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Copepoda from deep-sea hydrothermal vents and cold seeps

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Abstract

Recent explorations of hydrothermal vents in the eastern Pacific (Juan de Fuca spreading zone, Guaymas Basin in the Gulf of California, East Pacific Rise at 21° N and 13° N, and Galapagos Rift) and on the Mid-Atlantic Ridge have revealed many copepods, mostly siphonostomatoids with few poecilostomatoids. In these habitats in depths from 1808 to 3650 m water temperatures may reach nearly 15 °C. Among more than 22000 copepods from vents examined two new families, 11 new genera, and 32 new species were represented.

In addition, two new copepods were found in 3260 m at cold seeps at the base of the West Florida Escarpment in the Gulf of Mexico, an environment not thermally active, with water temperatures about 4.39 °C.

Some of these copepods were associated with host invertebrates such as a *Nuculana*-like protobranch bivalve, a polychaete, and two species of shrimps. Others were obtained from washings of bivalves or vestimentiferans or by means of corers or slurp guns.

Introduction

Manned deep-sea submersibles have made possible the exploration of the ocean floor at great depths. Such exploration resulted in the discovery in 1977 of communities of bivalves, crabs, and other macroorganisms on the Galapagos Rift in the eastern Pacific (Corliss & Ballard, 1977). Living organisms have since been found in abundance in localized areas, especially at hydrothermal vents and cold seeps. Population densities and biomass are high, but the vent communities are not particularly diverse (Grassle, 1983). Thanks to deep-diving by the *Alvin*, *Cyana*, and other submersibles, we now know that a varied fauna occurs at these special locations. For example, in 1985 60 species of invertebrates were known from the Eastern Pacific hydrothermal vents (Newman, 1985), and many more have since been added to the list.

Animals in vent areas live under very different conditions than those inhabiting the water column or shallow seas. The environment in the immediate vicinity of hydrothermal vents on the Galapagos Rift is aphotic, the water pressure is as great as 260 atmospheres, and the temperature may reach 15 °C (Grassle, 1985), substantially above the 2 °C ambient temperature a few meters away from the vents. The amount of suspended food is 300–500 times greater than immediately outside the vent areas. At hydrothermal vents bacteria multiply rapidly and are implicated in providing the basis of the chemosynthetic food chain by oxidizing hydrogen sulfide coming from

the vents, reducing carbon dioxide, and thereby synthesizing organic carbon (Jannasch & Wirsen, 1979). The life span of a vent is rather short, from several years to a few decades (Grassle, 1985).

In cold seeps found at the base of the West Florida Escarpment, in contrast to hydrothermal vents, the bottom water temperature averages 4.39 °C (Paull *et al.*, 1984). Hypersaline water of Lower Cretaceous fresh-water origin seeps into the sea from strata in the interior of the Florida Platform. No primary sulfide discharge is found but is secondarily produced in the sediments by bacterial sulfate reduction. Cold seeps have many of the same types of invertebrates that characterize the hydrothermal vent communities (Hecker, 1985).

Methods

The copepods were collected either from washings of macroinvertebrates such as the large clam *Calyptogena*, the mussel *Bathymodiolus*, and vestimentiferans (*Riftia* or other genera; see Jones, 1985), or from sediments obtained by means of corers or slurp guns. Copepods were recovered in depths from 1,808 to 3,650 m.

The slurp gun, as operated from the DSRV *Alvin*, by which many of the copepods were collected, consists of a large container in the opening of which are fitted a tube whose external inlet can be directed to chosen collecting sites by the pilot in *Alvin*, a filter, and a pump that draws water into the container (see Editor, National Geographic Magazine, 1979). In operation organisms including copepods are filtered out and collect at the bottom of the container. Excess water is ejected by the action of the pump.

Results

Copepoda have been found at hydrothermal vents at the Juan de Fuca spreading zone off Washing-

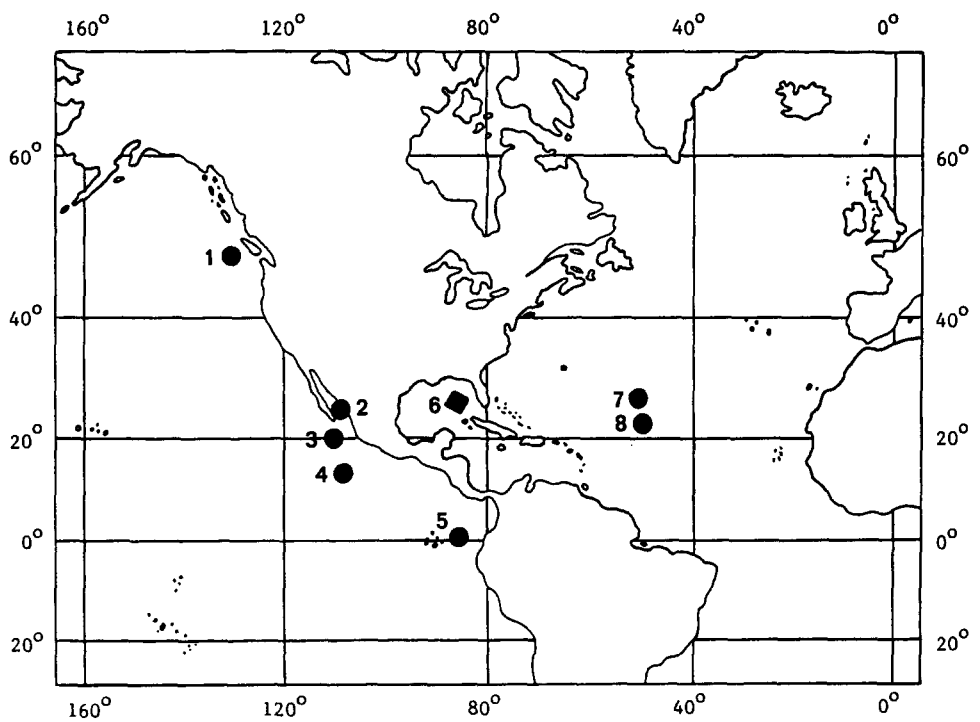

Fig. 1. Locations of hydrothermal vents and cold seeps where poecilostomatoid and siphonostomatoid copepods have been collected. 1 = Juan de Fuca spreading zone, 2 = Guaymas Basin, 3 = East Pacific Rise at 21° N, 4 = East Pacific Rise at 13° N, 5 = Galapagos Rift, 6 = West Florida Escarpment, 7 and 8 = Mid-Atlantic Ridge.

ton and British Columbia, in the Guaymas Basin in the Gulf of California, on the East Pacific Rise at 21° N and 13° N, at the Galapagos Rift, and on the Mid-Atlantic Ridge at approximately 26°N, 45°W (Fig. 1). The first copepod obtained from a hydrothermal vent area was *Ceuthoecetes aliger* Humes and Dojiri, 1980, a siphonostomatoid, washed from vestimentiferans at the Galapagos Rift and the East Pacific Rise (Humes and Dojiri, 1980). A second siphonostomatoid, *Benthoxynus spiculifer* Humes, 1984, was recovered from vestimentiferans at the Juan de Fuca spreading zone (Humes, 1984).

I now report the results of a study of many thousands of copepods from deep-sea vents. These copepods compromise two new families, 11 new genera, and 32 new species, including both poecilostomatoids and siphonostomatoids (Table 1). (Descriptions of these taxa will be found in Humes, 1987, in press a, b, and work in preparation).

Poecilostomatoids are represented by four genera: *Hyphalion* in the family Clausidiidae, *Erebonaster* in the new family Erebonasteridae, *Oncaea* in the family Oncaeidae, and *Laitmatobius* of uncertain familial position. *Hyphalion* is clearly a clausidiid and constitutes the sole case where a family well known in shallow seas is represented also in deep-sea regions. *Erebonaster* is remarkable in having a very large palp on the mandible.

The siphonostomatoids include three families, the Dirivultidae, established by Humes and Dojiri (1980), with the new genera *Aphotopontius*, *Exrima*, *Nilva*, *Rhogobius*, *Scotoecetes*, and *Stygiopontius*; the Ecbathyriontidae with the new genus *Ecbathyrion*; and the Megapontiidae with *Hyalopontius* Sars, 1909. Another siphonostomatoid new genus, *Fissuricola*, has an uncertain familial position. In addition, three new species of *Ceuthoecetes* were found. Among the copepods examined during this study poecilostomatoid and siphonostomatoid copepods are abundant and diverse at vent areas. Many thousands of individuals were collected from cores, slurp gun samples, or from washings of large invertebrates. Siphonostomatoids are more numerous both in species and individuals. Poecilostomatoids comprise three genera with four species; siphonostomatoids 10 genera with 29 species. In spite of the fact that the samples of copepods were not taken quantitatively, it is evident that copepods may occur in very large numbers. For example, more than 8000 copepods were found in washings of several vestimentiferans from *Alvin* dive no. 1214.

Siphonostomatoid families well represented in shallow seas, such as the Artotrogidae, Asterocheridae, and Dyspontiidae, are apparently absent from deep-sea vent areas. One poecilostomatoid family, the Clausidiidae, with numerous species in shallow waters, is represented by one species in the Guaymas Basin and another in the Gulf of Mexico.

Insufficient collections have been made to provide adequate information on the worldwide distribution of vent copepods. However, it appears that genera may be widespread in these unusual and transient environments around the world. The genus *Stygiopontius*, for example, is known both from the eastern Pacific and from the Mid-Atlantic Ridge, but the species in the two areas are different. Three species were found in three locations, the Galapagos Rift, the East Pacific Rise at 21°N and at 13°N: *Aphotopontius arcuatus, Nilva torifera*, and *Ceuthoecetes acanthothrix*. Only one species, *Aphotopontius mammillatus*, occurred at the Galapagos Rift, at the Guaymas Basin, and at the East Pacific Rise at 21° N. All other species were found at no more than two locations. Eighteen species occurred at one location, the East Pacific Rise at 21° N.

The color of one living copepod, *Stygiopontius flexus*, from the Guaymas Basin, has been observed (by Holger Jannasch of the Woods Hole Oceanographic Institution). The copepods, seen alive in a slurp gun sample on fragments of mats of the bacterium *Beggiatoa*, were bright red, a color often seen in other deep-sea crustaceans.

Although the number of eggs carried by females is small, with siphonostomatoids often having only one or two eggs in each egg sac, reproduction is highly successful. Presumably fertilized eggs must be extruded often in order to produce the large numbers of adults observed. The abundance of suspended food particles and perhaps also the

Table 1. Number of species of poecilostomatoid and siphonostomatoid copepods in the deep sea at hydrothermal vents and cold seeps.

	Juan de Fuca spreading zone 46° N, 130° W	Guaymas Basin 27° N, 111° W	Galapagos Rift 37–48′ N, 86° W	East Pacific Rise 21° N, 109° W	East Pacific Rise 13° N, 104° W	West Florida Escarpment 26° N, 85° W	Mid-Atlantic Ridge 26° N, 45° W
Poecilostomatoida							
Clausidiidae	–	1	–	–	–	–	–
Erebonasteridae	–	1	–	–	–	1	–
Oncaeidae	–	1	1	1	1	–	–
Family uncertain	–	1	–	–	–	–	–
Total	–	4	1	1	1	1	–
Siphonostomatoida							
Dirivultidae	3	4	8	14	9	–	1
Ecbathyriontidae	–	–	1	–	–	–	–
Megapontiidae	–	–	1	–	–	–	–
Family uncertain	–	–	–	1	–	1	–
Total	3	4	10	15	9	1	1
Grand total	3	8	11	16	10	2	1

numerous potential host invertebrates in the vent areas may enable the copepods to reproduce rapidly.

Certain copepods in the vent regions seem to be associated with host invertebrates. *Erebonaster protentipes* lives in the mantle cavity of a *Nuculana*-like protobranch bivalve in the Guaymas Basin. *Stygiopontius sentifer* has been washed from the body of the polychaete worm *Alvinella*, the gastropod *Neomphalus*, and the bivalves *Bathymodiolus* and *Calyptogena*. Whether there is a real association in these cases is uncertain, however.

Much more collecting needs to be done in order to determine whether the copepods now known from hydrothermal vents are restricted only to immediate vent areas or may occur more widely in the surrounding deep sea.

From cold seeps only two species of copepods are known, one a siphonostomatoid, the other a poecilostomatoid. Females of the siphonostomatoid *Bythocheres prominulus* (described by Humes, in press a) were collected by means of a slurp gun in 3243–3266 m along the base of the West Florida Escarpment (Fig. 1). The macroinvertebrate fauna here is similar to that found at the vents in the eastern Pacific (Hecker, 1985; Grassle, 1985). It would be interesting to study copepods from these cold seeps more extensively in order to learn whether these small crustaceans have comparable representatives at both vents and seeps.

Bythocheres does not appear to belong to any of the recognized siphonostomatoid families. Until males of this copepod are found it is preferable to leave the family undesignated.

No information on a possible association of *Bythocheres* with a host is available. The large prominent siphon suggests, however, that some kind of association exists. There is no lack of potential hosts, since anemones, vestimentiferans, gastropods, mussels, clams, galatheid crabs, ophiuroids, and holothurians occur in the vicinity of the cold seeps (Paull *et al.*, 1984; Hecker, 1985).

Recently females of a new species of *Erebonaster*, a poecilostomatoid genus previously known only from one species in the Guaymas Basin, have been found at the West Florida Escarpment. The discovery of this genus in both the Gulf of California and in the Gulf of Mexico suggests a wide distribution in the deep sea.

As a result of studies over the past few years, made possible by the introduction of new techniques of collection using deep-diving submersibles, 36 species of poecilostomatoid and siphonostomatoid copepods are known from deep-sea hydrothermal vents and cold seeps in depths of 1000 m or more. We are, however, only at the beginning of understanding the copepod fauna of these unusual and interesting environments.

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