Iso Topics

Zircons Are Forever

Featured Faculty Research

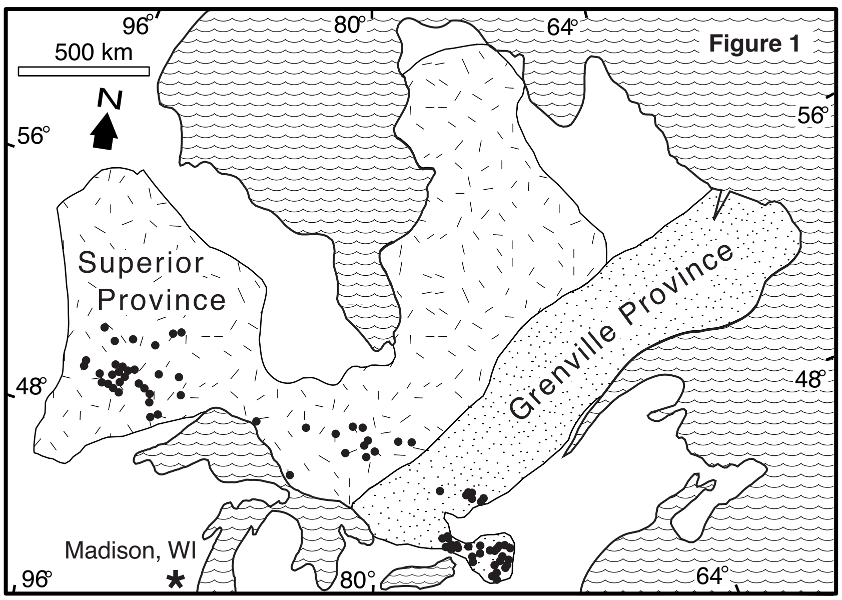
John W. Valley, William H. Peck, Elizabeth M. King

New techniques for oxygen isotope analysis, developed at UW-Madison, have lead to the first studies of oxygen isotope geochemistry of zircons (1, 2). Zircon is shown to be highly retentive of oxygen isotope ratios, preserving the best record of igneous composition even in samples that have enjoyed (not suffered!) high grade metamorphism or hydrothermal alteration.

Zircon is a ubiquitous trace mineral ($ZrSiO_4$) in many igneous, metamorphic, and clastic sedimentary rocks. Its ability to concentrate uranium and exclude lead forms the basis of U-Pb geochronology and its refractory nature and concentric growth patterns create robust records of crystallization age.

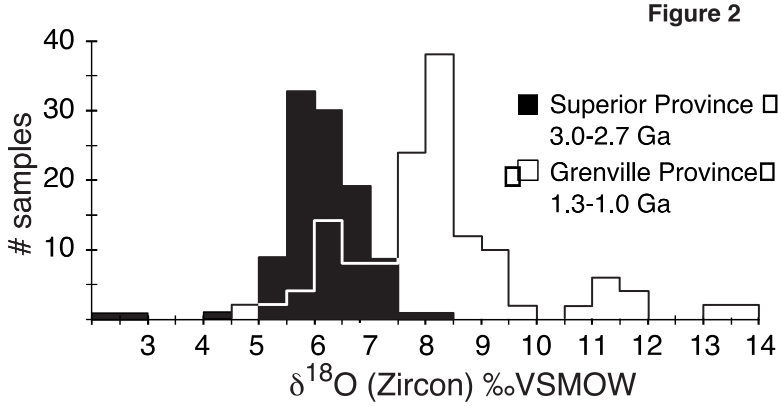
The ability to analyze oxygen isotope ratios in a sample that has been dated, directly links the magmatic composition to known geologic events and has opened many new and exciting avenues for study. Several recent graduate theses at UW have incorporated some aspect of zirconology: Carrie Gilliam (MS 1996) and Salma Monani (MS 1999) showed that shallowly intruded, sub-volcanic Tertiary granites from the Isles of Skye and Arran, Scotland formed by melting of anomalous rocks in the deep crust (3, 4). Liz King (MS 1997, PhD cand.) completed a comprehensive survey of Archean igneous rocks in Canada (5) that lead to a reevaluation of the genesis of one of the world's richest base metal ore deposits (6). William Peck (MS 1996, PhD cand.) is studying anorthosite and related Proterozoic granitoids in the Grenville Province and has discovered oxygen isotope provinciality that appears to identify a cryptic continental suture and an accretionary plate margin that is now buried in the deep crust (7).

Another advantage of oxygen isotope studies of zircons stems from the fact that oxygen is the most abundant element in the crust. Thus oxygen is affected by different processes than trace elements or radiogenic isotopes that are commonly employed to study crustal growth and evolution. This difference is dramatically revealed by a comparison all existing data for zircons (8) from the Canadian Shield (Fig. 1). Archean age samples (2.7 to 3.0 Ga) have a very restricted range of $\delta^{18}O$ value



(5.7±0.6‰) that is consistent with high temperature equilibrium with a primitive mantle reservoir (Fig. 2). In contrast, the Proterozoic samples from the Grenville show a much larger range and a higher average value (8.2±1.7‰). These anomalous values in the younger terrane result from processes that can only occur at the Earth's surface: weathering and low temperature alteration. The high $\delta^{18}O$ signature of surfical processes must be buried in the form of sediments and altered rocks to near the base of the crust in order to become incorporated in granitic magmas by melting and assimilation. Thus, the deep crust beneath the Grenville Province is dramatically different from the more primitive, early crust of the Superior Province. The quantity of high $\delta^{18}O$ supracrustals is much smaller in the Archean. These results lead to speculation that the differences seen in N. America may be worldwide trends and that sedimentation may have been less voluminous and of a different character during early Earth history. The Wisconsin group is now actively studying zircons from many other terranes, including: less than 1Ma rhyolites at Yellowstone (Bindeman and Valley, unpbd), the world's oldest known zircons from Australia (>4.3 Ga, Peck, Wilde and Valley, unpbd), and mantle-derived megacrysts from Kimberlite pipes (9). The results suggest that this trend is worldwide and that a major, non-uniformitarian change occurred either at the end of the Archean (2.7 Ga) or with the evolution of oxygen-rich atmospheres and weathering (~2 Ga). Since the zircons are forever, we have plenty of time to work this out.

Figure 2



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Elizabeth King in the field.

Chronology of the Last Glaciation in the Southern Hemisphere

Featured Faculty Research

Brad Singer, UW-Madison
Wes Hildreth, USGS-Menlo Park
Yann Vinzce, University of Geneva, Switzerland

Telling geologic time in the Late Pleistocene beyond the range of carbon-14 dating has been a challenge that until recently posed a barrier to addressing many problems in paleoclimate, paleomagnetism, neotectonics, and volcanology. However, remarkable improvements in radioisotopic methods including $^{40}Ar/^{39}Ar$ dating of lava flows and ash deposits and the development of surface exposure dating using cosmogenic nuclides such as ^{26}Al, ^{10}Be, and ^{3}He are breaking down these barriers and opening up exciting new avenues of research.

It is clear that Earth's orbital position relative to the sun has modulated global climate in an oscillatory pattern for the past 2 million years. There is growing evidence, though, that deglaciation and warming were not exactly globally synchronous following the last glacial maximum, and perhaps earlier ice ages (e.g., Blunier et al., 1998). Instead oceans, atmosphere, topography, and biota interact in a complex network of feed-backs such that regional responses to shifts in solar radiation may differ in tangible ways between the hemispheres (Alley and Clark, 1999; Gillespie and Molnar, 1995). Because much of our understanding of paleoclimate is heavily biased by interpretations of northern hemisphere records—and very little quality data exist south of the equator—I am interested in the terrestrial responses to climate change in the southern hemisphere.

As an example, my colleagues and I have obtained precise constraints on the timing of deglaciation in the central Andes of Chile by dating several lava flows erupted in the Laguna del Maule basin along the crest of the Andes at 2100 m elevation using the $^{40}Ar/^{39}Ar$ geochronometer. Steep-sided valleys and unconformaties within older Quaternary volcanic deposits indicate that this region at 36° South latitude (Fig. 1) was glaciated repeatedly during the Pleistocene (for comparison, Yosemite Park is at 36 °N, at the same elevation). One lava flow that was striated and grooved by overriding glacial ice (Fig. 2) after its eruption was dated at 25,600±1,200 yr BP (Fig. 3). Three other lava flows each covering 4 to10 km^2 of the basin floor are morphologically pristine and show no sign of burial or erosion by glacial processes. The three lavas yielded $^{40}Ar/^{39}Ar$ isochron ages of 23,300±600 yr BP, 21,200±3,000 yr BP, and 20,700±1,200 yr BP (Fig. 3), indicating that this corridor of the Andes was glacier covered between 26,000 and 23,000 years ago, but that the glaciers retreated for the last time before 23,000 years ago.

Our results are controversial because carbon-14 dated moraines farther south in New Zealand and at Lago Lanquihue, and Torres del Paine, Chile (Fig. 1) suggest that glacial advances occurred 14,000 and 11,000 years ago (Lowell et al., 1995; Marden, 1997). Our new ages are, however, consistent with evidence that portions of

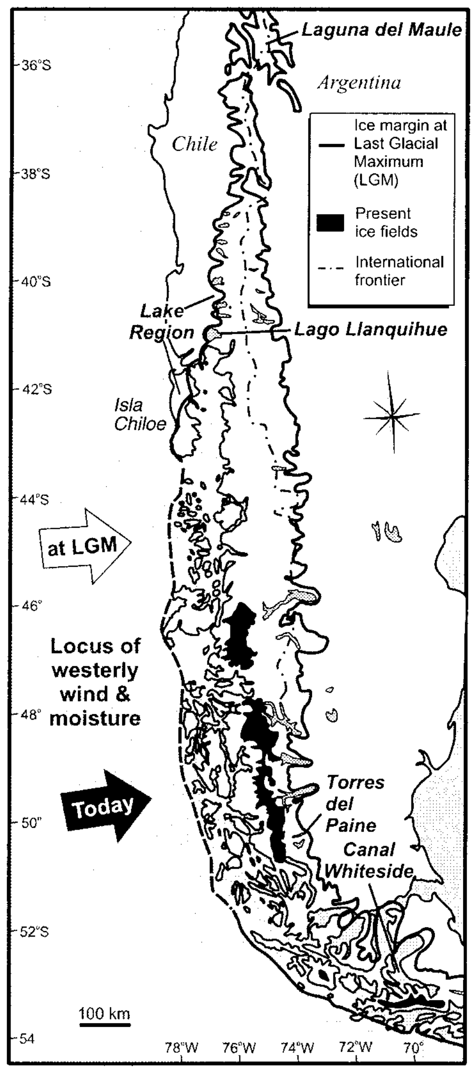
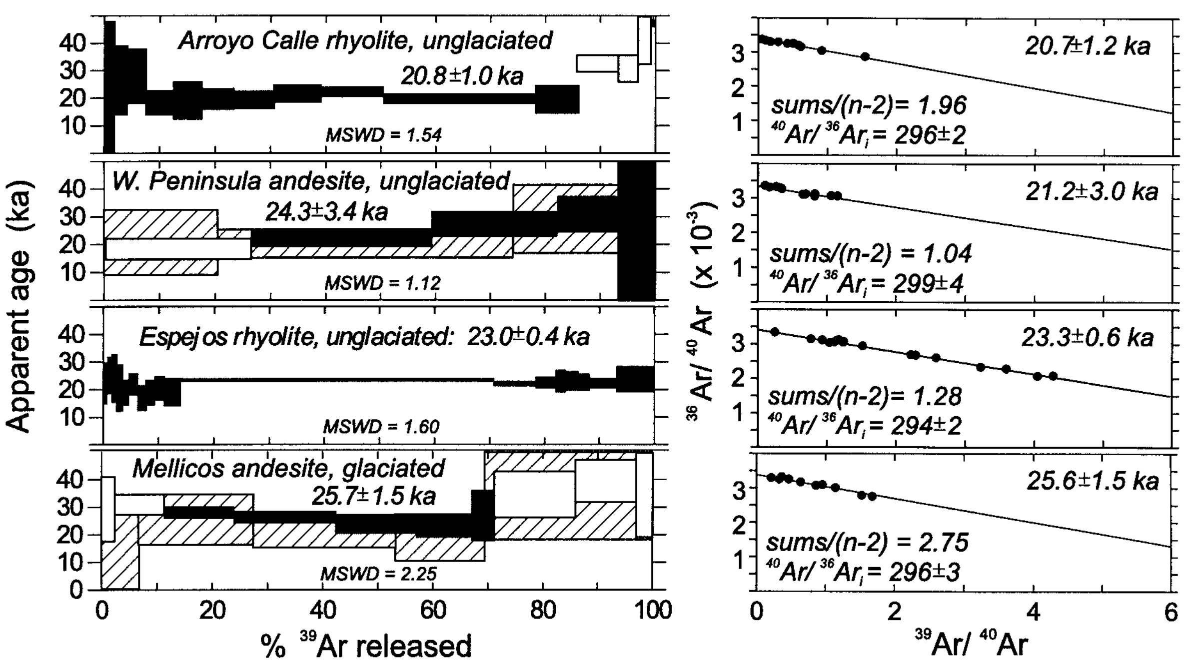


Figure 1. Location of Laguna del Maule and sites of radiocarbon dating discussed in the text.

(Above) Figure 2. A glacier carved striations and grooves into the surface of the Mellicos andesite after it erupted ca. 26,000 yr BP. Younger lavas forming the western shore of Laguna del Maule (middle ground) are 23,000 to 21,000 years old and do not show signs of glacial erosion.

the southern hemisphere, like Canal Whiteside (Anderson and Archer, 1999; Fig. 1) emerged from the last ice age as much as 5,000 years ahead of the northern hemisphere. We postulate that the early ablation of glaciers at 36°S reflects an increase of solar radiation in southern hemisphere several thousand years prior to the north (recall that tilt and precession of the Earth's rotational axis in its orbital plane mean that the magnitude of incoming solar radiation and seasonality in the two hemispheres evolve according to a complex but opposing periodicity). This accumulated solar energy may also have ablated extensive Antarctic sea ice (Kim et al., 1998), which in turn allowed a rapid poleward contraction of the circumpolar westerly winds (the roaring 40's) which carry all the precipitation required to sustain Andean glaciers of any size (Heusser, 1989). This hypothesis explains continued glaciations to the south of Laguna del Maule and the present position of the Patagonian ice fields (Fig. 1). I hope to test this hypothesis in the new UW-Madison Rare Gas Geochronology Laboratory through further dating of lavas on more southerly Andean composite volcanoes.

(Below) Figure 3. $^{40}Ar/^{39}Ar$ age spectra and isochron plots from six incremental-heating experiments. Plateau increments are solid boxes; discordant increments omitted from the plateau and isochron calculations are shown as open boxes. Replicate experiments were performed on the Mellicos and West Peninsula andesite samples with plateau increments shown in diagonal pattern. All errors ±2σ.



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Has she been naughty or nice? Santa's elves Kristin Anderson and Megan Mandernach watch as incoming department Chair, Mary Anderson, is about to find out what Santa thinks.

Santa (Brad Singer) and his team at the Geoclub Holiday party.

The Alumni Field Trip stopped at Parfrey's Glen, May 8, 1999.

The department's athletic prowess was proven by this formidable assortment of Geo-bowlers, "The Strikin' Dips," representing the Geoclub in '99.