even with a shorter exposure to antigen or in the presence of low antigen concentrations. This global increase in T cell responsiveness to antigenic stimuli is mimicked within the local LPC-deficient sites of wild-type mice. Conceivably, T cells found within lymph nodes would be exposed to lower amounts of LPC than T cells in the circulation (see the figure). Thus, differential exposure to LPC or differential activation of G2A may contribute to the highly efficient and effective antigen-driven activation of lymph node T cells compared with T cells in almost any other site of the body (*2*).

LPC may promote the initiation of an immune response while also limiting the extent of that response. This lysophospholipid is generated by hydrolysis of phosphatidylcholine—which is present in low density lipoproteins (LDLs) and the plasma membrane of cells—by phospholipase A_2 (*6, 7*). LPC produced from the disintegrating plasma membranes of necrotic and apoptotic cells may nonspecifically recruit T cells to sites of tissue damage (*6*), but then, high levels of LPC may serve to put the brakes on further T cell activation. Establishing a higher threshold for antigen-specific responses driven by LPC would promote immune responses with greater antigenic specificity or selectivity, even in the presence of a wide spectrum of inflammatory mediators.

Atherosclerosis may represent the most extreme demonstration of this immune regulation pathway (*8*). The accumulation of oxidized LDLs on arterial walls serves to recruit monocytes and T cells—the LPC in oxidized LDLs is a prominent chemoattractant (*6, 7*)—and to promote the growth of atherosclerotic plaques. Oxidized LDLs also convert recruited monocytes into lipid-filled "foamy" macrophages, which produce large quantities of inflammatory factors (*8*). With time these foamy macrophages die in situ, contributing to the formation of atherosclerotic plaques that block blood flow through the blood vessel. Although most studies examine how monocytes are implicated in plaque formation, mice deficient in a variety of immune regulatory molecules hint that activated T cells and interferon γ may also be involved (*8*). Inhibition of T cell activation by G2A and LPC could be overcome by strong and persistent inflammatory signals emitted by the developing plaque.

The notion that the interaction of LPC with G2A regulates T cell responses is attractive, but several elements still require testing. First, the effects of LPC are merely implied by the phenotype of G2A-deficient mice. Does direct application of LPC decrease the extent or kinetics of antigen-driven T cell proliferation or cytokine production? Second, G2A can be detected in both CD4 and CD8 T cell populations, but the prevalence of expression within these populations during development or activation is unknown (*5*). Third, LPC is a known chemoattractant for monocytes and macrophages, but G2A expression in these and other antigen-presenting cells has not been examined (*6, 7*). This must be done because T cell responses are shaped by their interactions with antigen-presenting cells. Failure to detect G2A expression in antigen-presenting cells might indicate the existence of other LPC receptors. Finally, exposure of B cells to DNA-damaging agents or strong mitogenic stimuli induces them to express G2A (they are normally G2A-negative) (*4*). This pattern of induction suggests that LPC may inhibit B cell activation, although this remains to be demonstrated.

Despite these gaps in our knowledge, the key findings of Kabarowski *et al.* underscore the growing realization that the immune system does not operate independently of the tissues that it defends (*2*). Specifically, identification of LPC as a high-affinity ligand for a T cell G protein–coupled receptor implies that regulation of T cell responses is too important to be left solely to the "professional" cells of the immune system. Rather, lymphocyte responses recognizing a vast array of antigens are regulated by more than antigen-presenting cells, antigen, or the limited production of chemokines and rare immunoregulatory peptides. They are likely to be shaped by common and abundant products of hydrolysis, such as LPC produced by tissue macrophages, stromal cells and other "nonprofessional" cells

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PERSPECTIVES: GEOLOGY

The Smile of the Cheshire Cat

Jan Kramers

The interval between the formation of the planets, about 4500 million years ago (Ma) ago and the age of the oldest known rocks on Earth [4000 million years (Myr)] has been termed the Hadean era. This term conjures up a profoundly disagreeable environment. Yet among the oldest known rocks on Earth are water-deposited sediments that contain evidence of life and photosynthetic activity before 3700 Ma (*1*). Earth thus appears to have emerged from the Hadean with liquid water and possibly even life already established on its surface.

At this time, Venus probably already had its greenhouse atmosphere, which became irreversible by loss of water (*2*). The environmental switches that helped Earth escape this fate were thus set in the Hadean. But apart from the knowledge, by analogy with dated lunar structures (*3*), that impacts were frequent (terminating in a "cataclysm" around 3800 to 4000 Ma), we know little about tectonics and geodynamics during the Hadean. How prevalent was continental crust during the Hadean, and since when? The precise calibration of the decay constant of ^{176}Lu reported by Scherer *et al.* on page 683 of this issue (*4*) is an important step toward answering these questions.

Continental crust is unique in the solar system. It is mainly produced by complex partial melting processes of mantle rocks rendered water-rich by subduction of hydrated oceanic crust. Relatively enriched in Al, Si, Ca, and Na, it has a lower density than oceanic crust and therefore stays at Earth's surface, where it can persist for billions of years. Continental crust is also enriched in elements such as P, K, and Mo, which do not fit well into the lattice of the main mantle minerals. Through weathering, these become available to biota. Furthermore, silicate weathering converts CO_2 to HCO_3^-, which is sequestered in sedimentary carbonate rocks. Over geological time, this has been the main mechanism for removing CO_2 from the atmosphere (*5*) and averting a strong greenhouse. Continental crust has thus changed Earth itself.

Today, the oldest rock units, at 3700 to 4000 Myr, are found in West Greenland, Canada, and West Australia. An intensive search for even older crust has yielded nothing, suggesting that if it ever existed, it must have since been destroyed by erosion, large impacts, or melting processes.

Yet where the Cheshire cat has gone, its smile may linger (see the second figure, next page). Detrital grains of zircon (a resistant mineral rich in uranium) in ancient metamorphosed sediments from Jack Hills,

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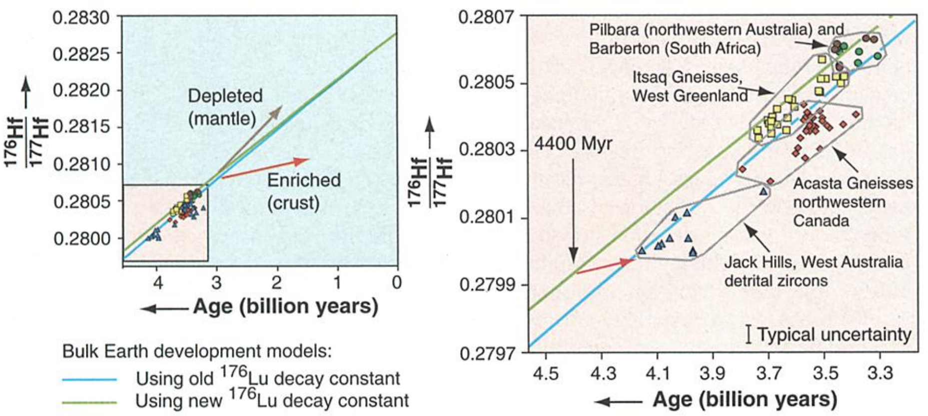
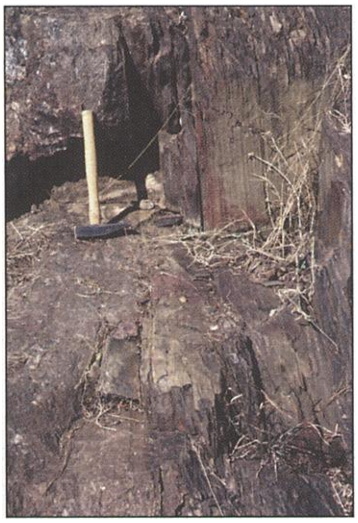


Growth of the ^{176}Hf/^{177}Hf ratio with time. Bulk Earth models based on chondritic meteorite data (*7*). Blue line: calculated with previously accepted ^{176}Lu decay constant. Green: calculated with new value (*4*). (**Left**) Overview over full Earth history showing position of zircon data and effects of Lu/Hf ratio fractionation in crust formation. Red arrow: slow growth of ^{176}Hf/^{177}Hf in continental crust (Lu/Hf ratio about 1/3 of bulk Earth). Brown arrow: faster growth of ^{176}Hf/^{177}Hf in depleted mantle. (**Right**) Detail from (A), showing zircon populations analyzed by (*8*, *9*) in relation to the old and new bulk Earth Hf isotope development models. Red arrow indicates derivation of crust that produced the Yilgarn detrital zircons at 4400 Ma.

West Australia, have yielded U-Pb ages of around 4300 Myr. One grain appears to be close to 4400 Myr old. Oxygen isotopes indicate that the magma that produced these grains had encountered surface water (*6*).

Of course, one grain does not make a continental crust. But zircon has an added benefit: It contains Hf, the geochemical twin of Zr. This provides a window on past crust formation in the following way (*4*) (see left panel in the first figure): ^{176}Lu decays to ^{176}Hf. Therefore, the ^{176}Hf/^{177}Hf abundance ratio of any system increases with time at a rate proportional to the Lu/Hf abundance ratio. In the partial melting processes that form continental crust, more Lu stays in the mantle than Hf. As a result, the Lu/Hf ratio in the crust is much lower than in the bulk Earth, and the ^{176}Hf/^{177}Hf ratio increases more slowly (red arrow in left panel in the first figure). The reverse is true for the mantle, in which the Lu/Hf ratio increases by mass balance (brown arrow). A high ^{176}Hf/^{177}Hf ratio, as observed in today's mantle (*7*), thus indicates that large amounts of continental crust have been extracted.

As it crystallizes, zircon incorporates up to 2% Hf by weight but only traces of Lu. The mineral therefore has a very low Lu/Hf ratio, and its Hf isotope composition hardly changes with time. This means that zircon, while being a chronometer for U-Pb, is a time capsule for Hf.



Older than their years? 2800 Ma siltstones (**right**) overlie a 3600 Ma gneiss (**left**) in the Belingwe Greenstone Belt, Zimbabwe. Note the weathering in the gneiss, which predates 2800 Ma. Rocks like the sediments on the right can contain records much older than the rocks themselves.

This feature has been exploited to deduce the source of the magma that crystallized ancient zircons from their Hf isotope composition (*8*, *9*) (see right panel in the first figure). Two populations of zircons (Acasta gneisses and the detrital Jack Hills grains) seem to come from continental crust. The others (West Greenland, northwestern Australia, and South Africa) lie above the blue line and, therefore, appear to have been derived from portions of mantle with anomalously high ^{176}Hf/^{177}Hf ratios, indicative of voluminous crust production in the early Hadean.

This interpretation [blue line in right panel, following (*7*)] is, however, based on a best estimate of Bulk Earth evolution with the previously accepted ^{176}Lu decay constant (*7*, *10*). The recalibration of the ^{176}Lu decay constant reported by Scherer *et al.* (*4*) fundamentally changes the interpretation of the data because it shifts the reference framework to higher ^{176}Hf/^{177}Hf ratios (green line). The initial ratios of the zircons hardly shift because of their low Lu/Hf ratio (*10*).

It can be seen that no evidence remains, outside experimental error, that mantle with anomalously high ^{176}Hf/^{177}Hf ratios existed around 3500 Ma. Therefore, the apparent evidence for large amounts of crust early in the Hadean falls away.

On the other hand, even the oldest Jack Hills and Acasta zircons lie substantially below the green line. These zircons, and the rocks in which they originally formed, must have inherited very much older crustal material. Hf isotope development estimates for the Jack Hills zircons (red arrow in right panel in the first figure), based on the Lu/Hf ratio of average continental crust, indicate that the crust that gave rise to this zircon population was derived from the mantle around 4400 Ma. This is quite similar to the oldest U/Pb age obtained for this population (*6*).

The Hf data now confirm the conclusion from (*6*) that some continental crust was generated as early as 4400 Ma. Many less ancient zircons in the same population also appear to have crystallized from parts of this very old system. It thus survived as a geochemical entity large enough to contain magmatic processes, from 4400 to 4000 Ma. On the other hand, the lack of anomalously radiogenic Hf in the mantle around 3500 Ma indicates that such crust was rare.

The Jack Hills zircons are so far the only population pointing back to 4400 Ma, but the Acasta samples point back to 4100 Ma, and there are many zircon populations from ancient cratons that have yet to be investigated in this way. Parallel to this work, more studies of meteorites will constrain the Hf isotope evolution of the bulk Earth.

As more indications of very ancient crustal material are found, it will be interesting to correlate Hadean crust ages based on Hf in zircons with regional geochemical parameters that have so far escaped notice or for which there has been no explanation. For example, variable ^{207}Pb/^{204}Pb ratios indicate very early fractionation of the U/Pb ratio. Such work will help to bridge the gap between the known Earth history and planetary accretion.

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