be happy, especially as this would be in addition to NIH and National Science Foundation funding. Nevertheless, there is a palpable sense of unease about the extent of involvement apparently already developed by the DOE in these early stages of the project and the prospect of yet greater control. There were clear indications at the recent NIH gathering of a desire to organize and coordinate the mapping (and subsequent sequencing) project within the university and research institute community, "without being encumbered with hidebound bureaucracy," as Bodmer repeatedly stressed.

Perhaps in response to this new mood, Smith was strikingly less bullish in promoting the DOE's role in the future of the genome project than he had been at the Cold Spring Harbor gathering at the beginning of June.

With the notable exception of Walter Gilbert, of Harvard University, who earlier proposed the establishment of a Human Genome Institute that would be focused on sequencing the human genome, most of the United States contingent at the NIH meeting was distinctly cool about sequencing as against mapping. From Europe, John Tooze, of the European Molecular Biology Organization, said that he had elicited "a distinct lack of enthusiasm for sequencing the whole genome, until the process could be extensively automated." Sydney Brenner, of the Medical Research Council's Laboratory of Molecular Biology in Cambridge, England, said that "The idea of trudging through the genome sequence by sequence does not command wide and enthusiastic support in the U.K."

In Japan, by contrast, researchers at the University of Tokyo and the Riken Institute in Tokyo are already gearing up a $3 to $4 million, highly automated sequencing effort that, within 2 years will be churning out 1 million bases a day. The idea is then to sequence the smallest of the human chromosomes, number 21, which has 48 million bases, within a 5-month period. "But there is no plan to sequence the entire genome," said Nobuyoshi Shimizu of Keio University, Tokyo. "Sequencing the human genome is an organizational challenge and no such structure exists in Japan."

Enthusiasm for sequencing the entire human genome can therefore be seen to have generally diminished and has been replaced by enthusiasm for mapping. "Doing the sequence should be phase 2 in our plans," said Watson. "Phase 1, which is getting a library of overlying cosmids, a map, is acceptable. There should be more urgency for pursuing phase 1 than there is, because of the great benefits for genetic diseases and common diseases. We can't think intelligently about phase 2 until we have phase 1."

A switch of favor from sequencing to mapping represents something of a victory for classical genetics. It is true that the existence of a physical map of the genome would facilitate tracking down genes and cloning, which is the stuff of molecular genetics. But for classical genetics a map is even more valuable, provided that it is scattered with informative markers. With such markers it would be possible to carry out linkage studies with many loci, which would at last give a real insight into some of the common but genetically complex diseases, such as heart disease, psychiatric disease and autoimmune disease.

Phase 1, the mapping effort, might be completed within 3 years, given sufficient coordination and about $20 million. The cost and duration of phase 2 will depend entirely on the state of sequencing technology and the proportion of the genome that is considered worth sequencing. For, although some observers insist that it should all be done, others argue that only a small proportion is actually of interest. On to this Gilbert adds phase 3: "the complete understanding of all human genes; this is the goal of all biology."

Reflecting on meetings of molecular biologists at NIH just a decade ago, when the beginning of recombinant DNA technology stirred uncertainty and fear, Fredrickson characterized the current prospects as follows: "We now face a new challenge, this time more awesome than dangerous." ■

ROGER LEWIN

Tracing a Young and Malleable Moho

The boundary between the continental crust and the mantle in Nevada appears to be younger than the continent itself

IF the earth is like a layer cake, the 30- to 40-kilometer-thick continental crust would be the thin uppermost layer, thin enough really to be a glaze of icing that overlies the darker, denser mantle layer extending 2900 kilometers to the core. In 1909 Andrija Mohorovičić detected the boundary between crust and mantle in the differing velocities of seismic waves in the two layers. Called the Moho for linguistic simplicity, this seismically detected boundary between chemically differing layers became in the eyes of many geophysicists as clean, simple, and unchanging as the layers of a cake. Modern applications of Mohorovičić's techniques suggested that the boundary might actually have a thickness of several kilometers, but the image of the Moho remained fuzzy at best.

The application of a second, higher resolution seismic approach, the seismic reflection technique borrowed from oil exploration, has revealed a complex and variable Moho of interleaving crust and mantle. A new seismic reflection study of the Moho beneath Nevada and western Utah reveals not only a complex reflective zone at the base of the crust often resembling a double Moho, but also evidence that the Moho there formed long after that part of North America did. Among the explanations of how a new boundary between crust and mantle could form is the idea that the lower crust grew at the expense of the mantle.

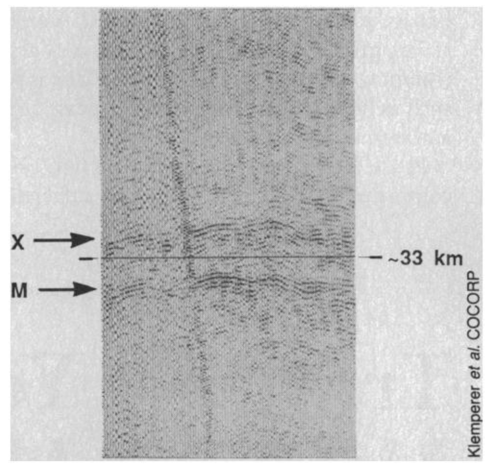
The new study is based on an exceptionally long, 1000-kilometer seismic profile made by the Consortium for Continental Reflection Profiling (COCORP) across the Basin and Range province of Nevada, where crustal stretching has broken the surface into wave after wave of mountain ranges separated by sediment-filled basins. In reflection profiling, truck-mounted vibrators send seismic waves downward that reflect back to receivers on the surface from any variation in rock properties sufficiently strong to act as an obstacle to the waves, much the way radar works in the atmosphere at far shorter, electromagnetic wavelengths. The resulting 50-kilometer-deep, 1000-kilometer-long image can reveal details in the horizontal dimension larger than about 2 kilometers and in the vertical larger than about 100 meters. That is a far sharper picture than that obtainable by refraction profiling, the original method used to define the Moho.

Because in the refraction method seismic waves gently dip into the crust and bend back to the surface after passing horizontally through many kilometers of rock, only large blocks or layers of rock having different seismic velocities can be defined.

The COCORP profile revealed that the Moho beneath Nevada has all the complexity that had been reported from scattered sites elsewhere, but most remarkable was the Moho's strength and continuity. A strong reflection at the apparent base of the crust, from about the same 30- to 35-kilometer depths of the Moho determined by seismic refraction, appeared in 75% of the profile across Nevada. Where this reflection Moho is not evident, often beneath the seismically absorptive and distortive basins, Simon Klemperer and his colleagues at Cornell University, where COCORP is headquartered, find evidence that reflected signals from Moho depths would be unlikely to reach the surface without being swamped by noise. They conclude that "the Moho reflectors are apparently continuous across all [450 kilometers] of the COCORP Nevada lines." Although the reflection Moho gently undulates as much as 7 kilometers, the COCORP group could find no offset in the Moho larger than their detection limit of about 0.5 kilometer, despite offsets on faults near the surface of up to 5 kilometers. In fact, reflectors that dip into the Moho, presumably representing faults in the lower crust, end abruptly at the Moho.

The Nevada profile revealed other features seen consistently along the reflection Moho that had been noted on shorter lines elsewhere. Mantle reflections from below the Moho were rare, in contrast to the often highly reflective lower crust. Up to 4 kilometers above the strong reflector taken to be the Moho, there is a second strong reflector that appears along 75% of that part of the profile of sufficient quality to reveal the Moho. Often forming a band of reflectors between them, the pair of strong reflectors may mark the top and bottom of a transition zone between crust and mantle, the COCORP group suggests.

The continuity of the Nevada Moho is remarkable in light of the hodgepodge of continental crust encompassed by the reflection profile. More than half a billion years ago western Nevada and California were simply not there—the edge of the continent reached only to central Nevada. Then drifting ocean plates plastered a scrap of ocean crust against the continent, followed by the addition of a wedge of island arc-like crust and finally by the accretion of a third crustal fragment. A smooth, continuous Moho underlies them all. By 150 million years ago, ocean crust was diving into the mantle to the west and sending magma upward into the crust to form the rock that would become the Sierra Nevada. The Moho appears to be continuous beneath the eastern edge of that terrane as well. To explain the Moho's uniformity across such disrupted crust as well as other geological constraints, the COCORP group suggests that the present Moho there probably formed since 30 million years ago, when the crust began to stretch and break up to form the Basin and Range province.



A young Moho: *M marks the Nevada reflection Moho formed well after the assemblage of the continent. X marks a lower crustal reflection.*

Crustal extension might have formed a new Moho in one of several ways. The different amounts of extension in the crust and the mantle might have been accommodated by slipping at Moho depths that distorted the rock into seismically reflective forms. Or the crustal heating accompanying the extension might have altered the crystalline form of the lowermost crustal rock so as to give it mantle-like seismic properties.

The COCORP group prefers a third hypothesis for the formation of the Basin and Range Moho, the downward growth of the crust by means of the volcanism that accompanied the extension. On its way toward the surface, lighter magma from deep within the mantle might have been held up near the original Moho, where denser mantle rock gave way to crustal rock even lighter than the magma. Thus, the density contrast at the Moho could lead to ponding of magma. Mantle-like minerals would then crystallize from the magma and collect at the bottom of the ponding, and the remainder at the top would eventually solidify to form new lowermost crust. Where the magma managed to intrude between layers of crustal rock, a thick layer of reflectors like that seen above the Nevada reflection Moho would form. Such interleaving has been seen in ophiolites, which are thought to be scraps of ocean crust that were pushed up on land, and has been inferred from a few seismic reflection profiles of ocean crust.

A Moho formed by ponding and intrusion would be a far cry from the simple, static two-layer model. A dynamic Moho could erase preexisting crust-mantle transitions, cut off disruptions due to faults, and interleave crust and mantle across a broad zone. It could also be the site of vertical crustal growth by ponding and underplating. The COCORP group emphasizes that, although the Moho at other sites of extension and volcanism bears some resemblance to the Nevada Moho and may also involve crustal underplating, the Moho elsewhere can look quite different. The refraction Moho, for example, can be denoted in reflection profiles only by a disappearance of reflectors. Even a "small sample of the many COCORP surveys shows that the expression of the Moho on reflection profiles is variable," says the group, "and hence, perhaps, that the Moho has a variable origin and/or a variable evolution."

A survey of southern Alaska near Valdez illustrates just how variable the evolution of the boundary between crust and mantle can be. Robert Page of the U.S. Geological Survey (USGS) in Menlo Park and his colleagues reported recently on seismic refraction, geologic, gravity, and magnetic data collected as part of the USGS Trans-Alaska Crustal Transect project designed to describe the crust along the oil pipeline corridor. Pinning down the crust-mantle transition turned out to be as much a semantic as a technical problem. The accreted crustal scraps making up southern Alaska are only 10 kilometers thick, according to the refraction data. Beneath them is a stack of three or perhaps four slabs of what may be ocean crust accompanied by slivers of mantle rock. Instead of one transition to higher velocity, mantle-like rock, there are three "Mohos." It would appear that thick ocean plates diving into the mantle, the process that welded the accreted terranes to the continent, peeled apart time and again, leaving the ocean crust, a few kilometers of mantle, and the intervening Moho behind. Now there are at least two "Mohos" in the old plates that are securely underplated to the overriding continent and overlie the actively subducting ocean plate. ■

Richard A. Kerr

ADDITIONAL READING

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