis owensensis Hershler, 1989
Fig. 6

"Undescribed form of *Fontelicella*"(?).—Taylor 1985:318 (Owens Valley, E Fork Walker River; unfigd.).

Pyrgulopsis owensensis Hershler, 1989:187 (numerous localities in eastern Owens Valley; figs. 26a–d, 27–32).

Material examined.—California. Mono County: Spring, W side East Fork Walker River, USNM 860452.—Nevada. Lyon County: Spring at Wiley Ranch, USNM 860453.

Diagnosis.—A small- to moderate-sized species with globose to ovate-conic shell. Penis large relative to head/foot; lobe enlarged, filament short. Penial glandular ridges, 2–6; ventral ridge borne on pronounced swelling.

Remarks.—Populations in Walker Basin represent significant range extension of species (previously known only from Owens Valley) into pluvial Lahontan System.

Pyrgulopsis wongi Hershler, 1989
Fig. 7

Pyrgulopsis wongi Hershler, 1989:196 (numerous localities in Owens Valley area; figs. 41–47).

Material examined.—California. Mono County: Springs SW of Conway Summit, USNM 860454; Spring, Pizona, USNM 869034; Upper Pizona Spring, USNM 869035; Spring in West Queen Canyon, USNM 860511; Truman Spring, USNM 860512. Inyo County: Spring NW corner of Round Valley, USNM 860455; Spring, SW corner of Round Valley, USNM 860456; "Smoke Spring," USNM 853926; Springs, Marble Canyon, USNM 860457 (upper spring), 860458 (lower); Spring, 1.2 km NW of Big Pine Spring, USNM 860459; Spring at McMurry Meadows, USNM 860513; Spring on N side of Red Mountain, USNM 860514; Spring in canyon N of McGann Springs, USNM 860515; McGann Springs, USNM 869036; Tub Springs, USNM 869037; Spring, 0.1 km N of Independence Creek, USNM 860460; Springs SW of Lone Pine, USNM 869038 (North), USNM 869039 (South); Spring at Lower Diaz Creek, USNM 869040; Springs at Upper Diaz Creek, USNM 869041 (North), USNM 869042 (South); Spring S of Carrol Creek, USNM 869043; Stream, Talus Canyon, USNM 860461; Canyon N of Johnson Canyon, USNM 853925; Johnson Canyon, USNM 853928; Stream, Tunawee Canyon, USNM 860462; Canyon S of Tunawee Canyon, USNM 853927; Stream, Sacatar Canyon, USNM 860463 (N Fork), USNM 860464 (S Fork). Nevada. Esmeralda County: Springs at Dyer Ranch, USNM 860465. Mineral County: Huntoon Spring, USNM 869033.

Diagnosis.—A small- to moderate-sized species with globose to low conical shell. Penis elongate and broad relative to head/foot; filament large and lobe moderate-sized. Glandular ridges, 7–12, of which two are borne on prominent ventral swellings located near distal edge of lobe.

Remarks.—The Inyo County populations fall into previously known range of species. Localities in Fish Lake Valley and Mono Valley represent significant range extensions. The latter area, with a recent history of significant volcanic activity (Gilbert et al. 1968, Kilbourne et al. 1980), previously had been considered devoid of perennial water mollusks (Taylor 1985:318).

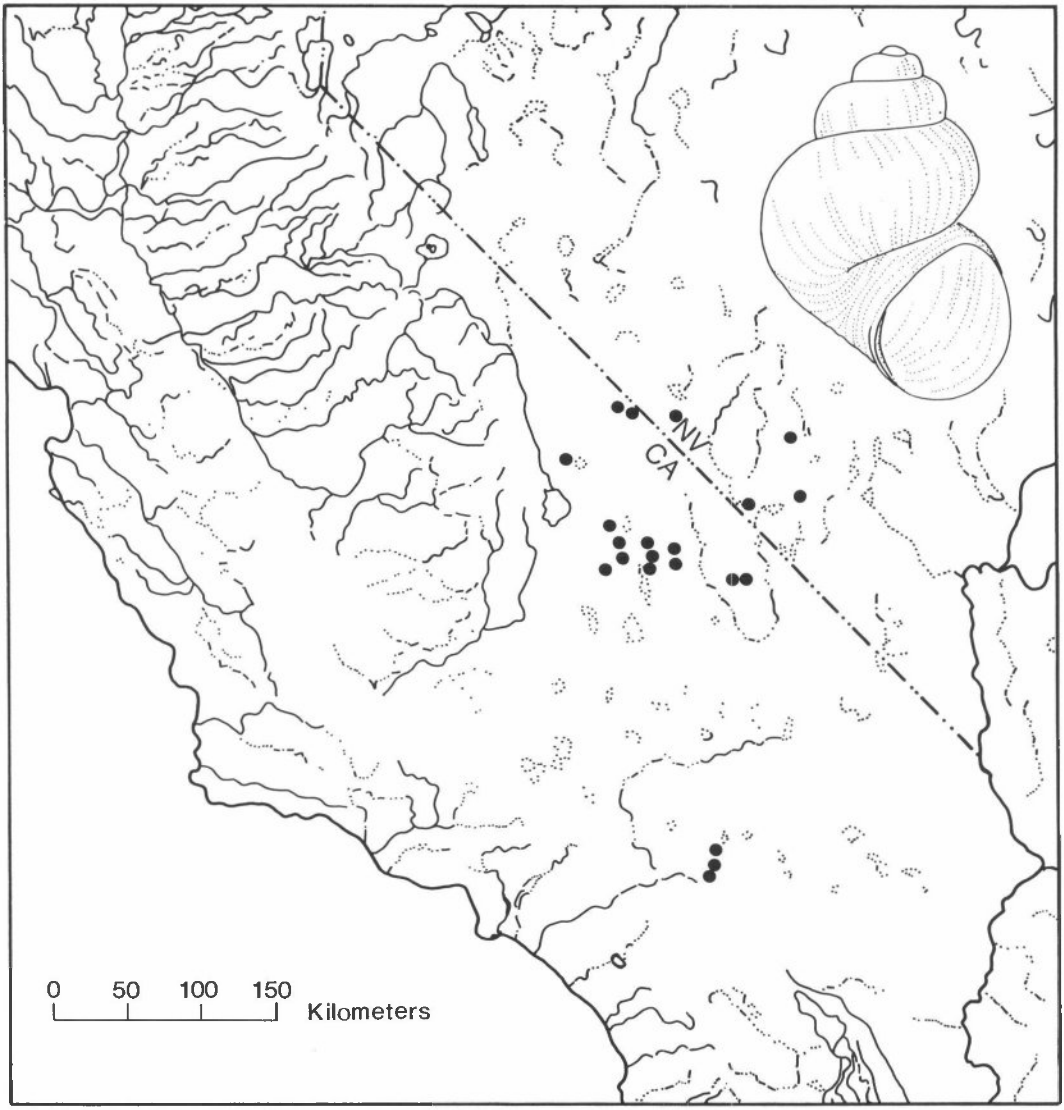

Fig. 5. Distribution of *P. micrococcus* (Pilsbry).

Discussion

In an earlier paper, Hershler (1989) concluded that springsnail zoogeography (in part) supports the frequently advocated hypothesis that a highly integrated pluvial drainage was present in Death Valley System (Fig. 8) during late Quaternary, pluvial period (10,000–100,000 B.P.). These data also provide evidence of historic connections between the system and adjacent regions, some of which were probably pre-Quaternary. Results of this study support this conclusion insofar as additional examples of both of the above features have been discovered, which are synthesized with the earlier data below.

Pyrgulopsis is the most diverse (13 spp.) and among the most widespread genera of

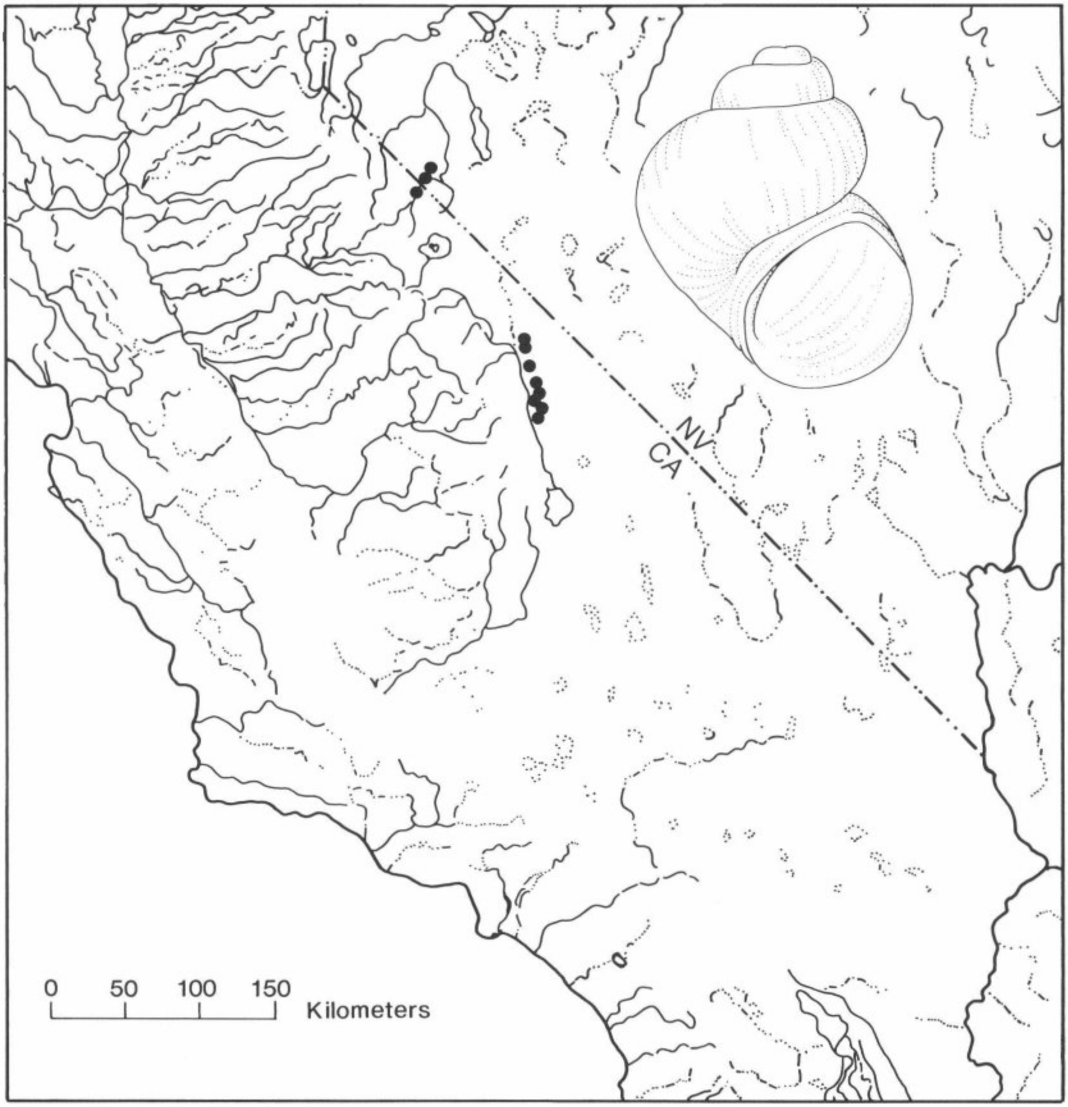

Fig. 6. Distribution of *P. owensensis* Hershler.

freshwater mollusks in the Death Valley System, and therefore is a highly suitable subject for zoogeographic inquiry. Other prosobranchs associated with perennial waters, *Tryonia* Stimpson, 1865 (Hydrobiidae), and *Assiminea* Fleming, 1828 (Assimineidae), are less diverse and considerably more localized in the system (Taylor 1985, Hershler 1987, Hershler & Sada 1987, Hershler 1989), and largely are excluded from further discussion.

Distributions of Death Valley System *Pyrgulopsis* are summarized in Table 2. For purposes of discussion, it is assumed that non-aquatic dispersal of these snails is insignificant, on a large scale, and that distribution of a species reflects past or present continuity or near-continuity of aquatic habitat.

Evidence for pluvial integration of Death

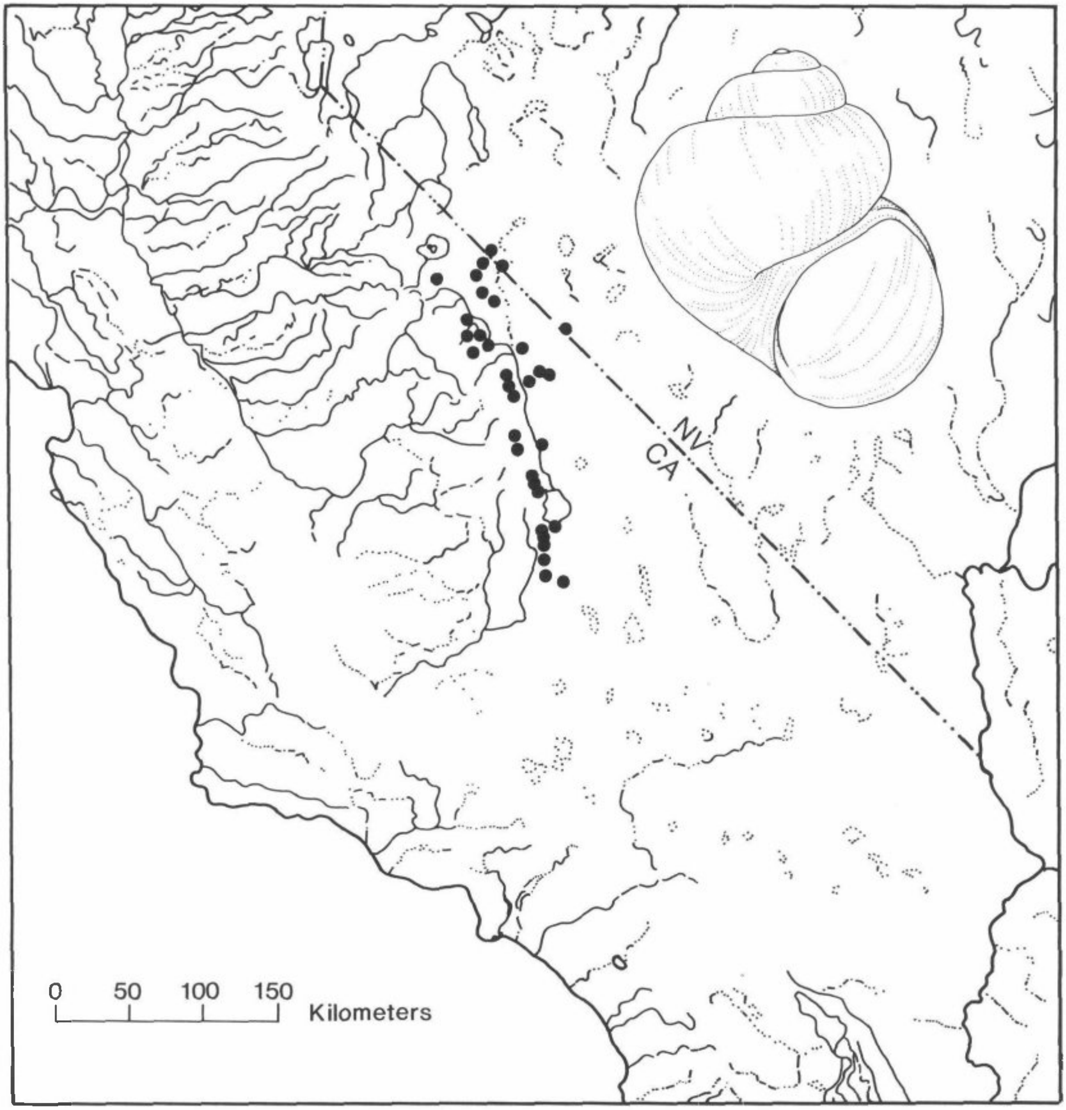

Fig. 7. Distribution of *P. wongi* Hershler.

Valley System is provided by distributions of two of the more widespread forms. The range of *Pyrgulopsis wongi* (Fig. 7) closely approximates pluvial Owens River drainage, as this snail extends from Mono Valley through both Adobe and Long Valleys into Owens Valley. This supports inclusion of the former valley (currently without surficial water connection to Owens Basin and considered of uncertain historic relationships by Hubbs & Miller 1948:79) in pluvial Owens River drainage. Distribution of *P. micrococcus* (Fig. 5) similarly supports integration of now-isolated sub-units of pluvial Amargosa River drainage (i.e., sites along modern course of river, Ash Meadows, northern Death Valley). This species also has been found (Quade & Pratt, pers. comm.) in Wisconsin pluvial sediments of Chicago Valley, a now dry tributary of the

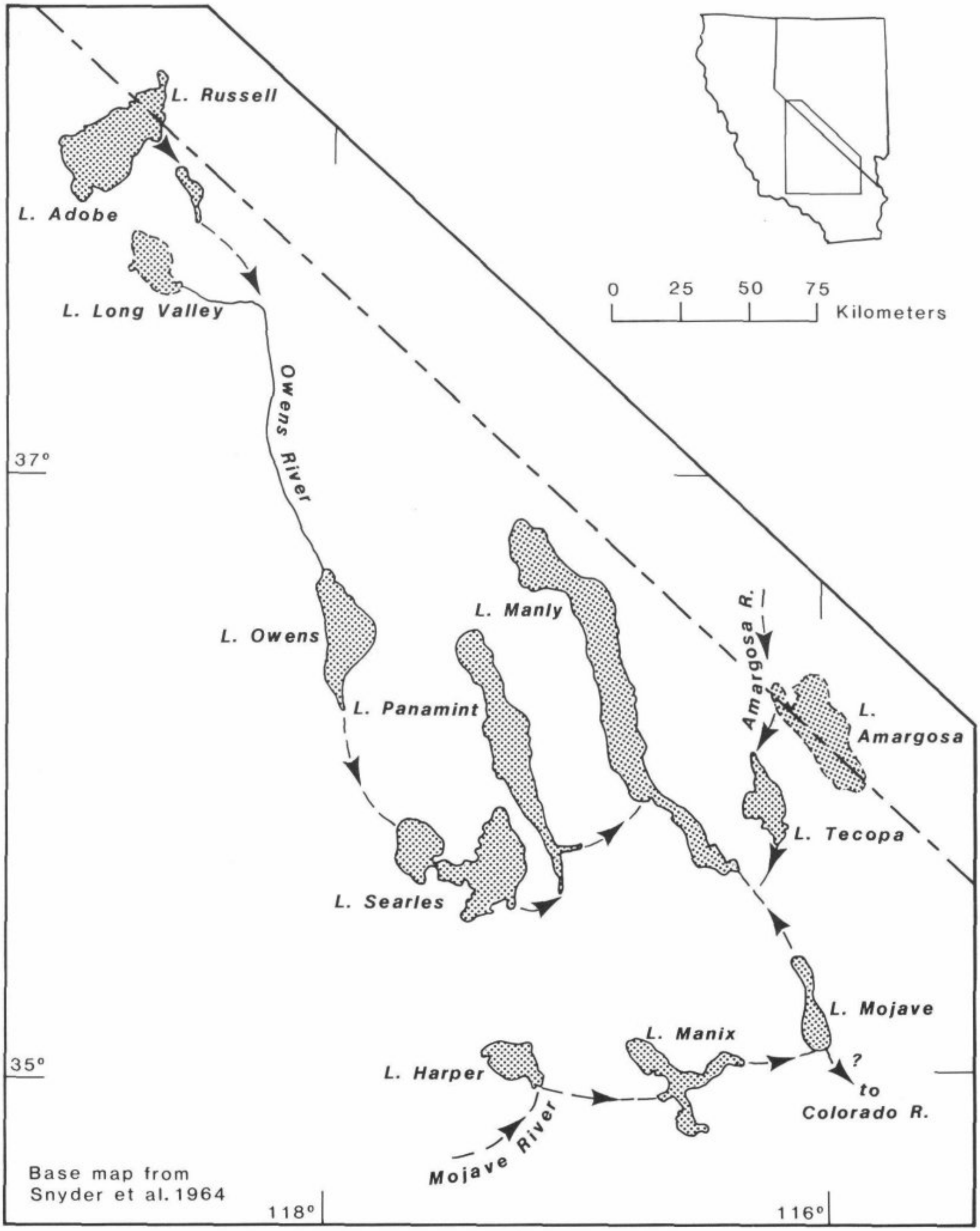

Fig. 8. Pleistocene Death Valley System showing drainage relations (not necessarily contemporaneous). Stippled areas encircled by dashed lines may not have contained lakes for significant portions of the pluvial period.

Amargosa Basin, together with two other snails from Amargosa drainage, *Tryonia variegata* Hershler and Sada and an undescribed *Assiminea* species now living at Ash Meadows and elsewhere in the drainage. In addition, presence of *P. micrococcus* in Panamint Valley and San Bernardino Mountains more generally supports pluvial integration of the three rivers comprising Death Valley System (Owens, Amargosa, Mohave).

Snail distributions also imply the following historic drainage connections: a) between Owens Basin and both Lahontan System, and Deep Springs and Fish Lake Valleys; b) between lower Owens Basin and adjacent Kern River Valley; c) between Mohave and Los Angeles Basins; d) between Amargosa Basin and both Frenchman Flat and Indian Springs Valley; and e) between the system and Saline Valley.

Implied connections between Amargosa Basin and both Frenchman Flat and Indian Springs Valley (which do not currently drain into the system) are intriguing because these areas are currently separated by low, presumably labile divides of alluvial material and could have drained to the Amargosa possibly during the Quaternary ("alluvial cone [drainage] connection" of Hubbs & Miller 1948:147). However, other examples are clearly untenable within the framework of modern regional topography and probably reflect Neogene conditions. For instance, distribution of *P. wongi* implies former aquatic connections between Owens Basin and Deep Springs and Fish Lake Valleys to the east. These areas are profoundly separated by White Mountains, and surficial water connections between them during pluvial period is extremely unlikely. (The latter two valleys drained [if at all] into Lahontan System [Miller 1928, Hubbs & Miller 1948].) Note, however, that inception of Basin and Range was a relatively recent event (ca. 2–6 million years B.P.) in Owens Valley area (Bachman 1979, Giovannetti 1979, St. Amand-Roquemore 1979) and distribution of *P. wongi* could reflect prior drainage relationships. A second example involves *P. micrococcus,* whose distribution suggests a former aquatic connection between Saline Valley and pluvial Owens drainage. Saline Valley is a small, but deeply downthrown basin that probably was closed to external drainage during pluvial times (Hubbs & Miller 1948). The valley is separated from Panamint Valley (which was part of the pluvial Owens System) by the Nelson Range, which connects the Inyo and Cottonwood Ranges. However, Grapevine Canyon, at the eastern end of the Nelson

Table 2. Distributions of *Pyrgulopsis* spp. Basins or valleys considered part of the Death Valley System by Hubbs & Miller (1948:table 1) are indicated by asterisks.

Species	Distribution
P. aardahli	Northern Owens Valley*
P. amargosae	Lower Amargosa Basin*
P. crystalis	Ash Meadows (Amargosa Basin)*
P. erythropoma	Ash Meadows (Amargosa Basin)*
P. fairbanksensis	Ash Meadows (Amargosa Basin)*
P. giulianii	Indian Wells Valley,* Kern River Valley
P. isolatus	Ash Meadows (Amargosa Basin)*
P. micrococcus	Frenchman Flat, Indian Springs Valley, Amargosa Basin,* Northern Death Valley,* Panamint Valley,* Saline Valley, San Bernardino Mtns. (Mohave,* Los Angeles Basins)
P. nana	Ash Meadows (Amargosa Basin)*
P. owensensis	Owens Valley,* E Fork Walker Basin
P. perturbata	Northern Owens Valley*
P. pisteri	Ash Meadows (Amargosa Basin)*
P. wongi	Mono Valley,* Long Valley,* Adobe Valley,* Owens Valley,* Huntoon Valley, Deep Springs Valley, Fish Lake Valley

Range, is the trace of a predominantly slip-strike fault (Cemen et al. 1985:fig. 1), and restoring 10 km of movement along this fault would open Saline Valley to Panamint Valley drainage.

Taxonomic affinities of Death Valley System *Pyrgulopsis* can only be addressed in a general sense owing to relative paucity of data on adjacent extra-limital faunas, but are consistent with the above in that they point toward a diverse origin of resident forms. *Pyrgulopsis wongi* from western portion of system (and Lahontan System) is not closely related to other local forms, but is very similar to *P. californiensis* (Gregg & Taylor), from west and south of the system (Taylor 1981:152). Also present in Owens Basin is an apparent species flock, comprising *P. owensensis* and three local endemics, without obvious affinities to other snails found in the system. The presence of *P. owensensis* in Lahontan System suggests possible derivation of the Owens Basin group from the north via Neogene Owens River. Note that *P. nevadensis* (Stearns), from Lahontan System, has a pattern of penial glandular ridges (discerned in rehydrated material; Hershler & Thompson 1987) suggesting a close relationship with this group. *Pyrgulopsis micrococcus* has affinities with *P. amargosae* Hershler from lower Amargosa Basin, but is much more similar to *P. stearnsiana* from west of the system. Ash Meadows endemics include (at least) two species flocks composed of pairs of very similar forms: a) *P. erythropoma* (Pilsbry) and *P. crystalis* Hershler & Sada, having trochoid shells and unlobed penes bearing single, central ventral glandular ridge; and b) *P. nanus* Hershler & Sada and *P. isolatus* Hershler & Sada, having globose-conic shells and large-lobed penes bearing single glandular ridge at terminus of lobe. Inclusion of *P. pisteri* in the former group and *P. fairbanksensis* Hershler & Sada in the latter is conjectured on basis of general penial similarity, but these display other significant morphological differences from respective group members and may represent additional lineages. Ash Meadows snails are dissimilar to an undescribed form of the nearby Las Vegas and Pahrump Valleys, which is closely related to *P. deserta* (Pilsbry) from Virgin Basin; and preliminary observations suggest that the fauna, except *P. micrococcus,* instead was derived from that of White River drainage. For example, *P. fairbanksensis* is similar to undescribed taxa from Pahranagat, White River, and Railroad Valleys in southeastern Nevada, whereas both *P. nana* and *P. isolatus* closely resemble *P. avernalis* (Pilsbry) of Moapa warm springs complex (also in southeast Nevada).

A hypothetical model of the history of Death Valley System and adjacent drainages is described below, based on both geological evidence and distributions of springsnails and other fauna of perennial waters. The model, which partly conforms to interpretations advanced by Hubbs & Miller (1948), Taylor (1985), and Minckley et al. (1986), is heuristic in intention, and presented as a framework for testing hypotheses generated from study of zoogeography of regional aquatic organisms.

In early Miocene time (Fig. 9), the Mohave River region probably drained to the Pacific, in the Los Angeles Basin area, as did most of the region immediately east of the present Sierra Nevada.[1] Fauna in these drainages included progenitors of the present Pacific coastal *Pyrgulopsis* and snails in Mohave System which gave rise to *P. micrococcus.* The White–Virgin River region,

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[1] Occurrence of *P. micrococcus* in San Bernardino Mountains, Los Angeles Basin, suggests former drainage of the Mohave through this area. Three other freshwater mollusks (*Anodonta californiensis* Lea, *Pisidium compressum* Prime, *Valvata humeralis* Say) also occur (or occurred until recently) in both Los Angeles Basin and Death Valley System and not in coastal California immediately to the north (Taylor 1981, 1985). Additionally, one of the three primary freshwater fishes of Los Angeles Basin, *Pantosteus santaanae* (Snyder), may have originated within the ancestral Colorado River drainage (Smith 1966, Minckley et al. 1986).

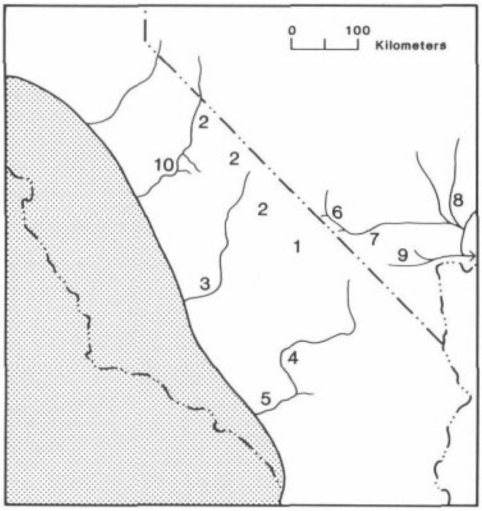

Fig. 9. Death Valley System and adjacent drainages during early Miocene, >16 Ma, before the development of basin and range structure. Screened areas are Pacific Ocean. Drainage lines are diagrammatic. It is doubtful whether any drainage, possibly excepting the San Joaquin on west slope of Sierra Nevada (Huber 1981) even approximately followed its modern course at this time. 1 = Future area of Death Valley; 2 = Future area of Owens drainage; 3 = Discharge of Owens–Kern drainage to Pacific; 4 = Ancestral Mohave River; 5 = Los Angeles Basin area; 6 = Amargosa River (included for convenience, existence in early Miocene uncertain); 7 = Ash Meadows; 8 = White–Virgin River system; 9 = Pahrump Valley (present location, which dates from late Miocene); 10 = Ancestral San Joaquin River.

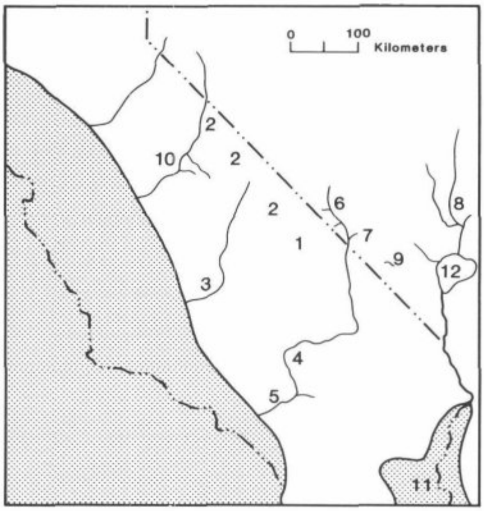

Fig. 10. Death Valley System and adjacent drainages during later Miocene, <15 Ma, after development of basin and range structure in southern Nevada. 1 = Death Valley region; 2 = Owens drainage region; 3 = Discharge of Owens–Kern drainage to Pacific; 4 = Ancestral Mohave River; 5 = Los Angeles Basin area; 6 = Amargosa River (see note in Fig. 9); 7 = Ash Meadows; 8 = White–Virgin River system; 9 = Pahrump Valley (see note in Fig. 9); 10 = Ancestral San Joaquin River; 11 = Bouse Embayment; 12 = "Lake Hualapai."

including the ancestral Amargosa and Colorado Rivers, drained eastward across northern Arizona and southeastern Utah to the Gulf of Mexico (Nilsen & McKee 1979), and was then inhabited by progenitors of the present Moapa River and Ash Meadows species complexes.

Shift to an extensional tectonic regime and uplift of the basin ranges in the late Miocene (Dickinson 1979) produced major alterations in drainage relations (Fig. 10). Uplift of the Spring, Sheep, Las Vegas, Pahranagat, and associated minor ranges, severed the Amargosa Basin; transferring its drainage to the Death Valley System and introducing progenitors of the Ash Meadows *Pyrgulopsis* to the system.[2] *Pyrgulopsis micrococcus* penetrated upstream into the Amargosa drainage and presumably gave rise to the local *P. amargosae.* Direction of flow of Colorado River was reversed, with the river coursing westward in approximately its modern path. Ponding in the present Lake Mead–Lake Mohave area produced the Hualapai limestones. These have been interpreted as marine (Blair & Armstrong 1979), but Taylor (1983) showed that the late Miocene molluscan fauna, as far downstream as Parker Dam, consisted of typically freshwater species (and not the marine taxa characteristic of the Bouse Embayment). Accordingly, we map the area of the Hualapai

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[2] Progenitors of the endemic goodeid fish *Empetrichthys* (sister group to *Crenichthys* of White River drainage; Parenti 1981) also may have been introduced by this event.

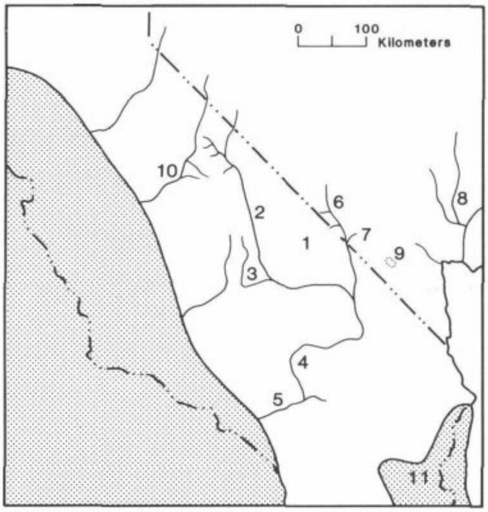

Fig. 11. Death Valley System and adjacent drainages during middle Pliocene, ca. 5 Ma, after initiation of major tilting of Sierra Nevada block fault. 1 = Death Valley region; 2 = Owens River; 3 = South Fork Kern River; 4 = Ancestral Mohave River; 5 = Los Angeles Basin area; 6 = Amargosa River; 7 = Ash Meadows; 8 = White–Virgin River system; 9 = Pahrump Valley; 10 = Ancestral San Joaquin River; 11 = Bouse Embayment.

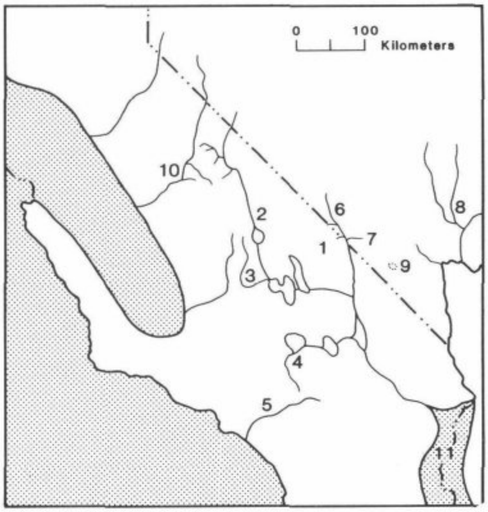

Fig. 12. Death Valley System and adjacent drainages during late Pliocene, ca. 4 Ma, after uplift of Transverse Ranges and before formation of Death Valley graben. 1 = Death Valley region; 2 = Owens River; 3 = South Fork Kern River; 4 = Mohave River; 5 = Los Angeles Basin; 6 = Amargosa River; 7 = Ash Meadows; 8 = White–Virgin River system; 9 = Pahrump Valley; 10 = Ancestral San Joaquin River; 11 = Bouse Embayment.

member as a lake, informally termed "Lake Hualapai." Note that Taylor (1983:294) recorded *P. avernalis,* presently surviving in the Moapa River drainage, in the Hualapai sediments.

During Pliocene time, tilting of the Sierra Nevada fault block beheaded trans-montane drainage, which was diverted southwards and formed the Owens River, which drained to the Pacific via Mohave River. Uplift began at the south, moving northwards (Huber 1981). Various evidence indicates that Owens Valley was forming by 6 Ma (see above), and the present Owens drainage probably was formed by not long after that time (Fig. 11). Coastal *Pyrgulopsis* of the *P. californiensis* group were transferred with the beheaded source areas, and gave rise to *P. wongi.* Severence of the trans-montane headwaters of the San Joaquin River is dated at 3.2 Ma; thereafter drainage was to the Mono Basin, and over the southern sill to the Owens River (Huber 1981). This drainage change may have allowed progenitors of the *Pyrgulopsis owensensis* group to invade the system from the north.[3] The South Fork Kern River was tributary to the Owens Basin.[4] Walker Pass, inter-

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[3] In addition to *P. owensensis* and *P. wongi,* two other freshwater mollusks (*Helisoma newberryi* [Lea], *Vorticifex effusus* [Lea]) occurred in Lahontan and Death Valley Systems during historic times (Taylor 1981). These and another three Lahontan species (*Pisidium ultramontanum* Prime, *Valvata utahensis* Call, *Stagnicola kingi* [Meek]) were widespread within the latter during the Quaternary (Taylor 1985). The Tui Chub, *Gila bicolor* (Girard), also occurs in both areas (although differentiated in Owens and Mohave drainages; Miller 1973), and several other fishes of Death Valley System are closely related to Lahontan fauna (Minckley et al. 1986).

[4] As evidenced by distribution of *P. giulianii.* Schreck and Behnke (1971) suggested a similar drainage connection based on relationships of endemic Upper Kern River Valley golden trout, *Salmo aguabonita* Jordan.

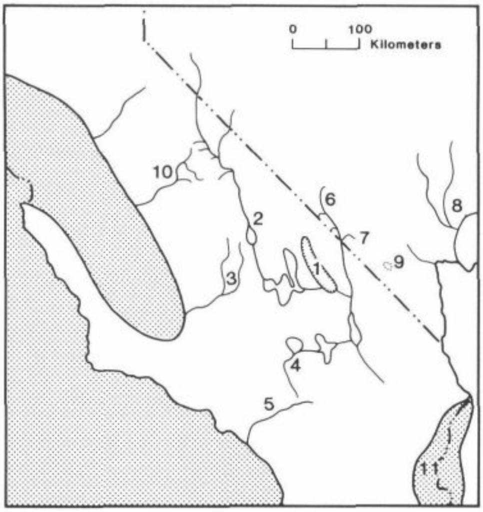

Fig. 13. Death Valley System and adjacent drainages during late Pliocene, <3 Ma, after formation of Death Valley graben and beheadal of ancestral San Joaquin drainage. 1 = Death Valley region; 2 = Owens River; 3 = South Fork Kern River; 4 = Mohave River; 5 = Los Angeles Basin; 6 = Amargosa River; 7 = Ash Meadows; 8 = White–Virgin River system; 9 = Pahrump Valley; 10 = San Joaquin River; 11 = Bouse Embayment.

preted as a wind gap in this model, is approximately 700 m above the margin of Indian Wells Valley, suggesting that drainage severence occurred no earlier than 2.5 Ma (based on uplift rates in the Deadman's Pass area; Huber 1981), and possibly more recently as uplift rates increased southwards. During the late Pliocene (Fig. 12), uplift of the Transverse Ranges, which enclose the present internal drainage of the Mohave Desert, resulted from compression accompanying the northward movement of the crustal block west of the San Andreas Rift zone (Woodburne 1975). Drainage direction of the Mohave River was reversed, probably with considerable dislocation, rerouting, and ponding. Drainage of the Death Valley System was shifted from the Los Angeles Basin to the Bouse Embayment. Deposition in basins east of the San Bernardino Mountains apparently shifted from eastern-derived to western-derived sediments around the Hemphillian-Blancan transition (Woodburne 1975). Late Pliocene tilting of the Sierra Nevada block (Cole & Armentrout 1979) transferred South Fork Kern River from the Owens to the Kern system. Development of internal drainage in the Death Valley rift occurred in early Pleistocene, establishing a new base level and transferring the drainage sump of the Death Valley System from the Bouse Embayment to Death Valley (Fig. 13), thereby completing development of the present system.[5]

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[5] Although extensional tectonics of the Death Valley region have been extensively studied (e.g., Wernicke et al. 1988 and references cited therein), little has been published regarding drainage. Cemen et al. (1985) recorded a late Pliocene (to 4 Ma) basin oriented roughly from north of the Black Mountains to Salt Creek, at approximately a 45° angle to the present valley. Hunt and Mabey (1966) made a convincing case for deposition of the "no. 2 gravel" alluvial fans, estimated at 0.5 Ma, under an external drainage regime. They considered major movement of the normal fault along which the valley has been downthrown to be late Quaternary in age.

Ryan and P. Greenhall (both NMNH, Invertebrate Zoology) drafted maps, and prepared and digitized camera lucida drawings of shells, respectively. The section on history of the Mohave–Death Valley region benefited from comments by D. L. Weide.

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Appendix

Localities visited. Data are name of site, county, state, township and range coordinates, elevation of site, and date of visitation.

I. Walker Basin and environs. Cedar Creek (unnamed on topo sheet), Slinkard Valley, Mono Co., CA; T 8N, R 22E, NE ¼ sec. 9, 2025 m, 7-12-88.—"Tin Cup" Spring, Mono Co., CA; T 9N, R 22E, NW ¼ sec. 20, 1928 m, 7-12-88.—Spring in unnamed canyon, Slinkard Valley, Mono Co., CA; T 9N, R 22E, SE ¼ sec. 19, 2050 m, 7-12-88.—Springs by cabin, Slinkard Valley, Mono Co., CA; T 8N, R 22E, NE ¼ sec. 9, 1983 m, 7-12-88.—Springs in SE corner of Slinkard Valley, Mono Co., CA; T 8N, R 22E, SW ¼ sec. 15, 2135 m, 7-12-88.—Springs in SE corner of Slinkard Valley (ca. 75 m SE of above), Mono Co., CA; T 8N, R 22E, SW ¼ sec. 15, 2135 m, 7-12-88.—Springs entering small creek in northern Little Antelope Valley, Mono Co., CA; T 8N, R 22E, SE ¼ sec. 13, 1684 m, 7-12-88.—Springs in meadow in northern Little Antelope Valley, Mono Co., CA; T 8N, R 23E, NW ¼ sec. 19, 1684 m, 7-12-88.—Spring N of Camp Antelope, Mono Co., CA; T 8N, R 23E, NE ¼ sec. 16, 1708 m, 7-14-88.—Leakage from holding tank (of spring), Spring Creek Canyon, Mono Co., CA; T 8N, R 23E, SW ¼ sec. 23, 1952 m, 7-13-88.—Spring zone along E side of West Walker River in canyon, Mono Co., CA; T 6N, R 23E, NE ¼ sec. 9, 2013 m, 7-13-88.—Spring zone along W side of Little Walker River upstream from above, Mono Co., CA; T 6N, R 23E, SW ¼ sec. 15, 2050 m, 7-12-88.—Brownie Creek, Mono Co., CA; T 6N, R 22E, SW ¼ sec. 27, 2184 m, 7-13-88.—Spring by Cloudburst Creek, Mono Co., CA; T 6N, R 22E, NE ¼ sec. 27, 2159 m, 7-13-88.—Spring at Marine Corps Center, Mono Co., CA; T 6N, R 22E, NW ¼ sec. 24, 2080 m, 7-13-88.—Sceps along Junction Creek, Mono Co., CA; T 6N, R 23E, NE ¼ sec. 20, 2098 m, 7-12-88.—Spring along E side of Little Walker River, Mono Co., CA; T 5N, R 23E, NE ¼ sec. 4, 2263 m, 7-14-88.—Burcham Creek, Mono Co., CA; T 6N, R 23E, NW ¼ sec. 11, 2257 m, 7-12-88.—Stream along Burcham Flat Road, Mono Co., CA; T 6N, R 23E, SW ¼ sec. 14, 2211 m, 7-12-88.—Fales Hot Springs, Mono Co., CA; T 6N, R 23E, SE ¼ sec. 24, 2227 m, 7-12-88.—Stream, Yaney Canyon, Mono Co., CA; T 5N, R 24E, SE ¼ sec. 15, 2098 m, 7-12-88.—Spring W of Bridgeport Ranger Station, Mono Co., CA; T 5N, R 24E, NW ¼ sec. 23, 2098 m, 7-12-88.—Spring just S of above, Mono Co., CA; T 5N, R 24E, NW ¼ sec. 23, 2074 m, 7-13-88.—Buckeye Hot Spring (seepage), Mono Co., CA; T 4N, R 24E, NE ¼ sec. 4, 2166 m, 7-13-88.—Seepage along Buckeye Creek, Mono Co., CA; T 4N, R 24E, NW ¼ sec. 4, 2166 m, 7-13-88.—Spring N of Twin Lakes, Mono Co., CA; Matterhorn Peak, CA (15), T 4N, R 24E, NW ¼ sec. 28, 2318 m, 7-13-88.—Summers Creek and springs in Summers Meadows, Mono Co., CA; T 3N, R 25E, NW ¼ sec. 6, 2172 m, 7-13-88.—Stream from Cameron Canyon, Mono Co., CA; T 3N, R 25E, NE ¼ sec. 6, 2135 m, 7-13-88.—Spring SW of Little Bodie Mine, Mono Co., CA; T 3N, R 25E, SW ¼ sec. 1, 2306 m, 7-11-88.—Spring ca. 0.4 km NE of above, Mono Co., CA; T 3N, R 25E, SW ¼ sec. 1, 2306 m, 7-11-88.—Warm Springs, Mono Co., CA; T 4N, R 26E, SW ¼ sec. 16, 2342 m, 7-11-88.—The Hot Springs, Mono Co., CA; T 4N, R 25E, NW ¼ sec. 9, 2013 m, 7-11-88.—Travertine Springs, Mono Co., CA; T 5N, R 25E, SW ¼ sec. 34, 2050 m, 7-11-88.—Small springs along East Walker River NW of Bridgeport, Mono Co., CA, between 1952–2013 m: seep with pool, E side of river, T 6N, R 25E, NW ¼ sec. 26; piped spring on W side of river, T 6N, R 25E, NW ¼ sec. 23, 7-11-88; seep on E side of river, T 6N, R 25E, SE ¼ sec. 14, 7-13-88; spring W of river and just N of Murphy Creek, T 6N, R 25E, NE ¼ sec. 14, 7-14-88; seeps (2) on steep hill along E side of river, T 6N, R 25E, SW ¼ sec. 12, 7-13 and 14-88; small seeps on W side of river, T 6N, R 25E, SW ¼ sec. 12.—Spring at Wiley Ranch, Lyon Co., NV; T 8N, R 25E, NW ¼ sec. 5, 1922 m, 7-11-88.

II. Mono Basin. Springs SW of Conway Summit, Mono Co., CA; T 2N, R 25E, NE ¼ sec. 2, 2318 m, 11-8-88.

III. Adobe Valley and environs. Spring, Pizona, Adobe Valley, Mono Co., CA; T 1N, R 31E, SE ¼ sec. 4, 2135 m, 5-27-89.—Upper Pizona Spring, Adobe Valley, CA; T 1N, R 31E, SW ¼ sec. 11, 2227 m, 5-27-89.—Huntoon Spring, Huntoon Valley, NV; Huntoon Valley, NV–CA (15) (sections unplated), 11.4 km NW from SE corner of quadrangle, 1891 m, 5-28-89.

IV. Fish Lake Valley. Springs ca. 2.4 km SW of The Crossing, Esmeralda Co., NV; T 1S, R 36E, SW ¼ sec. 16, 1449 m, 7-16-88.—Spring just NE of The Crossing, Esmeralda Co., NV; T 1S, R 36E, NE ¼ sec. 10, 1449 m, 7-16-88.—Springs at Dyer Ranch, Esmeralda Co., NV; T 2S, R 35E, SE ¼ sec. 13, 1440 m, 7-16-88.—Spring W of cemetery, Esmeralda Co., NV; T 2S, R 35E, SW ¼ sec. 24, 1458 m, 7-16-88.—Seep in canyon WSW of Dyer School, Esmeralda Co., NV; Mt. Barcroft, CA–NV (15), 12.5 km SE of NW corner of quadrangle, 1684 m, 7-16-88.—Cottonwood Creek, Inyo Co., CA; T 6S, R 37E, NW ¼ sec. 5, 1708 m, 7-16-88.

V. Owens Basin. Spring in West Queen Canyon, Mineral Co., NV; T 1N, R 32E, SW ¼ sec. 16, 2013 m.—Truman Spring, Mineral Co., NV; T 1N, R 32E, SW ¼ sec. 7, 2166 m.—Spring NW corner of Round Valley, Inyo Co., CA; T 5S, R 31E, NW ¼ sec. 25, 1800 m.—Spring, SW corner of Round Valley, Inyo Co., CA; T 6S, R 31E, SE ¼ sec. 31, 1586 m, 8-12-88.—Springs, Marble Canyon, Inyo Co., CA; T 7S, R 35E, SE ¼ sec. 35, SW ¼ sec. 36, 1891–2074 m.—Spring, 1.2 km NW of Big Pine Spring, Inyo Co., CA; T 9S, R 33E, NW ¼ sec. 16, 2074 m, 5-14-88.—Spring at McMurry Meadows, Inyo Co., CA; T 10S, R 33E, NW ¼ sec. 22, 2044 m.—Spring on N side of Red Mountain, T 11S, R 34E, SE ¼ sec. 31, 1403 m.—Spring in canyon north of McGann Springs, Inyo Co., CA; Mt. Pinchot, CA (15), 13.6 km NW of SE corner of quadrangle.—McGann Springs, Inyo Co., CA; T 13S, R 34E, NW ¼ sec. 4, 1708 m, 5-21-89.—Tub Springs, Inyo Co., CA; T 13S, R 34E, SE ¼ sec. 17, 1952 m, 4-30-89.—Spring, 0.1 km N of Independence Creek, Inyo Co., CA; T 13S, R 34E, SW ¼ sec. 21, 1830 m, 6-21-88.—Springs SW of Lone Pine, Inyo Co., CA; T 16S, R 36E, SE ¼ sec. 2, 1952 m, 4-29-89.—Spring at Lower Diaz Creek, Inyo Co., CA; T 16S, R 36E, SE ¼ sec. 5, 1312 m, 4-29-89.—Springs at Upper Diaz Creek, Inyo Co., CA; Lone Pine, CA (15), 10.3 km NE from SW corner of quadrangle, 1830 m, 5-27-89.—Spring in canyon 1.6 km S of Carrol Creek, Inyo Co., CA; Lone Pine, CA (15), 7.5 km SW from NE corner of quadrangle, 1617 m, 5-9-89.—Stream, Talus Canyon, Inyo Co., CA; Monache Mtn., CA (15), 10 km NNW from SE corner of quadrangle, 1830 m, 10-2-88.—Stream, Tunawee Canyon, Inyo Co., CA; Monache Mtn., CA (15), 7.5 km NNW from SE corner of quadrangle, 1769 m, 3-28-88.—Stream, Sacatar Canyon, Inyo Co., CA; T 23S, R 37E, secs. 3–4, 1769–1830 m, 5-18-88.

VI. Indian Wells Valley. Stream, Ninemile Canyon, Inyo Co., CA; Lamont Peak, CA (7.5), 2.1 km SSW from NE corner of quadrangle, 1769 m, 7-18-88.—Stream, Grapevine Canyon, Inyo Co., CA; T 25S, R 37E, NE ¼ sec. 23, 1281 m, 4-14-88.—Stream, Short Canyon, Inyo Co., CA; T 25S, R 38E, SW ¼ sec. 31.

VII. Mohave Basin and envions. Spring, Cow Canyon, Kern River Valley, Kern Co., CA; Walker Pass, CA (7.5), 5.0 km WSW from NE corner of quadrangle, 1330 m, 11-4-88.—Canebrake Creek, Kern River Valley, Kern Co., CA; T 25S, R 36E, SW ¼ sec. 14, 1086 m, 11-4-88.—Spring, Spring Canyon, Kern River Valley, Kern Co., CA; T 25S, R 36E, SE ¼ sec. 34, 1171 m, 11-4-88.—Brown Spring, Kern Co., CA; T 27S, R 35E, NW ¼ sec. 5, 946 m, 11-4-88.—Kelso Creek, SW of Rocky Point, Kern Co., CA; T 27S, R 35E, NW ¼ sec. 20, 988 m, 11-4-88.—Horse Canyon Spring (and spring just to E), Kern Co., CA; Horse Canyon, CA (7.5), 7.6 km SSW of NW corner of quadrangle, 1464 m, 7-18-88.—Bird Spring (dry), Kern Co., CA; Horse Canyon, CA (7.5), 4.1 km ENE of SW corner of quadrangle, 1208 m, 7-18-88.—Frog Spring, Kern Co., CA; T 28S, R 35E, NE ¼ sec. 10, 1196 m, 11-4-88.—Shoemaker Spring, Kern Co., CA; T 28S, R 35E, center of section 12, 1452 m, 11-4-88.—Butterbredt Spring, Kern Co., CA; T 29S, R 36E, SE ¼ sec. 28, 1281 m, 11-3-88.—Spring, Poleline Canyon, Kern Co., CA; T 30S, R 37E, NE ¼ sec. 8, 854 m, 11-3-88.—Alphie Spring, Kern Co., CA; T 29S, R 36E, SE ¼ sec. 35, 964 m, 11-3-88.—Spring, Hoffman Canyon, Kern Co., CA; T 30S, R 36E, SW ¼ sec. 3, 1098 m, 11-3-88.—Sweetwater Spring, Kern Co., CA; T 32S, R 34E, SE ¼ sec. 14, 1388 m, 7-20-88.—Springs S of Proctor Lake, Kern Co., CA; T 32S, R 34E, S ½ sec. 32, 1257 m, 7-20-88.—Spring, Bean Canyon, Kern Co., CA; T 10N, R 14W, SW ¼ sec. 4, 1238 m, 11-3-88.—Indian Spring, Los Angeles Co., CA; T 7N, R 14W, SE ¼ sec. 18, 891 m, 7-21-88.—Little Rock Creek, ca. 8 km upstream from dam, Los Angeles Co., CA; Juniper Hills, CA (7.5), 5.7 km NNE from SW corner of quadrangle, 1159 m, 11-5-88.—Pallet Creek, Big Rock Creek, Los Angeles Co., CA; T 4N, R 9W, SW ¼ sec. 6, 1086 m, 7-21-88.—Icy Springs, Los Angeles Co., CA; T 3N, R 9W, NE ¼ sec. 1, 1757 m, 11-5-88.—Spring, Sawmill Canyon, Los Angeles Co., CA; T 3N, R 8W, NE ¼ sec. 11, 2074 m, 11-12-88.—Spring, Grapevine Canyon, San Bernardino Co., CA; T 4N, R 2W, NW ¼ sec. 26, 1147 m, 11-6-88.—Rabbit Springs, San Bernardino Co., CA; T 4N, R 1W, NW ¼ sec. 11, 885 m, 7-21-88.—Broadbent Spring (unnamed on topo sheet), San Bernardino Co., CA; T 3N, R 1E, NW ¼ sec. 3, 1144 m, 7-21-88.—Cushenbury Springs, San Bernardino Co., CA; T 3N, R 1E, NE ¼ sec. 10, 1251 m, 7-21-88.—Cottonwood Spring (dry), San Bernardino Co., CA; T 4N, R 2E, SE ¼ sec. 25, 970 m, 7-21-88.—Spring NW of Old Woman Springs (dry), San Bernardino Co., CA; T 4N, R 3E, NE ¼ sec. 31, 976 m, 7-22-88.—Old Woman Springs, San Bernardino Co., CA; T 4N, R 3E, NE ¼ sec. 31, 985 m, 7-22-88.—Two Hole Spring, San Bernardino Co., CA; Old Woman Springs, CA (15), 11.1 km NE of SW corner of quadrangle, 1165 m, 7-22-88.—Spring zone SW of Big Bear Ranger Station, San Bernardino Co., CA; T 2N, R 1E, NW ¼ sec. 17, 2074 m, 7-21-88.—Springs SW of Fawnskin, San Bernardino Co., CA; T 2N, R 1W, SW ¼ sec. 14, 2089 m, 7-21-88.—Mill Creck at Thurman Flats Picnic Area, San Bernardino Co., CA; T 1S, R 1W, NE ¼ sec. 8, 1074 m, 7-27-88.—Little Morongo Creek, below Morongo Lakes, CA; T 1S, R 4E, SE ¼ sec. 24, 756 m, 11-11-88.—Spring, Big Morongo Canyon (upper portion), San Bernardino Co., CA; T 1S, R 4E, SE ¼ sec. 18, 1110 m, 11-6-88.—Springs, Big Morongo Canyon (lower portion), San Bernardino Co., CA; T 1S, R 4E, SE ¼ sec. 28, 744 m, 11-10-88.—Spring, Smith Water Canyon, Riverside Co., CA; T 2S, R 7E, NW ¼ sec. 5, 1293 m, 11-10-88.—Fortynine Palms Oasis, San Bernardino Co., CA; Queen Mtn., CA (7.5), 3.1 km SE of NW corner of quadrangle, 854 m, 11-10-88.—Garlic Spring, San Bernardino Co., CA; T 13N, R 3E, SW ¼ sec. 11, 708 m, 4-9-86.—Mohave River, Afton Canyon, San Bernardino Co., CA; T 11N, R 5E, SW ¼ sec. 13, 428 m, 4-10-86.—Seepage, W side of Soda Lake, San Bernardino Co., CA; T 12N, R 8E, NW ¼ sec. 2, 290 m, 7-22-88.—Old Mormon Spring (dry), San Bernardino Co., CA; Avawatz Pass, CA (15), 1.8 km NNW of SE corner of quadrangle, 634 m, 11-9-88.—Snake Spring, Granite Mtns., San Bernardino Co., CA; T 8N, R 13E, SE ¼ sec. 5, 1220 m, 11-7-88.—Cottonwood Spring, Granite Mtns., San Bernardino Co., CA; T 8N, R 13E, NW ¼ sec. 7, 1366 m, 11-7-88.—Arrowhead Spring, Providence Mtns., San Bernardino Co., CA; T 9N, R 13E, SE ¼ sec. 22, 1208 m, 11-7-88.—Van Winkle Spring, San Bernardino Co., CA; T 8N, R 13E, NW ¼ sec. 23, 1098 m, 11-8-88.—Goldstone Spring, Mid Hills, San Bernardino Co., CA; T 10N, R 14E, SW ¼ sec. 31, 1415 m, 11-8-88.—Live Oak Spring, Mid Hills, San Bernardino Co., CA; T 13N, R 13E, NW ¼ sec. 19, 1568 m, 11-7-88.—Keystone Spring, Mid Hills, San Bernardino Co., CA; T 14N, R 16E, NW ¼ sec. 29, 1781 m, 7-23-88.—Dove Spring (dry), New York Mtns., San Bernardino Co., CA; T 15N, R 17E, SW ¼ sec. 19, 1452 m, 7-23-88.—Pachalka Spring, Clark Mtn., San Bernardino Co., CA; T 17N, R 12.5E, NE ¼ sec. 36, 1488 m, 7-23-88.—Ivanpah Springs, Clark Mtn., San Bernardino Co., CA; T 17N, R 13E, SE ¼ sec. 24, 1269 m, 7-23-88.—Bonanza Spring, Clipper Mtns., San Bernardino Co., CA; T 7N, R 15E, NW ¼ sec. 22, 634 m, 11-14-88.—Piute Spring, San Bernardino Co., CA; T 12N, R 18E, NW ¼ sec. 24, 915 m, 7-25-88.

VIII. Amargosa Basin and environs. Choppo Spring, Inyo Co., CA; T 21N, R 7E, SE ¼ sec. 2, 610 m, 7-25-88.—Tule Spring (dry), California Valley, San Bernardino Co., CA; Tecopa, CA (15), 8.8 km NNW of SE corner of quadrangle, 720 m, 7-25-88.—Beck Spring, Kingston Range, San Bernardino Co., CA; T 20N, R 10E, NE ¼ sec. 31, 1354 m, 7-25-88.—Cold Creek, Clark Co., NV; T 18S, R 55E, NE ¼ sec. 1, 1867 m, 9-5-77.—Willow Creek, Clark Co., NV; T 18S, R 55E, NE ¼ sec. 2, 1830 m, 7-31-77.