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# Radio-active waste disposal and deep-sea biology

Radio-active waste
Deep-sea
Abyss
Biology
Déchets radioactifs
Mer profonde
Abysses
Biologie

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## ABSTRACT

The deep-sea has been widely thought of as a remote, sparsely populated, and biologically inactive environment, well suited to receive the noxious products of nuclear fission processes. Much of what is known of abyssal biology tends to support this view, but there are a few disquieting contra-indications. The realisation, in recent years, that many animal groups show a previously unsuspected high species diversity in the deep-sea emphasized the paucity of our knowledge of this environment. More dramatically, the discovery of a large, active, and highly mobile abysso-bentho-pelagic fauna changed the whole concept of abyssal life. Finally, while there is little evidence for the existence of vertical migration patterns linking the deep-sea bottom communities with those of the overlying water layers, there are similarly too few negative results for the possibility of such transport mechanisms to be dismissed.

In summary, biological knowledge of the abyss is insufficient to answer the questions raised in connection with deep-sea dumping, but in the absence of adequate answers it might be dangerous to ignore the questions.

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## RÉSUMÉ

## Rejet des déchets radio-actifs et biologie abyssale

Les grands fonds marins ont généralement été considérés comme un environnement éloigné, très peu peuplé et biologiquement inactif, tout à fait propre à recevoir les produits nocifs résultant de la fission nucléaire. La plupart des connaissances sur la biologie abyssale tendent à confirmer ce point de vue, mais il y a quelques contre-indications inquiétantes. On a réalisé ces dernières années, qu'en mer profonde, beaucoup de groupes animaux montrent une grande diversité spécifique que l'on ne supposait pas auparavant ce qui accentue la pauvreté de nos connaissances sur ce milieu. La découverte d'une faune abysso-bentho-pélagique importante, active, et très mobile a changé tout le concept de la vie abyssale. Finalement, bien qu'il y ait peu d'évidence de l'existence de migrations verticales liant les communautés benthiques profondes à celles des couches supérieures, il y a en même temps trop peu de résultats négatifs pour que la possibilité de tels mécanismes de transport soit rejetée.

En résumé, la connaissance biologique des abysses est insuffisante pour répondre aux questions provoquées par l'immersion en mer profonde, mais en l'absence de réponses appropriées, il pourrait être dangereux d'ignorer les questions.

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## INTRODUCTION

Little more than a century ago the best informed scientists of the day were convinced that the depths of the sea were totally devoid of life. The earliest trawlings in abyssal depths, that is deeper than 3 000 m or so, accomplished during the 1860's and 1870's, dispelled this idea, and subsequent work has demonstrated the existence of living organisms even in the very deepest parts of the world ocean, beneath 11 000 m of water. Nevertheless, the abyss is still widely believed to be a strange, alien and sparsely populated environment, totally remote from the world in which we live. Indeed, the very word Abyss conjures up visions of a dark, still and bottomless pit to fall into which would be to disappear for ever. Little wonder, then, that confronted with the problems of disposing of the most obnoxious materials which have ever existed, the products of nuclear fission processes, men quickly thought of the abyss as a potential refuse dump, for once safely deposited on or in the floor of the deep-sea we could surely, and with justification, happily forget about it.

The abyssal sea bed represents some 80% of the total area of the oceans (see Fig. 1), and yet it is the least well-known of the world's environments, having been visited by mankind hardly more frequently than has the surface of the moon! For the blanket of water overlying the ocean floor forms a remarkably effective barrier, both physical and psychological, making its study extraordinarily difficult.

In recent decades the use of sound waves to penetrate this relatively opaque medium, along with direct sampling, has furnished geologists with considerable information about the form and make-up of the ocean basins. Similarly, precise sampling techniques and *in situ* measurements have provided physical oceanographers, and to a lesser extent chemists, with at least the basis for empirical overviews of their sciences. In contrast, the deep-sea biologist is often still literally groping in the dark. Not only are the biological systems extremely complex, but obtaining reliable samples of them is very difficult and, despite modern technology, many of the gears employed have hardly improved over the last century. There is, for instance, still no effective method of obtaining quantitative data for the larger, and particularly for the more active, deep benthic organisms. Consequently, even seemingly simple questions about the fauna of the deep ocean are apt to elicit so many qualifications or downright "don't knows" that the answers become virtually meaningless. It is no surprise, therefore, that currently fashionable mathematical models designed specifically to forecast the fate of waste materials dumped in the abyss have almost without exception either totally ignored biological transport mechanisms or dismissed them in a few words. It is unlikely that all of the precise numerical data necessary to redress this imbalance will become available in the near future, though significant progress towards this end is being made by a number of groups around the world. The purpose of this paper is simply to point out that, in the meantime, and despite our truly abysmal ignorance, such a cavalier approach by modellers is potentially dangerous. For although much of what we know of the abyss tends to confirm the age-old impression of it as a slow, sparsely populated and rather inactive world, there are a few small indications that we may not be justified in assuming that it is totally different, and remote, from the much shallower coastal waters with which we are relatively familiar.

Let us therefore examine the criteria which any potential dump site should fulfill, and the extent to which the biology of the deep-sea appears to satisfy these requirements.

## DESIRABLE CHARACTERISTICS OF A DUMP-SITE

The general requirements of a dump-site are that the dumping procedure should be achieved with the minimum difficulty and expense, and that the natural conditions should minimise the chances of subsequent migration by the waste material. From these general requirements a number of rather more specific criteria follow naturally, and several of these are strictly non-biological. For instance, the environment should clearly be geologically

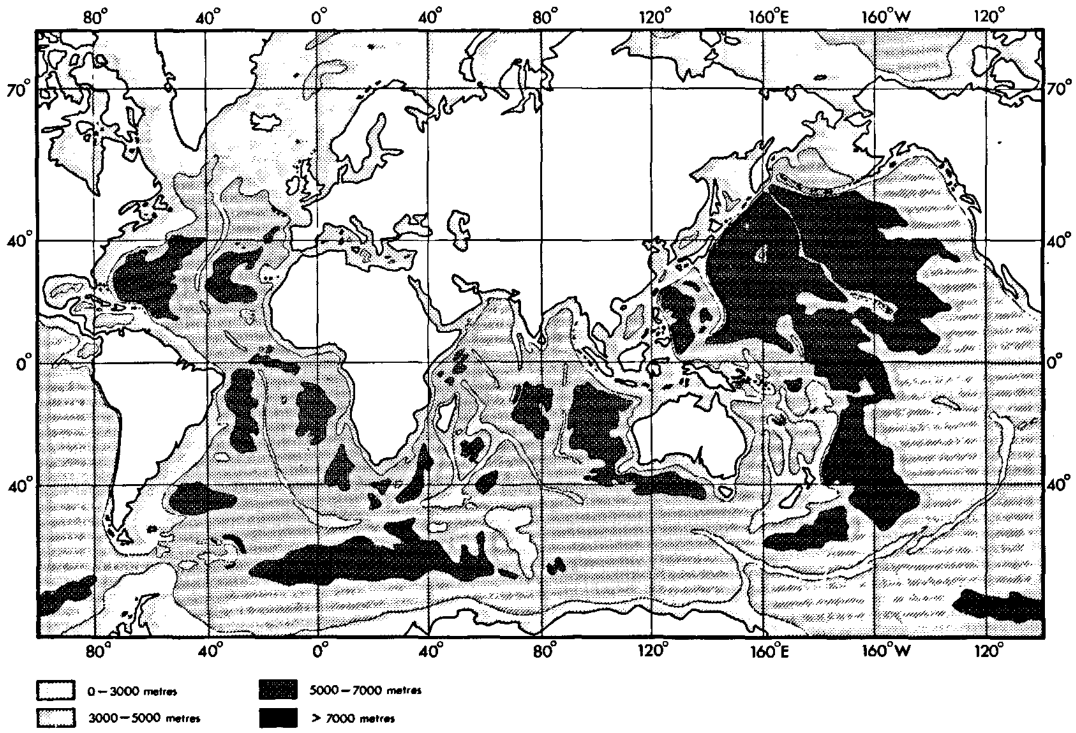

Figure 1
*Bathymetry of the world ocean. The abyss extends from the foot of the continental slope at about 3 000 m to the margins of the deep-sea trenches at about 6 000 m.*

stable, with bedding media possessing good retention properties. It should also be climatically stable, that is not prone to sudden or extensive changes in the physico-chemical conditions. Thirdy, there should be little chance of disturbance by man, so that the dump-site should be as remote as possible from the existing areas of human activity and should have no great economic potential which might attract such activity in the future. Finally, the overlying water masses should also be as static as possible, with minimal near bottom water movements, vertical or horizontal, which might transport suspended material away from the dump-site.

These requirements must be, and indeed are being, examined by geologists, physicists, chemists and engineers, but to begin our examination of the biological criteria we must assume that the deep-sea floor, or at least some parts of it, would satisfy these non-biological criteria and that dumping might therefore proceed. The waste material would not, of course, be simply dropped onto the sea-bed, but would almost certainly be embedded in glass, surrounded by concrete and also by some kind of metal container, and it would probably be buried some tens or hundreds of metres beneath the surface of the sediment. In such a situation it would be remote from any significant biological activity and we must therefore make one further assumption; that by some means, either by accident or the normal processes of diffusion or other physical and chemical transport mechanisms, the waste material reaches the upper few tens of centimetres of the sediment where biological factors might become significant. To minimise the risk that the waste might ultimately find its way onto the fishmonger's slab, the environment should ideally exhibit low biological activity, that is a low standing stock together with low energy turn-over rates, and there should also be no processes which tend to transfer it from the sea-bed to the immediately adjacent water layers, and ultimately to the more superficial levels.

## LOW STANDING STOCK

The earliest abyssal trawlings, particularly those obtained during the famous *Challenger* Expedition from 1872 to 1876, dispelled the old idea of a totally "azoic" deep-sea, but they nevertheless indicated that with increasing depth and increasing distance from the land the benthic fauna became poorer both in numbers of individuals and numbers of species. Subsequent trawlings during three quarters of a century tended to confirm this view, but improved sampling techniques in the 1950's and 1960's revealed that, far from being poor in species, the deep-sea benthos is highly diverse, many taxonomic groups being represented there by more species than in most shallow water communities (Hessler, Sanders, 1967). But the numbers of individuals in a given area certainly does decrease in the deep-sea and this, together with a general tendency for the average size of the organisms also to decrease, results in a dramatic reduction in the standing stock or biomass. In round figures the total wet weight of bottom-living organisms in and on each square metre of sea-bed decreases from 10-100 g on the continental shelf, to 1-10 g on the continental slope, and to only 0.1-1.0 g on the abyssal plain (Fig. 2) (Zenkevitch, 1969; Zenkevitch *et al.*, 1971). As might be expected, these variations in benthic biomass generally follow similar trends in the mid-water communities above them, for the economy of the sea, like that of the land, is dependent upon the photo-synthesis of plant cells which in the oceans is restricted to the well-illuminated upper few tens of metres. Because of the availability of nutrient salts, high plant productivity is generally

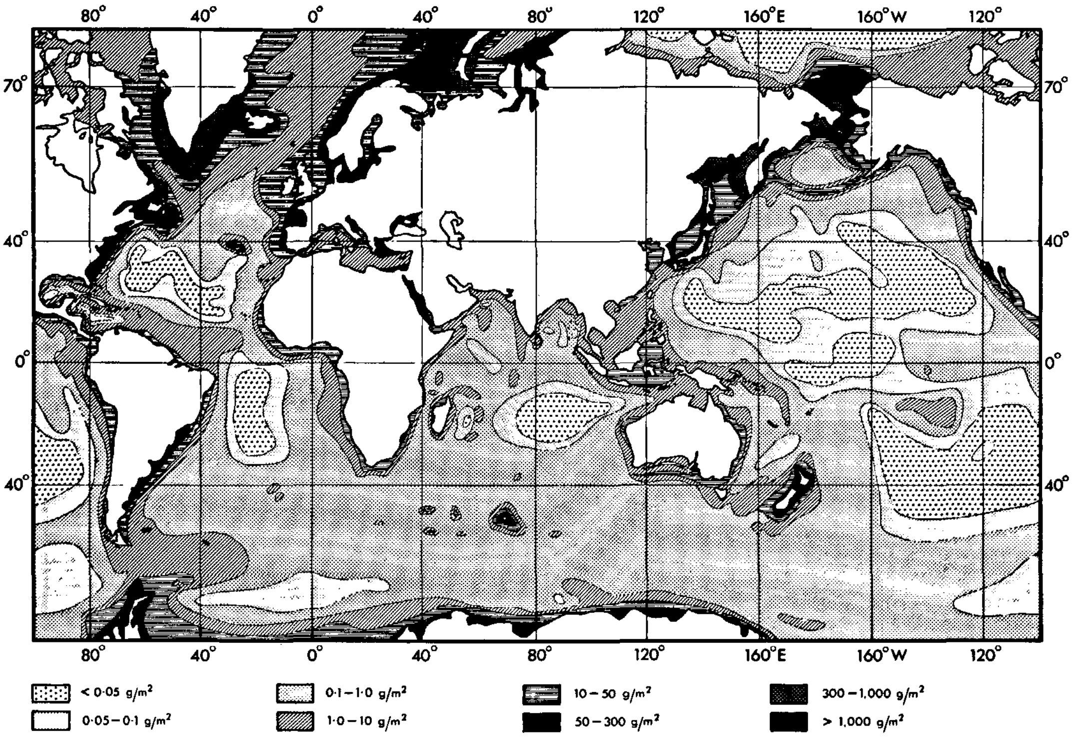

Figure 2
*Distribution of benthic biomass in the world ocean, showing that it generally decreases with increasing depth (modified from Zenkevitch* et al., 1971).

restricted to continental shelf regions, but where local hydrographic conditions cause upwelling of nutrient rich water over deeper areas the benthos may be correspondingly richer (Zenkevitch, 1969).

Similarly, in some mid-oceanic areas where the surface productivity is particularly low, the benthic populations may be even poorer than usual. In the central north Pacific and in parts of the Mediterranean, for instance, the abyssal benthic biomass may be as low as 0.01.0.05 g/m$^2$ (Zenkevitch, 1969).

## LOW METABOLIC RATE

These measurements of very low biomass or standing stock in the deep-sea provide a quite convincing indication of a generally low level of biological activity. However, in the same way as a measurement of the alfalfa crop in a tropical field would not reveal just how productive such an environment is without the additional knowledge that two, or even three, crops are produced each year, an adequate impression of the biological activity of the deep benthic community requires a knowledge of the rate at which energy passes through the system. Direct measurements of metabolic, growth, and reproductive rates in deep-sea animals are extremely difficult, for few of them survive the journey back to the surface in a trawl, dredge or grab, and those which do so almost certainly suffer irreparable physiological damage from the drastic decompression to which they are subjected. The technology to allow benthic animals to be retrieved at their normal temperature and pressure is being developed and, indeed, is already in existence for microbial organisms. Similarly, manned submersibles and remotely controlled free vehicles are beginning to be used to conduct *in situ* experiments on the sea-bed and thus avoid the problems of bringing the animals to the surface (Smith, Teal, 1973; Heirtzler, Grassle, 1976; Smith *et al.*, 1976). During the next few years such techniques will undoubtedly furnish a good deal of the much needed information on deep-sea metabolic rates, and they have already indicated that oxygen consumption rates by the bottom-living community at abyssal depths may be one hundred times lower than those of the continental shelf benthos (Jannasch, Wirsen, 1973). But knowledge of growth and reproductive rates must at present be gleaned by less direct means, including the use of any clues which can be obtained from an examination of population structures.

## SLOW GROWTH AND REPRODUCTIVE RATES

Any animal community which suffers a sustained high mortality rate from any source tends to be composed mainly of young individuals. In addition, to withstand the high mortalities the animals tend to mature early and to produce large numbers of young. In the deep-sea a totally different situation is generally found, with the benthic populations being dominated by the larger size groups and with much smaller broods being produced than those of their shallower-living relatives. These population characteristics are interpreted as indicating relatively low mortality and recruitment rates, and correspondingly slow growth rates, with the clear implication that deep-sea organisms are much longer lived than those from shallow seas (Grassle, Sanders, 1973).

In shallow areas the seasonal changes in light intensity, temperature and particularly in food supply result in variations in growth of the skeletal tissue of fishes and molluscs which can then be used for age determinations. In the deep-sea this seasonality is greatly reduced or non-existent, so that the interpretation of any growth rings in skeletal tissue from this environment is very difficult. Fortunately, an alternative radiometric method of age determination exists, analogous to the carbon-14 technique widely used to age terrestrial organic material, but in the deep-sea using the known decay rate of radium-228. Using this technique, a small deep-sea bivalve mollusc, *Tindaria colistiformis*, has been estimated to mature at an age of 50-60 years and to have a longevity of 100 years or so, that is an order of magnitude greater than typical shallow water species (Turekian *et al.*, 1975). This is the only available estimate for such a deep-sea species and may, of course, not be characteristic, but it does seem to support the other indications of low metabolic rates and slow growth in the abyssal environment.

## SLOW RECOLONISATION

One final piece of evidence for low biological activity levels in the deep-sea has come from recolonisation experiments in which defaunated trays of sediment were placed on the sea-bed at some 1 760 m depth and retrieved or sampled, along with the surrounding sediment, after two months and 26 months (Grassle, 1977). Even after 26 months these sediment trays contained only a very small proportion of the fauna found in the surrounding area, both in terms of numbers of individuals and of species. In contrast, a similar tray placed in shallow water, at a depth of 10 m, after only two months contained almost as many individuals and species as an equivalent area outside the tray (Table). Moreover, whereas the species in the shallow water two-month tray were represented by all stages from post-larvae to adults, those in the deep-sea trays were dominated by juveniles even after more than two years.

So far, then, all the evidence seems to support the idea that biologically the deep-sea floor might not be a bad

Table

*Colonisation of experimental trays of azoic sediment placed in and recovered from shallow water and the deep-sea (from Grassle, 1977).*

| | Depth 10 m | | Depth 1 760 m | | |
|---|---|---|---|---|---|
| | Control | 2-month tray | Control | 2-month tray | 26-month tray |
| Individuals/m$^2$. | 48,375 | 35,714 | 5,189 | 160 | 536-564 |
| No. of species. | 61 | 47 | 103 | 14 | 10-31 |

site for the disposal of waste, for the observed low standing stock, and low metabolic, growth and reproductive rates would all seem to minimise the movement of radio-active waste away from such an environment. As indicated in the introduction, there are rather few contra-indications, but in view of the general paucity of knowledge of deep-sea biology they are nevertheless significant and deserve serious consideration.

The evidence for biological mechanisms which might transport waste material out of the sediment and towards the surface waters can be broadly grouped under three main headings; bioturbation, mobile and active megafauna, and vertical migration.

## BIOTURBATION

Bioturbation is the disturbance of the sediment by organisms living in, on or close to the sea-bed, tending to prevent the permanent burial of material within the sediment. Although such disturbance normally extends no more than a few tens of centimetres beneath the sediment/water interface, it could be important in resuspending waste deposited within this layer, thus providing the first step in its transport back towards the surface waters.

In shallow areas bioturbation is wide-spread and involves many animal groups. Echinoderms, molluscs and worms bury themselves more or less within the sea-bed and either ingest the sediment itself, filter material from the overlying water, or select organic particles from the sediment surface. In all cases the sediment is disturbed to a greater or lesser extent, and in extreme cases may be discharged as plumes resuspending sedimentary material and producing mounds protruding from the bottom. Many crustaceans and even some fish produce extensive burrow systems within the sediment, discharging the excavated material onto the surface. Direct observations of such processes in the abyss is, of course, very difficult, but the existence here of animals similar to the known bioturbators in shallow waters indicate that deep-sea sediments are disturbed in this way, albeit much less intensively since the faunal density is so much lower. More direct evidence of deep-sea bioturbation is provided by photographs showing craters, mounds, burrow entrances and faecal casts, though the organisms responsible often cannot be identified (Figs. 3 and 4) (see also Heezen, Hollister, 1971; Lemche *et al.*, 1976).

Finally, shallow sediments are disturbed, not only by truly benthic organisms moving within and on the bottom, but also by large active bentho-pelagic animals, such as fishes, swimming over the sea-bed. Such disturbance of deep-sea sediments was not suspected until recent years since few large active animals are taken in abyssal trawls. As we shall see, however, there is now good photographic evidence for the existence of an active deep-sea megafauna which may not only disturb and re-mobilise sedimentary material but may also transport ingested matter considerable distances both horizontally and vertically.

## THE EXISTENCE OF A MOBILE AND ACTIVE DEEP-SEA MEGAFAUNA

Until the late 1960's an abundance of large and active animals in the deep-sea was not to be expected since the food supply to the abyss was thought to consist almost entirely of the fairly constant but thin rain of small particles falling from the surface layers of primary

Figure 3

*Mound, pits and faecal casts from the abyssal plain off North-West Africa at a depth of about* 4 000 *m. The mound is about* 20 *cm high.*

Figure 4

*More evidence of bioturbation at a depth of* 4 000 *m off the North-West African coast. The mounds and craters are clearly the work of burrowing animals. The smaller spherical objects in the background, however, are not worm casts, but the bodies of xenophyophores, a poorly known protozoan group.*

productivity which would hardly support such creatures. The use of baited cameras deployed for hours or days on the sea-bed has, however, revealed the presence of extraordinary numbers of large and active scavengers which are quickly attracted to, and consume, the bait. This community, which seems to exist even in the deep trenches and in the food-poor north Pacific Gyre, includes representatives of many taxonomic groups, including polychaete worms, amphipod and decapod crustaceans, ophiuroid and holothurian echinoderms, and many fishes (Fig. 5) (Isaacs, 1969, 1974; Dayton, Hessler, 1972; Shulenberger, Hessler, 1974; Dahl *et al.*, 1976; Laubier, Sibuet, 1977; Guennegan *et al.*, in press; Laubier, Sibuet, in press). Though many of these scavengers undoubtedly obtain some of their food from the benthic community, they seem to be particularly fitted to take advantage of the carcasses of large animals falling to the sea-bed from the overlying water masses. Such falls must be relatively infrequent and many of the near-bottom megafaunal creatures are probably opportunistic, being able, for instance, to maintain their reproductive organs in an advanced state of development, perhaps for long periods, in readiness for the next fall of suitable food. In search of such falls they probably roam over wide areas of the sea-bed, and although the baited camera photographs give no proof of this, the fact that fishes continue to arrive at the bait many hours after it first reaches the bottom indicates that they have been attracted from considerable distances (Guennegan, Rannou, in press). These roving scavengers must be important in the economy of the deep-sea benthos in distributing material which initially arrives there in large masses, for their faeces will be consumed by the much less mobile deposit feeders. But in the context of deep-sea dumping they might also be important in transporting, horizontally and perhaps also vertically, material which would otherwise remain confined within a relatively small area. The extent of such migrations is at present totally unknown, and in the case of the horizontal ones is likely to remain so for some time, since the usual method of studying these movements in shallow areas is by tagging and recapture, a technique which is clearly difficult in the deep-sea. Vertical migration patterns are also difficult to study, but adequate techniques do exist and some indications that deep-sea animals undertake them have already been obtained.

## VERTICAL MIGRATION IN THE DEEP-SEA

Many mid-water organisms undertake extensive and regular vertical migrations. Some of these have a relatively long timescale, the species involved occupying different depth horizons at different times of the year or at different stages in the life cycle. Others have a diurnal period and, while the details vary from species to species, they generally involve a movement towards the surface at night and downwards during the day. These migrations are clearly related to the light/dark cycle in the upper layers of the oceans and it is in the near surface zone, down to a few hundreds of metres, that they were first detected and have been most exhaustively studied. But with the use in recent years of acoustically monitored opening and closing nets which can be fished at great depths in discrete horizons it has been possible to investigate the vertical distribution pattern of animals living many hundreds or even thousands of metres beneath the surface. Extensive migrations are made by many species with daytime depths down to 1 000 m or so, but beneath this level and down to 2 000-2 500 m, the limit of sufficiently detailed investigations, there is little evidence of diurnal vertical migrations (Longhurst, 1976).

Figure 5

*The mobile abyssal megafauna. This ophidioid fish, photographed in a fish trap on the Horseshoe Abyssal Plain west of Gibraltar at a depth of* 4 800 *m, is almost* 1 *m long. The bait bag has also attracted large numbers of amphipod shrimps.*

Figure 6

*Deep-sea fish attracted to a baited camera at a depth of* 5 852 *m in the central north Pacific. This photograph, and Figure* 7, *are reproduced by permission of Dr. John Isaacs, Scripps Institution of Oceanography.*

Less regular migrations, however, may occur at these deeper levels and direct evidence for these movements is now accumulating. Juvenile and adult rattail fishes, normally taken only very close to the sea-bed, have been caught in mid-water many hundreds of metres above the deep-sea floor (Haedrich, 1974; Pearcy, 1976). Indirect evidence of upward feeding migrations is also furnished by the presence of mesopelagic organisms, that is mid-water animals from depths down to 1 000 m or so, in the guts of bentho-pelagic fishes from considerably greater depths (Pearcy, Ambler, 1974; Marshall, Merrett, 1977). These upward migrations will generally tend to accelerate downward movements of material through the water column rather than the reverse, since the adult fish must rarely be eaten during their upward forays. Some upward transport will nevertheless be achieved when, for instance, faecal material derived from near bottom feeding is voided at the upper levels. Potentially much more significant upward transport could be achieved by ontogenetic migrations in which the younger stages in the life cycle live at shallower levels than the adults, for these young stages must regularly be eaten by predators. This type of reproductive strategy, in which benthic and epibenthic adults produce large numbers of small eggs and larvae which spend days, weeks or even months in the near surface layers is very common in shallow water communities. It has been generally assumed that such a strategy would be unsuitable for abyssal bottom dwelling animals both because of the paucity of food in the near bottom layers and the greater distances involved in the larval migrations between the sea-bed and the surface waters. Very little is known about the reproduction of deep benthic animals but there is some evidence, particularly from the large egg size of many species, that long-lived pelagic larvae are not commonly produced in this environment, and many abyssobenthic fishes are known to be viviparous. But some groups, possibly including the most recent invaders of the deep-sea, do have typical pelagic eggs and larvae. For instance, the rattails which have been investigated from this point of view have all been found to have buoyant eggs, and the larvae of some species have been caught very close to the surface (Merrett, 1978). Similarly, planktonic molluscan larvae attributed to a species of which the adults are found at depths of 2 000-4 000 m in the North Atlantic have been found in plankton catches made within 300 m of the surface (Bouchet, 1976 *a*, *b*, in press).

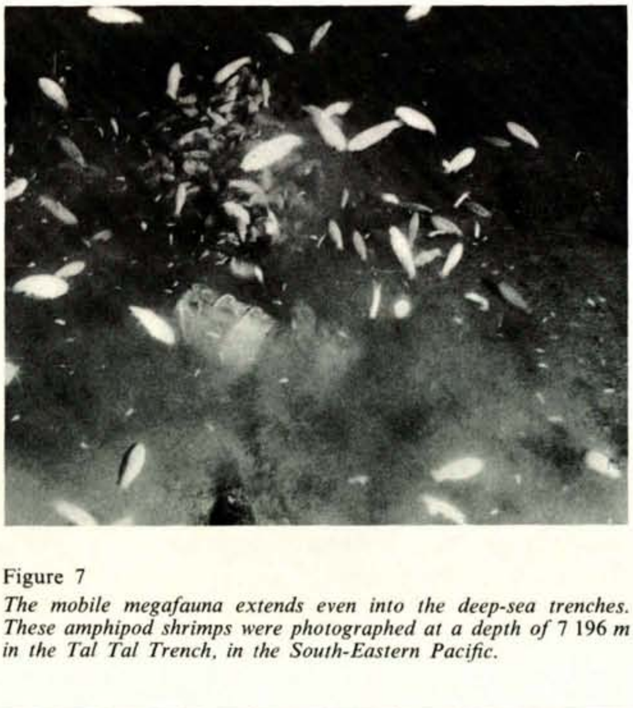

Figure 7

*The mobile megafauna extends even into the deep-sea trenches. These amphipod shrimps were photographed at a depth of* 7 196 *m in the Tal Tal Trench, in the South-Eastern Pacific.*

## EFFECTS OF RADIO-ACTIVE WASTE ON THE BIOSPHERE

So far we have examined the problems of radio-active waste disposal only from a very selfish but typically human point of view, considering only those features which are likely to determine whether or not our own well-being will be jeopardised. But the waste materials are likely to be just as harmful to the deep-sea organisms as they are to us, and might cause considerable damage to the communities exposed to them.

The difficult problem of whether we have the right seriously to alter the environment of our fellow creatures, even one as remote as the deep-sea, must be tackled by conservationists and industrialists. Here, I will avoid such moral questions and consider only those characteristics of the deep benthic community which are likely to affect its ability to withstand the damaging effects of toxic wastes.

As usual the situation is not simple, for some of the available data indicate considerable resilience, while others suggest susceptibility. Assuming that any waste dumping would be concentrated in a restricted number of sites and that lateral transport in highly toxic concentrations would be small, any really dramatic effects, such as the total annihilation of the animal community, should be quite localised. In the highly variable environments typical of many shallow water and land areas even such localised damage might be very serious, since populations of rare species whose distribution happened to coincide with the affected region might be considerably reduced or even become totally extinct. The observed relative constancy of the deep-sea environment would appear to minimise such effects since, in general, abyssal species tend to be very widely distributed so that devastation would have to be extremely extensive to cause such extinction.

On the other hand, this constancy of the abyssal environment probably means that the local effects of disturbance would be particularly severe. Indirect evidence for this is furnished by the high species diversity encountered in the deep-sea, for although there are differences of opinion amongst abyssal biologists about exactly how this diversity has arisen, there is general agreement that one key factor has been the stability of the physical and chemical environment over long periods (Sanders, 1969; Dayton, Hessler, 1972). The inevitable corollary is that the abyssal benthos is likely to be very sensitive to any sudden changes, and there is good evidence, from the observed slow growth and recolonisation rates, that it would carry the scars for a very long time.

## CONCLUSION

In this brief review I have probably over-emphasised those features of deep-sea biology which seem to argue against the abyss as a suitable dump-site for high-level radio-active waste and could therefore be accused of tilting at windmills. The tendency for the species diversity to increase and for the biomass to decrease in the deep-sea are well-established principles based on numerous samples. The data on growth and metabolic rates, colonization, longevity and vertical migrations, on the other hand, are based on very small numbers of observations and therefore cannot be attributed with the same reliability. However, in a matter as serious as this it is surely infinitely preferable to adopt an over cautious attitude rather than to make an irreparable error in blissful ignorance.

On balance, the available data certainly tend to confirm the impression that life in the abyss is generally sparse, slow growing and inactive, eking out an existence from a very reduced food supply. Under these circumstances the organisms would not be expected to indulge in activities requiring considerable expenditure of energy, such as extensive and regular vertical migrations. The evidence that such migrations nevertheless do occur is admittedly meagre, but they should certainly not be ignored. Because of the difficulty of biological sampling in the deep ocean relatively few samples have so far been obtained, particularly in mid-water beyond about 2 000 m. Further examples of extensive vertical migrations, from bathyal or abyssal depths, will undoubtedly be encountered in the future, though it is extremely unlikely that the phenomenon will prove to be at all common. The regular daily vertical movements of mid-water organisms in the upper layers clearly transport millions of tons of organic matter, both living and dead, through tens or even hundreds of metres in the space of a few hours. Such transport mechanisms from abyssal depths must be miniscule in comparison, but in the particular context of extremely toxic high-level radio-active waste products with half-lives of hundreds or thousands of years, even a very slow process might ultimately produce disastrous results.

Viewed in this light, some of the seemingly encouraging features of abyssal biology assume a somewhat sinister aspect. Studies of shallow water and terrestrial communities exposed to pollutants have clearly demonstrated the accumulation of contaminants into higher and higher concentrations both throughout the lifetime of individual organisms and towards the upper levels of the food pyramid, that is in the larger predators (Arima Marchand, Martin, in press). The observed low level of deep-sea biological activity, so attractive to the potential dumper, seems inevitably to be linked with slow growth and longevity which would tend to exacerbate such accumulation processes. An abyssal predator brought to the surface at the end of its life, either by its own volition or by some other means, might therefore represent a highly lethal package at a concentration out of all proportion to the mean level of contamination on the ocean floor.

Ideally, of course, we should have a thorough understanding of abyssal biology before any decision is taken to dump high-level wastes in the deep-sea. Because of the time scale involved this may not be possible, for it has already taken a century of painstaking effort by scientists of many nations to arrive at our present state of relative ignorance. Great advances have been made during the last two decades using modern technology, including photography, acoustic monitoring and command systems, and deep submersibles, but the unexpected discovery of a mobile and very active bathypelagic megafauna suggests that the deep ocean may still have some major surprises for us. In the past this element of surprise has given the abyss a mysterious quality beloved of authors from Tennyson to Wyndham and which few of us, including those engaged in its study, would surely wish to disappear completely. But if we do dump high-level radio-active waste here despite the inadequacy of our knowledge, we may find that we have replaced this air of mystery with the morbid fascination engendered by an unexploded bomb!

### Acknowledgements

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