Mountains, Weathering, and Climate

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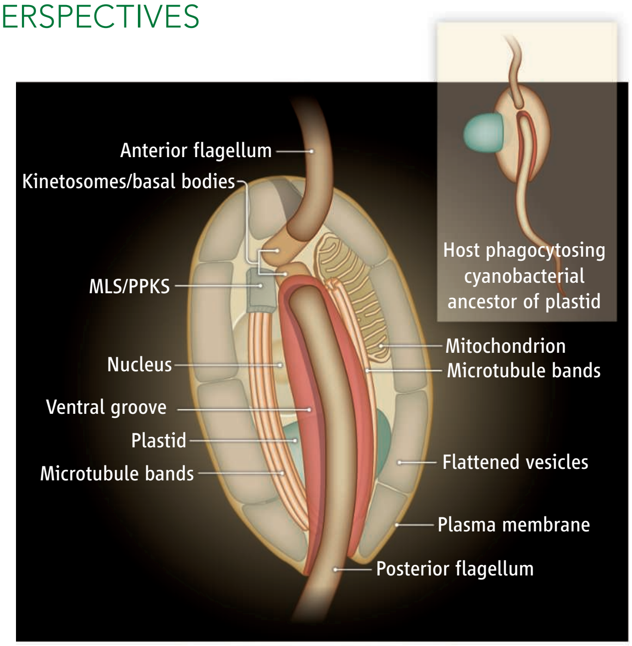

Hypothetical first alga in Plantae. After a phagocytic host was colonized by a cyanobacterium (**inset**), the chimeric first alga (shown in ventral view) probably had the following characters (*5*, *9–15*): a nucleus, mitochondrion, flagella, and sex found in all major lineages of eukaryotes; a ventral groove supported by microtubule bands shared by *Cyanophora,* Excavata, SAR (Stramenopila, Alveolata, and Rhizaria), and Amoebozoa; a band of microtubules with a laminated structure at its proximal end (multilayered structure/parakinetosomal structure, abbreviated as MLS/PPKS) shared by these groups and streptophyte greens; and flattened vesicles underlying the plasma membrane shared by glaucophytes, SAR, and Hacrobia. Unique features of the first alga were the primary plastid and loss of phagocytosis.

respects and the species-rich lineage as completely "advanced." However, all organisms are mosaics of inherited homologous characters. Some characters were derived after a common ancestor had undergone speciation and are unique to the lineage in which they appear. Some characters were derived in the last common ancestor of the lineage and its sibling lineages and are unique to that set of lineages. Some characters, the most primitive set, were those that the common ancestor inherited from its ancestors deeper in the phylogeny and are shared widely. We need an independently derived phylogeny to be able to tell what category a homology falls into.

Price *et al*. show unambiguously that *C. paradoxa* has both primitive and derived genomic characters. Some are indicative of its membership in Glaucophyta to the exclusion of other Plantae. Others are indicative of its inclusion in Plantae to the exclusion of other eukaryotes. Finally, there are some that are indicative of being eukaryotic. Most important, Price *et al*. show that the plastids of glaucophytes are not completely primitive with respect to the plastids of other Plantae (*8*, *9*). *C. paradoxa* is, as should be expected, a mosaic of characters. The authors also note that, despite the wealth of data at their disposal, they could not resolve which of the three major lineages of Plantae branched basally with respect to the other two. Thus, the glaucophytes may not even have a position in the Plantae tree of life to allow them to be considered "primitive."

Price *et al*. do not discuss the appearance or life history of the original Plantae, but their conclusion that Plantae is monophyletic allows us to do just that, because their data are independent of morphological and life cycle characters. By comparing features of members of Plantae with those shared with organisms in other major eukaryotic lineages (*9-15*), some of the characteristics of the first alga can be postulated (see the figure).

Some of the traits inferred for the first Plantae (see the figure) may also provide clues to the properties of eukaryotes in general 1 to 1.5 billion years ago. Careful examination of the literature on protist cells, combined with phylogenomic results such as those of Price *et al*., may elucidate the evolutionary events in eukaryotes at all levels, from the molecular to the morphological.

Lynn Margulis, who championed the idea that eukaryotic cells were chimeras of hosts and endosymbionts long before the hypothesis was accepted, died on 22 November 2011 (*16*). It is a shame that she missed out on this most recent vindication of her tenacity. It is nice that an obscure protist (her preferred term was protoctist) was so integral in advancing the story of how plastids spread through the eukaryotes.

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GEOCHEMISTRY

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Adina Paytan

Changes in the lithium isotope composition of seawater over the past 70 million years elucidate the links between weathering and climate.

Earth is sustained as a habitable planet through close interactions and feedbacks among the lithosphere, hydrosphere, atmosphere, and biosphere (*1*). These interactions occur through material and energy transfer between Earth's reservoirs, referred to as global biogeochemical cycles, and result in chemical and physical changes within each reservoir. Seawater chemistry has varied through Earth's history in response to changes in global climate and tectonics (*2*, *3*), making past records of seawater chemistry a powerful archive for reconstructing how these interactions and feedbacks changed over time. On page 818 of this issue, Misra and Froelich (*4*) report how the lithium isotopic composition of seawater (δ^7Li_{SW}), recorded in shells of tiny organisms living in the ocean, has changed over the past 70 million years. The results illustrate the tight interplay among the location of mountain belts, mountain erosion processes, and climate.

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The Li isotope record reported by Misra and Froelich reveals a 9‰ increase in δ^7Li_{SW} over the past 50 million years, suggesting a general increase in continental weathering and erosion. The observed increase is not monotonous, but rather shows periods of rapid change punctuated by times of little or no change.

Continental weathering, and specifically the weathering of silicate rocks, involves the drawdown of the greenhouse gas carbon dioxide from the atmosphere:

$$CaSiO_3 + 2CO_2 + 2H_2O \rightarrow CaCO_3 + SiO_2 + CO_2 + 2H_2O$$

Changes in weathering rates thus affect climate (*5*, *6*). The general increase in weathering over this time interval has been previously recognized from Sr, Os, and Ca isotopes and other records (*3*). However, interpretation of these weathering proxy records in relation to climate change is difficult, because each of these proxies is controlled by multiple processes that do not directly result in atmospheric CO_2 consumption (see table S1). The Li isotope record is unique in that it responds specifically to the changes in weathering of silicate rocks.

Furthermore, changes in δ^7Li_{SW} reveal information about the weathering regime. Li can be transported to the ocean as dissolved Li ions in river water, or these Li ions may attach to clay particles that are also transported with the river flow. When all of the Li is delivered as ions in solution, its isotopic signature reflects the Li in the silicate rocks from which it was derived (1.7‰). But as Li is incorporated into the clay particles, ^6Li is preferentially taken out of solution, leaving the river Li enriched with the heavier isotope ^7Li. Under these conditions, δ^7Li delivered to the ocean in solution is high (21‰) and, all else being constant, δ^7Li_{SW} also increases. Thus, δ^7Li_{SW} is sensitive to river clay particle load, which in turn is related to the weathering regime.

Weathering rates and the associated solute and particle transport to the ocean depend mainly on topography (high relief enhances weathering) and climate (greater rainfall and higher temperatures enhance weathering) (*7*). Flat terrains do not erode much regardless of climate, and erosion of high mountains in dry climate is also low. Weathering of high mountains in warm and wet climates is dominated by intense chemical weathering with little particle transport, whereas high mountains in cool and wet climates exhibit high physical and chemical weathering, high denudation rates, and higher river particle loads.

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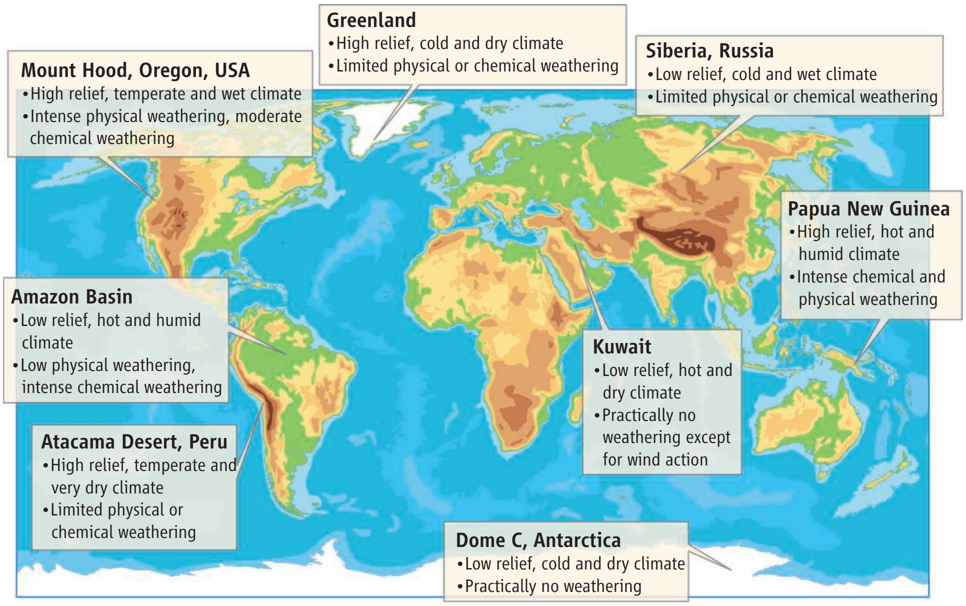

Weathering around the world. Weathering regimes differ around the world depending on both topography and climate. In the geologic past, the locations of mountain regions relative to climatic zones have been different, changing the overall weathering regimes. Misra and Froelich's record of the Li isotope composition of seawater can track such changes in weathering regime.

All these different weathering regimes occur around the world at any given time, but the relative proportion of the different weathering processes on a global scale can vary in space and time depending on the location of mountain ranges relative to climate belts (see the figure). Changes in the slope of the δ^7Li_{SW} curve reveal different weathering regimes: δ^7Li_{SW} will increase during periods of high physical weathering of silicate rocks and mountain denudation but will plateau when chemical weathering dominates. The plateaus may thus indicate high chemical weathering, which can be associated with higher rates of CO_2 drawdown. The record thus provides insight into the links among weathering regimes, mountain denudation, and climate on continental scales.

However, enhanced weathering of silicate rocks associated with either weathering regime consumes atmospheric CO_2, muddling the relation between Li isotopes and climate records (*8*). Moreover, as with all other proxies used to reconstruct past conditions on Earth, the system is underconstrained. The reservoirs participating in the global rock cycle are numerous, and fluxes between them are mostly unknown. Therefore, assumptions about their change must be made to solve the mass balance equations, and the proposed solutions are never unique.

One of the exciting opportunities provided by Misra and Froelich's study is the possibility of constructing coupled models that will better resolve the system. Different isotopes and elements are sensitive to distinct sets of forcing mechanisms or processes, and modeling Sr, Os, Li, and Ca isotopes as well as Sr/Ca and Mg/Ca and potentially other isotopes such as Pb, Hf, and Nd (*9*) together may thus constrain possible solutions (see table S1). Hf isotopes in particular also respond to weathering regimes (*10*). Additional proxies for processes that respond to changes in weathering and denudation, such as phosphate delivery to the ocean and related changes in ocean productivity (*11*) or records of the accumulation of weathering products such as soil clays (*12*) or sediments (*13*), could also be considered. This approach may reveal how the combination of different processes changed over time and how these processes are linked to climate.

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Supporting Online Material

www.sciencemag.org/cgi/content/full/science.1218342/DC1
Table S1

10.1126/science.1218342