Adaptations of hydrothermal vent organisms to their environment

Françoise Gaill, Magali Zbinden , Florence Pradillon, Juliette Ravaux, Bruce Shillito
Adaptations aux milieux extrêmes, UMR 7622, CNRS, Université Pierre et Marie Curie, 7 Quai Saint Bernard Paris 75005 France

Introduction

The deep sea hydrothermal vents are one of the most unusual habitats found on earth (review in Humphris *et al.* 1995). Vents are surrounded by a dense community which is supported by primary production through chemoautotrophic bacteria. Most of this fauna is composed of sessile animals that harbor bacteria as intracellular symbionts. Such geothermally-driven communities are dependent on the reduced sulfur compounds found in the emerging hot hydrothermal fluid (up to 400°C), which are the main energy source for free-living and symbiotic bacteria.

The vent ecosystem as a remarkable benthic hotspot for carbon production

The tubeworm *Riftia pachyptila* and its endosymbiotic bacteria are thought to be major primary producers of the East Pacific Rise hydrothermal vent ecosystem (Tunnicliffe, 1991). Tube production rates were measured for worms maintained alive in pressure aquaria (Gaill et al, 1997). Upon annual extrapolation, and considering *in situ* animal densities, these rates would reach almost 400 g $C.m^{-2}.year^{-1}$ for worms from the 13°N site (Shillito et al,1999). Thus, vestimentiferan tube growth alone would place the vent ecosystem as a remarkable benthic hotspot for carbon production. Last, it seems that these rates differ depending on the *in situ* origin of the animals, thus suggesting that in the future, this type of experiment may provide quantitative information concerning the vitality of different vent sites.

The vent surroundings : an extreme environment

The hydrothermal environment is harsh, considering the pressure (260 atmospheres), temperature (350°C) and toxicity of the hydrothermal fluid which is acid, anoxic, and rich in metallic sulfides (Tunnicliffe 1991). Deep-sea hydrothermal vent organisms are often cited as examples of adaptation to extreme environmental conditions (Gaill 1993, Sicot et al, 2000). *Alvinella pompejana* is a polychaetous annelid from the East Pacific Rise inhabiting one of the most extreme environment of the earth for animals (Desbruyères *et al.* 1998). Because of their position on active sulphide chimney walls, these animals are facing mineral precipitations resulting from the fluctuating thermal and chemical hydrothermal fluid/sea-water interactions. The tubes they secrete are characterized by a tremendous chemical and thermal stability, their structure being still preserved at 80°C (Gaill & Hunt 1991).

The pompeii worm tube micro-ecosystem

These extracellular matrices protect the worm tissues from the mechanical stress generated by the rain of mineral particles. Furthermore, Zbinden *et al.* (2000) have shown that the more a tube is mineralized, the more iron-rich is its outer face. In contrast, the only particles observed within the tube thickness are zinc sulphides of remarkably constant composition whatever the tube considered. These results indicate that, by structuring the fluid-seawater interface, these exoskeletons allow the animals to regulate their own physical microsurroundings. In contrast with sulphides usually observed in deep sea hydrothermal environments, the unique sulphide found within the exoskeleton of the pompeii worms had a $(Zn_{0.88}Fe_{0.12})S$ composition, forming typical alignments parallel to the main tube layering (Zbinden et al, 2001). This was the first characterization of minerals precipitated within a biological matrix from hydrothermal vent organisms. These minerals represent a new example of zinc-iron biologically induced mineralization. Such layers of nanocrystalline zinc-iron sulphide minerals could be used as valuable markers of annelid tubes.

In vivo experiments

Complementary approaches have been recently used in order to evaluate the *in vivo* temperature tolerance of the hot 'pole' hydrothermal vent fauna or the thermal range of the alvinellid developmental process (Pradillon, in preparation). I*n vivo* heat-exposure experiments were conducted on hydrothermal polychaetes (*Hesiolyra bergi*) of the hottest part of the vent biotope, using a pressurised incubator IPOCAMP (Shillito et al, 2001) equipped with video-facilities,. With such an equipment, Shillito et al (2001) have shown that a worm, foraging around and into the tubes of the thermophilic *Alvinella* species, did not **tolerate** temperature exceeding 40°C. These results suggest that metazoans tolerance to high temperatures (> 40°C) is not a pre-requisite for life amongst alvinellid tubes. Behavioural responses (escape from heat) may be sufficient.

Sulfur filament producing microbes as primary colonizers of new surfaces

In order to study the colonisation process with non invasive methods, a specific device was designed by one of us. This device, the so-called TRAC for Titanium Ring for Alvinellid Colonization, consists in a hollowed titanium cylindrical structure (Fig.1). The device was deployed on a smoker wall at the interface of the hydrothermal fluid with oxygenated seawater, (20-40 ◦C) resulting in H2S emission concentrations on the order of 250-350 mM (Taylor et al ,1999). The experimental surfaces provided by the TRAC became the site for a very rapid colonization by H2S oxidizing, sulfur filament producing bacteria. A white filamentous sulfur mat appeared on the titanium surface in the range of up to 3 mm day^{-1} thickning rate. It appears that under typical continuous flow conditions of warm water vents, sulfur filament producing microbes can be prolific primary colonizers of new surfaces, producing thick mats in just a few days. Such microbiological production is providing a medium for the arrival of rock surface-dwelling animals such as the alvinellid worms.

Sea Floor Observatories : some constraints in Biology

In conclusion, It is obvious that *in situ* and *in vivo* studies will bring in the future new insights about adaptational strategies used by life to invade deep-sea hydrothermal vents and that Sea Floor Observatories would help in some ways to complete our knowledge of the deep sea fauna evolution. However, such observatories would have to respect some constraints for biological studies. The technologies will have to be of microscale type and non invasive, we will have to develop in a first time sensors and new ways of sampling and recovery processes as well as complementary technics of micro and macro-imaging.

Aknowledgements

We thank Mullineaux and C. Fisher for samples collected from the East Pacific Rise during various oceanographic cruises .

REFERENCES

Desbruyères D., Chevaldonné P., Alayse A.M., Jollivet D., Lallier F., Jouin-Toulmond C., Zal F., Sarradin P.M., Cosson R., Caprais J.C., Arndt C., O'Brien J., Guezennec J., Hourdez S., Riso R., Gaill F., Laubier L. & Toulmond A. 1998. Biology and ecology of the "Pompeii worm" (*Alvinella pompejana* Desbruyères and Laubier), a normal dweller of an extreme deep-sea environment: A synthesis of current knowledge and recent developments. *Deep-Sea Res.* 45: 383-422.

Gaill F. & Hunt S. 1991. The biology of Annelid worms from high temperature hydrothermal vent regions. *Rev. Aquat. Sci.* 4: 107-137.

Gaill F. 1993. Aspects of life development at deep sea hydrothermal vents. *FASEB J.* 7: 558-565.

Gaill F., Shillito B., Ménard F., Goffinet G. & Childress J.J. (1997) The rate and process of tube production by the deep sea hydrothermal vent tubeworm *Riftia pachyptila* , Mar. Ecol. Prog.Ser., **148**, 135 - 143.

Humphris S., Zierenberg R., Mullineaux L. & Thomson R. 1995. *Seafloor hydrothermal system: Physical, chemical, biological, and geological interactions.* Geophysical Monograph 91, American Geophysical Union, Washington. 466pp.

Shillito B., Ravaux J., Gaill F., Delachambre J., Thiebaut E., Childress J., 1999, Preliminary data on carbon production of deep sea tube worms, Mar Ecol. Prog. Ser., 183, 275-279

Shillito B. , Jollivet D., Sarradin P.M., Rodier P., Lallier F., †, Desbruyeres D., , Gaill F., 2001, Temperature Resistance of Annelids Living on Deep-Sea Vent Smoker Walls, Mar. Ecol. Prog. Ser., in press

Sicot F., Mesnage M., Masselot M., Exposito J., Garrone R., Deutsch J. & Gaill F. 2000. Molecular adaptation to an extreme environment: Origin of the thermal stability of the Pompeii worm collagen. *J. Mol. Biol.* 302: 811-820.

Taylor C.D., Wirsen C.O. & Gaill F. 1999. Rapid microbial production of filamentous sulfur mats at hydrothermal vents. *Appl. Environment. Microbiol.* 65: 2253-2255.

Tunnicliffe V. 1991. The biology of hydrothermal vents: Ecology and evolution. *Oceanog. Mar. Biol. Ann. Rev.* 29: 319-407.

Zbinden M., Martinez I., Guyot F., Compère P., Cambon-Bonavita M.A. & Gaill F. 2000. Characteristics of mineral particles associated with the Pompeii worm tubes. *Biol. Cell* 92(5): 382.

Zbinden M., Martinez I., Guyot F.. Cambon-Bonavita M.A & Gaill F. 2001 Zinc –iron sulphide mineralizeation in tubes of hydrothermal vent worms, Eur. J. Miner., in press

Fig. 1. The Titanium Ring for Alvinellid Colonisation (TRAC) before (Larvae 95, top) and after (HOT 96, base) its *in situ* deployment at the M vent smoker (EPR). Microorganisms coverage of the TRAC imaged during the HOT96 cruise after 5 days deployment(Base)