

THE FOSSIL FRESH-WATER SHELLS OF THE COLORADO DESERT, THEIR DISTRIBUTION, ENVIRONMENT, AND VARIATION.

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On turning to any authentic map it will be seen that the great range of the Sierra Nevada, as it approaches the south, makes a rather abrupt divergence in a westerly direction, between latitudes $35^{\circ} 30'$ and $36^{\circ} 30'$. Here also it throws out a great spur which, after extending for a considerable distance toward the east in a nearly easterly and westerly course, then deflects in its main mass toward the south-east, with broad flanks, finally breaking down into hills of greater or less elevation. These lower and somewhat detached portions reach the westerly margin of the Colorado River in the vicinity of Fort Yuma. This, the main spur, is known as the San Bernardino range, and the northerly (east and west section) is called the San Gabriel range, though topographically a part of the other. The rocky ramparts of the San Gabriel Mountains separate the depressed levels on the south from the more elevated plains of the Mojave desert. On the west, facing the westerly slopes of the San Bernardino range, are the San Jacinto Mountains, a part of the Peninsular range, which extends southerly into the Mexican territory of Lower California.

These mountain walls inclose a vast area of arid, desolate waste, the Colorado desert of California. Surrounded by mountains except in the south, and there opening out upon the head of the Gulf of California, it is seen that the desert was a portion of the old gulf which at some former time extended 200 miles above its present limits. The cause of the separation of the upper end of the former gulf, making what is now the Colorado desert, is so apparent that a moment's examination reveals it. The same agency is still operating, widening the space between the present gulf and the desert. Here, nearly 150 miles from the head of the ancient gulf, came in from the east side the Colorado River, bearing in its thick floods quicksands and the red mud from the great plateaus of northern Arizona. The contour of the country shows the gulf to have been narrow here. The filling in went on unceasingly as at the mouth of every great river which enters

the sea at a sheltered point. The water became constantly shoaler, until at length the separation was complete. The deposited material has steadily increased the distance between the gulf and the low bed of the desert, until now the division is marked by a narrow neck of 30 or 40 miles of land but little raised above the level of the sea.

To quote Professor Blake: If the alluvial deposits brought down by the Colorado River were removed, the gulf would flow inward and again occupy its ancient bed. When the stupendous work done by the Colorado River in cutting deep canyons along its course is considered, it is easy to realize the vast quantity of detritus brought down and deposited by that industrious and mighty stream.

The Colorado desert of California is only a portion of a much greater desert area, which extends on the easterly side of the river into western and southwestern Arizona, including the desert of the Gila, reaching for a long distance to the base of a mountain range in the Mexican State of Sonora, the Sierra del Nazareno (?), or spurs of that range outlying to the north, and on the westerly, south of the California boundary, an area of great extent reaches still farther to the south into Lower California, bordering on the gulf.

Here, also, we find a small depressed basin, known as Lake Maquata, its northern end about 10 miles south of the United States boundary, between the Peninsular and Cocopah ranges of mountains. Its surface is doubtless below sea level, but the sediment deposited by the Colorado has created a permanent barrier between it and the Gulf of California. Millions of fresh-water snail and "clam" shells are strewn over the bed or along the former shores of the lake, sufficient evidence that it had once been filled with fresh water.¹ In Sonora it embraces a large and indefinite area, of which but little is known. The northerly portion of the desert, that is to say, the California section, contains approximately 6,000,000 acres, included in the boundaries of San Diego and Riverside counties. To the east and northeast of the San Bernardino range, in these counties, lying between the range and the Colorado River, extending to the higher desert levels to the north, there is a region of numerous dry lakes and springs, the latter usually dry or intermittent, according to the seasonal rainfall. Of the desert region exterior to the California portion but little is known, and the Californian area, so far as the Mollusca are concerned, has been only partially explored. The species we are considering have been found in many places quite remote from the Colorado desert.

At the north, ranging as far as Death Valley in Inyo County, thence northeasterly to the shores of Sevier Lake in Utah. Turning southward, the occurrence of the *Paludestrina* in the States of Durango and Michoacan, Mexico, the latter region 1,800 miles south of the Colorado desert, may well be regarded as most extraordinary, as well as the

¹C. R. Orcutt, in *West American Scientist*, 1891.

circumstances under which the examples from this remote locality were discovered.

The southerly portion of the Great Basin, including the immense area from the easterly flanks of the Sierra Nevada across the State of Nevada to the westerly flanks of the Rocky Mountain ranges in Utah, is characterized by innumerable mountain ranges of varied extent, more or less detached or broken; with intervening valleys of a general desert aspect; with dry lakes and numerous springs of hot or cold, sweet or bitter waters, some perennial, others dry or intermittent, according to the precipitation of the seasons, which vary exceedingly when one year is compared with another; with an occasional season of excessive rainfall, like those of 1840, 1852, 1859, 1861-62, and subsequently, when every water course and depression was filled to overflowing, and springs that had been dormant for years, their sources replenished, became active and continued to flow for months afterwards.

In considering more particularly the Colorado desert region, we find that in these seasons of exceeding precipitation the more depressed portion becomes a lake 60 miles long and 30 wide, as in the winter months of 1861-62, through the inflow by the way of New River,¹ a branch of the Colorado which enters the desert from the south, forming the so-called Salton Sea of more recent years. Aside from these unusually rainy seasons, which are of infrequent occurrence, thunderstorms² of exceeding violence, with a downpour that may be called torrential, often occur during the hottest weather; these are usually of brief duration and their waters fall upon a comparatively limited area. They contribute, however, to the maintenance of animal life and help to perpetuate such forms as we are here considering. Atmospheric agitation at such times, as well as during the hotter weather in ordinary seasons, plays its part. Living and dormant individuals in and around the springs and pools, as well as the dead shells in their immediate neighborhood, are picked up by the wind and carried hither and thither, the greater part buried under the drifting sands, the spiral storms or sand spouts assisting in the general displacement.

¹What is known as "New River" had no existence before the year 1840, when it broke away from the Colorado and for a time partly submerged the desert. For several years after a chain of lagoons remained. The same thing has probably occurred many times in the history of the desert. H. G. Hanks in Second Report of State Mineralogist of California, 1880-1882, appendix, p. 238.

²Cloud-bursts and waterspouts, accompanied by fearful thunder and lightning, are of frequent occurrence. The ground near Frinks Spring and Flowing Wells stations, a distance of 17 miles, is cut and gullied in a most remarkable manner. In this distance there are no less than 75 bridges and culverts on the railroad track. The gullies vary from 5 to 25 feet in depth and about the same in width. The banks are so steep and precipitous that, in walking along, one does not see the canyon until it yawns at one's feet. These gullies are all caused by the rush of water from cloud-bursts and waterspouts. Joseph F. James in Popular Science Monthly, January, 1882.

While the winds and waters have no doubt played an important part in the dispersion of these and related molluscan forms, we are not restricted to these agencies to explain their widespread distribution. At the present day we find numerous species of aquatic birds frequenting the springs, pools, and marshes or wet meadows wherever such places occur within the larger or general desert area, both north and south. When the present deserts were lakes or lagoons, whose waters covered several hundreds of square miles, and the numerous springs, now dry or intermittent, filled their basins to overflowing, the number of swimming, diving, and wading birds throughout the region must have been very great. In their seasonal migrations or ordinary flights from lake to spring or spring to lake they would unavoidably have carried from one place to another such individual mollusks as adhered to their legs or feathers, and the sticky egg masses of these pond snails also; it is not unreasonable to assume that these were frequently transported in this way over considerable or even great distances.

It should be borne in mind that these tiny mollusks live in the midst of the conferva, and that the best way to obtain specimens is to collect a large quantity of this green scum-like material and spread it on paper in the sun, when it quickly dries up and the shells are easily shaken out. The carrying of these little forms from place to place is facilitated by the character of this vegetable growth which they frequent, as a comparatively small quantity, a little bunch of it, entangled in the feet or on the legs or among the feathers of a duck might contain many individuals.

That these minute forms (*Paludestrina*) are still living in many other localities in the Great Desert than the few which we now know of seems altogether probable when we consider their inconspicuous size and that their shells are usually coated over with the confervoid growth that is generally present in and around springs. Being immersed in this green vegetable scum, they escape detection and are not likely to be seen by persons not familiar with their habits or not especially interested in searching for them. Wherever they do occur they compensate by vast numbers for lack of size, for these little fellows are wonderfully prolific.¹

The evidence of lake or lagoon conditions resulting from the overflow of the Colorado River in the past, is corroborated by the perpen-

¹ Some idea of the immense number of these shells on the surface of the desert may be derived from the following: "We soon noticed that the soil was, to a large extent, made up of minute turreted shells, so small that they could hardly be distinguished from the grains of sand. At certain points they were blown by the wind into windrows, and lay in vast numbers, concentrated from the sands by a natural winnowing process. These are the * * * fossils described in the Smith. Misc. Colls., No. 144, part 3, folio 70. * * * On my return to San Francisco I made experiments showing that it required 166,000 of these minute shells to weigh a pound." H. G. Hanks in Second Report of State Mineralogist of California, 1880-1882, appendix, pp. 227-228.

dicular section exhibited in the well at Walter's station on the Southern Pacific Railroad, as noticed by me in 1879¹. This well was sunk to the depth of 45 or 47 feet when water was struck. The section showed a fine clayey sediment such as is precipitated from turbid waters in a sluggish or placid condition; this sedimentary deposit contained throughout examples of *Paludestrina* and *Physas*, or fragments of both.

At many places in the desert occur what are known as "dry bogs." These are the dried up pools of former years; they are a most dangerous menace to the unwary traveler; the vegetation which the waters of these former basins supported, when dried, is sufficiently strong to support the coating of drifted sand by which they are disguised; the weight of man or beast is sufficient to break through this thin crust and submersion is inevitable. Some idea of the number, extent, and character as well as of the appearance of the desert at the time when these bogs were pools or lagoons, may be seen at a glance in the locality known as Flowing Springs, 40 miles west of Yuma, where many of these so-called springs have the area of ponds or lakelets of considerable size and support a luxuriant aquatic vegetation. Here also may be seen thousands of birds of various species, swimmers, waders, etc., as well as land birds, and the part feathered tribes have performed in the distribution of these little conferva inhabiting mollusks is forcibly suggested.

THE PALUDESTRINÆ.

The forms under consideration were collected by the writer in 1882, in the immediate neighborhood of various stations along the line of the Southern Pacific Railroad in the Colorado desert of California.

Favorable circumstances afforded considerable time at each of the places stopped at, so that a large number, many thousands, of the few species that are so abundant on the surface of the desert were obtained. The shells specially reviewed belonging to the genera *Paludestrina* and *Physa*, inhabit springs, pools, and the shallow, marshy borders of ponds and lakes; they appear to prefer quiet waters rather than flowing brooks or larger streams. Though classed as fresh-water species, they are not infrequently found in waters that are alkaline or saline, also in springs of a temperature as high as 100° F. The particular species of *Paludestrina* mentioned has heretofore been variously referred to the genera *Amnicola*, *Melania*, *Hydrobia*, and later to Stimpson's genus *Tryonia*; ² still later to *Bythinella*. It has been

¹ Remarks on fossil shells from the Colorado Desert, in the American Naturalist, March, 1879 (read before the California Academy of Sciences).

² For Stimpson's figure of the type of *Tryonia*, see fig. 29, and pp. 48 and 49 of Researches upon the *Hydrobiinae*, etc., Smithsonian Miscellaneous Collection No. 201, August, 1865. Binney's figure in Land and Fresh Water Shells of North America, p. 71, Part III, Smithsonian Miscellaneous Collections, September, 1865, does not represent it.

widely distributed in the course of exchanges between conchologists as *Tryonia*; the latter genus is based on external or shell characters only, and upon these characters is readily separable from any of the numerous varieties of the much commoner form illustrated herein.

From Flowing Springs, many miles from the railway and the station known by said name, I have received probably over a thousand examples of *Paludestrina* since the major portion of this paper was written¹.

The species assigned to the first of these genera which exhibits the numerous varietal aspects figured below, as well as certain other forms hereinafter mentioned, was first detected by Prof. William P. Blake² and Dr. Thomas H. Webb. It was described by Dr. A. A. Gould in March, 1855, as *Amnicola protea*, and by T. A. Conrad as *Melania exigua*, in February, 1855. Gould's description was published first, therefore his name has precedence. Binney placed it in Stimpson's genus *Tryonia*, which error has been continued by subsequent authors, including the writer, who removed it in 1893 to *Bythinella*.

As the numbers of the Smithsonian publications containing Binney's Land and Fresh-water Shells of North America are out of print, and the original descriptions are accessible only to a small number of students, I have quoted Gould and Conrad as below from Binney.³

AMNICOLA PROTEA Gould.

Shell elongate, slender, variable; whirls seven to eight, rounded, divided by a deep suture, simple or variously ornamented, and barred with revolving ridges and longitudinal folds; aperture ovate; lip continuous, simple, scarcely touching the penultimate whirl. Length of the largest specimen, three-tenths, breadth, one-tenth inch.



FIG. 1.—AMNICOLA PROTEA.

From the Colorado Desert (Gran Jornada), Dr. T. H. Webb, W. P. Blake.

Peculiar from its large size and slender form, though differing greatly in its relative proportions. It differs from all others in being variously sculptured with revolving ridges and longitudinal folds, like most *Melania*. It varies greatly also in the relative proportions of length and breadth. It is as slender as *Amnicola attenuata* Hald., and much larger. This appears to be the same shell as that subsequently described by Mr. Conrad, under the name of *Melania exigua*. (Gould.)

MELANIA EXIGUA Conrad.

Turreted; volutions eight, disposed to be angulated and somewhat scalariform above, cancellated, longitudinal lines wanting on the lower half of the body whorl;

¹The great canal system of the Imperial Company by which the waters of the Colorado River are in part diverted so as to irrigate hundreds of square miles of the desert is rapidly approaching completion. The water is already flowing in a considerable portion of the system and soon a part of the sandy waste will give place to green and fertile fields, forming an oasis in the midst of the arid desert.

²Pacific Railroad Reports, V, 1857, p. 332.

³Part III, p. 70 (*Tryonia*).

columella reflected; aperture elliptical. Length, one-fifth of an inch. Colorado Desert, California (Dr. LeConte).

The specimens are numerous and of a chalky whiteness, showing that they are all dead shells. Said to have been found 120 miles distant from any stream passed on the route.

Following Dr. Pilsbry, whose familiarity with these puzzling little shells entitles his conclusions to acceptance, the present status and synonymy should be arranged as below.

Genus PALUDESTRINA Orbigny.

PALUDESTRINA PROTEA Gould (Pilsbry).¹

Plates XIX-XXI.

- = *Bythinella protea* GOULD (Stearns, 1893)².
- = *Amnicola protea* GOULD 1855.³
- = *Melania exigua* CONRAD, 1855.⁴
- = *Trygonia protea* GOULD (Binney et auct., 1865).⁵
- + *Bythinella seemani* FRAUENFELD (Pilsbry, 1893)².
- = *Hydrobia seemani* FRAUENFELD, 1863.⁶

This species from 1854, the year of its discovery, was regarded as extinct until June, 1888, when Mr. C. R. Orcutt, of San Diego, collected numerous living examples in Indian or Fish Springs, some 15 miles northwest of the station known as Salton, on the Southern Pacific Railroad. These pools and springs, of which there are several, varying from 10 to 20 feet across, are at the base of the San Jacinto Mountains. "They are only a few feet deep and are surrounded with an almost impenetrable mass of tules, canegrass, and mock willows; the mesquit, screw bean, and various shrubs, rushes, and sedges form the bulk of the wild vegetation." The water is warm, in Mr. Orcutt's judgment not under 100° F., and tastes like the water of the Dos Palms Springs, 6 miles north of Salton, on the opposite side of the desert, at the base of the Chuckawalla or Lizard mountains. An analysis of the water from the latter springs showed slight traces of alum, soda, sulphur, and considerable salt, but not so much as to make it unfit for use.

These springs are all below the present sea level about 100 feet,

¹ "Includes *Bythinella* Moq. Tand. and authors generally," Pilsbry in Catalogue of Amnicolide of the Western United States, Nautilus, March, 1899, pp. 121-127.

² Report on the Land and Fresh-Water Shells collected in California and Nevada by the Death Valley Expedition, North American Fauna No. 7, Part II, U. S. Department of Agriculture, May, 1893, p. 278.

³ Boston Soc. Nat. Hist., V, p. 129, March, 1855; Otia, 217.

⁴ Proc. Acad. Nat. Sci. Phila., VII, p. 269, February, 1855.

⁵ Land and Fresh-Water Shells of North America, Part III, Smithsonian Miscellaneous Collections, No. 144, September, 1865, p. 72.

⁶ Verhandlungen der k. k. zoologisch-botanischen Gesellschaft in Wien, Jahrgang, 1863, p. 1025.

judging from the fact that Salton, lying in the depression between Dos Palmas and Indian Springs, is reported to be 250 feet below the sea level from actual measurements. These springs and pools, like those before named, are surrounded by a luxuriant growth of cane grass, tules, etc., and the mesquit, screw bean, and other trees of the same order occur in great numbers. Specimens from this place, presented by Mr. Orcutt, are contained in the National Museum (No. 104886).

Orcutt's discovery was followed, in 1891, by the detection of living examples far to the north in Saratoga Springs, Inyo County, where Mr. E. W. Nelson collected several hundred, and a large number were collected in a marsh near the springs by Mr. Vernon Bailey. These, also, are warm springs, situated in the extreme southeast end of Death Valley, near the bend of the Armagosa River, so called (usually nothing more than a dry wash), at an altitude of 352 feet. The valley is the deepest depression in North America, being 480 feet below the level of the sea. The geographical range, as shown by dead or semi-fossil examples, is far greater and most extraordinary, extending from the shores of Sevier Lake, in middle Utah, as seen by Dr. H. C. Yarrow's collection in 1872¹ (U. S. N. M., No. 73960), to Andocutira, in the State of Michoacan, Mexico. From the latter locality examples were sent to the National Museum (No. 73908) by Prof. A. Dugès some years ago, with the following interesting note:

"Ces mollusques ont été trouvés dans une fourmilierie à Andocutira, Etat de Michoacan. La personne qui me les a remis pense qu'ils proviennent d'une ancienne formation lacustre, aujourd'hui couvert par des terrains postérieurs."²

¹ Explorations and surveys of Lieut. G. M. Wheeler, U. S. A., V, p. 498; also G. W. Tryon, in Proc. Acad. Nat. Science, Phila., May 1, 1873, or to Dr. H. C. Yarrow's collection.

Mr. Call, in his interesting paper on the recent and fossil shells of the Great Basin, has not credited this form to either of the ancient lake areas. Attention is directed to Bulletin No. 11 of the U. S. Geological Survey (1884), which contains Call's paper and the following from Prof. G. K. Gilbert's introductory sketch of "The Quaternary lakes," etc.:

"In the northern portion of the Great Basin there were two large water bodies; the one, Lake Bonneville, covering the Great Salt Lake and Sevier deserts, in western Utah; the other, Lake Lahontan, occupying a group of communicating valleys in western Nevada."

The elevation of Pyramid Lake is given by Gannett as 4,890 feet, and Sevier Lake, by the same authority, is 4,600 feet above sea level.

² With these shells from Professor Dugès there was a single example (U. S. N. M. No. 73907) of the very rare and little known *Valvata humeralis*, collected by Thomas Say in Mexico, and described by him nearly three-quarters of a century ago in the New Harmony Disseminator of Useful Knowledge, II, No. 16, August 12, 1829. See Binney's Bibliography of North American Conchology, 1863, part 1, p. 204.

The foregoing is the third instance that has come under my observation of important though indirect assistance rendered by the lower animals in furnishing biological and geological data.

Here we find the southerly range extending 1,800 miles from the Colorado desert, as before mentioned, and the occurrence of this form is corroborated and its presumable wide dispersion in that country shown by Frauenfeld's examples from Durango. The Michoacan and Darangó shells, like the Death Valley specimens, belong to the smooth variety which occurs with the other varietal facies in the Colorado region of California.

This smooth form has recently been detected by Dr. Pilsbry¹ in some fluviatile débris from South Spring Creek, near Roswell, New Mexico.

Orcutt's Fish Spring examples are finely granulose. I am further indebted to Mr. Orcutt for several specimens, recently received, that were detected by him living in the Dos Palmas Springs. The Dos Palmas shells vary from individuals with a smooth surface to those that are sculptured by fine revolving threads.

The Sevier Lake (middle Utah) specimens collected by Dr. Yarrow in 1872 are so much weathered as to efface the sculpture. It should be borne in mind, however, that the Yarrow specimens are so few in number that it would be quite unsafe to assume that many other varietal aspects do not occur at the Bonneville localities.²

The collection made by me in 1882, now in the U. S. National Museum, included some 40,000 examples of *Paludestrina* from the surface of the desert at the localities known as Indio, Walters, Dos Palmas, and Volcano Springs. These stations are all within the great depression, being, respectively, 20, 195, 253, and 225 feet below sea level. At these places several hundred specimens of the pond snails *Physa* were collected, as well as a few examples of *Paludestrina longinqua* (= *Amnicola longinqua* Gould), for which no special search was made. A dwarfed aspect of *Fluminicola (columbiana)* occurs occasionally, and two or more species of *Planorbis* are met with, but the absence of any form of the genus *Limnæa* is noteworthy.

In considering the principal varietal features of *P. protea*, we may conveniently group them as follows:

VARIATION IN FORM.

First. It is seen that some individuals are much more attenuated than others. In certain instances the shells are quite robust as compared with length, the basal whorl being conspicuously larger and forming nearly two-thirds of the total length as compared with five-ninths or much less than one-half in other specimens. In diameter the extremes are as 13 to 20.

¹ Nautilus, XIII, November, 1899, p. 79.

² *P. protea* was not detected by Call in the Lahontan region, its place being apparently taken by *Pyrgulopsis nevadensis*, which, though not found in the Lahontan beds, occurs in countless thousands living in Pyramid Lake as well as in Walkers Lake (dead only?).

Second. The convexity or angulation of the whorls is another marked feature. This, it will be seen, is exhibited in various degrees, by comparing figs. 1-4 with 7, 9, 12, and others, until the extreme of angulation and tabulation is reached, as in examples 8 and 11, where, as in the latter, the flattening of the upper part of the whorls is remarkably uniform and produces a turreted effect. Both 8 and 11 are exceedingly rare varieties, only one of each in the many thousands of specimens critically examined.

Third. The aperture or mouth, it will be noticed, is quite variable, both in shape and size, often small, as in fig. 14; the edges simple or thin, generally continuous; again more or less thickened or flattened and flaring, as in figs. 6, 12, and 14; sometimes closely appressed to the basal whorl, frequently barely touching, and often free or not touching it. These latter aspects suggest an umbilicus, as in fig. 13, but the gap is only superficial. In fig. 10 it will be seen the lip is not continuous. The aperture may be round, or very nearly so, rounded ovate, ovate or angulated ovate, as in fig. 11. The length of the aperture and its position as related to the axis of the shell varies in different examples. Compare 9, 11, and 12 with 1, 3, 5, and 10. In 11 there is a sinuous curving callous or fold in the umbilical region just above the mouth.

Gould remarks in his description of *protea*: "It varies greatly * * * in the relative proportions of length and breadth." He also noticed the strength of the sutural definition; and Conrad mentions the general scalariform aspect which is so strikingly exhibited in many of the examples, whether plain or sculptured.

VARIATION IN SCULPTURE.

First. Plain smooth shells like figs. 1 and 2 (with convex whorls), from Death Valley, at Saratoga Springs (Nelson and Bailey); in the Mexican States of Michoacan (Dugès), and Durango (Frauenfeld); near Roswell, New Mexico (Tinsley-Pilsbry). The eroded Sevier Lake, Utah, specimens (Yarrow) may be included with the above. Then follow the smooth-surfaced forms, with whorls somewhat angulated on the upper part, as shown in fig. 6, and the unique, strongly angulated example, fig. 8. In this the pronounced angulation of the whorls points toward my species, *Pyrgulopsis nevadensis* of Pyramid Lake.

Second. Spirally lirate or threaded (whorls convex), the liræ more or less prominent, as in figs. 3 and 4. All of Orcutt's Dos Palmas Springs, ten living specimens are of this pattern. In fig. 9 is shown an unusually robust example (whorls slightly angulated above), the liræ distinct, but much less conspicuous than in the slenderer, more strongly angulated and threaded fig. 10. In fig. 11 the angulation of the part of the whorls is extremely developed, passing into tabulation or flattening, producing a turreted effect, and the spiral threading numerous, closely set, and well defined.

Third. A connecting link between the above and the cancellated forms—that is to say, forms that are sculptured both transversely and longitudinally—as seen in fig. 12. Robust, angulated, spirally lirate, and longitudinally plicate on the third and fourth whorls from the tip of the apex; the eccentric character of the aperture makes this a unique example. In fig. 5 is presented a slenderer form with the chief sculpture characters of fig. 12. In this the threading of the penultimate whorl is inconspicuous, increasing in prominence on the three whorls above, which are also strongly ribbed longitudinally; the whorls are rounded above.

Fourth. Longitudinal sculpture strongest. In all of the following examples the spiral sculpture is seen and is more or less conspicuous. This character varies, however, in figs. 6 and 14; the liræ are numerous and closely, evenly placed; in these also the shells are slenderer, and the longitudinal ribs cross the spiral threading without interruption. In fig. 6 it will be noticed the whorls are convex, in fig. 14 somewhat angulated above, and the mouth in the latter is small. No. 5, in the third group, might be included here, perhaps, as appropriately as where I have placed it.

Fifth. Cancellated and nodose sculptures are the prominent features in the forms here included. The whorls in all are angulated above; the spiral threadings vary in number, and where crossed by the lengthwise ribs become tuberculated or nodose. In fig. 13 is seen a repetition of the slenderer aspect, and in fig. 18 is shown the maximum of robustness. On the basal whorl, close-set fine threading below, above a double threading is a conspicuous feature, with wider interspaces, which extends to the upper whorls.

In figs. 15 and 16 are examples intermediate in size and other characters. A ventricose example is presented in fig. 17, distinctly but not strongly threaded with many of the features of No. 18; in this the longitudinal sculpture is only suggested.

These filose, cancellated, and tuberculated varieties call to mind familiar forms belonging to the American *Strepomatida*, which, no doubt, were in Conrad's mind when he described certain aspects of the shells herein reviewed as *Melania erigua*.

Orcutt's recent examples, collected by him at the Fish Springs locality, contained in the U. S. National Museum (No. 104886), are not figured; in these the surface is finely granulose. As only a small number of shells from the Orcutt localities have been examined, it is not known whether the springs visited by Mr. Orcutt contain other varieties than those described.

It will be observed that the forms from the remote localities, namely, Death Valley and Sevier Lake in the north, Durango and Michoacan in the south, and New Mexico in the east, are sculptureless; that is to say, are of the smooth surfaced form described by Frauenfeld. These Roswell, New Mexico, examples determined by Dr. Pilsbry extend the

distribution so much farther in that direction than before known as to warrant the expectation of the finding of *P. protea* in some of its many varieties at intermediate localities.

The eighteen examples figured as representatives of the many facies of this exceedingly variable form are connected in one character or another by innumerable individuals which blend or intergrade, and which it would be impracticable to describe. The above are numbered in the U. S. National Museum Register 47854, with second or index numbers 1 to 18, in as many tubes corresponding to the number of each figure as given in this paper.

With the exception of the New Mexico and Durango localities, all of the others are represented in the U. S. National Museum collection.

The occurrence in the Colorado desert of California, of the well-marked form described by the late Dr. Stimpson as *Tryonia clothrata* has not been verified by any of the collections made by various parties, as well as myself; not a single example having been detected in the thousands of specimens examined. The only locality where it is definitely known to occur is in the Pahrnagat Valley, Nevada, where Dr. C. Hart Merriam collected a number of living specimens in a hot spring. The dead bleached shells collected forty years ago by Prof. W. P. Blake, and later by General Carlton in 1861-62, were probably found somewhere in the region of the Merriam locality, which is at a high altitude, 3,000 feet or more, in southern Nevada. There is a vast area between the Pahrnagat and California localities practically unexplored; of its molluscan life scarcely anything is known.

As to the causes of the extreme variation exhibited by the shells of this species, I will repeat what I have heretofore written by quoting from the "Report on the Land and Fresh-Water Shells collected in California and Nevada by the Death Valley expedition,"¹ as follows:

The suggestion that arises from the study of the forms above reviewed and the regions and conditions to which they are related point to the causes that induce variation and to the permanency of species and genera, or to the mutability of the same, as dependent on environmental characteristics.

If we are warranted in assuming * * * that with a volume of water ample or maximum and chemical proportions as related to volume minimum our *Tryonias* would be smooth, and that the smooth or sculptureless surface that so generally prevails in the *Bythinellas* and related groups is, in a conventional sense, normal, then we may reasonably assume that to the opposite of these conditions, with volume of water variable or minimum and chemical proportions as related to volume of water increased or maximum, the phenomena of variation may be attributed. That fluctuations in volume of water in the springs, pools, lagoons, etc., throughout the entire desert region above described are occasional, if not of frequent occurrence, is well known, and in some years the maximum is extreme, as has been pointed out.

¹North American Fauna, p. 280, U. S. Department of Agriculture, 1893.

In reviewing the forms herein considered it will hardly be questioned that the variation they exhibit is correlated with salinity, using the word as synonymous with alkalinity, or the mineral character of the waters in which the shells are found. In connection with the foregoing the suggestion arises that some of the many springs now obsolete contained what in common parlance may be called a distinct species, or shells that were characterized by a single facies of sculpture, etc. Thus, in Mr. Orcutt's Indian or Fish Springs specimens the surface is finely granulose. His Dos Palmos shells are spirally threaded, though these aspects of sculpture are not always—that is to say, in all the specimens—equally conspicuous. The Saratoga Springs examples of the Death Valley expedition are, like those of Michoacan, Durango, and New Mexico, smooth surfaced. The few Sevier Lake (Utah) specimens were sculptured, but so much eroded as to obscure the character of the surface. Doubtless many living springs remain to be explored and some of these may furnish special facies of this versatile form, perhaps shells with the longitudinal sculpture only. With the above facts and suggestions before us, a coming together of these various forms would, it may be assumed, lead to hybridization and the phenomenal variation of *P. protea* be thus explained. But here we must remember the fact that in all of the shells from all the localities, whatever may be the surface characters in the main, the apex and early whorls are universally smooth.

In the several hundred specimens recently received from the Flowing Wells locality, where the bodies of water are of considerable size, all of the varieties are included except Nos. 8 and 11.

From the suggestion of variation through hybridization the following hypothetical views as to the formation of sculpture may be indulged in:

The spiral sculpture or lirate character may be due to puckering of the mantle upon its being withdrawn into the shell, which would cause an increased deposit at certain points along or upon the edge of the outer lip, the lirate and intermediate depressed grooving corresponding to the wrinkling of the mantle edge. In examples that show the thread-like ridges on some whorls and not on others we may suppose that the shell-forming material, or lymph, as it may be called for convenience, was less abundant one time compared with another.

Where the double system of sculpture is exhibited the forming of the lirate ridges was at times interrupted by a short period of rest, when the rim or edge of the mouth received the greater proportion of the secretions, thus making the thread-like sculpture secondary to the longitudinal for the time being. It would seem that alternations in the volume of lymph deposited as suggested, or from pores around the edge of the mantle and possibly somewhat molded or shaped by the foot, may furnish a hint as to the various facies of sculpture.

The character of the lymph may have something to do with sculpture. It quite likely varies in density one time compared with another according to the proportions of conchiolin or lime; with the first maximum, would be greater fluidity and less tendency to set, at the expense of diffusion or quick spreading, than when the lime factor dominated and made it more viscous.

As to the proportions of the mantle and its size as related to the size of the mouth and other characters we have no certain knowledge. It may be that the edge of the mantle is thin and simple; that a series of pores occur that are parallel to but not quite at the edge of the mantle; that these pores are nearly equally spaced as to distance apart. In that case we may suppose the two forms of sculpture could be made at the same time—that is, the spiral or transverse and the longitudinal—the deposition from the mantle's edge forming on the edge of the outer lip the longitudinal plicæ and the secretions from the pores simultaneously deposited forming the liræ. In this case any differentiation in the size of the liræ—that is to say, coarseness or fineness—would be due to lack of uniformity in the size of the pores, and irregularity or differences in distance apart might be attributed to the partial or absolute congestion of some of them.

Angulation or shouldering, in some instances amounting to absolute distortion, as seen in asymmetry and bulging, are presumably due to hypertrophy of the visceral mass, especially the liver, and to entanglement at some time during the period of growth in the vegetable matter in the midst of which they live, and the flaring of the mouth, as seen in fig. 12, to the close pressing to some flat surface, like a tule stalk or the stem of some other aquatic plant.

The register number of the shells, figured 1 to 18 inclusive, is U.S.N.M. 47854.

OTHER SPECIES OF THE AMNICOLIDÆ.

There will generally be found in any collection of the Desert shells a small proportion of the following:

PALUDESTRINA LONGINQUA Gould (Pilsbry).

Amnicola longinqua GOULD, Proc. Boston Society Nat. History, Mar., 1855; BINNEY Land and Fresh Water Shells of North America, Part III, Smithsonian Miscellaneous Collections, No. 144, Sept., 1865, p. 87, fig. 173.

In Dr. Pilsbry's revised Catalogue of the *Amnicolidae*, etc., he includes this form in the genus above named. Its presence in the desert is inconspicuous when compared with the vast numbers of *P. protea*. Those factors in the environment to which is apparently attributable the variability of *P. protea*, do not seem to affect *P. longinqua*, for all of the shells in the latter have a smooth unsculp-

tured surface. This little species is widely distributed; it occurs not only in the Colorado desert in a semifossil state, but throughout the Great Basin, living and dead, as follows: Upper Lahontan beds at south end of Winnemucca Lake, and at Buffalo Springs (Call); Nevada and Utah (Hemphill); Bear Lake and Utah Lake (Hayden, Putnam); Southeastern Oregon (Gabb); at Campo and Springs in Cuyamaca Mountains, San Diego Co. (Hemphill); Indian and other localities in Colorado desert (Stearns). Dr. Gould's specimens were collected in the "Cienaga Grande" by Prof. William P. Blake, of the Pacific Railroad surveys.

Dr. Pilsbry regards *Bythinella intermedia* Tryon, as a synonym and speaks of *P. longinqua*¹ as "extremely variable, * * * often incorrectly identified." [U.S.N.M. No. 104885.]

FLUMINICOLA COLUMBIANA (Hemphill) Pilsbry.

Fluminicola columbiana PILSBRY, Nautilus, XII, No. 11, March, 1899, p. 125.

Fluminicola nuttalliana var. *columbiana* HEMPHILL manuscript.

Columbia River, near Wallula and near mouth of Snake River in southwest Washington; Snake River near Weiser, western Idaho (Hemphill). Colorado desert, semifossil (Stearns).

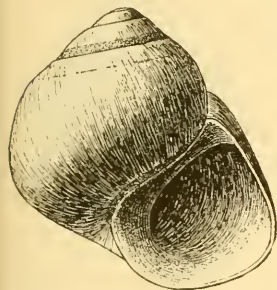


FIG. 3.—FLUMINICOLA COLUMBIANA (Hemphill).

A single example was detected by me while examining the 40,000 examples of *P. protea*, etc. I had labeled it *F. nuttalliana*. It agrees so well with Dr. Pilsbry's description of *F. columbiana* that I have no doubt it belongs to that species. [U.S.N.M. No. 3847.]

The following forms collected by the Death Valley Expedition in 1891 were first made known in the report of said expedition published in 1893.² As the report has long since been out of print and many persons interested in the study of the mollusca have never seen the descriptions or figures, it is thought advisable to republish them in this connection, although the shells have not as yet been detected in that portion of the Great Desert to which this paper in the main refers.

¹The figure (173) in Binney is so very poor that the species could hardly be determined by it. The figures in the text numbered 2 and 3 are by Dr. McConnell. The latter form has not been figured before.

²North American Fauna No. 7, Part II, U. S. Dept. Agriculture, pp. 269 to 283.

Through the courtesy of the Hon. James Wilson, Secretary of Agriculture, and the kindness of Dr. C. Hart Merriam, chief of the Biological Survey of above Department, I am able to present the figures of these species.

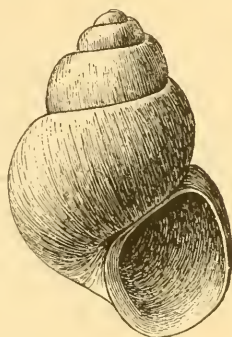


FIG. 2.—AMNICOLA LONGINQUA (Gould).

AMNICOLA MICROCOCCUS Pilsbry.

Shell minute, globose, with short conic spire and narrow umbilicus. Whorls $3\frac{2}{3}$, convex, especially below the sutures, the apex very obtuse. Surface smooth, light olive colored. Aperture ovate, about half the length of the entire shell, bluntly angulated above; the inner lip is either free from the preceding whorl or in contact only at the upper part.



FIG. 4.—AMNICOLA MICROCOCCUS (Pilsbry).

Alt. 1.5, diam. 1.3 mm.

A smaller species than *A. granum* Say, with oval instead of round aperture and shorter spire.

Type from small spring in Oasis Valley, Nevada (U.S.N.M., No. 123622), by Dr. C. Hart Merriam, June, 1891. Collected also in Death Valley by Nelson and Bailey, February 4, 1891 (U.S.N.M., No. 123904).

Several examples of this interesting little shell were detected as above.

FLUMINICOLA MERRIAMII Pilsbry¹ and Beecher.

Shell small, globose turbinated, narrowly but distinctly and deeply umbilicated. Spire low conic, acute; whorls four, slightly shouldered below the sutures, the upper lateral portion rather flattened, periphery and base convex. Surface smooth, horn-colored. Aperture oblique, ovate, angled above, broadly rounded below; upper portion of the inner lip adherent to the body whorl, lower portion arcuate, without a callous thickening.

Alt. 3, diam. $2\frac{1}{2}$ mm.

This species differs from *F. fusca* Haldeman in the much more distinct umbilicus, thin texture, and the *nonthickened* lip.

Collected from a warm spring (temperature 97° F.) in Pabranagat Valley, Nevada, by Dr. C. Hart Merriam, May 25, 1891 (U.S.N.M., No. 123626).

Dr. Merriam detected in the same spring numerous living examples of the long-sought-for *Tryonia clathrata* Stimpson, previously known only by dead or semifossil examples collected by Prof. William P. Blake in 1855 and General Carlton in 1861-62. It is quite evident that the term "Colorado desert," as used in connection with the Blake-Carlton shells, included a much larger part of the Great Basin than is now understood when the "Colorado desert" is mentioned. Attention is again called to the figure "139, *Tryonia clathrata*," as given in Binney,² which does not represent Dr. Stimpson's shell; for

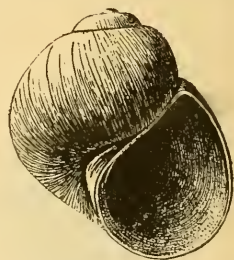


FIG. 5.—FLUMINICOLA MERRIAMII (Pilsbry and Beecher).

¹ The Nautilus, V, Apr., 1892, p. 143; also XII, Mar., 1899, p. 121 *et seq.*

² Smithsonian Miscellaneous Collection, No. 144, p. 71, Sept., 1865.

a proper figure see the last author's Researches upon the Hydrobiæ,¹ etc., page 48.

THE PHYSAS.

Associated with *Paludestrina* and scattered far and wide over the desert in immense numbers are various forms of *Physa*. Though less numerous than the former, they are particularly abundant in the depressed portion (below sea level) from Indio to Volcano Springs, their larger size making them far more conspicuous. The desert is strewn in like manner with the dead shells of *Planorbis* and *Anodonta*, far to the south, along the course of New River especially. This distribution extends to the "dry lake," the before-mentioned Laguna Maquata, south of the United States boundary line, where Mr. Orcutt observed "along the bottom of the lagoon numerous examples of the same species of *Physa*, *Planorbis*, and *Anodonta*" that are found at the north. He also mentions the occurrence of certain marine shells, *Tagelus* and *Cylichna*. The first of these, as well as a single example of *Ocenebra poulsoni* Nuttall, were collected by me near Indio.

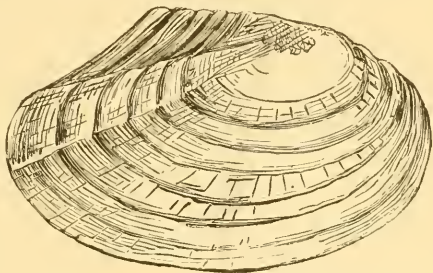


FIG. 6.—ANODONTA CALIFORNIENSIS (Lea), somewhat reduced.

Regarding the large *Planorbis ammon* Gould, Mr. Orcutt found it "about equally abundant * * * in a fossil state with *Physa leuerosa*." At the stations where I collected both *P. ammon* and *P. gracilentus* Gould (? = *P. liebmanni* Dunker) were apparently scarce. So also with *Paludestrina longinqua* (= *Ammicola longinqua*) Gould.

The surface of the desert in the neighborhood of these localities and for miles beyond those visited by me is covered with the glittering fragments of *Anodonta californiensis* Lea, which form a noticeable feature of the region, as seen from the moving cars. Perfect valves are frequently met with.

Probably there is no area of equal extent on the face of the earth where such an immense number of shells of the genera above named may be seen. Millions of the tiny shells of *Paludestrina*, with their varied and beautiful sculpture and the countless thousands of many species and varieties of *Physa*, indicate this region above all others that are known as the metropolis of these groups and prove that the environmental conditions throughout this vast territory must have been preeminently conducive to their multiplication and development.

While the *Physas* of the desert, as before remarked, are, as a whole, rather above the average of their congeners elsewhere in point of size,

¹ Smithsonian Miscellaneous Collection, No. 201, Aug., 1865.

the maximum of development in this direction is farther to the south, as shown by the fine, large, highly polished shells of the west Mexican species *P. (Aplera) aurantia* Carpenter, of Mazatlan. This form, which the author remarks as "not common" at that place, sometimes measures nearly an inch and a half in length.¹ As *Limnæa stagnalis* and *L. megasoma* of more northerly latitudes exhibit the culmination in size of the *Limnæidæ*, so in the south does *P. aurantia* of the *Physidæ*.

That several species of *Limnæa* occur at numerous localities in the Great Basin to the north, at various elevations from 1,300 to 4,000 feet² and upward, and eastward in Arizona at Tucson, elevation 2,300 feet, to the higher altitude of Walker Lake, in the San Francisco Mountains, 8,250 feet, and (*L. bulimoides*) still nearer, both in distance and altitude, at Daggett, on the Mojave River, in the Mojave Desert, 2,000 feet, points to the thermal factor of the lower levels in this region as the uncongenial feature which excludes *Limnæa* from the desert. Thus *L. humilis* becomes a mountain species in the Sierra Laguna of Lower California, and other species of the genus occur to the southward not far from the coast, at lower levels, within reach of the cool winds and fogs of the Pacific. Evidence is not wanting to show that depauperation in the *Limnæa* is coincident with high thermal conditions,³ where such temperatures are continuous or prevail the greater part of the year.

In considering the *Physas* of Indio and other desert localities, a glance at Plate V shows many forms that are familiar to students of North American *Limnophila*. To facilitate comparison, on Plate IV are presented several figures from Binney⁴ of described species from regions both north and south of the desert. With the distributive agencies previously indicated in mind, it may be well to turn to these forms and note the localities at which they were detected. Call credits *P. gyrina*, which he suggests is a variety of *P. heterostropha*, to the Upper Bonneville beds, near Salt Spring Creek, and the variety *P. elliptica*, to Warm Spring Lake, near Salt Lake City, both places in Utah. Of the latter he says it occurs "abundantly and of large size." The same author remarks of *P. heterostropha* that it has not been found in the lake beds of either Bonneville or Lahontan, but is abundant as a semifossil on the surface of Sevier Desert. Both *P. heterostropha* and *P. gyrina* were found living by the Death Valley expedition at many places in the Great Basin much farther south than the Lahontan and Bonneville regions. *P. heterostropha* was collected

¹Over a hundred were obtained by me at Acapulco in 1868. [R. E. C. S.]

²Mr. Vernon Bailey collected *L. palustris* in the Uintah Mountains in a creek at an elevation of 10,000 feet.

³Doubtless great extremes of temperature in either direction are detrimental to the existence of these forms.

⁴Land and Fresh Water Shells of North America, Smithsonian Miscellaneous Collections, No. 143, Part II, 1865.

by Mr. Vernon Bailey among moss "in an irrigation ditch" at Phoenix, Arizona, and by the same party at Magdalena, northwestern Mexico, "in a similar situation." It has been reported from other places in Mexico, as well as from Hot Springs, Lower California, where it was detected by H. and C. R. Orcutt in 1882.

P. lordi "is rare as a fossil; it does not occur living in the Bonneville Basin; a few examples have been found on the surface of the Sevier Desert."

For the distribution of the following I quote Dr. Cooper's catalogue.¹ "*P. gabbi*, northern California to Lower California. * * * *P. ampullacea*, Columbia River, latitude 49°, to Owens River, California. * * * *Physa diaphana*, Lake County, Cal., to Cape St. Lucas. * * * *Physa virginica*, Oregon and northwestern California to Santa Barbara, Cal."

Call found *P. ampullacea* common, living in the Bonneville area; it is found also in the Mono Basin, California. *P. gabbi* was collected by Professor Gabb in the Santa Ana River, Los Angeles County; *P. osculans* in Devils River, Arizona (Lloyd), and at Del Rio, Rio Grande Valley (Bailey); *P. mexicana*, "from Seven Wells, the Colorado River, and the Santa Cruz River near Tucson, Ariz., at Laguna, 20 miles north of Campo, and at Cameron's ranch, San Diego County, Cal. Some strongly shouldered specimens in a subfossil state, from the Colorado Desert, are perhaps a variety of this species, which is extremely variable" (Dall). Professor Dall also identifies a single specimen of a physoid form collected by Dr. E. A. Mearns in the drift of the Santa Cruz River near Tucson, Arizona, as *Aplexa hypnorum*.²

Physa virgata, described from specimens collected by Dr. Webb in the Gila River, Arizona; also occurs near San Diego and at Los Angeles, where I have collected numerous specimens.

Physa distinguenda, a species with which I am not familiar, was reported by Mr. Orcutt as occurring in a little creek near San Diego in 1890.

Of the 56 figures in Plate XXIII, Nos. 1, 2, and 3 have been made from a lot of 492 collected by Prof. I. C. Russell at Pyramid Lake, Nevada, in the extinct Lahontan Lake region. These give a fair idea of the differentiation of *Physa humerosa* from that locality, a species quite persistent in its main characteristics, first described from the Colorado Desert by Dr. Gould. The other figures represent examples forming a second selection from over 1,500 individuals collected by the writer,

¹ Catalogue of West North American and many Foreign Shells, etc. Printed for the State Mining Bureau, Sacramento, April, 1894.

² This extends the distribution of *hypnorum* by an immense leap to the south, its previous most southerly locality considered. It may possibly be shown by additional examples to be a long spired variety of *alata*, which is found in Lower California, or a slender aspect of *nitens*, a Mexican species.

a first series, which exhibited the extremes and other aspects of variation more markedly, having unfortunately been misplaced.¹

A fair idea of the size as a whole is not given by the plate, the examples selected being simply to illustrate variation; they are considerably under the average.

SCULPTURE AND SALINITY.

The presence of sculptural characters in the *Physidae* is of rather rare occurrence, though frequently met with in many species of the *Limnæide*, which sometimes exhibit much diversity within quite limited geographical areas. While the Paludestrinæ of the desert are so conspicuous in prominence and diversity of sculpture, the Physas, on the contrary, show only the usual incremental lines more or less defined. The following species of *Physa*, as described by various authors,² are said to be sculptured: *P. costata* Newcomb, from Clear Lake, California;³ *P. lordi* Baird, Lake Osoyos, British Columbia; *P. vinosa* Gould, Lake Superior; *P. plicata* De Kay, Manhattan Island; *P. solida* Philippi, New Orleans.

In all of the foregoing, excepting Dr. Newcomb's *P. costata*, the sculpture consists either of fine liræ or indented grooving, which crosses the incremental striæ or lines of growth. This is what I have called *transverse* sculpture.

The elevation of Clear Lake is 1,350 feet, with an area of 80 square miles. It is subject to only slight fluctuations in volume.

The incremental striæ, though sometimes quite conspicuous, are ordinarily exceedingly fine or nearly obscure. They can only be regarded as sculpture in a negative sense. These are, of course, longitudinal, being parallel to the axis of the shell, or nearly so. In some instances "fine broken microscopic wrinkles parallel to the lines of growth occur," as mentioned by Philippi in his description of *P. mexicana*. *P. philippii* Küster is described as having "waving wrinkles."

Where these forms of sculpture are present the result is seen in a more or less finely decussated or reticulated surface, which may extend over a part or cover the entire surface of the shell, the latter rarely.

Dr. Newcomb's *Physa costata* is the only species which exhibits really conspicuous longitudinal sculpture. In this regard it is a remarkable exception to all others of the *Physidae*. It is a very pretty

¹ See Plate xxiv.

² See Binney's Land and Fresh Water Shells of North America, Part II, Smithsonian Miscellaneous Collections, p. 143.

³ Dr. Cooper, who collected some fifteen species of mollusks in Clear Lake, says: The borax, soda, alum, iron, sulphur, etc., found around the lake, do not affect the taste of the water, and do not seem to influence animal life except in limited spots where no mollusca are found, perhaps on account of subaqueous mineral springs. Proc. Cal. Acad. Science, IV, p. 154.

form, with ten to fourteen regularly occurring rounded undulations or ribs. Hemphill's *Pompholyx costata*, from near the Dalles of the Columbia River, has the same sculpture.

Another sculptural aspect that is not infrequently met with is what has been termed malleated.

De Kay's *P. plicata*, "in some specimens," exhibits "distinct square facets." *Physa carltoni* Lea, from near Antioch, at the junction of the Sacramento and San Joaquin rivers, is sometimes malleated. In *P. malleata* Tryon we have another illustration.

All of the various sculptural aspects above described occur also in the *Limnæide*, of which the following species may be named: *L. caperata*, *L. catascopium*, *L. columella*, *L. decollata*, *L. emarginata*, *L. elodes*, *L. lanceata*, *L. lepida*, *L. nuttalliana*, *L. palustris*, *L. sumassi*, *L. umbrosa*, and innumerable varieties or races of the above, and in Call's fossil *L. bonnerillensis*, from the quaternary of the Great Basin and his living *L. (Radix) ampla*, var. *utahensis* from Lake Utah.

It will be observed by reference to the descriptions of the many species of *Physa* herein quoted that no mention of salinity is made in connection with the waters in which the shells were found; the same remark also applies to the various species of *Limnæa* above named. Regarding the latter we find the longitudinal, transverse or spiral sculpture, the latter either incised or produced. The malleated aspect, etc., in *L. ampla*, and these in many and various aspects of differentiation in *Limnæa emarginata*, as may be seen in the National Museum (Cat. Nos. 123887 to 123894, inclusive).

In the large series from Eagle Lake¹ in central Minnesota, where neither saline or thermal conditions need to be considered, nearly all, if not all, of the sculptural characters that occur in the numerous species of *Physa* and *Limnæa*, above cited, are present, besides such features as relate to form and solidity.

The partially or wholly malleated surface so often met with in the *Limnæids* regardless of altitude or the salinity of the water, and less frequently in the *Physas*, is explainable by the character of the lake or pond bed in which these dented forms occur. The character of the bottom, even in a pond of limited size, often exhibits very considerable differences in the matter of compactness or density: alluvial mud, clayey mud, clay or sand, with fine or coarse gravel intermixed with fragments of aquatic plants and plant stems in varying proportions. The habits of these mollusks include, if not properly speaking burrowing, wallowing or submersion, and moving as they do with somewhat of a rotating motion, this, combined with the moderate impact of the surrounding matter, contribute to produce the malleated or dented surface, which frequently exhibits a somewhat spiral arrangement.

¹Proc. U. S. Nat. Mus., XXII, No. 1190.

The late Dr. James Lewis "attributed malleation to rapid growth in warm water, causing the shell to solidify unevenly. He also mentioned apparent metamorphoses of one species into another quite different, merely from change out of still canal water to that of a rapid brook."

Neither Dr. Lewis's hypothesis nor Call's *Limnea bonnevillensis* and the same author's variety *utahensis* of *L. ampla*, the latter occurring in an environment wherein salinity is a factor, are of much value as bearing on the phenomena of sculpture in these and related forms in the face of the Eagle Lake shells before referred to and Lea's *Physa carltoni* from near Antioch, at the junction of the San Joaquin and Sacramento rivers in California.

SCULPTURE AND THERMAL WATERS.

Physa frequently occurs in thermal springs or waters far above their ordinary summer temperature. Dr. Lea's *P. aurea* from Hot Springs, in Bath County, Va., included by Binney as a synonym of *P. heterostropha*, is an instance in point. Here waters of different temperatures come together forming a little stream—on one side of 106°, the other, 56°. Dr. Lea made no note of sculptural differences. Numerous examples of another form from a hot spring in Alameda County, California, examined by me, showed only fine growth lines. Dr. Merriam's specimens of *P. gyrina* from Hot Springs, Panamint Valley, California, "fine, large, dark-colored shells," exhibited no special sculptural features, and the same may be said of Bailey's examples of *P. heterostropha* from the same region. From the above we may conclude that sculptural character is not affected or developed by the thermal factor in springs, etc., and this is still further supported by the desert shells, which, outside of the hot springs, were subjected to the sun-heated waters of the shallow pools during the long and excessively hot summers of the desert region.

Incidentally, mention may here be made that the shells of *Physa* from thermal stations are noticeable for their fine texture, shining surface, and clear dark or light amber color.

SIZE AS RELATED TO HYPSONETRIC TEMPERATURES.

"Hypsometric distribution has received from conchologists," as Dr. Call has said, "much less attention than it apparently deserves. Within small areas, comparatively, there are presented by hypsometry those various physical conditions that must otherwise be sought through several degrees of latitude."

So it may be said that the paths of distribution of various living forms are along the lines of temperature, measurably, wherever such lines may lead, which may explain the southing of many so-called Northern species and the northing of so-called Southern forms, with

but little regard to lines of latitude. While altitude, which in this connection is equivalent to decreased temperature, has apparently no sculptural influence, it seems to bear a close relation to size in the *Physas*. That aspect of depauperation called dwarfing is shown in Call's (Table XIV) comparative measurements¹ of *Physa ampullacea* from Little Gull Lake, in the Mono Basin of California, altitude 7,000 to 7,500 feet, and Church Lake, near Salt Lake City, Utah, elevation about 4,300 feet, the ratio of lengths being $\frac{14.95}{12.97}$ and the ratio of widths $\frac{9.81}{8.45}$. The value of this comparison is impaired, first, because

the number of examples from these places is unequal, being only twelve from Gull Lake against eighteen from Church Lake, and, second, because a comparison of this kind to be satisfactory should embrace a much larger number of individuals.

As to the relation between depauperation and salinity, Call's table (XI) giving the measurements of thirteen examples of *Physa gyrina* from ponds near Salt Lake City, elevation about 4,500 feet, and thirty-nine specimens from brackish springs at Promontory, elevation 4,900 feet, the same objections apply. His tables (VI, VII, VIII, IX, X, and XI), based on comparative measurements of *Pompholyx effusa*, *Carinifer newberryi*, *Helisoma trivolvis*, *Limnophysa palustris*, and *Physa gyrina*, indicate, as he says, that "brackish water is correlated with depauperation."² While numerous examples of *P. gyrina* collected by Dr. C. Hart Merriam in Bennett Springs, Meadow Valley, Nevada, elevation 6,000 feet, and the large number (492) of *P. humerosa* from Pyramid Lake, 4,890 feet altitude, after comparison with Colorado desert shells of the same species, are affirmative testimony as to the dwarfing influence of higher altitudes (i. e., lower temperature), the desert shells being uniformly of larger size. This applies not only to the species just named, but to the desert *Physas* as a whole. Hypsometric or lower temperatures neutralized by thermal conditions, as related to size in the *Physas*, is illustrated by the examples of *P. gyrina* collected by Dr. Merriam at the Hot Springs in Panamint Valley, the shells being fine, large, and dark colored. Here the altitude above the level of the desert was not so very great, being about 1,500 feet. Call's Warm Springs, Utah, specimens of *P. gyrina* var. *elliptica* afford a similar illustration. "The variety" he says, "is found abundantly and of large size." The elevation of Warm Springs is over 3,800 feet.

From the consideration of the relations of sculpture to salinity and to thermal waters, of size in connection with hypsometric distribution, variation in form as related to environment attracts attention.

¹A comparison between forms from high altitudes with those from stations nearer to the level of the sea would be more satisfactory than that above quoted, where both localities are mountain stations.

²This point discussed elsewhere.

VARIATION IN FORM.

The *Physas* of the desert, however affected by the environment, in the matter of sculpture are absolutely wanting in the characters so conspicuous in the *Paludestrinae*. Evidence of hybridization is at once suggested when a large number of individuals is compared. Distortion and pathologic deformity are of frequent occurrence, and are exhibited in the strong shouldering of the basal whorl and the bulging of the latter, which is not uncommon, as in certain California species of *Limnaea* from sweet waters. This aspect of deformity may be attributed to abundance of food supply, resulting in hypertrophy of the viscera. The surface of the shells may sometimes be uneven and the incremental striae be coarse, as the whole is heavier than is usual in the shells of this genus from ordinary localities or stations. These characteristics are apparently due to the environment, but sculpture in the proper sense is not manifest. The excess of mineral matter in the waters is exhibited in greater solidity and a sturdier growth.

The *Physas* of the Great Basin from the extreme north to the Colorado River and beyond show a notable tendency to shortness of spire and shouldering or symmetrical bulging and flattening of the upper part of the basal whorl. These characters, when pronounced, approach distortion. Normal or typical individuals of *P. humerosa* exhibit these features moderately. *P. virgata* Gould, from the River Gila and near San Diego and at Los Angeles, a not remote neighbor of *P. humerosa*, which may be regarded as a less chunky aspect of the latter, show these peculiarities still less. Both *P. heterostropha* and *P. gyrina*, if these may be called different species, in some localities within the area above mentioned show moderate tabulation of the basal volution, with spires of variable height. *P. lordi*, sparsely represented in the Great Basin, is a conspicuous illustration of the low-spired ventricose body whorl type.

In this connection attention is called to figs. 1 to 10 on Plate XXIV, and the modification of the shell through hypertrophy is forcibly suggested by some of the figures on the same plate.

A glance at Plate XXIII and a comparison of the figures therein exhibits the range of variation from the low-spired, rather chunky shells of *P. humerosa* 1 and 10 to the elongated forms (approaching *P. gyrina*) *P. virginea* 53, 55, and 56, while 18, 23, and 26 may be assigned to *P. mericana*. In fig. 29 we have a typical *humerosa*. Figs. 51 and 54 may be regarded as robust examples of *P. heterostropha*, while hybridization is suggested by many of the intermediate forms not specified above.

Cooke gives several figures¹ illustrating the effect of salinity upon *Limnaea peregrina* and *L. stagnalis* from the salt marshes near the sea

¹ Cambridge Natural History, III, 1895, p. 85.

of Aral, and our desert *Physa* exhibit similar, if not as extreme, distortion. With the latter, as heretofore intimated, the abnormalities are quite as likely to be due to visceral hypertrophy through overfeeding as to the salinity of the waters.

To illustrate any species of *Physa* by a single figure is, in the present state of our knowledge of the susceptibility of the mollusks of this family to environmental influences, quite an absurd thing to do. While the shells of a colony of any one species inhabiting a spring or pool of limited area might be nearly or quite uniform in size, shape, texture, and color, another colony of the same species not very far distant, at a slightly higher or lower elevation, may present very considerable variation in one or more of these characters.

This variation or tendency thereto is sometimes exhibited when a large number of individuals are brought together from a pond or spring of large area where the volume of water is subject to seasonal mutations. Binney in illustrating *Limnaea palustris*¹ and certain other species of this genus has very properly given several figures. The same course is necessary in the *Physas*.

In Plate XXII, which follows, may be seen the figures of the types of several species, as given by Binney,² which will facilitate comparison with the figures in Plate XXIII and enable the student to draw his own deductions, though, as before stated, no species of *Physa* can be satisfactorily illustrated by a single figure, however accurately drawn.

The following notes have reference to the figures on Plate XXIII:³

- No. 7. Upper part of basal whorl extremely tabulated; variation from *P. humerosa*?
- No. 8. Basal whorl flattened; apex depressed and short; the same features less pronounced exhibited in 9 and 10.
- No. 11. Apex short; basal whorl rounded.
- No. 12. Much like a large ten; apertures patulous and reflected below.
- Nos. 21, 27, 28, and 49. Outer lip pinched above and sinuous.
- Nos. 28, 39, 46, and 47. Heavily calloused on body whorl, forming with the outer lip a nearly continuous rim.
- No. 33. Anterior portion of aperture or lip thrice repeated; see also fig. 4 in Plate VI.

Through the courtesy of the Secretary of the Smithsonian Institution the author has been permitted to use the cuts in Plate XXII; he is also indebted to Prof. W. H. Dall and Mr. C. T. Simpson of the U. S. National Museum for kind attention to various matters on several occasions.

¹ Land and Fresh Water Shells of North America, Part II, p. 47, and elsewhere.

² Idem, p. 75, et seq.

³ The majority of the forms have been compared with material in the National Museum; those not referred to in the index or notes are left to the judgment of the reader. Many of the determinations may be regarded as arbitrary; criticism on this point is excusable.

THE PLANORBES.

Of the numerous species of *Planorbis* inhabiting North America, the larger forms occur west of the Rocky Mountains and north of lat-

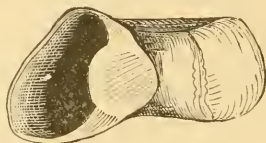


FIG. 7.—*PLANORBIS TRIVOLVIS*
Say (original).

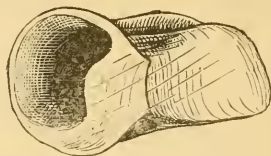


FIG. 8.—*PLANORBIS TRIVOLVIS*
Say, distorted (original).

itude 30° N. Thus we find *P. (Helisoma) trivolvis* of conspicuous size, as is shown by the accompanying figures. These represent examples from the cool waters of mountain lakes where the elevation is about 5,000 feet.

Another characteristic form peculiar to the West coast is *P. (Helisoma) ammon*. The metropolis of this species is apparently the Colorado Desert where, as previously stated, it is found in the greatest abundance. It is distinguished not alone by its rugged and rather irregular growth, but by the mass of the soft parts as seen in living examples, which probably exceeds that of any other species. In the case of this form we find it scattered over a large area at 200 feet below the level of the sea, where the waters of contiguous springs have a temperature of 100° F.

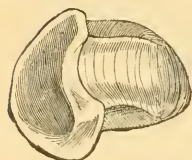


FIG. 9.—*PLANORBIS*
AMMON (Gould).

These forms exhibit a swollen ventricose irregularity and patulous expansion of the aperture attributable to visceral hypertrophy, quite as likely as to salinity, and the distortion of the example of *P. trivolvis*, above figured, is presumably due to the same cause, as the specimen was collected in the sweet

waters of a mountain lake.

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EXPLANATION OF PLATES.

The figures are all largely magnified. The length of the actual specimens, Nos. 1 and 2, are respectively twenty and sixteen hundredths of an inch; the diameters of the same, nine and six hundredths of an inch. The robust example, 18, is 0.23 by a diameter of a trifle over 0.1 of an inch. These dimensions exceed the average of any large number of shells. Particular attention is called to the variation in size and form of the aperture. The figures were all drawn by Dr. J. C. McConnell, whose skill and taste are too well known to require praise.

PLATE XIX.

Paludestrina protea Gould.

Slender, elongated forms with rounded whorls.

- Fig. 1. Whorls smooth, without sculpture.
 2. Same as above, dwarfed form.
 3. Whorls spirally threaded or lirate.
 4. Shorter form of same.
 5. Middle whorls cancellated, basal whorl threaded sculpture only.
 6. Longitudinal sculpture strongest throughout.

PLATE XX.

Paludestrina protea Gould.

Whorls angulated or tabulated above.

- Fig. 7. Surface smooth, upper portion of whorls angulated.
 8. Surface smooth, strongly angulate (unique example).
 9. Robust form slightly angulated above and faintly threaded.
 10. Rather slender form, strongly angulated and conspicuously threaded.
 11. Whorls flattened or tabulated above, and faintly threaded throughout (unique example).
 12. Whorls angulated above, basal and penultimate whorl, faintly threaded. The two whorls above these sculptured both ways; the mouth rimmed and reflected (a very rare form).

PLATE XXI.

Paludestrina protea Gould.

- Fig. 13. Whorls angulated above and exhibiting the two systems of sculpture, which in the middle whorls are subnodose at points of crossing.
 14. Longitudinal sculpture strongest; plications on middle whorls less numerous and farther apart than on basal whorl.
 15. Short form, with strongly latticed sculpture on principal whorls.
 16. Whorls angulated above, sculpture like middle whorls of thirteen.
 17. Robust form, angulated above, faintly threaded; longitudinal sculpture consisting of rather inconspicuous rounded swollen plications.
 18. Robust, angulated above, the middle of the whorls sculptured both ways, the lower part of basal whorl faintly sculptured transversely.

The various examples above figured are connected by an endless chain of intermediate forms.

PLATE XXII.

Recognized species of *Physa*.

The figures on this plate are taken from Binney's Land and Fresh Water Shells of North America, Part II, Smithsonian Institution Miscellaneous Collections No. 143, Washington, September, 1865. The numbers in parentheses and the page numbers correspond with those in the above publication.

- Fig. 1 (127). *Physa lordi* Baird (p. 76).
 2 (128). *Physa gabbi* Tryon (p. 77).
 3 (129). *Physa gabbi* Tryon (p. 77).
 4 (130). *Physa gyrina* Say (p. 77).
 5 (133). *Physa ampullacea* Gould (p. 79).
 6 (134). *Physa ampullacea* Gould (p. 79).
 7 (135). *Physa ampullacea* Gould (p. 79).
 8 (139). *Physa ancillaria* Say (p. 81).
 9 (140). *Physa obesa* De Kay (p. 82).
 10 (142). *Physa osculans* Haldeman (p. 83).
 11 (143). *Physa mexicana* Philippi (p. 83).
 12 (144). *Physa heterostropha* Say (p. 84).
 13 (146). *Physa osculans* Haldeman (p. 85).
 14 (156). *Physa virginea* Gould (p. 92).
 15 (157). *Physa humerosa* Gould (p. 92).
 16 (158). *Physa virgata* Gould (p. 93).
 17 (168). *Physa nitens* Philippi (p. 98).

PLATE XXIII.

Variations of desert *Physidæ*.

- Figs. 1, 2, 3, 5, 10, 17. *P. humerosa* and ordinary varieties.
 7. *P. humerosa*, extreme variation.
 29. *P. humerosa*, typical; compare with Binney's fig. 157.
 14, 16, 17. *P. humerosa*, unusually large.
 44, 46, 50, 52. Compare with *P. ampullacea*, Binney's 133.
 53, 55, 56. *P. virginea*; compare with Binney's 156 and same author's 129, *P. gabbi*.
 24. *P. mexicana*; compare with Binney's 139, *P. ancillaria*.
 6, 8, 9. *P. humerosa*, abnormal, very short apex, etc.
 24, 26. *P. mexicana*, nearly or quite typical; see Binney's 143.
 13, 18, 22, 23. *P. mexicana*, ordinary varieties.
 8, 27. Hybrids of *humerosa* and *mexicana*, or varieties of either.
 54. *P. heterostropha*, robust form, approaching *ampullacea*.

PLATE XXIV.

Variations of desert *Physidæ*.

The figures in this plate, illustrating diversity of form, were drawn by the author from specimens collected by Prof. George Davidson¹ at or near Indio in 1883, and referred to on page 290 as a "first series." The shells are now unfortunately misplaced or destroyed; but the drawings were made soon after they were received.

Fig. 1 is very near to fig. 7 in Plate XXIII and represents an extreme variation from *P. humerosa*.

3 is unique in being the only specimen of this form or shape.

4 may be compared with fig. 33 of Plate XXIII, showing a triple repetition of the anterior part of the aperture.

5-10. Varieties of *P. humerosa* or *P. mexicana*, or hybrids of the two species.

11. Another rare variety; should be compared with *P. osculans*, Binney's 142.

12, 13, 13a, 14, 14a, 14b. Varieties of *P. heterostropha* from sweet water.

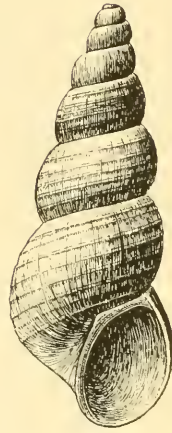
¹ American Naturalist, October, 1883, p. 1014 et seq.



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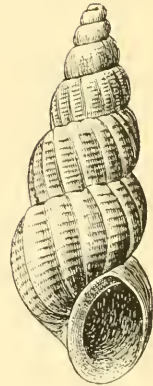
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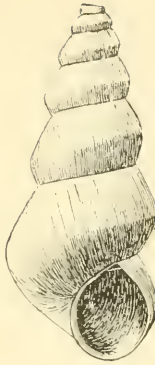
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VARIETIES OF *PALUDESTRINA PROTEA* GOULD.

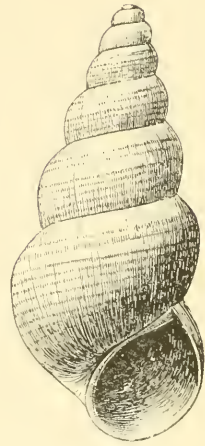
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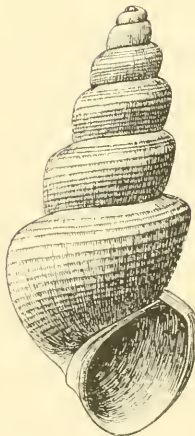
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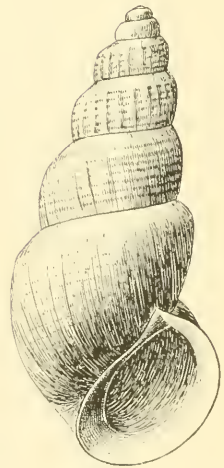
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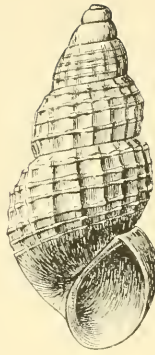
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VARIETIES OF *PALUDESTRINA PROTEA* GOULD.

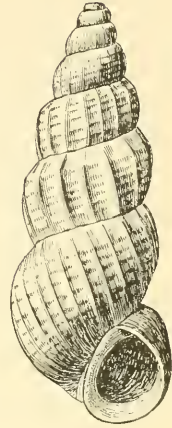
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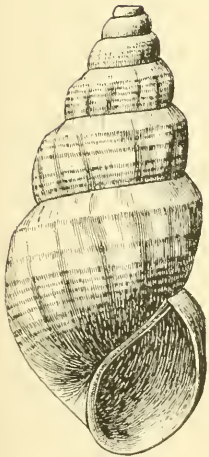
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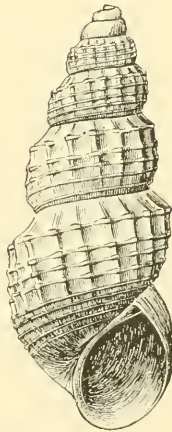
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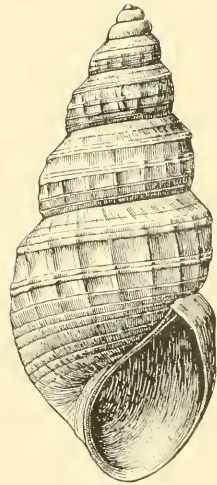
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18

VARIETIES OF *PALUDESTRINA PROTEA* GOULD.

FOR EXPLANATION OF PLATE SEE PAGE 298.



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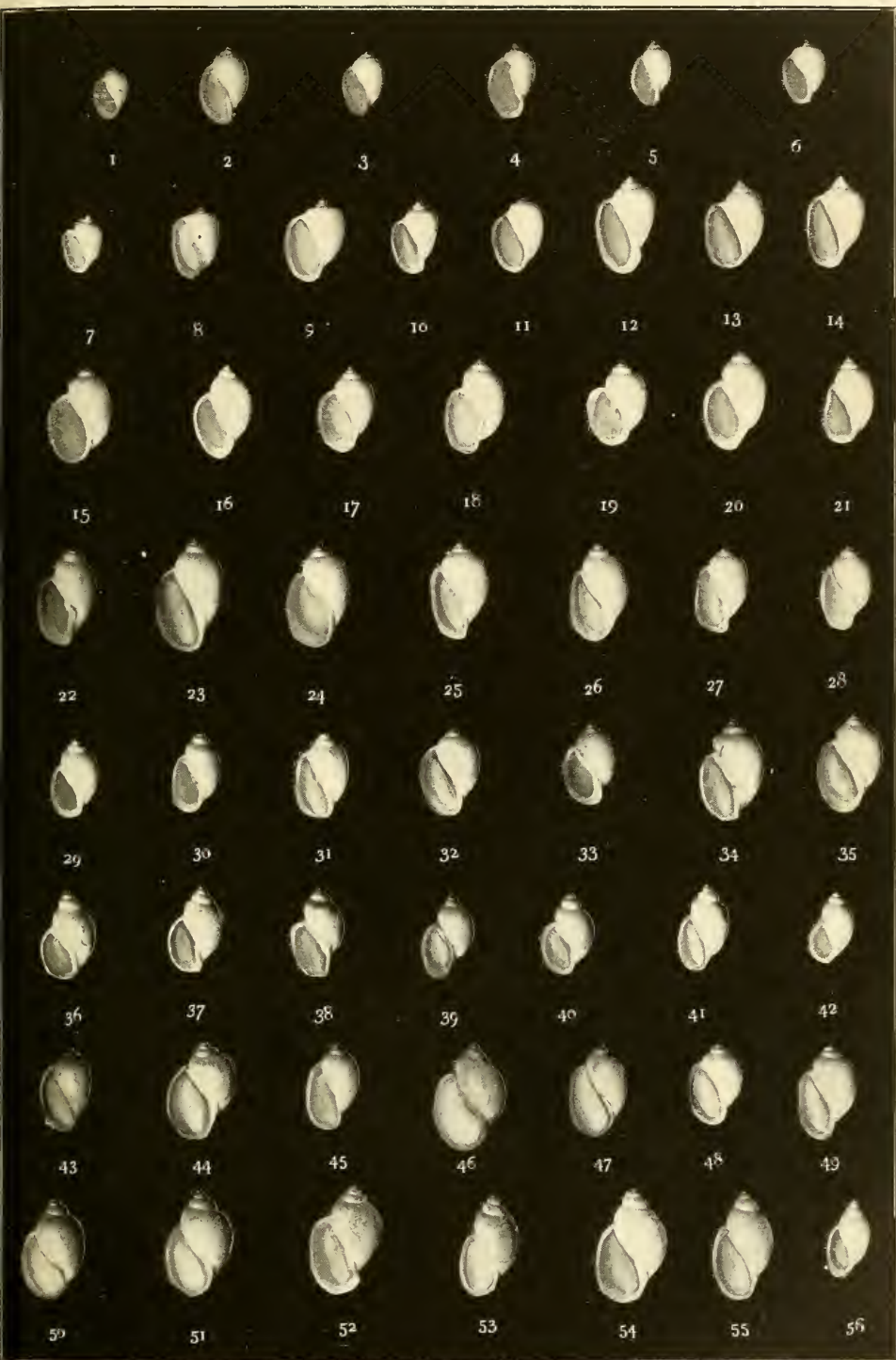
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17.

AMERICAN SPECIES OF PHYSA

FOR EXPLANATION OF PLATE SEE PAGE 299



VARIATIONS OF DESERT PHYSIDÆ.

FOR EXPLANATION OF PLATE SEE PAGE 299



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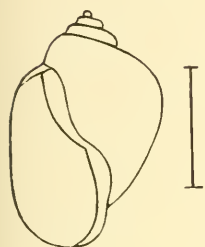
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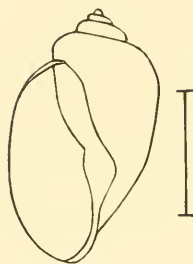
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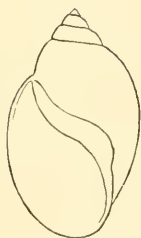
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13a



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14a



14b

VARIATIONS OF DESERT PHYSIDÆ.

FOR EXPLANATION OF PLATE SEE PAGE 299.

