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OTHER MICROSCOPIC BIOTA OF CLIPPERTON ISLAND,
TROPICAL EASTERN PACIFIC

*Mary McGann, Robert W. Schmieder,
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SHALLOW-WATER FORAMINIFERA AND OTHER MICROSCOPIC BIOTA OF CLIPPERTON ISLAND, TROPICAL EASTERN PACIFIC

MARY MCGANN¹, ROBERT W. SCHMIEDER², and LOUIS-PHILIPPE LONCKE³

ABSTRACT

The recent foraminiferal fauna and associated microbiota of Clipperton Island (10.2833°N, 109.2167°W) were investigated at 20 sites collected in the intertidal zone around the perimeter of the island and from the edge of the inner brackish-water lagoon. Due to the island's geographic location in a low productivity zone, a lack of variable habitats on and surrounding the island, and heavy surf that pounds the exposed land, a depauperate fauna was recovered although mixed biogeographic affinities are represented. The shallow-water foraminiferal assemblage has no endemics but primarily tropical Indo-Pacific and eastern Pacific (Panamic) affinities, as well as one species of Caribbean affinity. The most abundant taxa are *Sorites* spp. and *Quinqueloculina* spp. Noticeably absent are any species of *Amphistegina*, despite the fact that they are considered ubiquitous in the tropical Pacific. The molluscan fauna has Clipperton Island endemics, a tropical Pacific/Inter-Island endemic, and tropical eastern Pacific oceanic islands/Panamic Molluscan affinities. The ostracods included endemics found restricted to Clipperton Island lagoon, as well as Indo-Pacific and Panamic Province species. The foraminifera, mollusks, and ostracods are thought to disperse to Clipperton Island by way of the North Equatorial Countercurrent and North Equatorial Current, suggesting that the island is indeed a stepping stone for migration both east and west across the Eastern Pacific Barrier.

INTRODUCTION

Clipperton Island is an uninhabited French island in the tropical eastern Pacific Ocean (10.2833° N, 109.2167°W), much nearer to the continental shores of Mexico (1,100 km), the Central American mainland (1,300 km), and the Revillagigedo Islands to the north (~1,000 km) than to the nearest Pacific islands to the west (i.e., the Line Islands 5,700 km away) (Figure 1; Glynn et al., 1996). The island is of biogeographical significance because of its extreme isolation, situated between the vast 5000-km Eastern Pacific Barrier (EPB) separating the tropical Indo-Pacific environment to the east (Ekman, 1953) and the tropical Eastern Pacific (Panamic Province) to the west (Figure 2; Ekman, 1953; Combasch et al., 2008).

The remoteness of the island stimulated scientific interest, culminating in the “2013 Cordell Expedition” to Clipperton Island in February–March. Two expedition members (RWS and L-PL) were responsible for capturing airborne insects with a kite-lofted net, observing congenitally deformed masked boobies, searching for an invasive big-headed ant, counting plastic debris, and collecting sediment around the island (Schmieder, 2013). These two participants, and the remainder of the expedition members, also conducted amateur (“ham”) radio operations (TX5K; <http://www.tx5k.org/>), seeking to achieve radio communications over long distances and in exotic locales for brief periods of time. After the expedition, the sediment samples were returned to the United States where they were examined (by MM) for foraminifera and other microscopic animal and plant remains.

¹ U.S. Geological Survey, 345 Middlefield Road, Menlo Park, CA 94025, USA. Email: mmcgann@usgs.gov

² Cordell Expeditions, 4295 Walnut Blvd., Walnut Creek, CA 94596, USA. Email: schmieder@cordell.org

³ Belgian Adventurer, 30 rue Alois den reep, 7700 Mouscron, Belgium. Email: BelgianAdventurer@gmail.com



Figure 1. Location of Clipperton Island and other islands in the tropical eastern Pacific Ocean.

SETTING

Clipperton Island was first discovered by two Frenchmen, Martin de Chassiron and Michel Du Bocage, on April 3, 1711 who named it “Île de la Passion” (“Isla de la Pasi3n”) as they sailed past it on the French schooners they commanded, the *La Princesse* and *La D couverte*, respectively (Skinner and Schmieder, 1996; L vesque, 1998). The island is low and barren except for coconut palms that were originally planted in the early 1900s by Mexican troops stationed there (Figures 3A, 3B; Kaiser, 2007) and Clipperton Rock, a 22 m-high trachyte volcanic outcropping that lies on the southeastern edge of the island (Figures 3C, 4; Teall, 1898; Menard and Fisher, 1958). The island, therefore, is not a true atoll but an almost-atoll because of this small volcanic protrusion (Glynn et al., 1996; Goldberg, 2016). The surf continuously pounds the exposed land and due to the island’s low relief, storms are thought to occasionally wash completely over it (Limbaugh, 1959; Kaiser, 2007).

Clipperton Island is an egg-shaped ring of consolidated coral rubble ~2.7 km in diameter and 11.8 km in circumference, with only 1.7 square km of exposed land varying in width from 25–320 m (Figure 4; Kaiser, 2007). The ring surrounds a lagoon that makes up the majority (85%) of the island. Originally, the

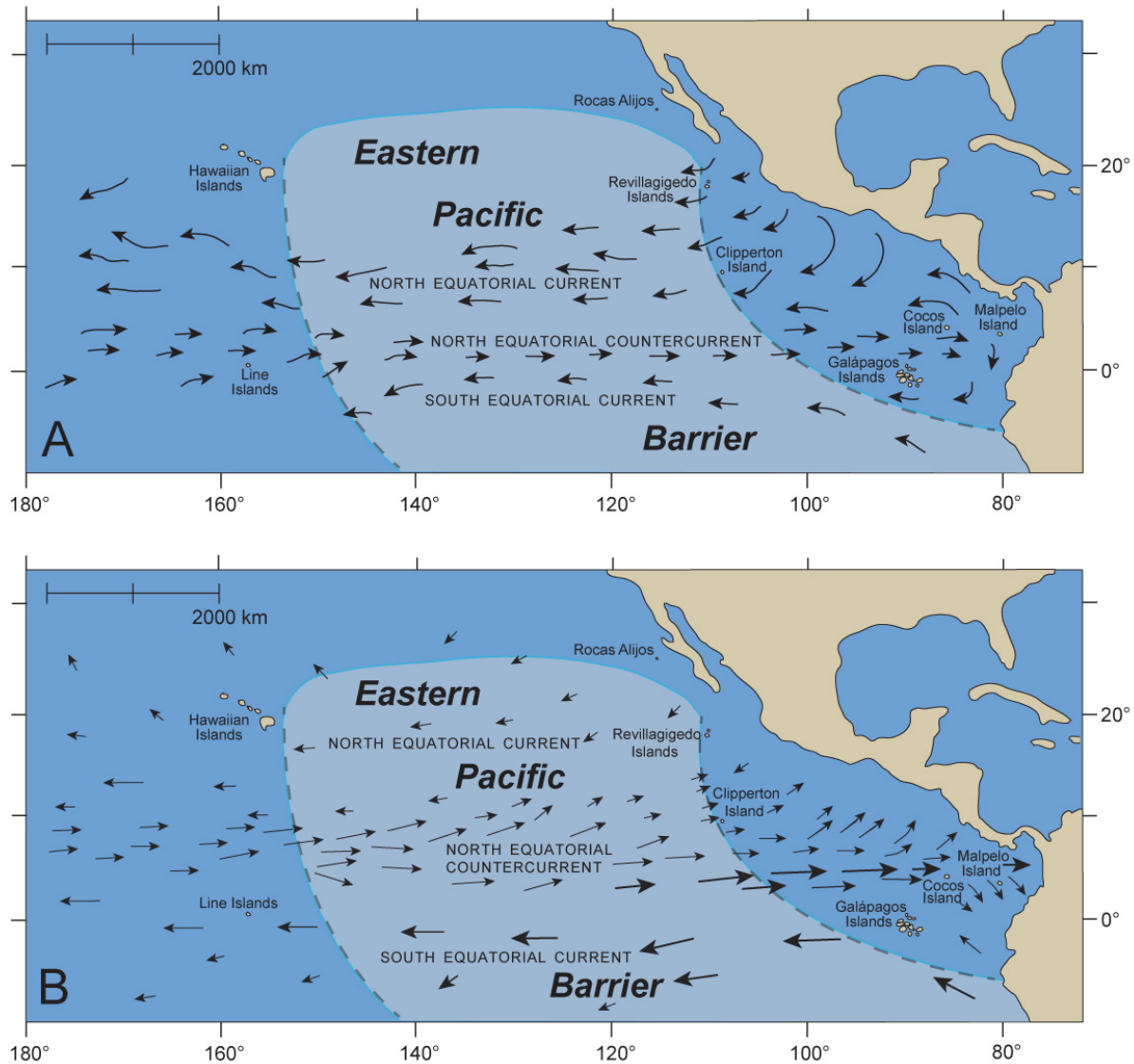


Figure 2. A. Generalized summary of the surface currents of the tropical central and eastern Pacific Ocean (modified from Geography Notes) and the approximate location of the Eastern Pacific Barrier (EPB) after Combosch et al. (2008). B. Currents shown for August when the North Equatorial Countercurrent is most pronounced (from Gorshkov, 1976). Current intensity on Figure 2B depicted by the thickness of the arrows, from >0.5 knots to >1.5 knots. After Glynn et al. (1996).

lagoon was open to the sea (Belcher, 1843; Sachet, 1963). This occurred by means of two passages, each on the NE and SE ends of the island, as shown on the first map drawn in 1939 (Charpy et al., 2010). Physical alterations due to hurricanes and severe storms most likely closed it off between 1839 and 1858 (Sachet 1962b), and certainly by 1861 (Skaggs, 1989). Charpy et al. (2010) suggest the lagoon was, in fact, closed by 1849 based on maps drawn in 1849 and 1858, and that the lagoon was completely transformed into a lake with fresh water at the surface by 1861 as reported by an American officer. The lagoon was still closed as of 2005 (Charpy et al., 2010) and 2007 (Kaiser, 2007), being brackish and plankton-rich at the surface, hydrogen sulfide-rich below 12–15 m, and gelatinous below ~18–34 m (Kaiser, 2007), although occasional storm waves washing marine water into it may increase the salinity of the surface waters (Limbaugh, 1959).

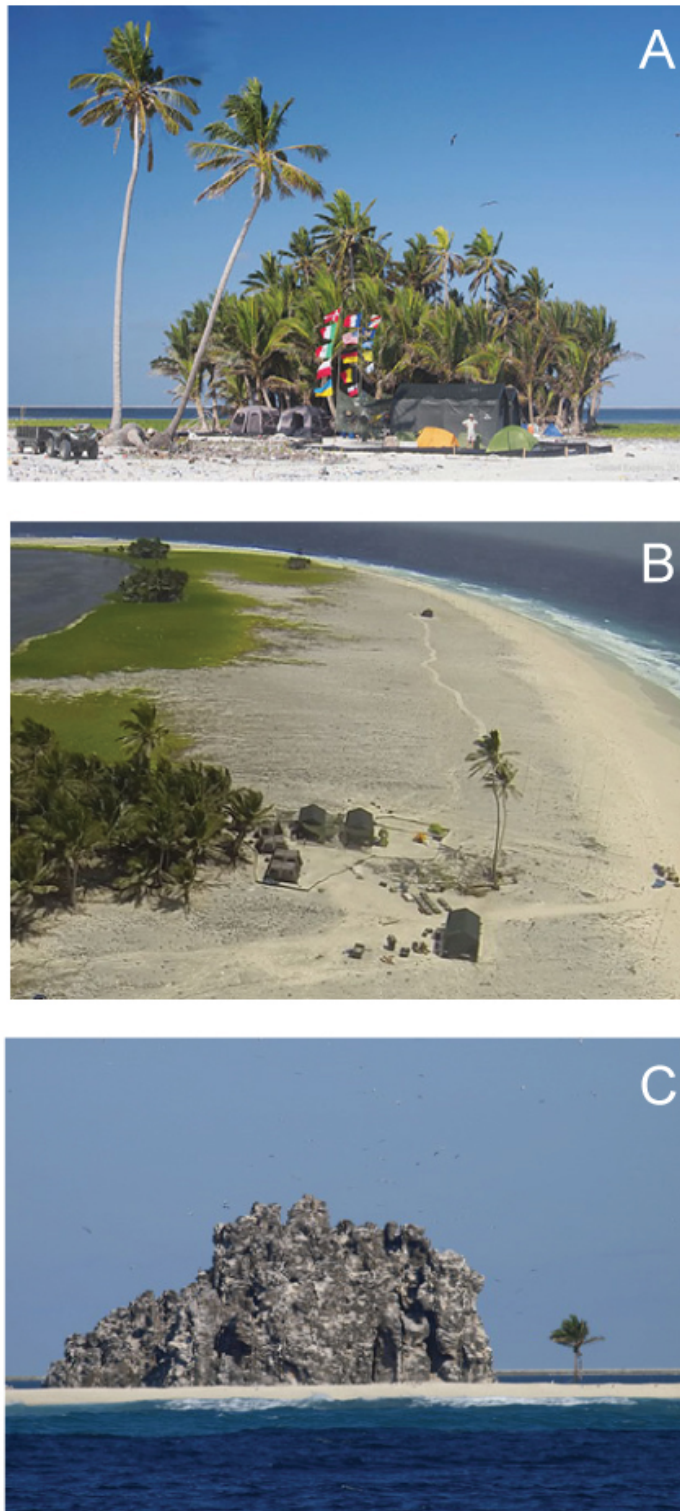


Figure 3. A. 2013 Cordell Expedition (TX5K) campsite on an open, flat sand deposit in front of a palm grove, with the lagoon in the background. B. Aerial photograph of the campsite. C. Clipperton Rock. Photographs courtesy of Cordell Expeditions (Schmieder, 2013).

This closed, meromictic lagoon is unique among atoll lagoons worldwide (Charpy et al., 2010). It transformed over less than 150 years from a marine lagoon to a permanently stratified lagoon due to its separation from the ocean and a dilution effect from high seasonal rainfall, resulting in greater precipitation than evaporation (Charpy et al., 2010). However, marine salinities (27–33) measured in 2005 in a small shallow bay indicate the lagoon is no longer totally isolated from the marine realm (Charpy et al., 2010). Possibly some oceanic water entered through a sandy barrier near the site of the previous SE passage (Charpy et al., 2010) and may continue to do so in the future.

Oceanward of the inner lagoon and coral rubble ring lies an intertidal reef flat and a weakly developed algal ridge (Allison and Holden, 1971). Beyond this is a gentle slope incised by scoured-out channels that opens out onto a submerged terrace 100–200 m in width at a water depth of 10–20 m. Here, coral growth abounds and continues down to a depth of ~30 m.

Abyssal ocean depths lie between Clipperton Island, the mainland, and the other four islands in the far eastern tropical Pacific: the Revillagigedo Islands of Mexico, Cocos Island of Costa Rica, Malpelo Island of Colombia, and the Galápagos Islands of Ecuador (Figure 1). And whereas upwelling occurs along the coasts of Baja California, the Gulf of California, the Gulf of Panama, and Peru resulting in surface water temperatures fluctuating as much as 6–10°C between the cold upwelling winter months and the summer (Crouch and Poag, 1987), on Clipperton Island upwelling is absent due to the steep slopes and narrow shelf, such that water temperatures rise several degrees higher than that found near the mainland at the same latitude (Lindberg et al., 1980).

PREVIOUS WORK

The first scientific expedition on Clipperton Island is supposed to have occurred in 1725, during which time the expedition leader, the Frenchman M. Bocage, lived on the island for several months (Wikipedia, https://en.wikipedia.org/wiki/Clipperton_Island, accessed 24 May 2019). However, Sachet (1960) reports the first landing on the island is supposed to have been made by a U.S. sailor (Benjamin Morrell) in 1825. A little more than a century later, from 1932 to 1938, the Allan Hancock Pacific Expeditions utilized the R/V *Velero III* to collect both macro- and microorganisms in the eastern Pacific Ocean in bottom dredges off the coasts of the United States, Mexico, Central America, South America, and the Galapagos Islands. The collections were incorporated into the Allan Hancock Foundation at the University of Southern California in Los Angeles, California. Faunal slides of the foraminifera collected during the expedition are now housed at the Santa Barbara Museum of Natural History in Santa Barbara, California. Of the >900 stations samples, one sample (427) was obtained off Clipperton Island at a shallow, but undescribed, depth at 10.2833°N, 109.2167°W on January 6, 1934 (Cushman and McCulloch, 1939). Two benthic foraminifera from this locality were identified in McCulloch's original field notebook which is part of the museum's library and in the later foraminiferal faunal compilations (Cushman and McCulloch, 1948 and 1942, respectively): *Angulogerina albatrossi* Cushman var. *ornata* Cushman and *Loxostomum limbatum* (H. B. Brady). McCulloch (1977) later described the findings of the expeditions in greater detail, identifying 21 additional species at the Clipperton Island site (Table 1), including eight that were type specimens.

As part of the 1957–1958 International Geophysical Year (IGY) expedition “DOLDRUMS,” the University of California Scripps Institution of Oceanography was tasked with describing the geography, geology, and biology of Clipperton Island using the R/V *Spencer F. Baird* (IGY Clipperton Island Expedition; Sachet, 1960, 1962a, 1962b, 1962c, 1963). Their first visit actually occurred in October–November 1956 and a second in August–September 1958, during which time they collected enough flora and fauna to significantly increase the number of known organisms. The expedition summary (Limbaugh, 1959) also mentions collecting foraminifera and states that they would be housed at the University of

Table 1. Species identified by McCulloch (1977) at Clipperton Island. ¹Taxa and taxon inquirendum with Clipperton Island as the type locality

<i>Briceia</i> sp. A McCulloch, 1977 = <i>Briceia</i> (?) sp. A in McCulloch (1977)
¹ <i>Coryphostoma clippertonense</i> McCulloch, 1977 = <i>Coryphostoma clippertonensis</i> in McCulloch (1977)
<i>Cycloforina semiplicata</i> (McCulloch, 1977) = <i>Quinqueloculina semiplicata</i> in McCulloch (1977)
¹ <i>Ehrenbergina clippertonensis</i> McCulloch, 1977
<i>Fissurina evolutiformis</i> McCulloch, 1977
<i>Fissurina sulphurensis</i> McCulloch, 1977
¹ <i>Glandulina clippertonensis</i> McCulloch, 1977 = <i>Glandulina?</i> <i>clippertonensis</i> in McCulloch (1977)
¹ <i>Globigerina clippertonensis</i> McCulloch, 1977 (taxon inquirendum)
<i>Globigerina galapagosensis</i> McCulloch, 1977 (taxon inquirendum)
<i>Globigerina hybrida</i> McCulloch, 1977 (taxon inquirendum)
<i>Globigerinella siphonifera</i> (d'Orbigny, 1839) = " <i>Globigerinella</i> " <i>aequilateralis</i> (Brady, 1879) in McCulloch (1977)
<i>Gypsina</i> cf. <i>G. vesicularis</i> (Parker & Jones, 1860)
¹ <i>Lagena clippertonensis</i> McCulloch, 1977
<i>Neohauerina socorroensis</i> McCulloch, 1977
<i>Quinqueloculina angustiformis</i> McCulloch, 1977
¹ <i>Quinqueloculina subparkeri</i> McCulloch, 1977
<i>Quinqueloculina</i> (?) sp. G
¹ <i>Rectobolivina clippertonensis</i> McCulloch, 1977
<i>Spirillina seymourensis</i> McCulloch, 1977
¹ <i>Svratkina clippertonensis</i> McCulloch, 1977 = <i>Svratkina</i> (?) <i>clippertonensis</i> in McCulloch (1977)
<i>Turrispirillina simplissima</i> McCulloch, 1977

California Museum of Paleontology in Berkeley. Unfortunately, those collections cannot be found (Finger, personal communication, 2013).

IGY Clipperton Island Expedition sediment and algae samples collected by free and SCUBA diving, as well as a single dredge (station B-8558), provided samples for an investigation of ostracodes from the island (Allison and Holden, 1971). Brackish lagoon, marine reef, and off-reef habitats were sampled, with species abundances, living versus nonliving specimens, and distributional relationships discussed.

In 1987, Crouch and Poag published a study of eastern Pacific inner continental shelf benthic foraminifera of the Panamanian Province, encompassing 49° latitude from Baja California Norte (32.5°N) to southern Peru (16.5°S) and ~9,300 km of coastline. The samples were collected as grabs at the sediment surface by SCUBA divers and were provided primarily by the Natural History Museum of Los Angeles County (NHM). Unfortunately, the dates of sampling were not published, and the original slides and sample residues could not be located by NHM staff. Only dead specimens were reported, including 229 species from 96 stations at 33 localities. Two of the stations (21 and 22) were off Clipperton Island, from which 33 species of benthic foraminifera were identified.

The investigations of Clipperton Island mollusks far outnumber those of the foraminifera. Franklin D. Roosevelt's Presidential Cruise of 1938 on board the USS *Houston* collected 12 species of mollusks, five of which were new species (Bartsch and Rehder, 1939). Between 1975 and 1980, several small expeditions were sent to Clipperton Island to acquire information relevant to a development plan for the island of interest to the French government (Kaiser, 2007). The focus of the 1980 trek undertaken by French, Canadian, and U.S. scientists and divers, led by Jacques Cousteau (1981) and his vessel *Calypso*, was an investigation of the inner lagoon as well as the birds and land crabs, yet a few worn mollusk shells were also collected on the beach. Two stations were investigated by Cousteau and S. Luke. In addition to

polychaete worms, decapods, isopods, sponges, and echinoderms among other invertebrates, eight species of gastropod, one cephalopod, and two bivalves were collected by hand at Station 1 (10.2833°N, 109.2167°W, S.W. reef in front of Palm Grove and French barracks) on March 13, 1980, and 11 species of gastropod and one bivalve were collected at Station 2 (10.3°N, 109.2167°W, N. end at opening to ocean) two days later (Figure 4; Benthic Invertebrate Collection at Scripps, 2019).

Sport and commercial fisherman frequent the waters surrounding Clipperton Island as well, in search of large tuna and other fish. Some of them took the time to land on the island, later documenting the difficult landing conditions they encountered and the mollusks they collected along the beach (Perrin, 1977; Schneider, 2004).

In 1994, Emerson published a comprehensive zoogeographic summary of the 92 species of mollusks from Clipperton Island known up to that time that preceded the Santa Barbara Museum of Natural History's "Clipperton 1994 Expedition". The purpose of the latter was to explore the mollusks of the undersea environment around the island using SCUBA, dredging, and tangle net deployments off the M/V *Royal Star* (Kaiser, 2007). Preliminary findings of the expedition were published by Small (1994, 1995) and Beals (1995). Although several other major expeditions were undertaken at Clipperton Island shortly thereafter (i.e., the 1997 Universidad Nacional Autónoma de México "SURPACLIP-I" and the French "Passion 2001"; Jost and Andrefouët, 2006), those most relevant to the present study are the 1998 Smithsonian Tropical Research Institute "STRI Clipperton Expedition," the 2004–2005 French "Expédition Clipperton," and the "Expedition Île Clipperton 2007." The results of these molluscan investigations are summarized by Kaiser (2007), in which the total number of known species increased by 210%, to 285.

MATERIALS AND METHODS

Sediment samples were taken by hand at 17 locations in the intertidal zone around the perimeter of the island as well as three locations from the margin of the inner brackish-water lagoon (Figures 4, 5; Table 2). In order to identify those individuals that were alive, or recently alive, at the time of collection (Bernhard, 1988, 2000), the samples were immersed in a mixture of 2 g of rose Bengal stain per 1 liter of >70% ethyl alcohol (Lutze and Altenbach, 1991) and left to soak for a month until the samples were returned from the field. The samples were then wet-sieved through nested 1.0 mm, 0.150 mm, and 0.063 mm screens to remove the clay fraction and excess stain, transferred to filter paper, and allowed to air dry. Because specimens were scarce, no microsplitter was used. Instead, the >0.063 mm size fraction of each sample was picked for foraminifera and other microbiota, placed on microslides, and identified. The microslides are on file at the U.S. Geological Survey in Menlo Park, California.

A Tescan Vega3 tungsten thermionic emission scanning electron microscope (SEM) housed at the U.S. Geological Survey in Menlo Park provided the micrographs of the foraminifera and other microscopic biota (Plates 1–3). The accelerating voltage for the electrons (HV) was 10.0 kV.

RESULTS

Twenty-nine taxa of benthic foraminifera and two species of planktic foraminifera were recovered from the 20 Clipperton Island samples (Tables 3, 4; Plate 1). In addition to the foraminifera, remains of other biologic groups were collected (Tables 3, 5; Plates 2, 3). Among the surf and beach samples, these include 15 species of gastropod, gastropod opercula, four species of ostracod, bivalve mollusks, bryozoans, crab claws, sea urchin spines, and worm tubes. In the inner lagoon, the remains of fish (bones and teeth), bivalve mollusks, gastropods, four species of ostracod, five benthic foraminiferal species, a winged insect, a tiny mammal bone (i.e., likely a proximal metapodial such as a second metatarsal; Plate 2, R) of a mouse-size animal (Samuels, written communication, 2018), seeds of aquatic plants (e.g., *Scirpus*), and charophyte

gyrogonites (i.e., calcium carbonate algal reproductive structures) were encountered. No living specimens were found among any of the biota collected.

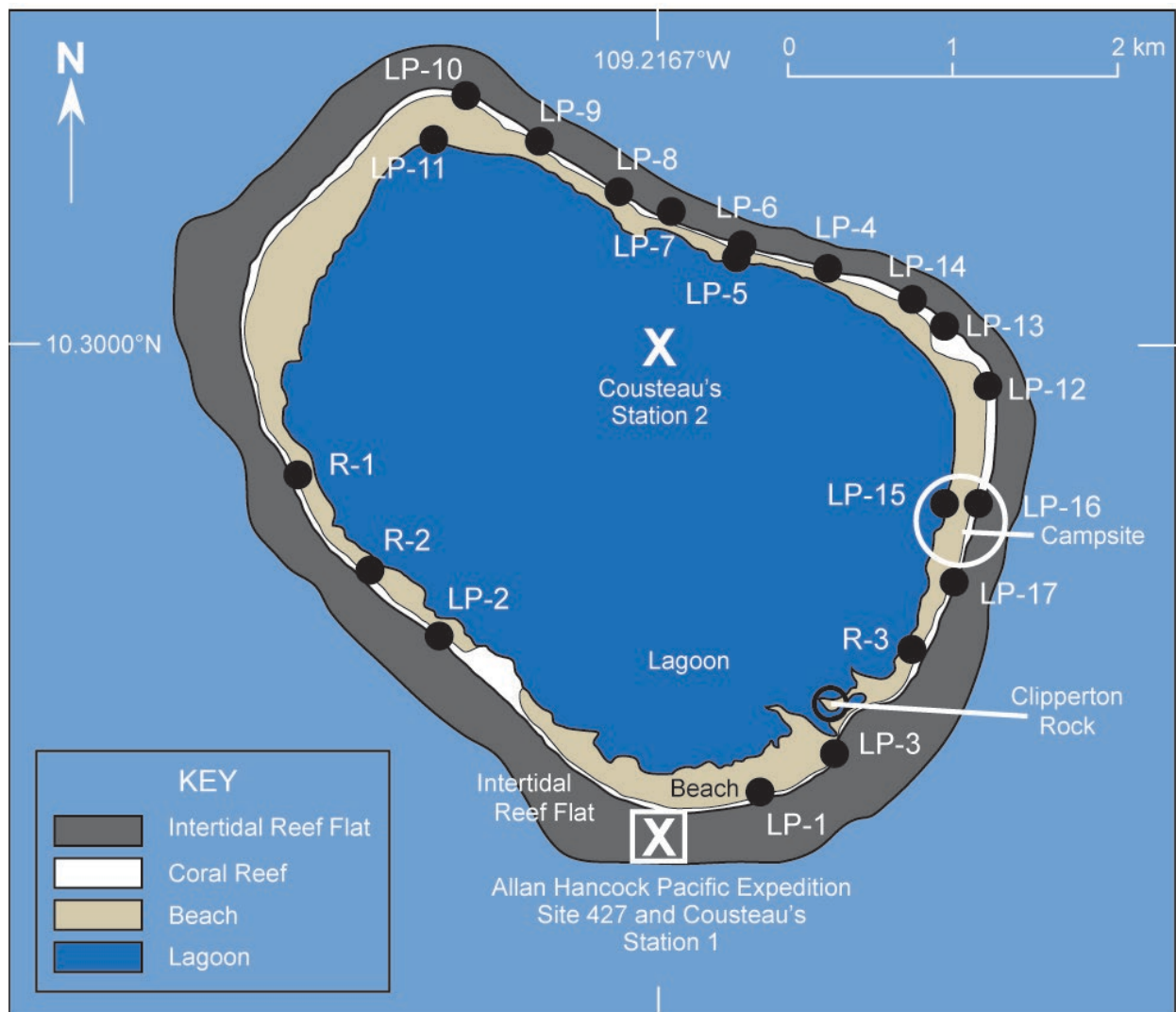


Figure 4. Map of Clipperton Island, showing the location of the 2013 Cordell Expedition (TX5K) campsite (white circle), the location of Clipperton Rock (black circle), the 20 sampling sites (black dots), the location of Cousteau's two sampling sites in March 1980 (X; Benthic Invertebrate Collection at Scripps, 2019), and the location of the Allan Hancock Pacific Expedition Station 427 in January 1934 (white square; Cushman and McCulloch, 1939). LP, samples collected by Louis-Philippe Loncke; R, samples collected by Robert W. Schmieder. Cousteau's Station 2 was reported to be at the north end of the island at the opening to the ocean but plots at the northern end of the lagoon and, therefore, may not be properly located.



Figure 5. Clipperton Island sampling sites. Photographic documentation of sites LP-12, LP-14, LP-16, LP-17, and R1-3 are not available.

Table 2. Sample number, collection date, location (latitude and longitude), water depth (cm), and generalized location of the Clipperton Island samples

Sample Number	Collection Date	Latitude (°N)	Longitude (°W)	Water Depth (cm)	Location
LP-1	March 8, 2013	10.287897	109.210928	20–30	beach
LP-2	March 8, 2013	10.295300	109.225369	20–30	beach
LP-3	March 8, 2013	10.289708	109.207044	20–30	beach
LP-4	March 9, 2013	10.311964	109.208103	20–30	beach
LP-5	March 9, 2013	10.312319	109.211461	20–30	lagoon
LP-6	March 9, 2013	10.312761	109.211383	20–30	beach
LP-7	March 9, 2013	10.314256	109.215233	20–30	beach
LP-8	March 9, 2013	10.315208	109.217258	20–30	beach
LP-9	March 9, 2013	10.317469	109.220811	20–30	beach
LP-10	March 9, 2013	10.319128	109.22365	20–30	beach
LP-11	March 9, 2013	10.317433	109.224017	20–30	lagoon
LP-12	March 9, 2013	10.306222	109.200275	20–30	beach
LP-13	March 9, 2013	10.308867	109.201981	20–30	beach
LP-14	March 9, 2013	10.310442	109.204081	20–30	beach
LP-15	March 9, 2013	10.301031	109.202308	20–30	lagoon
LP-16	March 9, 2013	10.301025	109.200572	20–30	beach
LP-17	March 9, 2013	10.297461	109.201783	20–30	beach
R-1	March 7, 2013	10.302778	109.231944	20–30	beach
R-2	March 7, 2013	10.297778	109.228278	20–30	beach
R-3	March 7, 2013	10.294667	109.203389	20–30	beach

Table 3. Microbiological constituents recovered on Clipperton Island

Benthic Foraminifera

Ammonia sp.
Bolivina sp.
Cibicides sp.
Elphidium aff. *E. crispum* (Linnaeus, 1758)
Elphidium sp.
Hauerina pacifica Cushman, 1917
Latecella reniformis (Heron-Allen and Earland, 1915)
Loxostomina limbata (Brady, 1881)
Nodobaculariella cassis (d'Orbigny, 1839)
Nonion pacificum (Cushman, 1924)
Peneroplis pertusus (Forskål, 1775)
Planispirillina tuberculatolimbata (Chapman, 1900)
Planorbulina mediterraneensis d'Orbigny 1826
Pseudohauerinella orientalis (Cushman, 1946)
Pyrgo cf. *P. oblonga* (d'Orbigny, 1839)
Quinqueloculina bellatula Bandy, 1950
Quinqueloculina catalinensis Natland, 1938
Quinqueloculina philippinensis Cushman, 1921
Quinqueloculina subcuneata Cushman, 1921
Quinqueloculina vulgaris d'Orbigny, 1826
Quinqueloculina sp. A
Quinqueloculina sp. B
Quinqueloculina sp. C
Quinqueloculina spp.
Sigmoihauerina bradyi (Cushman, 1929)
Siphonaperta distorquata (Cushman, 1954)
Siphonina tubulosa Cushman, 1924
Sorites sp. 1
Sorites sp. 2
Spirillina sp.

Planktic Foraminifera

Globigerinoides ruber (d'Orbigny, 1839)
Trilobatus trilobus (Reuss, 1850)

Vertebrate

Fish bone
Fish tooth
Mammal metapodial bone

Invertebrate

Bivalve mollusk
 ?*Barbatia* sp.
Bivalve unknown
Bryozoan
Crab claw
Echinoid spine
Gastropod
 Chrysallida limbaughii (Hertlein and Allison, 1968)

(continued on next page)

Table 3. (continued)

Gastropod (continued)
<i>Elachisina</i> sp.
<i>Fartulum</i> sp.
Hipponicidae sp.
<i>Lienardia rigida</i> (Hinds, 1843)
<i>Melanella</i> sp.
<i>Modulus</i> sp.
Naticidae sp.
<i>Omalogyra</i> sp.
<i>Pachystremiscus solitarius</i> Hertlein and Allison, 1968
<i>Triphora</i> sp.
<i>Turbonilla clippertonensis</i> Hertlein and Allison, 1968
Gastropod unknown sp. A
Gastropod unknown sp. B
Gastropod unknown sp. C
Gastropod operculum
Limpet
<i>Diodora</i> sp.
<i>Emarginula</i> sp.
Limpet unknown sp. A
Ostracod
<i>Bairdia teeteri</i> Allison and Holden 1971
<i>Cypridopsis oceanus</i> Allison and Holden 1971
<i>Limnocythere viaticum</i> Holden and Allison 1971
<i>Mutilus convergens clippertonensis</i> Allison and Holden 1971
<i>Triebelina sertata</i> Triebel 1948
Ostracod unknown sp. A
Ostracod unknown sp. B
Worm tube
<i>Spirobis</i> sp.
Worm tube unknown
Insect
Non-Winged
Winged
Plant
Charophyte gyrogonite
Seed

Table 4. Distribution (presence/absence) of foraminifera in the Clipperton Island samples

		Benthic																											Planktic						
Sample Location	Sample Number	<i>Ammonia</i> sp.	<i>Bolivina</i> sp.	<i>Cibicides</i> sp.	<i>Elphidium</i> aff. <i>E. crispum</i>	<i>Elphidium</i> sp.	<i>Hauerina pacifica</i>	<i>Latecella reniformis</i>	<i>Loxostomina limbata</i>	<i>Nodobaculariella cassis</i>	<i>Nonion pacificum</i>	<i>Peneroplis pertusus</i>	<i>Planispirulina tuberculatolimbata</i>	<i>Planorbulina mediterraneensis</i>	<i>Pseudohauerinella orientalis</i>	<i>Pyrgo</i> cf. <i>P. oblonga</i>	<i>Quinqueloculina bellatula</i>	<i>Quinqueloculina catalinensis</i>	<i>Quinqueloculina philippinensis</i>	<i>Quinqueloculina subcuneata</i>	<i>Quinqueloculina vulgaris</i>	<i>Quinqueloculina</i> sp. A	<i>Quinqueloculina</i> sp. B	<i>Quinqueloculina</i> sp. C	<i>Quinqueloculina</i> spp.	<i>Sigmoilhauerina bradyi</i>	<i>Siphonaperta distortaqueata</i>	<i>Siphonina tubulosa</i>	<i>Sorites</i> sp. 1	<i>Sorites</i> sp. 2	<i>Spirillina</i> sp.	<i>Globigerinoides ruber</i>	<i>Trilobatus trilobus</i>		
beach	LP-1		X	X		X		X	X	X	X		X	X	X				X	X	X	X			X	X	X	X	X	X	X	X	X	X	
beach	LP-2																													X					
beach	LP-3	X										X													X				X						
beach	LP-4							X																	X				X						
lagoon	LP-5					X																													
beach	LP-6																												X						
beach	LP-7																																X		
beach	LP-8																												X			X			
beach	LP-9																																		
beach	LP-10	X															X								X										
lagoon	LP-11																									X									
beach	LP-12															X																			
beach	LP-13																																X		
beach	LP-14																														X				
lagoon	LP-15		X						?															X	X				X						
beach	LP-16														X																				
beach	LP-17																																		
beach	R-1		X																						X				X						
beach	R-2																												X						
beach	R-3			X				X									X					X	X	X	X	X		X							

Table 5. Distribution (presence/absence) of microscopic vertebrate, invertebrate, insect, and plant remains in the Clipperton Island samples

Sample Location	Sample Number	Vertebrate		Invertebrate																		Insect	Plant																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																										
		Fish bone	Fish tooth	Mammal metapodial bone	Bivalve mollusk	Bryozoan	Crab claw	Echinoid spine	Gastropod										Ostracod					Worm																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																									
									<i>Chrysallida limbaughi</i>	<i>Elachisina</i> sp.	<i>Fartulum</i> sp.	Hipponicidae sp.	<i>Lienardia rigida</i>	<i>Melanelia</i> sp.	<i>Modulus</i> sp.	Naticidae sp.	<i>Omalogyra</i> sp.	<i>Pachystremiscus solitarius</i>	<i>Triphora</i> sp.	<i>Turbonilla clippertonensis</i>	Gastropod unknown sp. A	Gastropod unknown sp. B	Gastropod unknown sp. C		Gastropod operculum	Limpet	<i>Diodora</i> sp.	<i>Emarginula</i> sp.	Limpet unknown sp. A	<i>Bairdia teeteri</i>	<i>Cypridopsis oceanus</i>	<i>Limnocythere viaticum</i>	<i>Mutillus convergens clippertonensis</i>	<i>Tricheilina serrata</i>	Ostracod unknown sp. A	Ostracod unknown sp. B																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																													
<i>Spirobis</i> sp.	Worm tube unknown	Non-Winged	Winged	Charophyte gyrogonites	Seed																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																												
beach	LP-1	X		X	X	X	X		X			X	X			X		X		X		X		X		X	X	X	X																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																				</

DISCUSSION

The extreme isolation of Clipperton Island prompts several inquiries. What are the characteristics of the faunas? Are the faunas of mixed biogeographic affinities (i.e., the tropical eastern Pacific [Panamic] and Indo-Pacific Provinces) or just local or Inter-Island endemics? And if other provinces are represented, how do these organisms disperse to this location?

Characterization of the Faunas

Though most tropical islands have numerous habitats where organisms can live (i.e., muddy, silty, and sandy bottoms, rocky shorelines), and extensive plant life near the water such as mangrove forests and algal mats that serve as both refuge and food sources, these are lacking on Clipperton Island. Instead, coral and coral rubble covers extensive areas. Additionally, the island's geographic location places it in one of the lowest productivity zones of the eastern Pacific (Koblentz-Mishke, 1970; Parsons and Takahashi, 1973),

and the pounding surf around the entire island pulverizes biotic and sedimentologic debris that is eventually deposited in the surf zone and along the beach.

As a result of these limiting environmental factors, foraminiferal diversity is extremely low in the shallow-water environments around Clipperton Island compared to other islands in the tropical Pacific. Whereas almost 100 species were recovered in a very shallow-water coastal mangrove forest on Moorea (Langer and Lipps, 2006) and hundreds to thousands of species are typically encountered elsewhere on islands in the tropical Pacific (e.g., Makled and Langer, 2011; Debenay, 2012; Fajemila et al, 2015), only 29 taxa were recovered in this study (Table 4). The most common taxa are *Sorites* spp. and *Quinqueloculina* spp. The *Sorites* are further separated into two species: the most prevalent is *Sorites* sp. 1, characterized by a double row of apertures on edge view (Plate 1E, 1F), and *Sorites* sp. 2, with a single row of apertures on edge view (Plate 1G). Molecular data on the genus are inconclusive at this time (Holzmann et al., 2001; Merkado et al., 2013), with both apertural arrangements recently being attributed to the genus *Sorites* (Merkado et al., 2013).

Noteworthy is the apparent absence of any specimens of *Amphistegina*. The genus is reported to be ubiquitous in the tropical Pacific (Langer and Hottinger, 2000; Langer and Lipps, 2003), most often as *Amphistegina lobifera* Larsen or *Amphistegina lessonii* d'Orbigny, and often comprises a significant portion of the local sediment (Cushman et al., 1954; McKee et al., 1959; Moberly and Chamberlain, 1964; Sournia, 1976; Hallock, 1981; Vénec-Peyré, 1991; Whittaker and Hodgkinson, 1995; Bicchi et al., 2002; Debenay, 2012; Weinmann et al., 2013; Fajemila et al, 2015; Fujita and Omori, 2015). However, species of *Amphistegina* have not been encountered in the far eastern tropical Pacific, based on early surveys from California to Central America summarized by Culver and Buzas (1986, 1987), as well as in more localized investigations such as in the transitional boundary zone between the Surian and Panamanian Provinces off Baja California, Mexico (at Rocas Alijos; McGann, 1996), the southern Gulf of California (Halfar et al., 2000; Halfar and Ingle, 2003), the Panamanian Province from southern Baja California to southern Peru (Crouch and Poag, 1987), the Galápagos Archipelago (Humphreys et al., 2019), or in the Chilean–Peruvian Province (Boltovskoy, 1976). As Crouch and Poag (1987) as well as Langer and Hottinger (2000) suggested, species' distributions are controlled by water mass temperatures so it is possible that this genus is not represented in the far eastern tropical Pacific because it is not able to survive the cooler surface water temperatures in some areas, the seasonal effects of upwelling, or periodic episodes of cool eastern boundary currents penetrating into areas of warmer water.

Similar to the foraminifera, the diversity of the molluscan and ostracod faunas are impoverished at Clipperton Island compared to others in the tropical Pacific (Kaiser, 2007; Allison and Holden, 1971). Of the already meager molluscan fauna of just 285 species reported by Kaiser (2007), only 13 gastropods and 3 limpets were identified in this study. Nine of the 24 ostracod species reported by Allison and Holden (1971) were also recovered.

Because of the lagoon's isolation from the marine realm, the biota recovered there is somewhat distinct from the beach samples. The brackish water supports two species of ostracod (*Cypridopsis oceanus* and *Limnocythere viaticum*), aquatic plants (seeds of *Scirpus*), algae (charophyte gyrogonites), and fish (bones and teeth). However, the remains of marine-dwelling foraminifera (*Sorites* spp., *Cibicides* sp., *Elphidium* sp., and *Quinqueloculina* sp.), mollusks (*Pachystremiscus solitarius* and *Elachisina* sp.), and worm tubes, as well as the terrestrial-dwelling mammal (metapodial bone) are thought to be allochthonous, most likely transported to the lagoon from the marine realm and beach by waves sweeping over the island or, in the case of the mammal bone, from the limited land surface.

Biogeographic Affinities

The Clipperton Island biota, as determined by some of the earliest investigations, represent several faunal provinces. Bartsch and Rehder (1939), while reporting on the mollusks obtained on Roosevelt's 1938 Presidential Cruise, commented that the fauna was interesting and had an Indo-Pacific relationship that suggested it was a "drift fauna" (i.e., not endemic but carried by currents to this location). Additional

molluscan specimens collected a few decades later also suggested the shallow marine fauna of Clipperton Island was dominantly a mixture of Indo-Pacific and Panamic species, although lesser elements included Californian–Panamic, endemic, and cosmopolitan–circumtropical taxa (Hertlein and Emerson, 1953; Emerson, 1967, 1994; Emerson and Chaney, 1995). This was followed by an investigation by Kaiser (2007) who noted several biogeographical affinities in the molluscan fauna: tropical eastern Pacific (Panamic, 37.7%), Indo-Pacific (33.5%), inter-island endemics (8.9%), circumtropical (16.2%), endemic (2.6%), and western Atlantic (1.0%). Despite the low diversity of the molluscan species recovered in the present study, several biogeographic regions are represented: *Chrysallida limbaughi* and *Turbonilla clippertonensis* are endemic to Clipperton Island, *Pachystremiscus solitarius* is a tropical Pacific, Inter-Island endemic species, and *Lienardia rigida* is a tropical eastern Pacific species associated with the Panamic and/or Californian Province and tropical eastern Pacific oceanic islands (Revillagigedo Islands, Cocos Island, Malpelo Island, and Galápagos Islands; see Kaiser, 2007).

Allison and Holden (1971) reported on the ostracods collected during the 1958 IGY Clipperton Island Expedition, commenting that the fauna was derived from four biogeographical regions: a distinct Caribbean aspect, a weak Indo-Pacific link, a restricted west American aspect, and a cosmopolitan aspect. They also noted that some distinct species (i.e., the Family Loxoconchidae) from comparable Indo-Pacific habitats were missing on the island. In the depauperate ostracod fauna recovered in this study, *Cypridopsis oceanus* and *Limnocythere viaticum* are two of the nine endemic freshwater species Allison and Holden (1971) found restricted to the lagoon due to its isolation from the ocean for the last ~160 years, *Mutilus convergens clippertonensis* is a shallow marine species also reported from the Panamic Province in the Gulf of California and Gulf of Panama, and *Triebelina sertata* is another shallow marine species but with Indo-Pacific as well as Caribbean affinities (Allison and Holden, 1971).

Other marine organisms from Clipperton Island also display mixed biogeographic affinities to the tropical eastern Pacific (Panamic Province) and Indo-Pacific. These include fish (Briggs, 1961; Allen, 1995, Robertson and Allen, 1996), corals (Glynn et al., 1966; Carricart-Ganivet & Reyes-Bonilla, 1999; Flot and Adjeroud, 2009; Romero-Torres et al., 2018), crustaceans (Poupin et al., 2009), and echinoderms (Solis-Marin and Laguarda Figueras, 2009). Although remains of many of these organisms were recovered in this present study, none were identified with a degree of taxonomic precision suitable to distinguish their biogeographic affinities.

Like the mollusks and ostracods, the Clipperton Island benthic foraminiferal fauna has affinities to more than one biogeographic province as well, as do the faunas of other tropical regions (see Förderer and Langer, 2018; Förderer et al., 2018). Crouch and Poag (1987) published the most complete inventory of benthic foraminifera from the island, although it is only based on two samples. They concluded that 58 of their eastern Pacific species had western Pacific affinities and 29 of 57 species from the Panamanian Province also had affinities to the western Pacific. In the present study, of the 29 taxa of benthic foraminifera we recovered, none are endemic, seven have Indo-Pacific affinities (*Latecella reniformis*, *Peneroplis pertusus*, *Pseudohauerinella orientalis*, *Quinqueloculina philippiensis*, *Quinqueloculina subcuneata*, *Siphonaperta distorta*, and *Siphonina tubulosa* (Brenner, 1962; Crouch and Poag, 1987; Debenay, 2012), one is a disjunct Caribbean species (*Quinqueloculina vulgaris*; Crouch and Poag, 1987), and most of the remaining species are tropical (Halfar et al., 2000; Halfar and Ingle, 2003) and representative of the eastern Pacific Panamic Province (Crouch and Poag, 1987).

One of the dominant taxa, *Sorites*, is circumtropical with the widest latitudinal distribution (30°S to 40°N) of any of the larger symbiont-bearing foraminifera and whose distribution as represented by species such as *Sorites orbiculus* Forskål is limited by the 14°C winter isotherm (Langer and Hottinger, 2000; Langer, 2008). The genus is widespread in the Indo-Pacific (e.g., Cushman, 1933; Cushman et al., 1954; Cole, 1969; Langer and Lipps, 2003; Debenay, 2012; Fajemila et al., 2015), but has not reported from the eastern tropical Pacific at Rocas Alijos (McGann, 1996), the Gulf of California, Mexico (Halfar et al., 2000; Halfar and Ingle, 2003), or previously at Clipperton Island (Crouch and Poag, 1987). Instead, the dominant Soritidae reported present at the latter two locations is *Amphisorus hemprichii* Ehrenberg, a species which is morphologically similar to *Sorites*.

The two species of planktic foraminifera recovered in the Clipperton Island deposits [*Globigerinoides ruber* (d'Orbigny) and *Trilobatus trilobus* (Reuss)] are both warm-water species that live in the upper ~50 m of tropical and subtropical waters (Bé and Tolderlund, 1971). Through laboratory studies, it has been shown that *G. ruber* is associated with a temperature range of 14–32°C and salinity of 22–49 psu (Bé et al., 1977; Bijma et al., 1990). Clearly, these two species do not live in the intertidal to shallow subtidal waters of the island where they were retrieved but reside in the offshore water masses, their tests being carried to the nearshore after death.

Dispersal of Organisms

The transoceanic dispersal of exotic organisms into new biogeographic regions are known to occur by several processes. By far, the most likely mechanism by which organisms are dispersed into distant regions is broadcast spawners that release larvae that are capable of migrating over long distances (Richmond, 1987; Tay et al., 2012). Because the larvae have limited mobility, they depend on currents to disperse them to suitable habitats (Tay et al., 2012). Examples of such biota on Clipperton Island include mollusks (Allison and Holmes, 1971; Kaiser, 2007) and coral (Romero-Torres et al., 2018). Species with long dispersal stages are, in fact, more numerous than those species without on Clipperton Island (Kaiser, 2007). The faunal reliance on this type of dispersal ability, as well as the islands limited hard substrate biomes and paucity of other habitats (Kaiser, 2007), results in lower diversity on the island compared to most tropical Pacific regions (Allison and Holden, 1971).

Other biological introductions may be the result of rafting, such as coral larvae that have settled and grown on floating objects. These include mats of shallow-water vegetation, coconuts, logs, volcanic pumice, fishing floats, and ships' hulls (Crossland, 1952; Richards, 1958; Jokiel, 1984 and references therein). This dispersal mechanism may be fairly common. For example, the formation of vegetation mats and the release of coconuts happens daily (Lipps, personal communication, 2019). Depending on the location of currents, they could play an important role because they allow for much longer dispersal time and distance (up to several years and possibly 20,000–40,000 km traveled) as well as escape from predators than is possible from broadcast spawning that is only viable for short and intermediate distance dispersal (Jokiel, 1984; Richmond, 1987). Similarly, benthic foraminifera were found rafted on fishing floats, small boats, and docks from Japan to the west coast of North America and the Hawaiian Islands as a result of the Tohoku earthquake and tsunami of 2011 (Finger, 2018).

Microorganisms also may be passively distributed by being attached to, or inside of, other organisms. Two such examples are birds and fish. Allochthonous foraminifera have been reported on the feet of ducks in the Salton Sea area (Headlee, 1961) and within the guts of birds (Lipps, personal communication, 2019). Benthic foraminifera have also been recovered in the guts of shore fish that were eating food on the sediment surface (i.e., coral, algae, and possibly organic matter; Todd, 1961), as well as in the guts of invasive rabbitfish from the Red Sea that were found in the Mediterranean Sea (Guy-Haim et al., 2017). The latter is an example of ichthyochory (i.e., the live passage of organisms through fish digestive tracts) which may explain how some biological distribution patterns may be independent of oceanic currents.

Another mechanism of dispersal that has impacted Clipperton Island is due to unintentional anthropogenic efforts. In 1999–2000, a shipwreck of two large fishing boats resulted in the arrival of black rats [*Rattus rattus* (Linnaeus)] to the island (Pittman et al., 2006). By 2003, the rats became a common part of the island fauna. As a result, the crab and bird populations significantly declined while the vegetation increased (Pittman et al., 2006). These shipwrecks are likely responsible for the hand or foot bone (metapodial) of a mouse-size mammal found in lagoon sample LP-11.

Clipperton Island is thought to be a critical “stepping stone” in the migration pathway in the tropical Pacific (Allison and Holden, 1971; Glynn et al., 1996; Robertson and Allen, 1996; Romero-Torres et al., 2018) because it is situated on the eastern edge of the Eastern Pacific Barrier (EPB), far from any other land mass (Figure 2). Originally thought to be nearly impassable due to its expanse, as well as the relative speed of the zonal currents and the duration of larvae viability (Ekman, 1953; Thorson 1961; Heck and McCoy

1978), biological evidence now indicates that larvae breach the EPB in both directions (Romero-Torres et al., 2018). This was confirmed by the trajectories of drifting buoys in the North Equatorial Current (NEC) and North Equatorial Countercurrent (NECC), showing their paths crossing the EPB in both directions, with one example in the NEC of them circling around Clipperton Island (Glynn et al., 1996). For most of the year, the island is situated in the path of the NEC (Figure 2A; Geography Notes, 2018). This current is the major route for organisms migrating from the American coast to Clipperton Island. As a result, 38% of the molluscan fauna is from the eastern Pacific (Kaiser, 2007). Sea turtles have coastal affinities as well (Lorvelec et al., 2009), and two species of reef fish (Lessios and Robertson, 2006), a cone snail (Duda & Lessios, 2009), and coral (Wood, 2013; Hellberg et al., 2016) all have been documented migrating to, and westward of, Clipperton Island from the eastern Pacific.

Occasionally, shifting currents cause Clipperton Island to be exposed to the NECC instead of the NEC (Figure 2B; Glynn et al., 1996). The easternmost land masses of the Polynesian group that lie along the course of the NECC are the Line Islands (Briggs, 1961) and those species that are well adapted for long-distance dispersal can travel eastward from those islands across the EPB to the eastern Pacific (Briggs, 1961; Dana, 1975; Jokiel, 1984; Richmond, 1987; Glynn et al., 1996; Romero-Torres, 2018). This route is especially feasible during intense El Niño events when the NECC accelerates, reducing the transport time across the Pacific by one-half or more to ~50–80 days, which is still within the length of time some larvae are capable of settlement (Richmond, 1990; Grigg and Hey, 1992; Glynn et al., 1996; Romero-Torres, 2018). The existence of this NECC faunal dispersal route is supported by evidence of tropical central Pacific and Indo-Pacific species of reef fish (Lessios and Robertson, 2006; Lessios and Balm, 2017), shore fish (Briggs, 1961), mollusks (Allison and Holden, 1971; Kaiser, 2007; Lessios and Balm, 2017), echinoderms (Lessios and Balm, 2017), and corals (Richmond, 1987; Glynn et al., 1996; Lessios and Balm, 2017).

CONCLUSIONS

Twenty-nine taxa of benthic foraminifera, two species of planktic foraminifera, 15 taxa of gastropods, and seven species of ostracods were identified from 20 beach and lagoon stations on Clipperton Island. Endemics are recognized in the molluscan and ostracod (brackish lagoon-only) faunas, but not in the foraminiferal fauna. The benthic foraminiferal fauna is primarily of tropical Indo-Pacific and eastern Pacific (Panamic) affinities with one species from the Caribbean, whereas most species of the microbiota are representative of the tropical eastern Pacific (Panamic) Province, although species with affinities to the Indo-Pacific, Inter-Island Pacific, and Caribbean Provinces are also present. Clipperton Island appears to play a role as a stepping stone for the migration of marine organisms traveling both east and west across the East Pacific Barrier by way of the surface-dwelling North Pacific Current and North Pacific Countercurrent.

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PLATES

Plate 1. (see p. 20) Scanning Electron Micrographs of Clipperton Island foraminiferal specimens. A. *Latecella reniformis* (Heron-Allen and Earland), Station LP-4. B. *Planorbulina mediterranensis* d'Orbigny, Station LP-1. C. *Planispirillina tuberculatolimbata* (Chapman), Station LP-1. D. *Planispirillina tuberculatolimbata* (Chapman), detail of C, Station LP-1. E. *Sorites* sp. 1, side view, Station LP-3. F. *Sorites* sp. 1, oblique view of E showing the edge with a double row of apertures, Station LP-3. G. *Sorites* sp. 2, edge view showing a single row of apertures, Station LP-1. H. *Peneroplis pertusus* (Forskål), Station LP-3. I. *Pseudohauerinella orientalis* (Cushman), Station LP-1. J. *Sigmoihauerina bradyi* (Cushman), Station R-3. K. *Sigmoihauerina bradyi* (Cushman), Station R-3. L. *Nonion pacificum* (Cushman), Station LP-1. M. *Loxostomina limbata* (Brady), Station R-3. N. *Pyrgo* cf. *P. oblonga* (d'Orbigny), Station LP-12. O. *Hauerina pacifica* Cushman, Station LP-1. P. *Quinqueloculina catalinensis* Natland, Station R-3. Q. *Quinqueloculina philippinensis* Cushman, Station LP-1. R. *Quinqueloculina vulgaris* d'Orbigny, Station LP-1. S. *Quinqueloculina subcuneata* Cushman, Station LP-1. T. *Siphonaperta distorquéeata* (Cushman), Station LP-1. U. *Quinqueloculina bellatula*, Station LP-10. V. *Quinqueloculina* sp. A, Station LP-1. W. *Quinqueloculina* sp. B, Station R-3. X. *Quinqueloculina* sp. C, Station LP-15. Y. *Nodobaculariella cassis* (d'Orbigny), Station LP-1. Z. *Globigerinoides ruber* (d'Orbigny), Station LP-1. AA. *Trilobatus trilobus* (Reuss), Station LP-1.

Plate 2. (see p. 21) Scanning Electron Micrographs of Clipperton Island microbiological specimens. Mollusks (A–L). A. *Pachystremiscus solitarius* Hertlein and Allison, Station L-3. B. *Omalogyra* sp., eroded specimen in ventral aspect, Station LP-1. C. *Fartulum* sp., Station LP-1. D. *Lienardia rigida* (Hinds), Station LP-3. E. ?*Cerithiopsis* sp., juvenile, Station LP-3. F. *Turbonilla clippertonensis* Hertlein and Allison, Station LP-3. G. *Chrysallida limbaughi* (Hertlein and Allison), Station LP-3. H. *Elachisina* sp., Station LP-11. I. *Hipponicidae* sp., immature specimen, Station LP-3. J. *Chrysallida limbaughi* (Hertlein and Allison), protoconch, Station LP-1. K. *Turbonilla clippertonensis* Hertlein and Allison, protoconch, Station LP-3. L. *Turbonilla clippertonensis* Hertlein and Allison, protoconch, Station LP-3. Ostracods (M–Q). M. *Bairdia teeteri* Allison and Holden, Station LP-15. N. *Cypridopsis oceanus* Allison and Holden, Station LP-15. O. *Limnocythere viaticum* Holden and Allison, Station LP-15. P. *Mutilus convergens clippertonensis* Allison and Holden, Station LP-1. Q. *Triebelina sertata* Triebel, Station LP-1. R. Mammal bone, possibly a proximal metapodial such as a second metatarsal of a mouse-size animal, Station LP-11. Seeds (S–V). S. Seed, Station LP-11. T. Seed, Station LP-11. U. Seed, Station LP-11. V. Seed, Station LP-11. Algal reproductive structures (W–X). W. Charophyte gyrogonite, Station LP-11. X. Charophyte gyrogonite, Station LP-11.

Plate 3. (see p. 22) Scanning Electron Micrographs of Clipperton Island microbiological specimens. A, B. Fish vertebrae, Station LP-11. C. Fish bone, Station LP-11. D. Fish tooth, Station LP-11. E. Fish tooth, Station LP-1. F. Fish tooth, Station LP-1. G. Crab claw, Station LP-3. H. Crab claw, Station R-3. I. Fish tooth, Station LP-7. J. Bryozoan, Station R-3. K. Bryozoan, Station LP-1. L. Echinoid spine, Station LP-8. M. Echinoid spine, Station LP-1. N. Worm tube, Station LP-11. O. Worm tube, Station LP-15. P. Worm tube of *Spirobis* sp., Station LP-1.

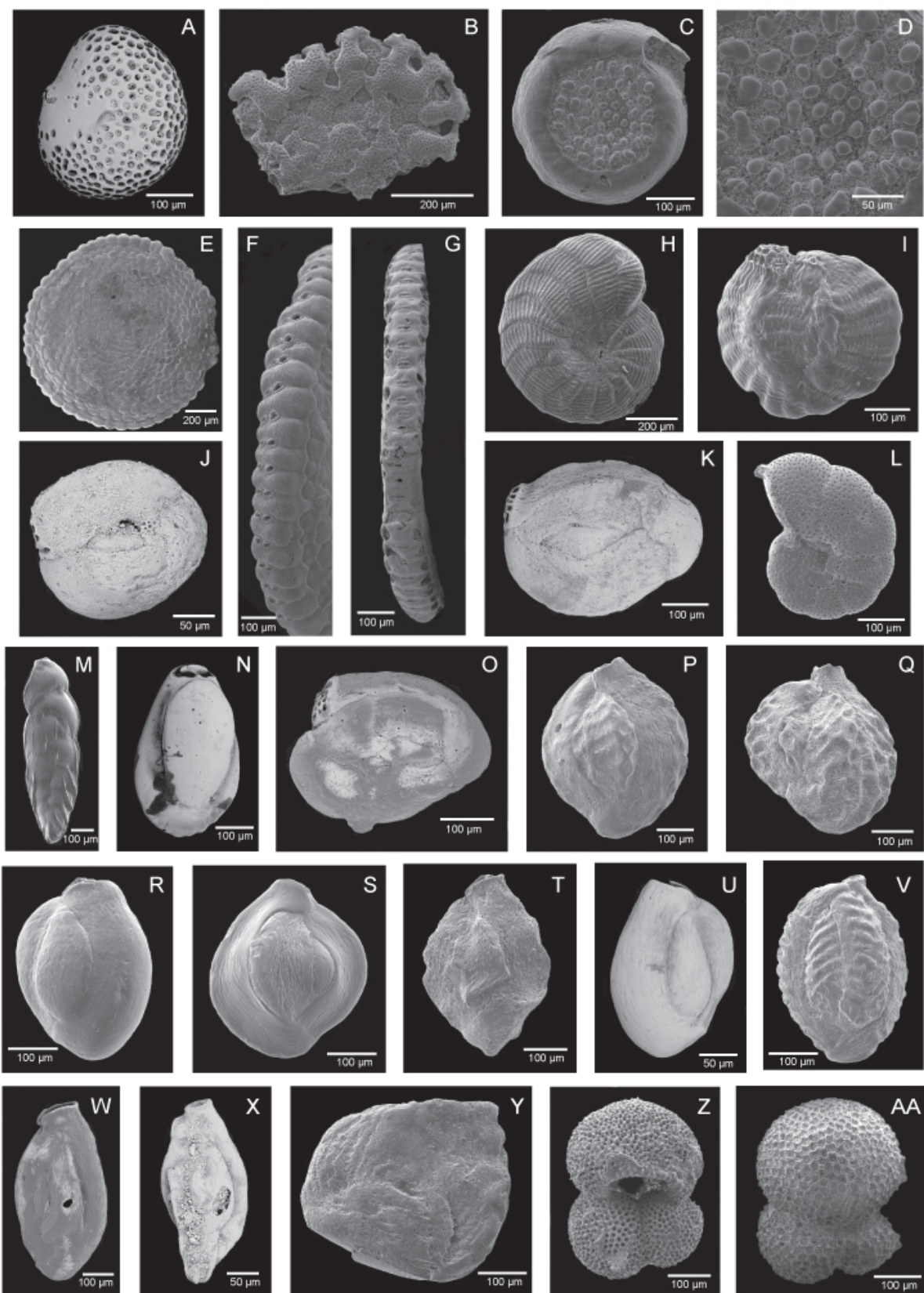


Plate 1

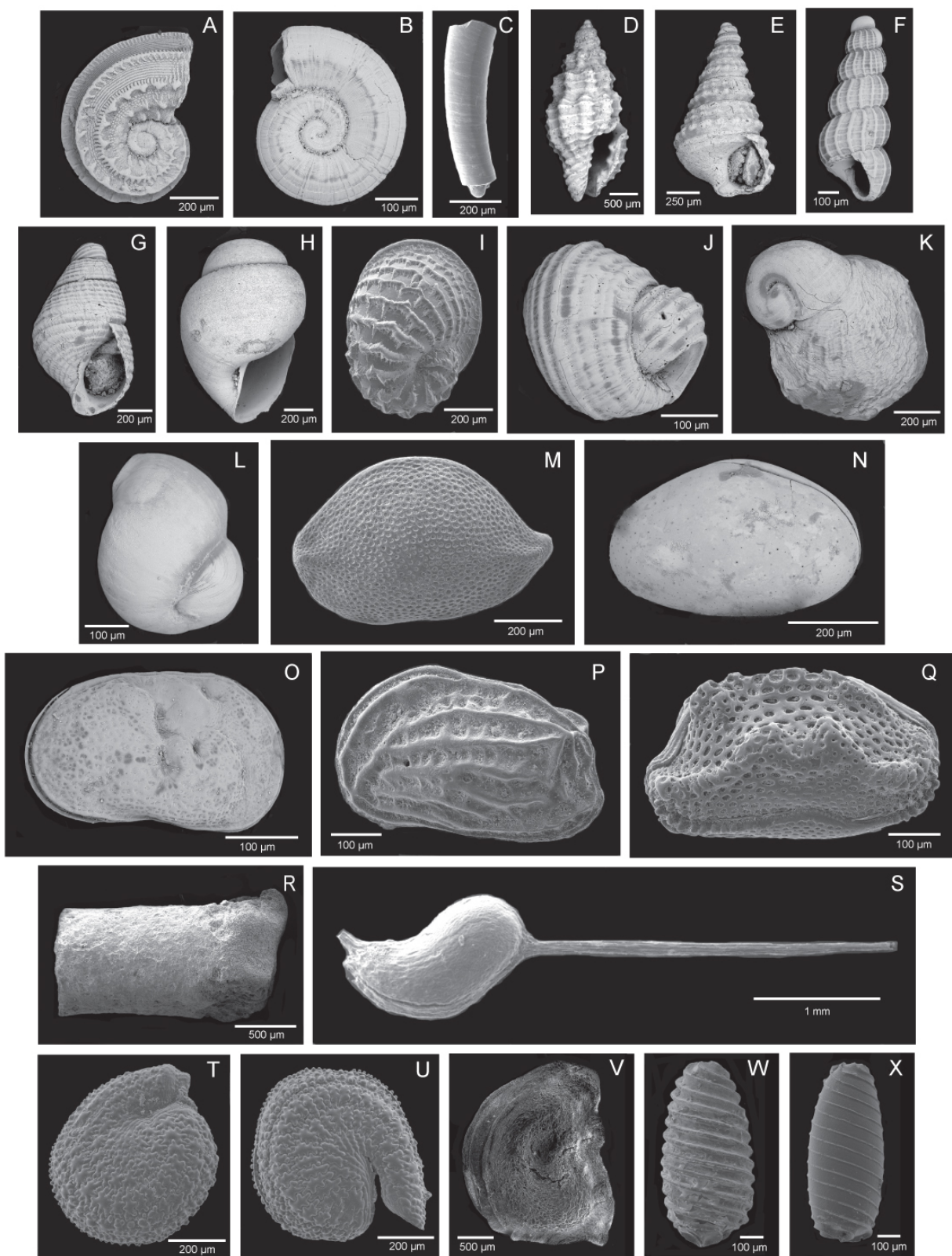


Plate 2

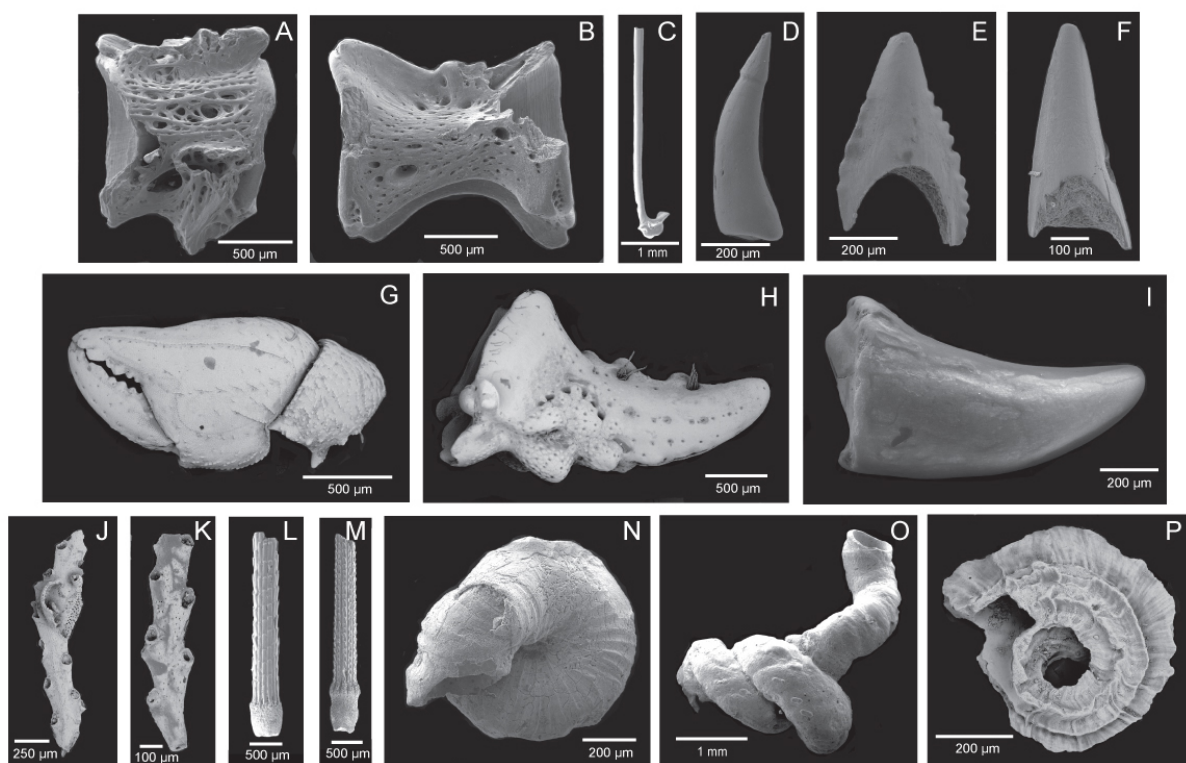


Plate 3

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