The Third Planet

AN INVITATION TO GEOLOGY

Konrad B. Krauskopf

Cover Photograph: David Muench

Front End Paper: Map of earthquake belts from National Earthquake Information Center, U.S. Geological Survey
Map of world's volcanic belts from the Seismographic Station, Department of Geology and Geophysics, University of California, Berkeley

Rear End Paper: Maps of drifting continents from the paper by J.D. Phillips and D. Forsyth, published in the *Bulletin* of the Geological Society of America, June 1972

Title Page Photograph: *Earthrise* from NASA

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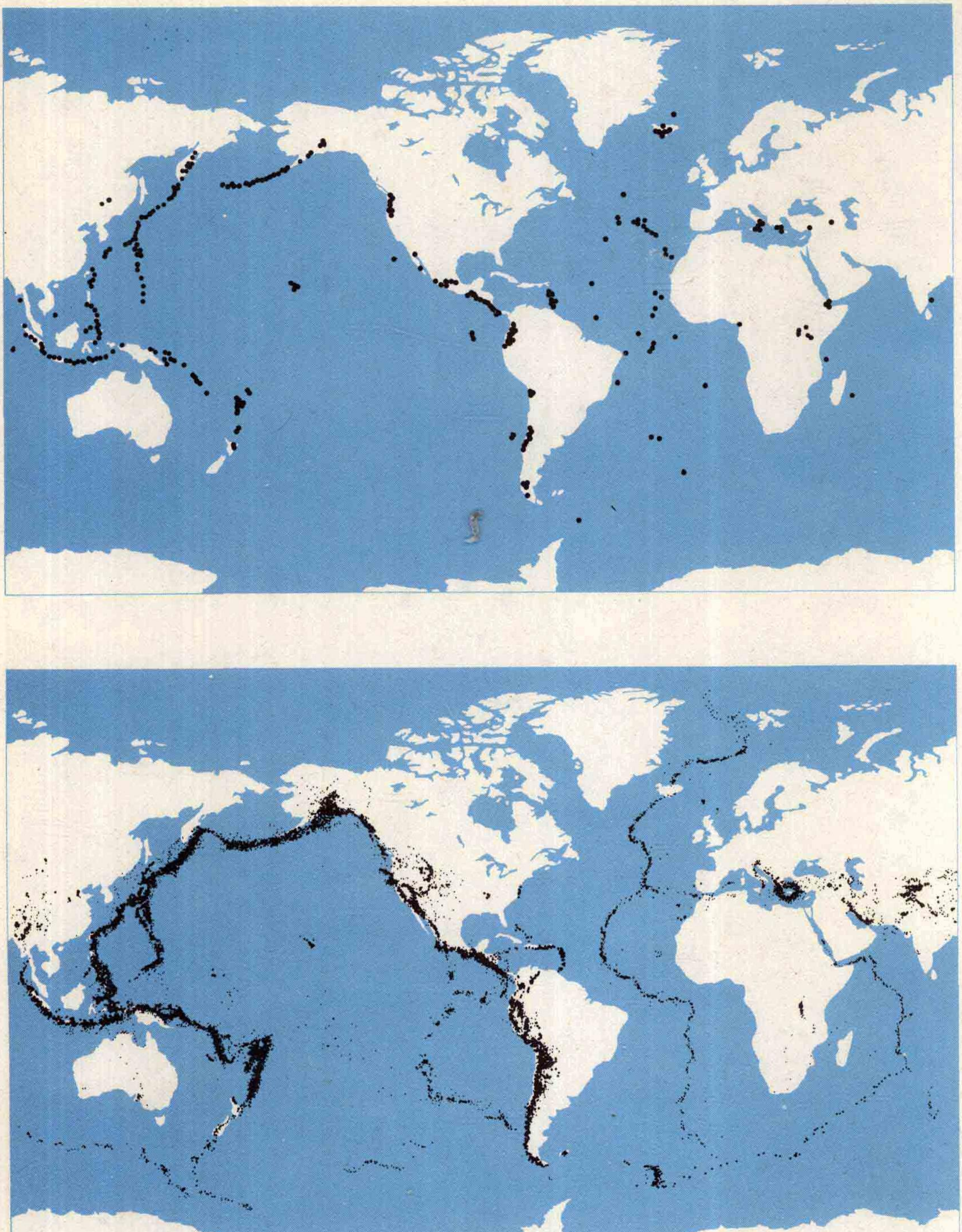

World-wide distribution of active volcanoes (upper) and earthquake epicenters (lower). The volcanoes include some, like those in the Cascade Range, whose activity apparently ceased within the last few thousand years. The earthquake epicenters are those recorded by the global network of seismograph stations during the period 1961–1969. (National Earthquake Information Center; Seismographic Station, University of California at Berkeley)

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COLOR PLATES

Preface

Geology is presented in this book as a personal enterprise of the reader. From the beginning he is asked to pose questions to himself about things he has seen. He takes immediately the role of explorer and detective, as should any beginner in science. In this role he can feel the excitement of observing things more carefully than he has done before, of piecing together fragments of evidence to check hypotheses, of discovering relationships that he had not suspected, of using his discoveries to reach out beyond immediate experience and bring order to the rocks and landscapes of wide regions. In the questions he is asked to formulate he must push his vision not only to the farthest reaches of the earth as it exists today, but backward into the long history revealed by rocks and forward to the state of the planet in a distant future. As the structure and history of the planet take shape, he develops a background for considering the uses that he and his fellows have made of their planetary environment, and the adequacy of that environment for their continued survival. Emphasis is kept on the conclusions the reader can draw for himself, not on his ability to learn the conclusions reached by others.

Of all the sciences geology is best suited to such an approach, for many of its principles are evident from simple application of common sense to everyday observations. The deeper insights that come from more specialized knowledge grow naturally from the broad principles, and the steps can be followed, at least in outline, by any student who brings a modicum of curiosity and enthusiasm to his work. The curiosity and enthusiasm should be self-generating, because geology seeks answers to basic questions that everyone has asked in childhood, questions that range from simple queries about how things work to the ultimate enigma of man's place in the universe.

To present geology in this way requires sacrifice of any hope of complete coverage. For many readers this will not be important. Students already committed to geology and seeking the shortest route to detailed knowledge will need additional material, of a sort that is readily available in many excellent paperbacks on particular geological subjects. For either kind of reader, specialist or nonspecialist, the book will have served its purpose if it helps to widen his vision of time and space, if it increases his awareness of the strange and beautiful planet on which we live, and if it helps him to formulate the penetrating questions without which there can be no progress in science.

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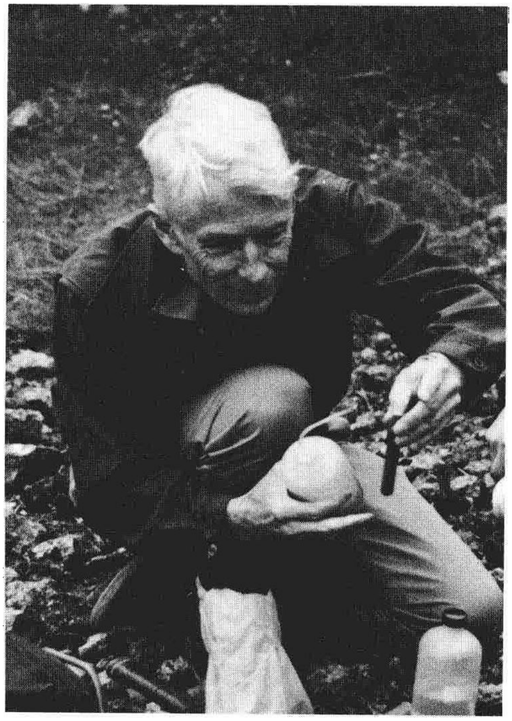

Fig. 1-1. Storm waves. See also Plate 1. (David Muench)

1

Where Land Meets Sea

As a student of geology, your laboratory is the world outside your door. You will bring pieces of that world inside to examine them more closely, but your center of interest is the world in its natural state. Like any other scientist, a geologist seeks to understand his world, to make predictions about it, and to gain some measure of control over it. Unlike others, he seeks such understanding and control primarily by sharpening his ability to observe things as they are rather than by analyzing their behavior in the artificial setting of an indoor laboratory.

So we begin with observation, and the easiest part of nature to observe is a landscape. It doesn't matter much what landscape we choose, so long as it is a place not greatly modified by man and his machines. Rolling hills, a flat plain, rugged mountains, a swamp or a desert—for any of these we could ask the same questions, and in framing replies get a feel for the way a geologist approaches his subject.

Take any landscape that is easily accessible and look at it *carefully*. The important thing is the care: don't just glance at the trees and sky and pass on, but sit down, relax, keep your mind open to all the details, and let your imagination have free play. Has this little fragment of the earth's surface always been as you see it now? What evidence do you note of processes that might be changing details here and there? Suppose that these processes go on unhindered for a very long time: could they ultimately change the entire scene before you? Suppose you had a movie camera focused on the landscape and timed so that a single frame would be exposed every decade; if you could take the film representing exposures for ten thousand years and run it through a projector at normal speeds, what sort of an animated picture would you get?

Fig. 1-2. A landscape in the high mountains of Colorado, with Long's Peak in the background. Is there any evidence in the picture that the landscape may be slowly changing? (National Park Service)

Ask such questions of any familiar landscape, and you will be starting to think like a geologist.

Meditation on a sea cliff

We need a particular landscape to concentrate on, and we pick a place where geologic activity is evident even to the most skeptical. We sit at the edge of a sea cliff, where the waves are pounding on the rocks beneath. The day is clear and breezy, with a few clouds in a bright blue sky. When we have grown used to the splendor of the scene, to the noise of the waves, to the feel of salt spray, we start looking at details. For each detail we ask the eternal scientific question "Why?", and the answers require a generous use of imagination (Plate 1).

Beneath us is a cliff of solid rock, vertical or nearly so. The cliff surface is colored in splotches and streaks of dull gray and brown, more yellow brown and red brown above and gray to black near the base. The cliff is cut by cracks and grooves in an irregular pattern; between the cracks the surface in places projects out a few feet and in places is deeply recessed. Plants cling to parts of the cliff, more numerous near the top and along some of the cracks. At the base of the cliff is a beach of sand and gravel, wide where the cliffs are recessed and absent where rocks project farthest into the sea. The material of the beach is constantly moved by the waves, shoreward as each wave breaks and runs up the beach, seaward as the water retreats. Coarse gravel and large loose blocks mixed with driftwood at the upper edge of the beach are mute evidence of the larger waves raised by occasional storms. Out to sea away from the shore are rocky islets where shorebirds sit in rows and seals crawl up to sun themselves. Patches of white water betray other rocky projections from the sea floor, now only reefs under the surface but probably exposed when the tide is lower. Among the reefs and islets float brown sea plants, probably attached to the bottom but with upper ends free to move with the waves. Shallow pools of quiet water nearer shore are lined with other forms of sea life, often in brilliant colors.

Now what meaning can we attach to this scene of jagged rock and moving water? Put in that form, the question admits of many answers. A seascape would have one sort of meaning for an artist, a different meaning for a philosopher, still a different one for a fisherman. Here we seek the geological meaning, a meaning that looks behind appearances to explain how details of the scenery have been formed.

Fig. 1-3. A desert landscape in southeastern California—looking westward across Death Valley to the Panamint Mountains. Would you expect changes in this landscape to be faster or slower than in the one of Fig. 1-2? (Mary Hill, California Division of Mines and Geology)

The cliff beneath us, for example: why should it stand as a vertical wall of rock, bare of vegetation except for a few plants in crevices? There is no mystery about the answer, if we imagine the gravel and angular blocks on the upper beach being lifted and hurled against the base of the cliff by storm waves. Hard as the rock of the cliff may seem, it must be chipped and abraded by this violent attack. Slowly, in successive storms, the base of the cliff is worn back. The upper part of the cliff is undermined, and once in a while a huge block must break off to be added to the other blocks on the beach. Erosion at the base, gravity pulling on loosened material above: surely these processes are sufficient to maintain the bare, vertical cliff.

The irregularity of the cliff, the parts that project and the parts that are deeply indented: how do we account for such details? Imagination suggests that the rock is not all of the same hardness, that the soft parts are eaten away more rapidly by waves, by slumping, and by rivulets during rains. We could check this guess by examining the rock in detail, but even without a check it seems a pretty obvious explanation.

What about the islets and reefs offshore? Again we appeal to imagination: if the cliff at present is being worn away, it must once have stood farther out to sea; as it was eroded to its present position, remnants of its harder materials have been left behind. The intricate crags and grooves and caves on the islets show how discriminating waves can be in picking softer materials to erode.

Then look at the beach: what determines its gentle seaward slope? A complete answer would not be easy, but the slope must somehow be determined by the movement of sand shifted back and forth by advancing waves and retreating currents. It must be affected by the nature of the sand and the average speed of water movement, although the precise relationship is not obvious. What about the slope offshore, between the rocky islets? We would only be guessing, because we cannot see the underwater slope from where we sit on the cliff top, but the islands and the beds of seaweed extending to a considerable distance offshore suggest that the water is fairly shallow—that the slope of the sandy bottom becomes more gentle away from shore.

Thus with a little rumination we can ferret out the processes that are shaping the present coastline. One dimension we have omitted, the dimension of time. To reason like geologists, we must ask questions about the past and future. What will this pleasant scene look like ten years hence? A hundred years hence? Ten thousand years hence? Or go backward: was this same cliff here 100 years ago? 100 thousand years ago? 100 million years ago?

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