Imperial Group invertebrate fossils Part 1: The science of the proto-gulf

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Introduction

The region of the Colorado Desert from which Imperial Group fossil invertebrates are observed and collected (where legal) is a place of spectacular beauty. Weathered mountains, hills and badlands, seemingly barren, come into a life of their own in the play of light under all kinds of conditions – stormy to sunny days. The pastel purples and golden tan of the Santa Rosa range in the morning hours are often transformed by the day's end to a fiery orange glow in the light of the setting sun and coming of dusk. A unique character is carved into the landforms of this region in steep canyon walls and wrinkled bluffs. In some places the buried fossils have contributed to this shaping of the landscape. Hardened beds of abundant oysters, sometimes several feet thick, resist erosion, and leave behind unique structures. Buried in this desert, the fossil invertebrates reveal the existence of the northern end of an ancient inland sea: the prehistoric Gulf of California (often called the proto-Gulf). These buried and exposed fossil invertebrate communities have recorded the environment of this ancient sea.

An understanding of the prehistoric proto-Gulf may be had by exploring the modern Gulf of California. Here are many environments, from long sandy stretches of shore, to boulder beaches, coves, hidden bays, and estuaries, including salt marshes in the north end of the gulf gradually replaced by mangroves to the south. There are corals in the gulf, but nowhere forming true reefs, except at El Pulmo, near the southernmost end of Baja California.

History of Gulf of California explorations

It is worthwhile to examine the history of exploration in the present day Gulf of California to understand our present state of knowledge about the organisms living there. Studies of the fossil invertebrate species of the Imperial Group are based on historical research of the same or closely related living species in the Gulf of California, as well as the Caribbean Sea. For centuries, ships have sailed the oceans of the world, but prior to the last century, relatively little scientific attention was paid to marine organisms. The Galapagos Islands were an exception. In 1826, the pioneer conchologist Hugh Cuming set out from Valparaiso, Chile on the yacht *Discoverer*. Five of the Galapagos Islands were on the itinerary, according to the *Report of the British Association for the Advancement of Science* for 1856. Cuming's collections of crustaceans and mollusks were extensive and contained a high proportion of species new to science. From the point of view of scientific exploration, the year 1835 stands out by itself. In that year the Beagle sailed northward along the coast of Chile and Peru and west to the Galapagos, with Charles Darwin on board. Although his observations were primarily on terrestrial species, with the birds taking much of his attention, marine shells from the beaches and fish from the sea comprise his contribution to marine zoology (Fraser, 1943).

In the last century, more attention was given to the Gulf of California as numerous scientific expeditions were sent there to explore the islands, marine depths and shores. Every kind of marine and land organism was collected. Each expedition tended to have a different study purpose or collecting scheme. For example, dredging was prevalent in some, whereas shore exploration or studies of terrestrial life were emphasized during others. Some expeditions studied and collected more land life, and other expeditions specialized in marine organisms.

One of the earliest expeditions of the past century into the Gulf of California was the 1921 California Academy of Sciences expedition aboard the 22-ton gasoline schooner *Silver Gate* (Williams, 2007). The ship carried a crew of four and the captain, John Ross. Also on board were eight scientists from the California Academy of Sciences and other California academic institutions, as well as the Museo Nacional de Mexico. Among the scientists was Dr. Fred Baker of Point Loma, California, Department of Paleontology. The purpose of the expedition was to make as comprehensive and thorough study of the fauna and flora of the islands in the Gulf, and of localities on the adjacent mainland, as time, funds, and weather conditions permitted (Slevin, 1923). Fraser (1943) noted that a good map of the Gulf of California was published in Slevin (1923), but erroneously stated the collecting was entirely terrestrial. Steinbeck and Ricketts (1941:170) referred to the 1921 California Academy of Sciences expedition as a "well known scientific expedition into the Gulf, about thirty years ago." They noted that the expedition collected 31 shallow water species of echinoderms from inside the Gulf and after only nine days of collecting in the Gulf, they had taken nearly double this total number of species.

From December, 1931 to March, 1941, a series of ten expeditions aboard the *Velero III* was funded through the Allan Hancock Foundation of the University of Southern California. These expeditions explored the eastern subtropical Pacific (southern California and northern Baja California) and tropical Pacific (southern outer coast of Baja California through the Gulf of California, to the west coast of Mexico and Central America). The paleontologist Leo H. Grant, of the California Academy of Sciences, was on the first expedition. Scientific reports followed these studies, published by the University of Southern California Press. The introduction by Fraser (1943) provides a good history of exploration of the tropical Pacific, from the nineteenth century to the time of the Allan Hancock Pacific Expeditions, but provides little detail about these later expeditions. At the time, Steinbeck and Ricketts (1941) valued this information, but lamented the cost and lack of availability of the reports. The motor cruiser *Velero III* was presented to the University of Southern California as floating research laboratory in January, 1939 (Fraser, 1943).

The Scripps Institution of Oceanography and the U.S. Geological Survey jointly sponsored another study. From October 5 to December 22, 1940, the auxiliary research schooner *E. W. Scripps* made a scientific cruise to the Gulf of California. The paleontologist J. Wyatt Durham joined the expedition in Guaymas, Mexico. Fossil invertebrates from the late Pliocene to early Pleistocene were collected from about 100 localities,between San Carlos Bay on the south and Angel de la Guarda Island on the north. All localities, except three on Tiburón Island, were collected along the eastern edge of Baja California, on the west side of the Gulf. The invertebrate species collected included pelecypods, gastropods, echinoids, corals, and barnacles (Durham, 1950).

One of the best known expeditions into the Gulf of California was not sponsored by a scientific institution, but rather was the idea of marine biologist Edward F. Ricketts and fiction writer John Steinbeck. Their adventure was driven by a shared desire to learn about the tide pools and marine organisms to be found along the shores of the Gulf. They left Monterey harbor on March 11, 1940 on the 75 foot long purse seiner *Western Flyer*, returning on April 13, after observing and collecting marine organisms along the western side of the Gulf of California. Their work is recorded in the book *The Sea of Cortez* (Steinbeck and Ricketts, 1941); including photographs and drawings, as well as a few color plates of marine life they collected and studied. Copies of this work are not easily obtained. The narrative portion of the book, the *Log from the Sea of Cortez* was later published without the figures and appendix of the original, and stands alone as an enjoyable account of exploration of marine life in the gulf (Steinbeck, 1951). The marine organisms collected by Steinbeck and Ricketts include newly described species, and the collections are currently stored and maintained by the California Academy of Sciences, where the collections of the 1921 *Silver Gate* expedition are also maintained.

An expedition sponsored by the San Diego Natural History Museum and the Belvedere Scientific Fund began from Bahía de los Angeles, Baja California on March 15, 1962 and concluded at La Paz, Baja California on April 21, 1962. On board the expedition's ship *San Agustín II* was William K. Emerson, chairman of the Department of Living Invertebrates, of the American Museum of Natural History. Fossil invertebrates; mostly mollusks, echinoids and corals, were collected (Emerson and Hertlein, 1964).

All of this exploration resulted in an increased knowledge of living and fossil invertebrates of the Gulf of California. Scientific journal articles provided the foundation that specialists eventually could build on. Two excellent references to marine invertebrates of the gulf are *Seashells of Tropical West America,* 2nd edition (Keen, 1971), and *Common Intertidal Invertebrates of the Gulf of California,* 2nd edition (Brusca, 1980). Marine invertebrates of the tropical Pacific are very closely related to species of the Caribbean Sea because they share ancestors from only a few million years ago when the ocean on both sides of Central America was connected (see discussion below, Caribbean connections). References on western Atlantic invertebrates are essential for comparison of some of the fossil ancestors in the Imperial Group of the Colorado Desert region. *American Seashells*, 2nd ed., by R. Tucker Abbott (1974), is highly recommended. This book covers North American mollusks and is an excellent reference to species from the Caribbean region.

History of paleontological research

At the beginning of the last century, relatively few scientific collections of modern invertebrates from the Gulf of California could be used for comparison with the related fossil species of the Imperial Group. Good collections of very similar modern tropical Atlantic invertebrates were available at this time, and might have been used for comparison and identification of the fossil species in the relative absence of modern examples from the tropical Pacific. However, the Atlantic species are generally not as closely related to the Imperial Group fossil species as are those from the Gulf of California.

Paleontologists realized that the invertebrate fauna needed for critical comparison was only to be obtained in the Gulf of California. G. Dallas Hanna, curator of the California Academy of Sciences, withheld his publication on the Imperial Group fossil species until the Academy sent its expedition there in 1921 (Hanna, 1926). This prevented a considerable number of inaccuracies which would have been inevitable had the report been published in 1921 and identifications were made more from Atlantic species than Pacific species.

Hanna's publication remains a good reference to Imperial Group invertebrate fossils; with 10 plates that illustrate mostly mollusks (one echinoderm test and one shark tooth are pictured). Descriptions of additional species of corals and echinoderms known from the time are given in the text. He described new species of mollusks, including Cassis subtuberosa, *Turritella imperialis*, and *Pecten* (*Chlamys*) *mediacostatus*. Hanna proposed the name "Imperial Formation" for the fossil coral reef beds around the Coyote Mountains. The designation "Imperial Group" is now used as a collective term for these tropical marine late Miocene to mid Pliocene fossil beds of the Salton Trough (Winker and Kidwell, 1996). Hanna also referred to the mollusk-rich sandstones of the region, derived from clear ocean waters of the proto-Gulf, as the "Latrania Sands." Today we refer to this deposit as the Latrania Formation. Hanna's contemporaries contributed significantly to our knowledge of the invertebrate fossils of the region of Anza-Borrego Desert State Park and the Coyote Mountains, including work on pectens by Ralph Arnold (1906), echinoderms by Kew (1914), and on corals by T.W. Vaughan (1917). Hanna's paper gives a very good historical account of these and other paleontologists who studied the Imperial Group fossils. We are indebted to this early research for our present day understanding of the marine deposits and invertebrate fossils of the region of the Salton Trough, throughout the Gulf of California, and north to the San Gorgonio Pass, where deposits from the northernmost extension of the proto-Gulf crop out. A few examples of more recent research include; a study of tropical marine fossil species from Miocene deposits in Baja California related to species of the Imperial Group (Smith, 1984), a study of giant pecten species from the California and the Tertiary Caribbean province (Smith, 1991a.), and Pliocene invertebrates from Travertine Point, Imperial County, California, just west of the Salton Sea (Powell, 2008).

Caribbean connections

During the time the Imperial Group invertebrate fossils were deposited, the eastern Pacific Ocean was connected with the Caribbean Sea through openings in the Central American land bridge. The fossil record indicates that the maximum extent of this Tertiary Caribbean fauna occurred during the Miocene. The distribution of fossil assemblages and radiometric data also show that an early gulf, similar in extent to the present one, existed as early as 13 million years ago. By the late middle Miocene the Gulf of California extended as far north as the Salton Trough, as indicated by Imperial Group invertebrate fossils at San Gorgonio Pass, California. Evidence from foraminifera, vertebrate, and sedimentology studies suggest that the connections between the Caribbean Sea and the eastern Pacific remained open until the middle Pliocene, 3.5 to 3.1 million years ago (Smith, 1991b.)

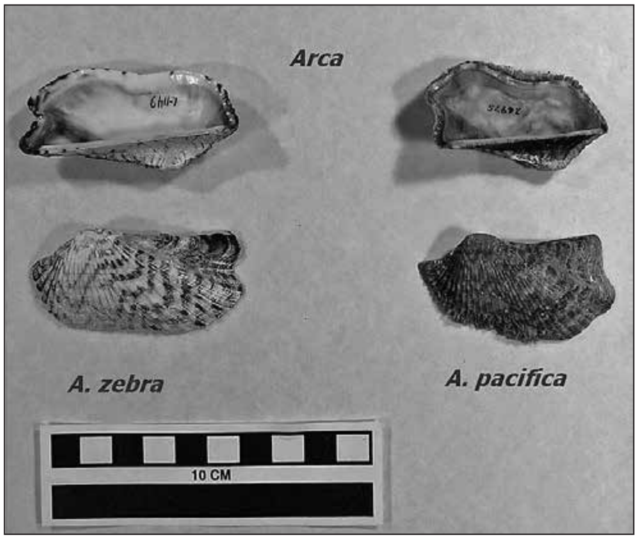

Figure 1-1. Ark clams; *Arca zebra* from the tropical west Atlantic (left), and *A. pacifica* from the Gulf of California (right). Photo by Lollo Enstad.

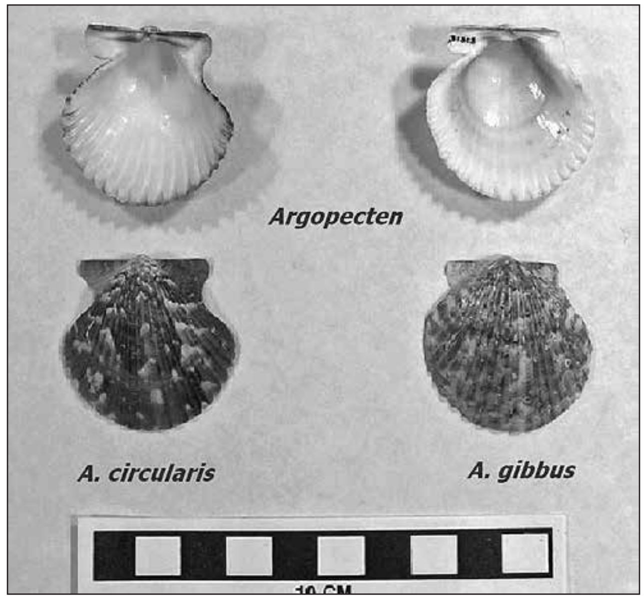

Figure 1-2. Bay scallops; *Argopecten circularis* from the Gulf of California (left), and *A. gibbus* from the tropical west Atlantic (right). Photo by Lollo Enstad.

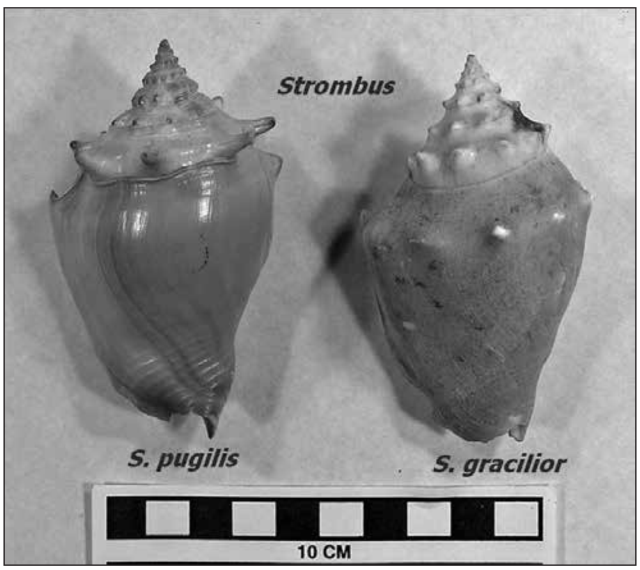

Figure 1-3. Fighting conches; *Strombus pugilis* from the tropical west Atlantic (left), and *S. gracilior* from the Gulf of California (right). Photo by Lollo Enstad.

In *The Sea of Cortez* (Steinbeck and Ricketts, 1941), the writers found a small statue of a Virgin Mary figure, "Our Lady of Loreto," in a church. They spoke of her with a scientific reverence, and observed that the Lady of Loreto was a very important factor to the community of the city, and that "not to know her and her strength is to fail to know Loreto." This observation was followed by a remarkable analogy to the Virgin figure:

> One could not ignore a granite monolith in the path of the waves. Such a rock, breaking the rushing waters, would have an effect on animal distribution radiating in circles like a dropped stone in a pool.

This passage is like a metaphor for the closing of the Central American seaway during the middle Pliocene. The closing of the openings between the Pacific and Atlantic oceans—a relatively recent event —resulted in a large scale evolution of descendent species pairs of invertebrates, fish, etc. through the process of allopatric speciation. Today we observe the existence of species "twins", with one species in the tropical eastern Pacific, and the other species in the western Atlantic. For example the most common large sea biscuit (Family Clypeasteridae) of the tropical Atlantic, *Clypeaster rosaceus*, closely resembles the Imperial Group fossil *Clypeaster bowersi*, though the later species tends to be more rotund than the former. The Imperial Group coral *Solenastrea fairbanksi* is very similar to the modern coral *Solenastrea bournoni* from the Caribbean. Three examples of mollusk species pairs are figured; ark clams (Family Arcidae, Figure 1-1), bay scallops (Family Pectinidae, Figure 1-2, and conches (Family Strombidae Figure 1-3)

While the majority of fossil species from the Imperial Group clearly are most closely related to the fauna of the modern Gulf of California, there are notable examples of species that seem to have a closer affinity to modern Caribbean species. All fossil

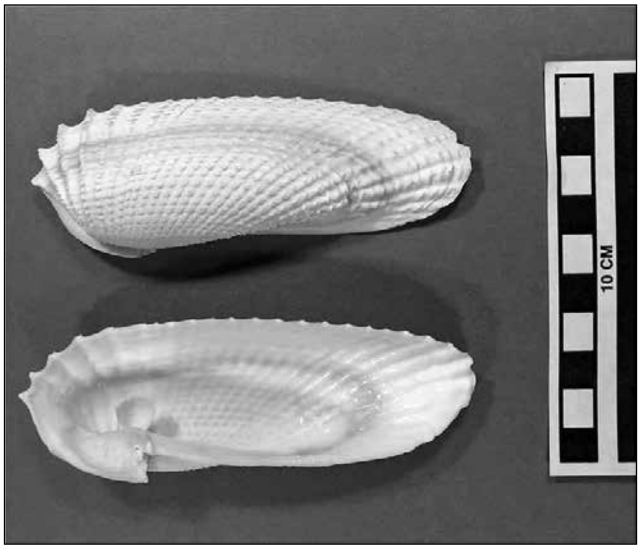

Figure 1-4. A modern angel wing, *Cyrtopleura costata*. This species is extinct in the east Pacific, but internal mold fossils of this bivalve are common in the Deguynos Formation. Photo by Lollo Enstad.

Figure 1-5. An internal mold of the fossil helmet snail species *Cassis subtuberosus* (left) with a similar sized modern shell of the Caribbean *Cassis flammea* (right). Photo by Hugh Vance

specimens figured are from the Kidwell Collection, discussed in Part II:

Cyrtopleura costata is common in the Deguynos Formation. This species is not present in the gulf today but lives deeply buried in the muds of mangrove estuaries in Florida and the Caribbean. (modern specimen, Figure 1-4).

The only helmet species (Family Cassidae) in the Gulf today are the small forms *Cypraecassis (Cypraecassis) tenuis* and *Cypraecassis (Levenia) coarctata*. Today, there are no species of *Cassis* in the tropical eastern Pacific, but there are three species in the Caribbean. Hanna considered the Imperial Group species *Cassis subtuberosa* to be most closely related to the Atlantic species *Cassis tuberosa*. However, *C. subtuberosa* was a relatively small species, not often exceeding 10 cm, and compares well with the smallest Atlantic species *C. flammea* (Figure 1-5).

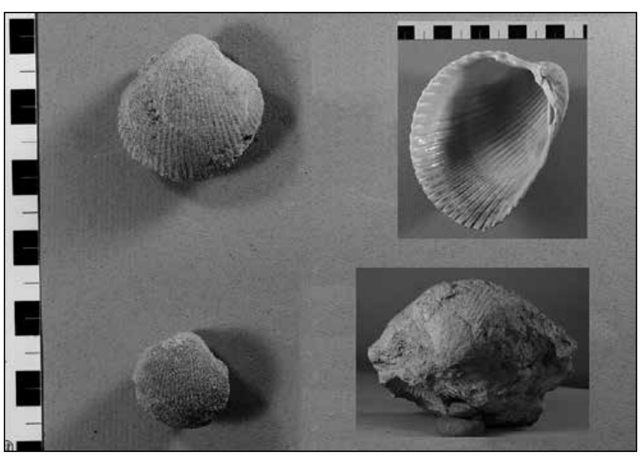

Figure 1-6. Juvenile internal molds of cf. *Dinocardium* sp (left) and a large (over 10 cm long) right valve internal mold (insert, lower right). A modern *Dinocardium robustum* right valve from the west tropical Atlantic is shown for comparison (insert, upper right). Photo by Hugh Vance.

The pecten *Euvola keepi* of the Imperial Group more closely resembles the Caribbean species *Euvola ziczac* than any living Gulf of California species.

The Imperial Group fossil pecten *Lindapecten corteziana* closely resembles the southeast Atlantic pecten *Aequipecten muscosus*, with about 18 scaly ribs, and a noticeably long anterior ear on the right valve.

The presence of the common large cockle cf. *Dinocardium* sp. in the Imperial Group collections is surprising. This genus occurs today on the Atlantic coast, not the Pacific Coast. Fossils match well with the modern *Dinocardium robustum* (Figure 1-6). This bivalve genus does not appear to have been described from the Imperial Group. There are many examples in the collection ranging from juveniles a few centimeters long to a very large steinkern valve over 10 cm long.

Figure 1-7. The rare extinct auger, *Terebra gauspata*, preserved with original calcitic shell. Note the clearly defined spiral groove. Photo by Hugh Vance.

Hanna (1926) observed the auger species *Terebra gauspata* more closely resembles *T. dislocata* of the Atlantic coast than its contemporary, *T. martini*, of the Pliocene of coastal southern California (Figure 1-7). *Terebra gauspata*, like *T. dislocata* has a deep groove high on the whorls that is not present in *T. martini*.

The gastropod *Architectonica nobilis* is present on both the Atlantic and Pacific coasts, and occurs as a fossil in the Imperial Group.

Living species give clues about the fossil environment

Different species may tell us about differences in the marine environment. The bay scallop, *Argopecten deserti* (Figure 1-8) resembles the modern species *A. circularis,* which is most common in eelgrass beds in calm bays. The fossil species *A. deserti* is very common in the Deguynos Formation, along with *Dendostrea*? *vespertina* and *Anomia subcostata*. These species lived on the flats of a vast estuary. *Argopecten deserti* closely resembles the Pliocene species *A. invalida* of the San Diego Formation (see Hertlein and Grant, 1972). The giant bittersweet, *Glycymeris gigantea* (Figure 1-9) is a thick-shelled, heavy clam that lives buried only a few cm in sand. The ark clam, *Arca pacifica* (Figure 1-10), lives in rocky areas, and attaches to the undersides of rocks with byssus threads. Another bivalve that lives in rocky areas but in deeper water, often attached to gorgonian corals, is the winged pearly oyster *Pteria sterna* (Figure 1-11). This bivalve is a tropical species that may be found as

Figure 1-8. Fossil bay scallop *Argopecten deserti* with the common oyster *Dendostrea? vespertina* attached, from the Deguynos Formation. Both species are preserved as original calicitic shell. The closely related modern *A. circularis* (right) from the Gulf of California is shown for comparison. Photo by Hugh Vance.

Figure 1-9. A modern giant bittersweet, *Glycymeris gigantea* from the Gulf of California, with a paired internal mold fossil (left). Notice the fragment of calcitic shell on the right side of the fossil pair. Photo by Hugh Vance.

Figure 1-10. A modern *Arca pacifica* pair (top), and two internal mold fossils (bottom). The specimen on the lower left shows the hinge side. Photo by Hugh Vance.

Figure 1-11. Fossil left valve of the winged pearly oyster, *Pteria sterna*, on a block of matrix. The valve is eroded and difficult to discern from the matrix, so it has been outlined in the photo. The tropical west Atlantic *Pteria colymbus* from Eleuthera, Bahamas (right) is shown for comparison. Photo by Hugh Vance.

Figure 12. A modern young specimen of the spiny jewel box, *Arcinella californica*, collected from off Cedros Island (southern Baja) next to an internal mold fossil adult pair (right). Photo by Hugh Vance.

far north as the southern coast of California, where stormy weather occasionally tosses one ashore with the red gorgonian corals they live on. The fossil valve of *Pteria sterna* is shown next to its Caribbean counterpart, *P. colymbus* (Figure 1-11). This is the only specimen in the Kidwell collection and may be the only example from the Imperial Group. Steinkerns of the spiny jewel box *Arcinella californica* look very different from the modern shell (Figure 1-12). This is because the internal mold only shows the form of the inner cavity of the shell and not the spiny outer surface. This species glues its lower valve firmly to subtidal rocks.

Conclusions

Fossil invertebrates are a common feature in the Colorado Desert. The presence of corals and large tropical gastropods and bivalves, among other kinds of invertebrates, are evidence that this region was once a prehistoric northern extension of the Gulf of California, often referred to as the proto-Gulf. The sediments in which these fossil invertebrates occur range in age from the late Miocene, when the environment was predominately a clear water tropical sea rich in marine species, to the mid Pliocene, when this sea was replaced by a vast shallow-water estuary with few species and abundant individuals. These deposits are collectively referred to as the Imperial Group. The similarity of living invertebrate species between the Gulf of California and the Caribbean, and the information from the fossil record from this region has provided evidence that these seas were connected in the late Miocene through the mid Pliocene through openings in the Central American land bridge. The present state of knowledge about the geological history of this desert region draws on the scientific history of exploration of the modern biology and paleontology of the Gulf of California. Continued research, such as that of Dr. Susan Kidwell, her colleagues, and other researchers described in Part II will further add to our knowledge of this fascinating region.

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Imperial Group invertebrate fossils Part 2: The Kidwell collection

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Dr. Susan Kidwell's extensive work on processes of fossil deposition have provided us with a greater understanding of the fossil record, including how accurate an interpretation of the paleoenvironment can be obtained from these fossil deposits. The majority of her work is done with sea floor bottom environments, both modern and fossil. From this setting, Dr. Kidwell collects vast amounts of data on the nature of shell deposits, including the interaction of live and dead animal communities, shell density, state of preservation, and many other factors that provide information about how these shell beds are preserved. This is precisely what she was doing in the Colorado (Sonoran) Desert, from the Anza-Borrego Desert State Park (ABDSP) to the Coyote Mountains during the mid-1980s to the early 1990s. Along with her graduate students, Dr. Kidwell collected a great number of invertebrate fossils from the desert region. These fossils constitute the most complete and largest stratigraphic collection of marine fossils from the ancestral Gulf of California. The data obtained from this research contributed to a study comparing fossil deposition in a recently rifted continental margin (Miocene/Pliocene Imperial Group, southeastern California) with a mature passive margin (Miocene Calvert and Choptank Formations, Maryland coastal plain) (Kidwell, 1987) in which low sedimentation rates were shown to be important for fossil accumulation.

The collection itself was not a primary objective during fieldwork in the 1980s. The fossils were collected in the field as sections were measured to provide specimen vouchers for stratigraphy and paleogeography. However, with good field data available to the level of fossil beds, and with the fossils identified to species, the collections will prove valuable to many workers in the field of paleobiology. Data from this field collection has provided material for research for more than two decades. Dr. Kidwell and her students were very concerned about the preservation and care of this great research collection. Through the tireless effort and dedication of volunteer members of the ABDSP Paleontology Society at the Stout Research Center (SRC), the collection was soon on its way home to ABDSP. Volunteers Jimmy and Judy Smith, Bob and Sandra Keeley, and Norbert Sanders went to Chicago in November 2009 to pack and prepare the fossils for shipment to the SRC (Bahar, 2009).

From 16 November 2012 to 21 March 2013, I identified the invertebrate fossil specimens of the Kidwell Collection, working together on bivalves with researcher Dr. Astrid Montiel Boehringer. Astrid is a post-doctoral fellow under Dr. Richard Norris, professor of Paleobiology at Scripps Institution of Oceanography. The objective of our research is to create an accurate and complete catalogue of the bivalve species of the Imperial Group. Astrid's research interests include the biogeography of the Salton Trough and the origin of bivalve families from the Gulf of California during the Miocene. The 9,643 specimens in the Kidwell Collection occupy a dozen standard-size museum cases in the SRC. The collection contains fossil material from the base of the Latrania Formation to the top of the Deguynos Formation (collectively known as the Imperial Group, Dorsey et al. 2011). This sequence represents changing paleo-ecosystems through time, from about 6 to 4.5 million years ago, late Miocene and early Pliocene. During this period, the marine environment went from a shallow-water inland sea to a vast estuary as the water became shallower. The older marine environments supported tropical marine bottom communities, including common corals not quite dense enough to be considered reefs. Later, in the shallower water of the estuary environment the corals and large tropical invertebrates eventually were replaced by dense beds of oysters, scallops and jingle shells (*Anomia* sp.). The Kidwell Collection invertebrates are characterized by high species diversity. Our work resulted in the identification of 175 taxa. Most of these are mollusks, including 94 bivalves and 56 gastropods. Other invertebrate species include 9 cnidarians (corals), 8 echinoderms, 5 arthropods, 1 sponge, 1 annelid, and 1 bryozoan (Table 1).

Because the specimens in the Kidwell Collection were recovered as voucher specimens for stratigraphic and paleo-geographic study and not selected as the best examples of the species present in the field, many of the specimens are not well preserved. In fact, this poor preservation of specimens contributed to the reasoning for the collection of voucher specimens – since they could not easily be identified in the field, relatively large numbers of these could be collected during field work to be identified later in the laboratory. Despite the prevalent poor state of preservation of these fossils, most internal mold specimens had enough of the form present that identification, usually to species, was possible. Where original shell material was preserved, especially common in collections from the Deguynos Formation, even fragments could be identified.

Fossils of most Imperial Group invertebrate species are preserved as steinkerns, or internal molds – the sediment trapped in the original clam or sea snail preserves the internal form of the shell, which was previously dissolved away. This is especially true of the late Miocene Latrania Formation. These internal molds are often preserved in a brown to reddish-brown fine to coarse pebbly sandstone. While mollusks are preserved as steinkerns in the Latrania formation, the sand dollars, sea biscuits, corals and arthropods, including barnacles, and crab parts, are preserved as a mineralized version of the original shell material (usually calcite). The more common internal molds of mollusks in the Latrania Formation are typically of fairly large tropical clam and gastropod species. In fossil material from the early Pliocene Deguynos Formation, where oyster and scallop species predominate, most of the mollusks have been preserved as original shell. These shells often have a yellowish tint to them, derived from the estuarine muds prevalent during the time of deposition.

Several very large species of tropical marine snails and clams stand out, measuring upwards from 10 cm. These include the gastropods *Pleuroploca princeps, Melongena patula, Strombus galeatus, Malea ringens*, and *Cassis subtuberosa*. and the bivalves *Pinna latrania, Spondylus bostrychites, Panopea globosa*, and *Pycnodonte heermanni*. The largest species of mollusks are impressive. The conch *Strombus galeatus* could reach an adult size of 20 cm. The juvenile of *S. galeatus* is conical, and was often mistaken by students for a very large *Conus* species, which would be nothing like any species present in the gulf today. The biggest bivalve species, *Pinna latrania*, grew even larger. Though not often found as complete fossils, adult valves of this species easily could reach 30 cm in size.

Identification issues

Often, the identification of internal mold fossils of the many mollusk species from the Latrania Formation is not difficult. This is because the shape of the mold follows the shape of the original shell in which it was formed. Some species however, resemble others. Juveniles of the large conch, *Strombus galeatus*, are conical and resemble large *Conus*, but are not as tightly coiled. Internal molds of *Cassis* are also often mistaken for *Conus* fossils. The disk shaped venerid clam *Dosinia* sp. looks like the lucinid clams *Codakia* and *Miltha*. A mold pair of *Miltha* is usually distinguished from the others by its much flatter profile. The mold of a Codakia pair is more inflated, with a central beak or hinge area. *Dosinia* has its hinge more to the anterior side and the beaks turn in that direction. However, if a mold pair of one of these species is badly worn, it can be impossible to discern it from one of the other species.

One species of tellinid clam in the Kidwell Collection had to be re-identified twice because of confusion with other taxa (Figure 2-1). The internal molds of this bivalve were first identified as *Tellina ochracea*, a common gulf species. But in time, it became apparent that this species may more closely match *Macoma secta*, common today on the outer coast of California and Baja, but not in the Gulf of California. The specimens had a small shelf-like extension of the mold pair on the posterior end that seemed a perfect match for modern valves of *Macoma secta*. However, a more likely species, *Psammotreta vidriotincta*, also could produce a shelf-like extension on the posterior portion of the pair, where the valves compress inward along a groove. The outline of *Psammotreta* was a better match for the fossil than that of *Macoma*. It is important that the identification of fossil species be accurate. If *Macoma secta* was the correct identification, this species, which lives along the exposed

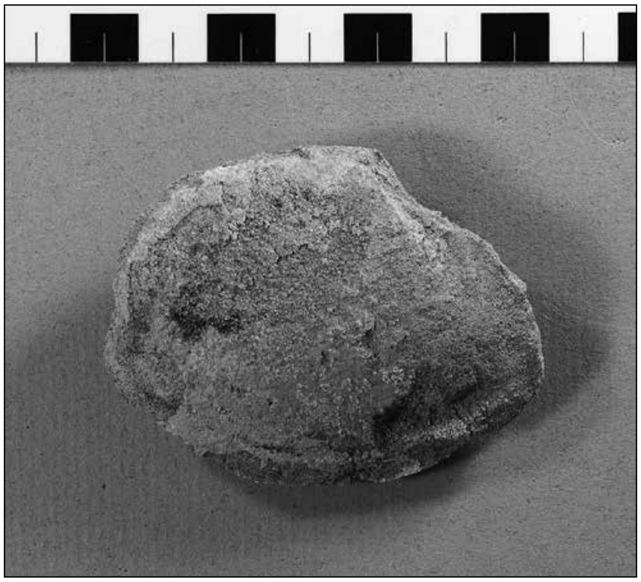

Figure 2-1. An internal mold pair of *Psammotreta viridotincta*, a species common today in the Gulf of California. In size and shape it is similar to *Tellina ochracea*, which is a bit more rounded and inflated, and *Macoma secta*, which lives outside the Gulf. Photo by Hugh Vance.

ocean today, could falsely support a hypothesis that there was a channel that went through the Baja peninsula, connecting the Gulf to the Pacific Ocean. Such a channel may have existed, but if correctly identified as *Psammotreta vidriotincta*, this tellinid fossil does not provide evidence to support this hypothesis.

Though it may be fairly easy to identify an internal mold fossil of a gastropod or bivalve from its distinctive form, it may be far more difficult to identify similar species within a genus. One very good example of this is the bivalve genus *Dosinia*. In the Gulf of California, there are at least three large (several cm in length) living species of *Dosinia*, including; *D. ponderosa*, *D. semiobliterata*, and *D. dunkeri*. There are small differences in surface sculpture of the valves between these species, but the overall shape of each species is very similar. Very few of the *Dosinia* specimens in the Kidwell Collection have any original shell material with some surface pattern. Thus, identification of *Dosinia* species may not be made with confidence. Specimens in the collection previously named *D. semiobliterata* and *D. delicatissima* (a fossil species) have been left as genus *Dosinia* sp. only. In the future, the few specimens with surface sculpture may be studied to determine the correct species present in the collection.

Some other genera in the collection consist of species that are very similar. Time did not permit the careful study of these genera. Several species of *Argopecten* are described for the Imperial Group, but it was decided that the smaller, generally convex *A. deserti* and the larger, generally flatter *A. mendenhalli* best described the material. Perhaps future research will reveal other species or subspecies of *Argopecten*. Species of oysters are even more difficult to distinguish. There are two ostreids present, *Dendostrea*? *vespertina*, and *Myrakeena angelica*, and the giant gryphaeid oyster *Pycnodonte heermanni*. All of these species may be confused with one another. It may be possible that among the *Dendostrea*? *vespertina* specimens, there is another very similar species, *Dendostrea frons*.

Uncommon species and others possibly new for the Imperial Group

There are too many invertebrate fossil species in the Kidwell Collection to describe more than a few in this paper. Several interesting bivalve and gastropod species are mentioned and figured in Part I. In addition to the prevalent mollusk fossils in the collection are beautiful examples of various coral species, and interesting arthropods, including a number of barnacle species (one of which burrows into coral). The full list of species is provided in Table 1.

In the collection are some species that are rare, and others that may be new records for the Imperial Group. The winged pearly oyster specimen, *Pteria perna*, described in Part I may be a new record. The rare fossil *Terebra gauspata* (See Part I) in the

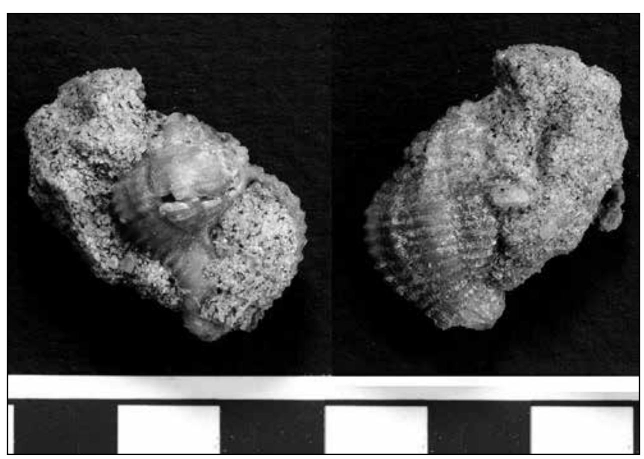

Figure 2-2. A species of *Cantharus* resembling *Gemophos ringens*; could be a new fossil species. Hanna (1926) figured a similar specimen as *Solenosteira anomala*. The pictured specimen is original calcitic shell.Photo by Hugh Vance

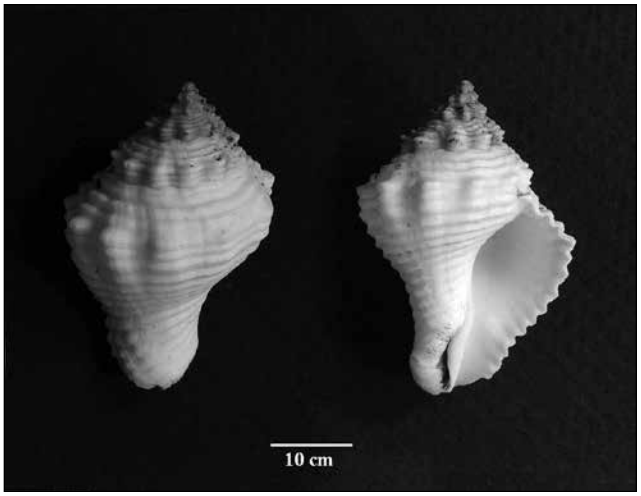

Figure 2-3. A modern specimen of *Solenosteira anomala* from Tumbes, Peru, for comparison with the fossil specimen in Figure 2. Note the fossil has a shorter siphonal canal, a more rounded shape, and differences in sculpture. Photo by Hugh Vance

collection was figured by Hanna (1926:Plate 22), who noted very few examples were available. A few specimens of another gastropod species from the collection are similar to that identified by Hanna as *Solenosteira anomala* in Plate 20 (Figure 2-2). However, the figured specimen, and those in the collection, more closely resemble *Gemophos ringens*, which has a lower spire, broader and more closely placed knobs on the whorls, equal sized spiral cords, and a short siphonal canal, compared to *S. anomala*. The specimen pictured in Hanna has a higher spire than those in the Kidwell Collection but looks closer to *Gemophos* with respect to all other characters. A modern specimen of *Solenosteira anomala* is shown for contrast with the specimen figured in Hanna (1926) and those in the collection (Figure 2-3).

Conclusions

Fossil material from the Kidwell Collection has already captured the interest of invertebrate paleontologists. Judith Smith, a research associate of the Smithsonian Institution, has examined the large pectens and *Spondylus* from the collection. A large cowry, *Muracypraea* collected by Charles Winker (a research associate of Dr. Kidwell) is the only specimen in a study of this genus to have precise locality data; from a specific shell bed in the Jackson Fork Member of the Deguynos Formation, in the North Fork of Fish Creek, Imperial County (Arnold, 1998). Many corals in the collection were accurately identified by Ann Budd (Professor of Invertebrate

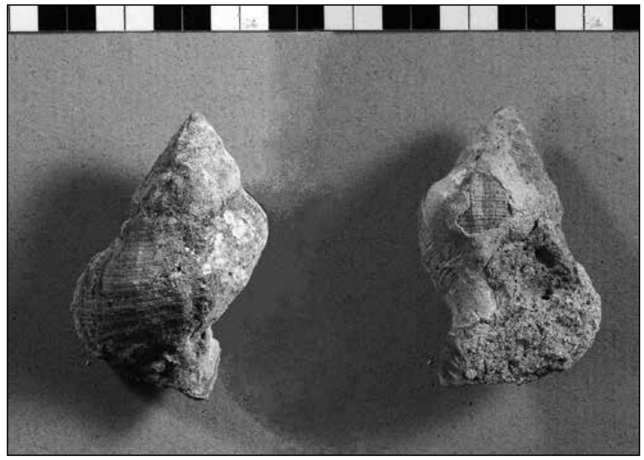

Figure 2-4. A possible new species of whelk, Family Buccinidae. The specimen figured is partly encrusted by a colony of the bryozoan *Biflustra commensale*. Photo by Hugh Vance.

Paleontology of the University of Iowa), whose research includes previous work with the corals of the Imperial Group (Foster, 1979).

Kidwell and Gyllenhaal (1998) described the paleobiology of bryozoan masses (bryoliths) of *Biflustra commensale* in Pliocene tidal channel deposits of the Deguynos Formation. These thick masses of bryozoans cover the valves of bivalves and a common undescribed buccinid whelk (Figure 2-4). This whelk has previously been tentatively named a

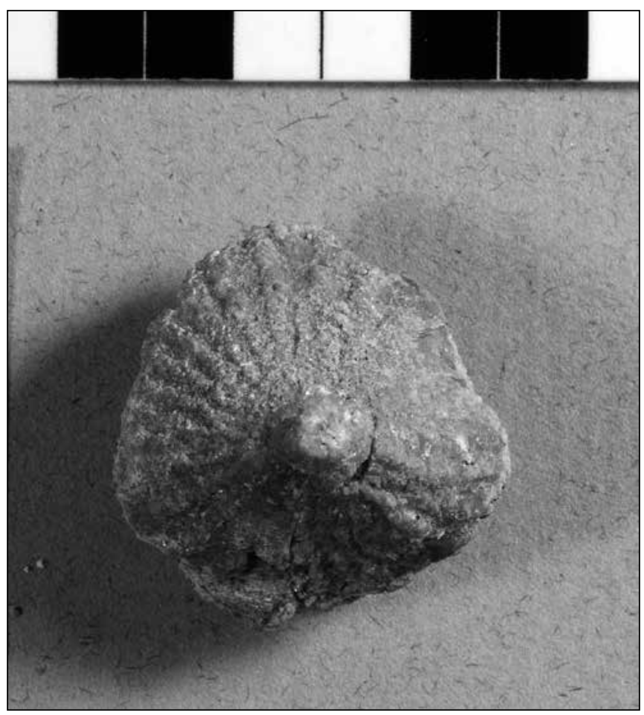

Figure 2-5. The cup-and-saucer snail, *Crucibulum* cf. *scutellatum*. This species is often found with the new buccinid (Figure 2-4) and commonly attached to other mollusk shells. Photo by Hugh Vance.

Table 1. Systematic list of fossil invertebrates in the Kidwell collection

- Phylum Porifera
- Class Demospongiae
  - Order Hadromerida
    - Family Clionaidae
- Phylum Annelida
- Class Polychaeta
  - Order Sabellida
    - Family Serpulidae
- Phylum Bryozoa
  - Order Cheilostomata
    - Family Membraniporidae
      - *Biflustra commensale*
- Phylum Cnidaria
- Class Anthozoa
  - Order Scleractinia
    - Family Faviidae
      - *Solenastrea fairbanksi*
    - Family Meandrinidae
      - *Dichocoenia eminens*
      - *Dichocoenia merriami*
      - *Eusmilia carrizensis*
      - *Meandrina bowersi*
    - Family Pocilloporidae
      - *Madracis* sp
    - Family Poritidae
      - *Porites carrizensis*
    - Family Rhizangiidae
      - *Astrangia haimei*
    - Family Siderastreidae
      - *Siderastrea mendenhalli*
- Phylum Mollusca
- Class Bivalvia
  - Order Nuculoida
    - Family Nuculanidae
      - *Nuculana* sp
    - Family Nuculidae
      - *Nucula* sp
  - Order Arcoida
    - Family Arcidae
      - *Anadara* cf. *adamsi*
      - *Anadara carrizoensis*
      - *Anadara concinna*
      - *Anadara formosa*
      - *Anadara* cf. *multicostata*
      - *Arca pacifica*
      - *Barbatia gradata*
      - *Barbatia reeveana*
    - Family Glycymerididae
      - *Glycymeris gigantea*
      - *Glycymeris multicostata*
  - Order Mytiloida
    - Family Mytilidae
      - *Lithophaga* sp
      - *Mytilus* sp
  - Order Pterioida
    - Family Isognomonidae
      - *Isognomon* cf. *alatus*
      - *Isognomon janus*
    - Family Pinnidae
      - *Atrina stephensi*
      - *Pinna latrania*
    - Family Pteridae
      - *Pteria sterna*
  - Order Ostreoida
    - Family Gryphaeidae
      - *Pycnodonte heermanni*
    - Family Ostreidae
      - *Dendostrea*? *vespertina*
      - *Myrakeena angelica*
    - Family Pectinidae
      - *Argopecten* cf. *abietis abietis*
      - *Argopecten bramkampi*
      - *Argopecten circularis*
      - *Argopecten deserti*
      - *Argopecten mendenhalli*
      - *Argopecten sverdrupi*
      - *Chlamys mediacostata*
      - *Euvola keepi*
      - *Flabellipecten carrizoensis*
      - *Leptopecten palmeri*
      - *Leptopecten tumbezensis*
      - *Lyropecten tiburonensis*
      - *Lindapecten corteziana*
  - Order Pectinoida
    - Family Anomiidae
      - *Anomia subcostata*
    - Family Plicatulidae
      - *Plicatula* sp
    - Family Propeamussiidae
      - *Amusium* cf. *lompocensis*
    - Family Spondylidae
      - *Spondylus bostrychites*
      - *Spondylus princeps*
  - Order Carditoida
    - Family Carditidae
      - *Carditamera affinis*
      - *Cardites laticostata*
      - *Cardites megastropha*
  - Order Lucinoida
    - Family Lucinidae
      - *Codakia distinguenda*
      - cf. *Ctena* sp
      - *Divalinga eburnea*
      - *Lucina undatoides*
      - *Lucinisca fenestrata*
      - *Miltha xantusi*
      - *Pegophysema edentuloides*
      - *Pegophysema* species A
      - *Pleurolucina leucocymoides*
  - Order Myoida
    - Family Corbulidae
      - *Corbul*a sp
    - Family Hiatellidae
      - *Panopea generosa*
      - *Panopea globosa*
    - Family Pholadidae
      - *Cyrtopleura costata*
    - Family Teredinidae
  - Order Veneroida
    - Family Cardiidae
      - *Americardia* cf. *bianglulata*
      - cf. *Dinocardium* sp
      - *Laevicardium* sp
      - *Papyridea* sp
      - cf. *Trachycardium consors*
  - Family Chamidae
      - *Arcinella californica*
      - *Chama* sp
      - *Pseudochama* sp
    - Family Crassatellidae
      - *Eucrassatella antillarum*
      - *Eucrassatella subgibbosa*
    - Family Mactridae
      - *Raeta undulat*a
      - *Rangia* sp
      - *Spisula* cf. *dolabriformis*
    - Family Psammobidae
      - *Gari* sp
    - Family Semelidae
      - *Semele* cf. *rosea*
    - Family Solecurtidae
      - *Tagelus affinis*
    - Family Tellinidae
      - *Macoma elytrum*
      - cf. *Macoma grandis*
      - *Psammotreta viridotincta*
      - *Psammotreta cognata*
      - *Psammotreta dombei*
      - *Tellina cumingii*
      - *Tellina ochracea*
      - *Tellina simulans*
    - Family Veneridae
      - *Callpita frizzelli*
      - *Chione* cf. *mariae*
      - *Chione* cf. *subrugosa*
      - *Dosinia* sp
      - *Globivenus isocardia*
      - *Megapitaria squalida*
      - *Periglypta multicostata*
      - *Pitar catharius*
      - *Pitar mexicanus*
      - *Pitar* cf. *pollicaris*
      - *Protothaca grata*
  - Order Anomalodesmata
    - Family Pandoridae
      - *Pandora* sp
    - Family Thraciidae
      - *Cyathodonta undulata*
- Class Gastropoda
  - Order Vestigastropoda
    - Family Trochidae
    - Family Turbinidae
      - cf. *Turbo* sp
  - Order Cycloneritimorpha
    - Family Nertidae
      - *Nerita scabricosta*
  - Order Neotaenioglossa
    - Family Bursidae
      - *Bursa* aff. *calcipicta*
    - Family Calyptraeidae
      - *Crucibulum* cf. *scutellatum*
    - Family Cassidae
      - *Cassis subtuberosus*
    - Family Cerithiidae
    - Family Cypraeidae
      - *Muracypraea* sp
      - *Macrocypraea cervinetta*
    - Family Ficidae
      - *Ficus ventricosa*
    - Family Hipponicidae
      - *Hipponix* sp
    - Family Naticidae
      - *Polinices bifasciatus*
      - *Polinices uber*
      - *Polinices unifasciata*
      - *Sinum debile*
    - Family Potamididae
      - *Cerithidea* sp
    - Family Strombidae
      - *Strombus galeatus*
      - *Strombus gracilior*
      - *Strombus obliteratus*
    - Family Tonnidae
      - *Malea ringens*
    - Family Triviidae
      - *Trivia sanguinea*
    - Family Turritellidae
      - *Turritella imperialis.*
      - *Vermicularia* sp
    - Family Vermetidae
    - Family Xenophoridae
      - *Xenophora* sp
  - Order Neogastropoda
    - Family Buccinidae
      - *Antillophos* sp
      - *Cantharus* sp
      - *Gemophos* aff. *ringens*
      - cf. *Northia* sp
      - new buccinid species
    - Family Cancellariidae
      - *Cancellaria* cf. *gemmulata*
      - *Cancellaria obesa*
    - Family Columbellidae
      - cf. *Anachis* sp
      - *Mitrella* sp
    - Family Conidae
      - *Conus* sp
    - Family Fasciolariidae
      - *Fusinus dupetitthouarsii*
      - cf. *Latirus* sp
      - *Pleuroploca princeps*
    - Family Melongenidae
      - *Melongena patula*
    - Family Mitridae
      - *Mitra* sp
    - Family Muricidae
      - cf. *Aspella cunninghami*
      - *Ceratostoma* sp
      - *Eupleura muriciformis*
      - *Hexaplex* sp
      - *Thais* sp
    - Family Nassariidae
      - *Nassarius* sp
    - Family Olividae
      - *Agaronia testacea*
      - *Oliva incrassata*
      - *Oliva porphyria*
      - *Oliva cf. spicata*
    - Family Pseudolividae
      - cf. *Macron* sp
    - Family Terebridae
      - *Terebra gauspata*
    - Family Turbinellidae
      - *Vasum pufferi*
    - Family Turridae
      - cf. *Knefastia* sp
  - Order Heterostropha
    - Family Architectonicidae
      - *Architectonica nobilis*
  - Order Cephalaspidea
    - Family Bullidae
      - *Bulla* cf. *gouldiana*
      - *Bulla striata*
- Phylum Arthropoda
- Class Malacostraca
  - Order Decapoda
    - Family Paguridae
- Class Maxillopoda
  - Order Sessilia
    - Family Balanidae
      - *Balanus* sp
      - *Megabalanus* sp
    - Family Tetraclitidae
      - cf. *Tetraclita* sp
    - Family Pyrgomatidae
      - *Ceratoconcha* sp
- Phylum Echinodermata
- Class Echinoidea
  - Order Camarodonta
    - Family Toxopneustidae
      - *Tripneustes californicus*
  - Order Cidaroida
    - Family Cidaridae
      - *Eucidaris thourarsii*
  - Order Clypeasteroida
    - Family Clypeasteridae
      - cf. *Clypeaster bowersi*
      - *Clypeaster* cf. *deserti*
    - Family Echinoneidae
    - Family Mellitidae
      - *Encope tenuis*
  - Order Spatangoida
    - Family Brissidae
      - cf. *Meoma* sp
    - Family Loveniidae
      - aff. *Lovenia* sp
    - Family Schizasteridae
      - *Schizaster morlini*

species of *Solenosteira*, and is referred to here as "new buccinid species" (Table 1). It superficially resembles in form the fossil and modern genus *Searlesia*. It also resembles *Cymia heimi* in form and surface sculpture (see Smith, 1984), except it does not bear the strong knobs of this species. The whelk and encrusting bryozoan are associated in the collections with the ever familiar *Argopecten deserti*, *Anomia subcostata*, and *Dendostrea*? *vespertina*. Also common in these collections are the barnacle *Megabalanus*, the coral *Astrangia haimei*, and the cup-and-saucer snail, *Crucibulum* cf. *scutellatum* (Figure 2-5).

The Kidwell Collection has already provided material for research for the last two decades, and there is great promise that this diverse collection of invertebrates will continue to serve the scientific community as a valuable resource in the future.

Acknowledgements

I would like to first thank Dr. Susan Kidwell for returning the Imperial Group fossil invertebrates from her research at the University of Chicago back to the Colorado Desert from where they came so they may be cared for by the dedicated volunteers and staff of the SRC. I am very thankful to George Jefferson and Lyndon Murray for reviewing this manuscript and for their support and guidance during the identification work. Linda Gilbert and Lou Bahar's tireless work overseeing the entering of the species names into the collection database is greatly appreciated by me and many others. I am also very grateful to Hugh Vance for the excellent photography. I appreciate Astrid Boehringer's enthusiasm and confidence in my work. I am especially grateful to Myrl Beck and Ann Nourse for sharing their homes while I stayed in the desert. I greatly appreciate Mark Roeder encouraging me to write this paper. I want to give a heartfelt thanks to the Stout Foundation, and the ABDSP Society who funded my work on the Kidwell Collection. And I can't forget the many volunteers who helped me move trays and shared their enthusiasm for the project. Thank you all.

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