kinase oncogene such as *neu*, presumably because it dephosphorylates the *neu* target." So in one case a tyrosine phosphatase has been shown to have anti-oncogenic effects.

Although the idea that tyrosine phosphatases might inhibit cell growth is one of the principal reasons people are interested in them, it's also clear, paradoxically, that in some circumstances the enzymes may be needed for cell proliferation. Matthew Thomas and his colleagues at Washington University School of Medicine developed a line of mutant T cells that no longer have a functional CD45 protein. Those cells were unable to proliferate, as they normally do, in response to antigen stimulation. "The cells lost the ability to signal through the antigen receptor," Thomas says. "Instead of being a negative regulator, [the phosphatase] was required for function." The effects of the tyrosine phosphatases—whether growth inhibitory or growth stimulatory—may depend, Hill suggests, on the type of cell in which the enzymes are active.

Researchers obviously still have a great deal to learn about how the tyrosine phosphatases operate. High priorities for future work include efforts to identify the external signals that activate the receptor proteins and turn on the phosphatases. And equally important will be the identification of the targets on which the phosphatases work.

Finding those targets will be no mean feat. Cell biologists began looking for the proteins phosphorylated by the kinase encoded by the *src* oncogene more than 10 years ago, and only in the past couple of years have they begun to understand fully just what the kinase does.

Although the researchers have their work cut out for them, they do not seem to be daunted by the prospective difficulties. "We're having fun," says Dixon. And the research does offer the opportunity to get a much firmer grasp on the intricate network of reactions that control cell division. If the 1980s was the decade of the tyrosine kinases, then the 1990s may become the decade of the tyrosine phosphatases.

■ JEAN MARX

ADDITIONAL READING

H. Charbonneau, N. K. Tonks, K. A. Walsh, and E. H. Fischer, "The leukocyte common antigen (CD45): A putative receptor-linked protein tyrosine phosphatase," *Proc. Natl. Acad. Sci. USA* **85**, 7182 (1988).

K. Guan and J. E. Dixon, "Protein tyrosine phosphatase activity of an essential virulence determinant in *Yersinia*," *Science* **249**, 553 (1990).

T. Hunter, "Protein-tyrosine phosphatases: The other side of the coin," *Cell* **58**, 1013 (1989).

G. A. Koretzky, J. Picus, M. L. Thomas, and A. Weiss, "Tyrosine phosphatase CD45 is essential for coupling T-cell antigen receptor to the phosphatidyl inositol pathway," *Nature* **346**, 66 (1990).

N. X. Kreuger, M. Streuli, and H. Saito, "Structural diversity and evolution of human receptor-like tyrosine phosphatases," *EMBO Journal* **9**, 3241 (1990).

A more accessible oceanic plateau? *The dark basaltic rock at the base of these cliffs may have been an oceanic plateau now sandwiched into southwestern Canada.*

Did a Burst of Volcanism Overheat Ancient Earth?

Marine geologists are tying a surge in volcanic activity about 120 million years ago to a uniquely warm climate

ONE HUNDRED MILLION YEARS AGO ALLIGATORS and crocodiles were thriving at the latitude of present-day Labrador. Ever since the fossil evidence of far northern tropical warmth began turning up, scientists have wondered what could have made it so warm, warmer than the greenhouse world of the next century.

Now marine geologists are seeing signs that the answer to this climate enigma may lie on the sea floor. They are becoming convinced that an extraordinary burst of submarine volcanic eruptions struck the Pacific basin about 120 million years ago, pouring vast amounts of gas-laden lava over the ocean floor. The primary evidence for this volcanic spasm is a collection of massive undersea lava plateaus that formed nearly simultaneously. The immense volume of magma brought to the surface to form these structures, a growing number of geologists believe, would have released so much carbon dioxide that the resulting greenhouse effect would help account for the warmest global climate in 500 million years. Once the surge of volcanism began to subside about 100 million years ago, climatic deterioration would have set in until the intermittent ice ages of the past few million years took hold.

One researcher in particular, marine geophysicist Roger Larson of the University of Rhode Island, has compiled considerable evidence for a pulse of volcanism in the mid-Cretaceous Period. He sees at least a 50% increase in the production of ocean crust—more than enough to produce the balmy climate of that time and perhaps an array of other geological phenomena as well (see box). And he's winning over some skeptics. Marine geologist Edward Winterer of Scripps Institution of Oceanography, who had long doubted claims that ocean crust production had surged in the mid-Cretaceous, is one such convert. "What's happened in recent years," he says, "is that we've become more aware of the enormous volume of material emplaced in oceanic plateaus."

Although plateaus cover only about 3% of the present sea floor, Larson's compilation of their volumes and ages suggests that at least in the mid-Cretaceous they loomed large in global volcanism. The standout of them all is the Ontong Java Plateau. Now more than 2 kilometers beneath the sea off the Solomon Islands, Ontong Java covers 1.5 million square kilometers. That rivals the extent of any of the great outpourings of lava that have spilled across the continents, such as the continental flood basalts of the Deccan Traps in India. But there is even more to Ontong Java than meets the eye. While the Deccan Traps' layer of lava is 1 kilometer thick, this plateau of new crust extends downward 36 kilometers, making a volume of 50 million cubic kilometers. That's equivalent to a cube of rock 370 kilometers on a side. And all this new crust may have spewed out in just a few million years—an extremely short interval on the geologic time scale.

According to Larson's calculations, the production of new ocean crust in the form of plateaus was low from 150 million to about 125 million years ago, when it suddenly jumped from 1 or 2 to 6 or 7 million cubic kilometers per million years. It remained at that level until 100 million years ago, when it began an irregular decline. And when plateau production was surging, the rate of crustal production at mid-ocean ridges around the world increased by a similar amount, Larson calculates from published data.

Not everyone is entirely comfortable with Larson's crustal production numbers. For one thing, oceanic plateaus are not well explored, notes marine geologist John Mahoney of the University of Hawaii. Some plateaus have so far yielded but a single rock for dating and geochemical studies, he notes. And much of the geologic record of crustal production has been lost forever as plate motions sent ocean crust diving into deep-sea trenches. This data void has forced Larson to make some debatable assumptions. For example, he has assumed that 6 of the 24 plateaus he's studied, including Ontong Java, once straddled a mid-ocean ridge, which means that they would have split in two and the unlucky halves would already have encountered a nearby trench. Larson thus doubles the known volumes of these plateaus in his calculations.

To reassure colleagues who find such calculations a bit too liberal for their tastes, Larson can point to a recent independent estimate of crustal production. In their compilation, Robert Duncan of Oregon State University and Mark Richards of the University of California, Berkeley, excluded mid-ocean ridge production because much of the record from the mid-Cretaceous has been lost, and they did not include any "lost twins" of plateaus. On the other hand, however, they did include continental flood basalt eruptions from around the world because, like oceanic plateau eruptions, they are large, rapid outpourings of fluid lava. Taken together, oceanic plateaus and flood basalts produced a "remarkable event" in the mid-Cretaceous, says Duncan.

If, as the evidence suggests, there was a surge of volcanism in the mid-Cretaceous, what caused it? Both Larson and Duncan and Richards presume that some part of the lower mantle—most likely a part of its bottom layer lying just above the molten core—became too hot and buoyant, broke away while still solid, and began rising through the solid but slowly deformable mantle.

Larson envisions a single "superplume" of deep mantle rock coming up primarily beneath the Pacific. The lower pressure near the surface would allow it to melt partially and give rise to plateaus across a 10,000-kilometer-wide oval. Duncan and Richards prefer a more widespread event in which numerous plumes rise around the globe. Either way, unmelted plume material would remain in the upper mantle where its heat would temporarily make the rock lying below the plates less viscous. That would reduce resistance to plate motions, according to Duncan, which would account for the speed-up of crustal production at mid-ocean ridges calculated by Larson.

Though the evidence for a volcanic surge is far from complete, there is ready support in the geologic record for an enhanced greenhouse in the mid-Cretaceous. Marine geochemist Michael Arthur of Pennsylvania State University, who until recently was a colleague of Larson's at URI, notes that deep ocean waters at that time were loaded with an exceptional amount of carbon dioxide, as evidenced in the extent of sediment corroded by seawater carbonic acid. And additional amounts of carbon dioxide were being stored away as organic matter in deep-sea sediments.

Earth's oceans could not have socked away all of the carbon dioxide produced by Larson's suggested volcanic pulse, says Arthur; a good deal would have piled up in the atmosphere as well. The geologic record suggests that is just what happened. Geochemists have measured indirectly the carbon dioxide content of the ancient atmosphere using several different methods, all of which depend in part on the carbon isotopic composition of marine sediments.

Preliminary application of Arthur's method yields a mid-Cretaceous peak of atmospheric carbon dioxide twelve times higher than today's concentrations. Other methods show peaks four to eight times higher than present. According to paleoclimate modeler Eric Barron of Penn State, all that is needed to account for mid-Cretaceous warmth would be carbon dioxide levels higher than twice present but less than twelve times present. So it could be true. A volcanic burp might really be enough to make Earth run a fever.

■ RICHARD A. KERR

Beyond a Volcanic Spasm

Not content to propose that mid-Cretaceous volcanism caused a record greenhouse warming about 100 million years ago, University of Rhode Island researcher Roger Larson has gone even further out on a limb by speculating that the same surge in volcanic outpourings led to high sea levels, formation of 50% of the world's oil, restructuring of the deep mantle, and a 41-million-year halt in the flipping of Earth's magnetic field. "This is interesting stuff," he says. "I don't know how much of it is true, but it does have interesting geological consequences."

Larson's colleagues tend to agree that volcanism surged and that a link to a warm climate is reasonable. Beyond that, he's on his own. "He's creating epic poetry," says marine geologist Edward Winterer of Scripps Institution of Oceanography, "but he may be on to something."

Like the proposed mid-Cretaceous greenhouse warming (see main text), Larson's even more speculative after effects of a volcanic pulse are widely discussed phenomena that have been looking for a root cause. For example, if a good chunk of the bottom of the mantle really did peel away to form a plume or plumes, as he and others have suggested, heat loss from the core would have increased as colder mantle moved nearer the core. That would have invigorated the heat-driven circulation of the core that generates Earth's magnetic field and, Larson surmises, stabilized it so that it could not flip-flop. That would account, he says, for the exceptionally long period from 124 to 83 million years ago during which the magnetic field failed to reverse.

Drawing on another long-discussed phenomenon, Larson notes that a plume-induced speed-up at mid-ocean ridges would mean more young, warm, and therefore buoyant ocean crust. Such crust floats higher on the underlying mantle, leaving less room in ocean basins so that seawater is pushed up onto continents to form inland seas. The mid-Cretaceous had the most extensive inland seas of the past 500 million years.

Plume-induced formation of inland seas leads Larson in turn to what might be called the geologic roots of the Persian Gulf war. The bottoms of inland seas are just the place for dead marine plankton to accumulate and form oil and gas, he notes. And greenhouse warmth and volcanically derived nutrients would stimulate plankton growth, he speculates. Given these plume-induced conditions, no wonder the mid-Cretaceous, especially in the Middle East is known for its abundance of oil formation, he says. So if Larson's chain of speculation is right, the foundation for war was laid 120 million years ago when gas-laden lava burst into the Pacific. ■ R.A.K.