CAMBRIAN OCEAN WORLD

ANCIENT SEA LIFE OF NORTH AMERICA

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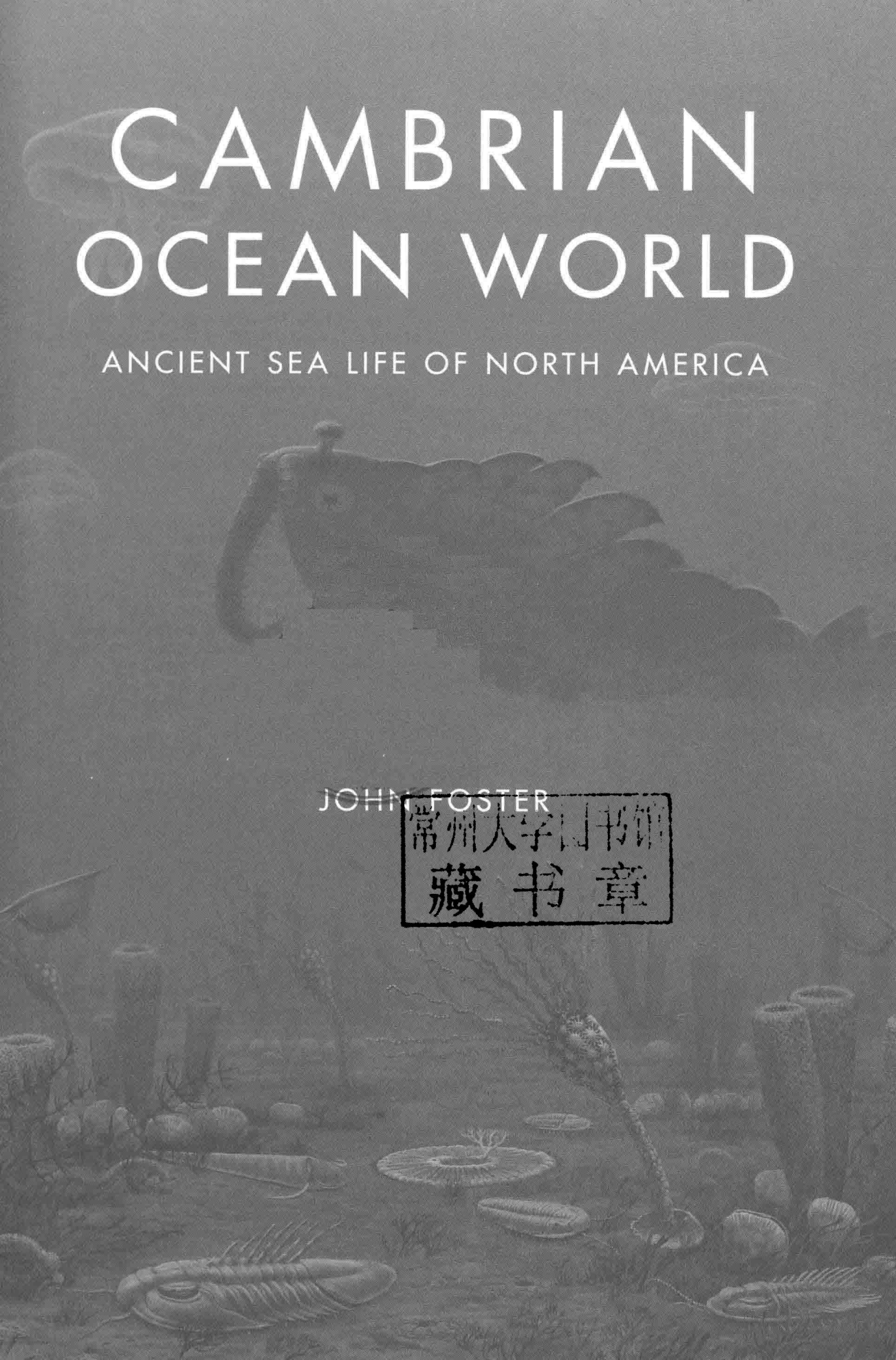

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Cambrian Ocean World

Life of the Past James O. Farlow, editor

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For ReBecca and Ruby, who have endured my many mental and physical absences with good humor and went along on a number of the expeditions (snow, rain, heat, or decent weather); and for my father, Russ Foster, who instilled in me a love of the desert without even realizing it. See the influence a little landsailing can have?

Old Ocean, none knoweth thy story;
Man cannot thy secrets unfold.

MARTHA LAVINIA HOFFMAN

Just what happened on Earth about 542 million years ago is still a bit of a mystery.

PATRICIA VICKERS-RICH

Preface

SOMEWHERE IN NEARLY EVERY STATE OR PROVINCE IN NORTH America are Cambrian rocks recording the history of life in one of the most important time periods in Earth history. In Vermont, Washington, Virginia, Wisconsin, California, Alberta, British Columbia, Sonora, New Mexico; in Nevada, Utah, Colorado, Pennsylvania, South Dakota, Oklahoma, Idaho, Texas, Alabama, Wyoming—the list goes on. Rocks of Cambrian age are almost everywhere. And in them we find some of the earliest complex animals to appear on Earth. The diversification of animals in the Cambrian is astounding.

By any human measure, the Cambrian period was an incredibly long time ago, but in terms of the story of our planet it only began after most of Earth history so far had already unfolded. It would be another 315 million years before mammals or dinosaurs would appear on the scene—or nearly five times as many years as have passed since the dinosaurs (other than birds) disappeared and left the world to the mammals, in our chauvinistic view. From the perspective of the most diverse major animal group of the Cambrian (the arthropods), however, the world of the Cambrian was theirs then, and still is now, as today the number of insect species alone is nearly one million. The only major loss to them since the Cambrian is that of the trilobites, the proverbial fossils of the Paleozoic era. Even trilobites outstripped other famous fossil groups in terms of diversity. We know of around a thousand species of dinosaurs from the fossil record; modern mammals number around six thousand species; birds are all the way up around ten thousand. The lowly trilobites? Twenty thousand species! Although they may have inflated numbers due to high preservation potential, as fossils trilobites own the Paleozoic.

The Cambrian period on Earth might as well have been another planet, compared with what we are used to today. This is the story of a different time and place. The time is incredibly distant; the place, not so.

The Cambrian period was obviously a very long time ago, but why was it important? It was nowhere near "early" in Earth history; 80 percent of that history occurred before the first years of the Cambrian. The world of the Cambrian represented a time quite different from most before it in terms of environmental conditions. This parallels differences in the biotas. But the Cambrian was probably most important because it was, quite simply, the birth of our modern biological world. Whereas the previous 3 billion years were occupied almost exclusively by microbes, and only shortly before had multicellular animals appeared, almost all

the modern groups of animals that we know today trace their origins to the time interval between 542 and 488 million years ago. Crabs, lobsters, insects, and horseshoe crabs? Their ancestors were there in a myriad of arthropods. Lions and tigers and bears? The first members of our phylum of chordates and vertebrates appeared during the Cambrian. Corals and jellyfish? Their ancestors were there. Worms of all kinds? Those, too.

The Cambrian radiation, or explosion as it has been called, has been argued about for ages. No less in recent years. More, in fact. Was the speciation rate for animals actually higher during the Cambrian than at any point since? Was the explosion an artifact of preservation? Were there more phyla (body-plan groups) of animals than today? Were phyla "weeded down" or did the modern phyla only appear then and continue? What does all this mean for the mechanisms of evolution? We will review some of these debates, but mostly we will concentrate on the Cambrian and the subaqueous Garden of Eden of modern animal diversity.

Plenty has been written about the Cambrian previously, and much of it is deservedly about the Burgess Shale and its spectacular window to the Cambrian biota. We will see that here, too. But we will also visit a lot of other places with fossil records that contribute to that picture as well, each in its own way. I hope that the picture painted here leaves you with an impression of just how ubiquitous Cambrian rocks and fossils are and how important this period is to the history of life on Earth. I will not assume all readers have backgrounds in geology or biology, and so chapter 1 will introduce some aspects of the Cambrian period and biology in general, and chapter 2 will introduce some key concepts in geology through a trip into the Grand Canyon. The rest of the book is a journey. We will travel forward in time, first through the Precambrian in chapter 3, and then through the Cambrian itself in chapters 4–8. We will visit the Early Cambrian in chapter 4, the early Middle Cambrian in chapter 5, the Burgess Shale in chapter 6, and the late Middle Cambrian in chapter 7. Chapter 8 takes us through the Late Cambrian. In each chapter, we will see some localities that exemplify each of the time stages, and the animal groups preserved at them will be presented in an order dictated in part by their abundance or preservation at each site. The journey through time dictates the order of sites we visit, and those sites dictate the order in which we discuss individual animal groups. Chapter 9 takes a look at the data from sites throughout the Cambrian, focusing in large part on the Burgess Shale due simply to its almost unbeatable record among North American sites. Chapter 10 is a brief summary of where the animals of the Cambrian have gone in the millennia since.

Scattered through the chapters are several boxes containing profiles of current researchers working on Cambrian issues. This is a small sampling of the modest army of people worldwide who study this time period, and it is, of course, not close to being wholly representative. But I hope it will give readers a better view into how we came to know what we do about the Cambrian and its fossils.

All specimens illustrated in this book were collected by Museum of Western Colorado crews and photographed by the author, except where noted. A number of specimens were photographed by the author in the field. Specimens collected by other institutions or individuals, photographed by others, or in other institutions' collections are noted.

Acknowledgments

THIS PROJECT IS PART OF A RETURN TO MY PALEONTOLOGICAL FIRST love, a renewed interest in fieldwork and research on the topic that led me into paleontology in the first place. Although paleontology of all types was of interest to me as a young undergraduate, it was the Cambrian of the southern Great Basin that really got me hooked. But after that initial undergraduate work, graduate school led me down a long, winding path of Mesozoic vertebrate paleoecology that I continue to tread today. After more than 15 years of this, however, I knew I needed to expand my research horizons and work on some additional (and totally different) project so as not to start plodding the same ground repeatedly–for my sake and everyone else's. The fact that I had started out working in the Cambrian in the Mojave Desert, and that I had returned regularly over the years just for the fun of it, made the answer obvious. I needed to get back to where I started, to the rocks and fossils that had never really been left behind. The Cambrian called again. It was time to stop picking around and start trying to answer some of the questions that I had begun to ask as I worked in the Mojave. Thus began my return to the Cambrian. I had a lot of catching up to do because a lot had happened in the ensuing years, and the self-imposed crash course was intense. The idea for this book came a little later, on a cross-country drive a few years ago. But it has only intensified the learning curve.

Because of the journey begun as I just outlined, and because the Cambrian is 54 million years of appearances of a whole range of animal phyla and dozens of geologic units (just in North America), it is a massive task to attempt to bring this together in a manageable way. I have been pleasantly surprised by how much help I have been willingly given by a whole range of researchers who have assisted in ways small and large, but all important. As a "lost son" of the Cambrian who has only relatively recently returned to the fold of the most important period in Earth history, I have appreciated this help beyond my ability to fully express to those that have assisted. It is almost cliché to say, but it is true: I could not have done this without them.

First off, I have to thank my undergraduate advisors, Don Prothero and Jim Sadd, whose fault it is I ever got addicted to the Cambrian in the first place. In recent years, trilobite specialists Stew Hollingsworth and Fred Sundberg have answered many questions, shared specimens, and provided many references for a number of projects and have served as de facto postgraduate advisors. A number of others helped at various stages of this and related projects by answering one or a whole host of

questions; generously providing reprints, figures, or data; introducing me to field areas; donating specimens; and offering advice on collecting and preparation of some more challenging specimens. These are, in no particular order, Dave Rudkin, Mark Webster, Eben Rose, John Taylor, John Sibbick, Dave Liddell, Simon Conway Morris, Bruce Lieberman, Steve Rowland, Derek Briggs, Fredrik Terfelt, Per Ahlberg, Rachel Wood, Brigitte Schoenemann, Paul Strother, James Hagadorn, Graham Budd, Malgo Moczydlowska, Xingliang Zhang, Jean-Bernard Caron, Talia Karim, Loren Babcock, Joachim Haug, Marilyn Kooser, Kevin Peterson, Paul Myrow, Krista Brundridge, Bob Gaines, Laura Wilson, Brian Pedder, Martin Smith, Andrew Milner, Josh Bonde, J. W. Schopf, Arvid Aase, Mark Fahrenbach, Norm Brown, Joe Collette, Melissa Hicks, Val and Glade Gunther, Mike Cuggy, Diego García-Bellido, Andrew Knoll, Harry Mutvei, and Dave Comfort. Becky Bernal of the Colorado Mesa University library was instrumental in obtaining many references, and never met an interlibrary loan she could not track down. Jill Hardesty (KU) and Tom Jorstad (Smithsonian) helped with some of the borrowed figures. The artists John Agnew, Terry McKee, Matt Celeskey, and Karen Foster-Wells really brought the Cambrian to life with their work. Joe Fandrich and Pete Bucknam provided equipment and expertise for the thin-section photo-micrographs. Thanks to the Museum of Western Colorado field crews (and associates from the Raymond Alf Museum) that collected many of the data and specimens seen here. These included ReBecca Hunt-Foster, Ray Bley, Zeb Miracle, Mike Perry, Darrell Bay, Tom Lawrence, Andy Farke, and Amy Jackson-Ayala. Thanks also to the Monterey Bay Aquarium and to the folks at Western Slope Aquatics in Grand Junction. Access to museum collections was generously provided by Colleen Hyde (GRCA); Dave and Janet Gillette (MNA); Bruce Lieberman (KU); Pat Holroyd and Mark Wilson (UCMP); Andy Farke (RAM); Marilyn Kooser (UCR); Oklahoma Museum of Natural History; Mary Stecheson (LACM); Mark Florence, Finnegan Marsh, Doug Erwin, and Conrad Labandeira (Smithsonian Institution, NMNH); and Logan Ivy (DMNS). Special thanks to those who agreed to be profiled for the boxes: Malgo Moczydlowska, Diego García-Bellido, Eben Rose, Xingliang Zhang, James Hagadorn, Andrew Knoll, Kevin Peterson, and Bob Gaines. Special thanks also to Bob Sloan, Jim Farlow, Jenna Whittaker, Nancy Lightfoot, Dawn Ollila, Jamison Cockerham, Tony Brewer, and everyone else at Indiana University Press for their hard work making this project happen. Finally, thanks to the Bureau of Land Management, National Park Service, USDA Forest Service, and Parks Canada. These land management agencies are charged with protecting the land on which most of the localities mentioned in this book are found, and without their work these Cambrian sites would not be preserved for future generations nor would the data about the Cambrian world be available to researchers and, ultimately, the general public.

Abbreviations

DMNS Denver Museum of Nature and Science, Denver, Colorado

GRCA Grand Canyon National Park Museum, South Rim, Arizona

KUMIP University of Kansas, Lawrence, Kansas

LACMIP Natural History Museum of Los Angeles County, Los Angeles, California

MNA Museum of Northern Arizona, Flagstaff, Arizona

MWC Museum of Western Colorado, Fruita, Colorado

RAM Raymond Alf Museum, Claremont, California

UCMP University of California Museum of Paleontology, Berkeley, California

UCR University of California, Riverside, Department of Geology Paleontology Collections, Riverside, California

USNM National Museum of Natural History (NMNH), Smithsonian Institution, Washington, DC

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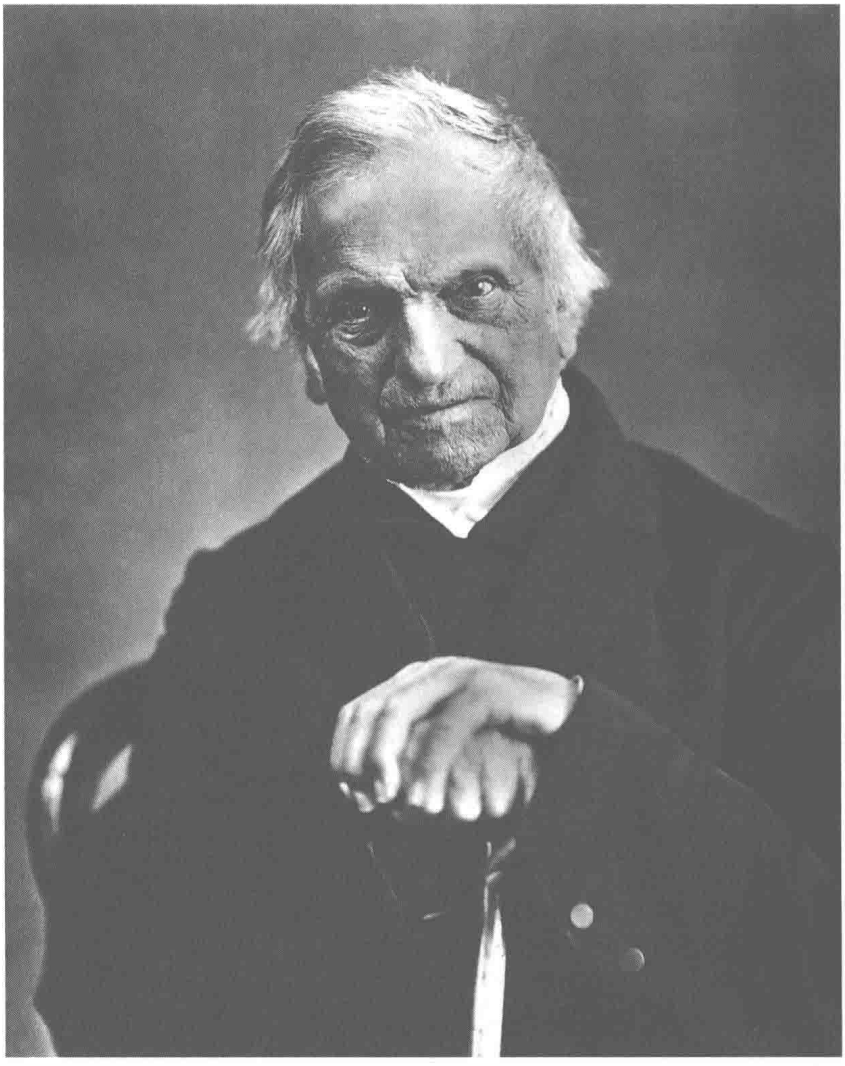

1.1. Adam Sedgwick, the man who named the Cambrian period, in an 1867 photograph by William Farren. Sedgwick was 82 at the time and had named the Cambrian 32 years earlier.

Courtesy of the Sedgwick Museum of Earth Sciences, University of Cambridge. Reproduced with permission.

Natural Mystic: An Introduction to the Cambrian

1

IMAGINE A TROPICAL MORNING ON THE OCEAN. THE AIR IS comfortably warm and moist, but it is not muggy or hot; scattered clouds are slightly pink with the last colors of dawn as the sun glares orange, low on the eastern horizon. The ocean on which you are floating is deep blue, and the surface waves are only a few feet high. From all appearances, it could be offshore Hawaii. Pitching lightly on a large, inflatable dinghy, we prepare technical diving gear and extra tanks and notice that there is no land in sight; we are probably at least several tens of miles from the nearest land beyond the horizon to the south, but how far we can't tell. We are going deep, and this type of diving requires special training, equipment, and experience. As the sun climbs in the sky we notice that the sea surface color transitions to a lighter blue away to the south and west.

Ducking under the waves in our diving gear we see a world of medium blue all around and below us. There are no fish in sight. We aim toward the deep and begin kicking our way down into the azure world below. As the pressure increases to nearly 100 pounds per square inch on our bodies and puts pressure on our lungs and ribs, the water around us is turning darker and darker blue. The sea around us now is midnight blue and we can barely see; we have reached the edge of available light at nearly 91 m (300 ft.) down. Knowing that we are near the bottom of the ocean in this area we pull out our dive lamp and turn it on. The bottom soon comes into view as a flat, muddy plain, and suddenly we see movement as indistinct animals shrink into burrows in the bottom sediments. Hovering 2 m (6 ft.) above the seafloor and watching the scene below us, we notice an inch-long, segmented arthropod moving slowly like a sowbug across the bottom muds. There is a scattering of tube- and cup-shaped red and purple sponges; a few tufts of green algae; and one or two short, orange, stalked organisms that look a little like spindly flowers. Suddenly a few feet below us a silvery shape flutters into our lamplight, startling us and reminding us that this ocean is an exotically distant one. The animal is about 45 cm (1.5 ft.) long and is shaped like a segmented halibut. A rounded head contains stalked eyes, followed posteriorly by multiple flap-edged segments that ripple consecutively in waves along each side as on a hovering cuttlefish, and the tail consists of pairs of elongate blades reaching up and out from a central segment. The animal moves along smoothly, thanks to the waving of the lateral flaps. Most strangely, the animal has two spined appendages protruding down from under the head. This odd inhabitant of the deep disappears out of view of our light and we are left looking at each other is amazement. *What*