

# 8

## A plate tectonics failure: the geological cycle and conservation of continents and oceans

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The rock cycle requires basalt of ocean floors and granitic rocks of the continents to be recycled. Plate tectonics explains the cycle by seafloor spreading driven by convection currents recycling basalt which re-appears at spreading sites, and subduction of sediments derived from continents to be re-incorporated in the continents. Arguments are presented that the rock cycle cannot produce new basalt for the oceans. Most continental erosion products are deposited in sites that preclude re-cycling. Quantification of erosion and uplift rates also cast doubts on the efficacy of plate tectonic mechanisms to recycle either continental or oceanic components of the Earth system.

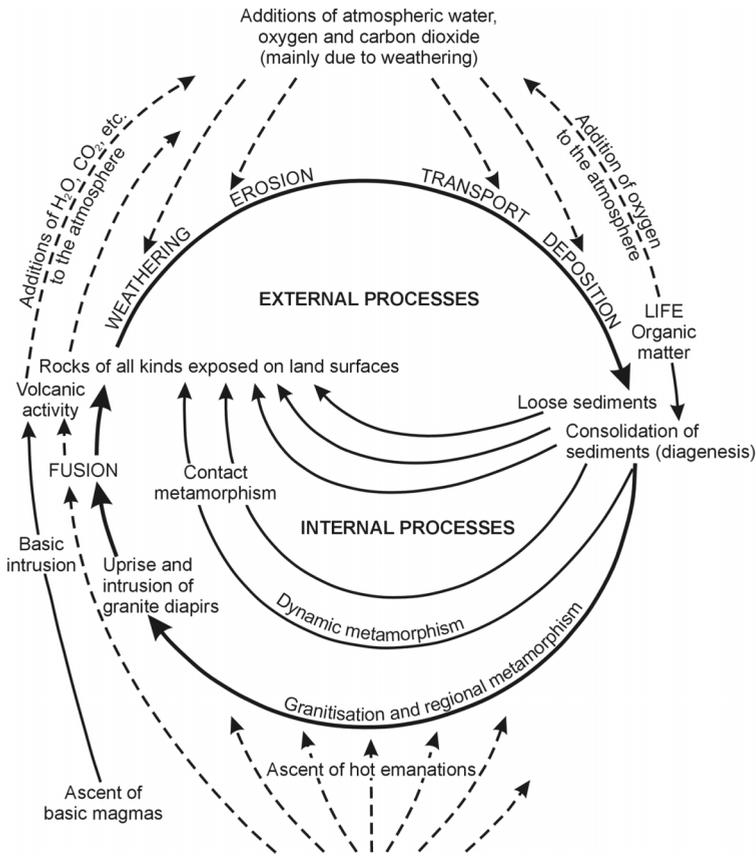
### 8.1. INTRODUCTION

Cycles have been much used in geology, and there are at least three kinds of cycle, and they are sometimes confused: the rock cycle, the material cycle, and the plate tectonic cycle.

Since the days of Hutton who, in 1788, saw «No signs of a beginning and no prospect of an end» the geological cycle, or 'rock cycle', has been a basic idea in Earth science. The Earth evolves through a cycle of geological events, driven by its internal and external heat engines. Rocks at the surface, such as granite, are weathered, and loosened particles of rock and mineral are eroded off their parent bedrock. This debris is transported by rivers, ice or wind, and eventually deposited as layers of sediment (strata) in the sea. The strata may be lithified to form sedimentary rocks. Deep burial may metamorphose sedimentary rocks into metamorphic rocks, and deep Earth processes may eventually turn metamorphic rocks into granite. After tectonic uplift and erosion of overlying rocks granite may be exposed at the ground surface, and it will weather, and so the cycle may be repeated.

This cycle, with only minor variations, is depicted in nearly all books of general geology, usually with little comment. Figure 8.1 can be regarded as an excellent example, being based on a figure in the famous textbook of Holmes (1965). This simplified account of the geological cycle ignores features such as chemical and biological sediments, such as rock salt, limestone and coal, but they can easily be added as minor elaborations to the cycle, and present no great problem.

The rock cycle was first envisaged at a time when the Earth was conceived as of constant size, and no great difference was seen between continents and oceans. Sea floors could alternate with land areas, and old sedimentary basins could be uplifted to form new land. This was still the dominant view when the geosyncline theory of mountain formation was enunciated, which tacitly produced a way of preserving land areas. By 1950 some writers were already noting that the oceans were dominantly underlain by basalt, while the continents were underlain by granite. The concept of sial and sima had arrived. For a while this was not seen as inconsistent with a fixist model of the Earth. Bucher (1950), one of the most eminent geophysicists of his day, described the sial and sima Earth, but



**Fig. 8.1.** The geological cycle (after Holmes, 1965). Note that basalt is not really part of the cycle, but comes in from the 'side' of the diagram. Yet basalt covers about three-quarters of the Earth's surface.

wrote (p. 67) «In short, everything that is now known concerning the configuration and structure of the floors of the oceans proves conclusively that Wegener's hypothesis of continental drift is wholly untenable.» Very few people accept this view today. Even by the mid 1960s the idea of plate tectonics (which accepts and explains continental drift) was widely accepted, and is now the ruling dogma in Earth science. But problems of conserving continents remain.

I shall now examine the cycle concept in relation to the conservation of basaltic sea floor and siallic continents. The plate tectonic cycle will be included in discussion of the supposed cycling of sea floor basalt, and the mechanisms for continental preservation. It will be seen that the latter can be partially quantified by considering rates of uplift and erosion of continents, which is part of the material cycle.

## 8.2. BASALTIC OCEAN FLOORS

The most significant feature of the rock the cycle as shown in fig. 8.1 is that it ignores volcanic rock, especially basalt. Note how in Holmes's figure the basalt comes into the cycle from the side, as an unremarked addition to the cycle.

But basalt is not cyclical. Indeed, basalt erupted at the Earth's surface will weather, erode, and so forth. But there is no accepted process that can produce new basalt from cycling the Earth's materials. The rock cycle may go on, but new basalt is added from a different source.

If basalt were only a minor component, this fact might be ignored, like salt and coal, but it is not. Basalt covers about three quarters of the Earth's surface, so is the major component. The conventional geological cycle fails to account for the most massive component.

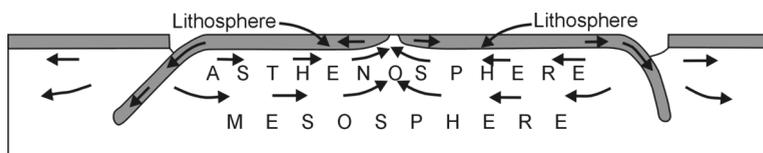
Added to this is another major feature, unexplained by the cycle. Most basalt is under the ocean. Furthermore, all the ocean-floor basalts are younger than 200 Myr old. Did the geological cycle exist before 200 Myr?

### 8.2.1. Plate tectonic explanations of the basalt cycle

In plate tectonics the oceans are growing at spreading sites, such as the mid-ocean ridges in the Atlantic and southern oceans. The seafloor moves away from the spreading sites – so-called seafloor spreading. The spreading rate is a few centimeters per year, so the ocean is growing. To maintain the Earth at a constant size, the newly created crust must be compensated somewhere by removal of crust. Seafloor crust must be disappearing somewhere, and this is supposedly by subduction, where a down-going plate is subducted beneath an overriding plate. Subduction is thought to occur mainly in deep sea trenches along continents and island arcs. The oceanic material is then returned beneath the ocean plate where it re-emerges. There is a convection cell, and indeed convection is envisaged as the engine driving plate movement. A simple version of convection cells and associated seafloor spreading and subduction is shown in fig. 8.2. There are few areas on Earth where the situation is that simple. In the Atlantic, for example, though spreading is simple and symmetrical, there are no subduction sites around Europe or Africa, South and North America, and the only subduction sites are the Caribbean and Scotia Island arcs. So we come to more elaborate scenarios, in which some seafloor spreading pushes continents apart and elsewhere pushes them together, and in yet other sites leads to subduction. Converging continental plates make supercontinents, which eventually break up at rift valley spreading sites, which in turn become new seafloor spreading sites.

### 8.2.2. Problems with this story

a) Spreading sites are about three times longer than subduction sites, so we are producing about three times more basalt seafloor than is consumed, if the rates of plate movement are maintained. Rates of convergence of plates at subduction sites should be much greater than rates of divergence at spreading sites.



**Fig. 8.2.** An elementary view of convection cell cycling (modified from Isaacs *et al.*, 1968, fig. 1). Although this figure has been reproduced in many texts, it does not seem to have been remarked that the arrows do not make a closed convection cell! Flow away from the mid-ocean ridge is confined to the lithosphere, the entire asthenosphere is taken up in return flow, yet the subducting slabs extend below the returning material. Other authors have figures that show flow away from the mid-ocean ridges in the upper asthenosphere (*e.g.*, Strahler, 1963, fig. 22.14; Tarling, 1978, fig. 4).

b) Much subduction is at island arcs, many of which are separated from the continent by more spreading sites, so re-cycled material should appear in the arc, and not back on the major continents.

c) The downgoing slab consists of basalt, and an unpredictable load of sediments with different chemical compositions depending on the continental rocks that provide the offshore sediments. After remelting, contamination, segregation of minerals, emplacement of batholiths and eruption of andesitic volcanoes, the basalt returns to the mid-ocean ridge. Miraculously the subduction-associated processes have cleaned up the basalt so that what appears in the mid-ocean seafloor spreading sites is not just basalt, but a specific type of basalt, the Mid-Ocean Ridge Basalt (MORB). Despite great variation in continental rocks that provide a great variety of sediments to continental margins, and the complications of arc or no arc, trench or no trench, steep or gentle Benioff Zone, the re-cycled subducted material that is recycled in the convection cell retains its great uniformity and eventually emerges as MORB.

d) Helium is an inert gas that does not combine with other elements. It is very light, and its escape velocity is such that it is eventually lost to space. It is not recycled in the geological cycle and has no part in any biological cycle. The helium content of the atmosphere is determined by the rate of release of helium from the solid Earth and by the escape rate of helium from the atmosphere into space. New helium is produced at the world's spreading sites, mid-ocean ridges and rift valleys.

The most obvious conclusion from the consistent composition of MORB basalt, and the eruption of new gases, is that the basalt is being erupted for the first time. Only the need to fit into the global cycle leads to the conclusion that it is recycled.

Furthermore, helium comes in two isotopes. Helium-4 is not a surprise, as it is a product of the radioactive decay of uranium and thorium. Helium-3 is more mysterious, as there is no mechanism for its production in the Earth. It is generally assumed it is primordial, left over from planetary formation 4500 Myr ago (Holland, 1984; Gold, 1987). Alternatively, perhaps it is produced in the Earth. Herndon (2003) believes it is as formed by a nuclear generator deep in the Earth. In either case, it is very remarkable that the highest values for helium-3 are at spreading sites and rift valleys. Once again we see new material produced at spreading sites, not evidence of re-cycling.

g) Other volatiles. Argon, carbon dioxide, juvenile water, methane and others volatiles are still being produced (Gold, 1987), presenting further obstacles for simple cycling of Earth materials.

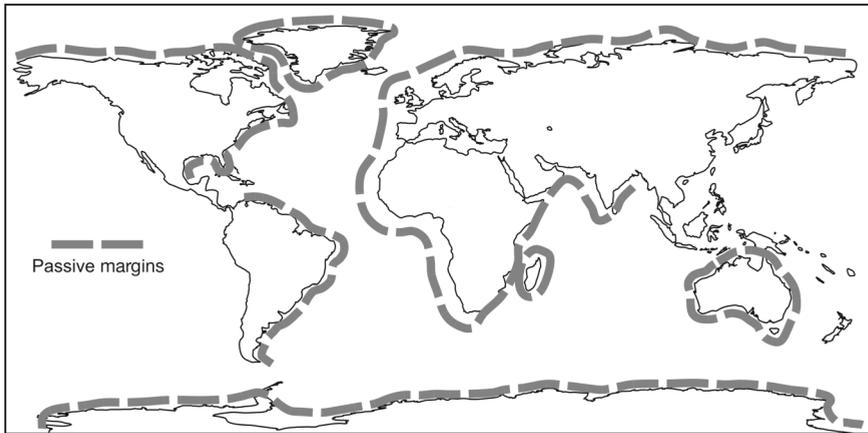
### 8.3. THE CONSERVATION OF CONTINENTS

The problem is that if continents are eroded, and sediment deposited in the sea, the continents will simply be worn down to sea level unless some other mechanism intervenes. The continents will get thinner, and increase in area. The plate tectonic answer is to push sediments back at active, collisional plate boundaries. The sedimentary pile deposited at the edge of the continent is supposed to be thrust on to the continent (thin-skinned tectonics), or subducted and metamorphosed, possibly granitised, and generally made into part of the continent. There are many variations on the theme, but none of them work!

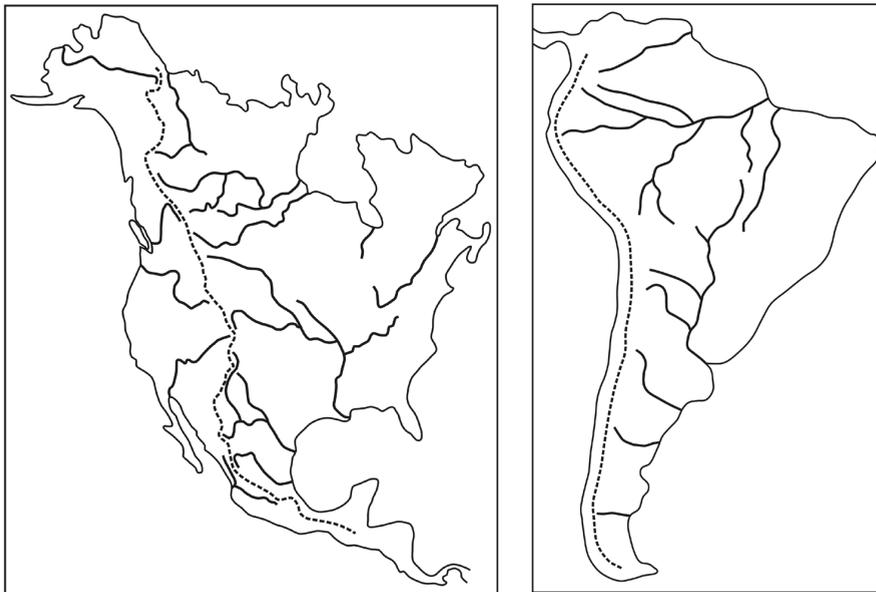
#### 8.3.1. Problems of the continent conservation in the plate tectonics model

The problem that plate tectonics has in explaining the restoration of continents is that it is confined to active, collisional sites. These are the western edge of the Americas, island arcs, and possibly sites associated with the closure of the Tethys Ocean to form the Alpine-Himalayan belt. The main problems are:

a) Location of sediment on passive margins. Most sediment eroded from continents is deposited on the continental shelf of passive continental margins, where there is no postulated mechanism for returning it to the continents. Passive margins are about three times the length of active margins (fig. 8.3).



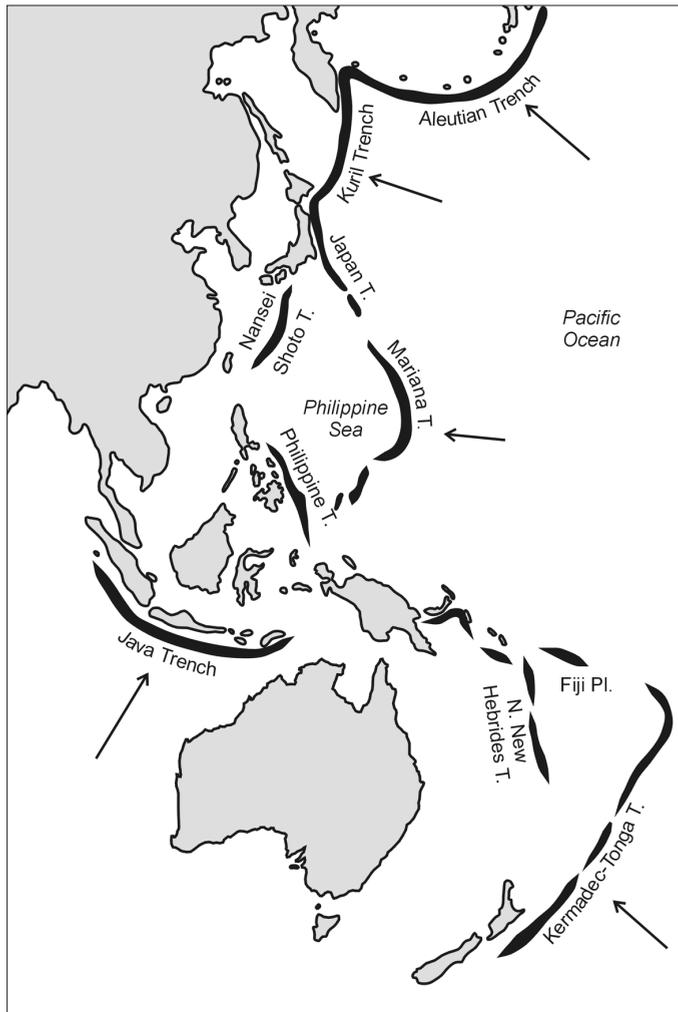
**Fig. 8.3.** The global distribution of passive margins. Sediments deposited on these margins cannot be returned to the continent by subduction.



**Fig. 8.4.** The great divides in both North and South America are very near the west coast, and most drainage (and sediment) goes to the passive margins on the east.

Antarctica is isolated, and ever since its separation from other parts of Gondwana its eroded sediments have been accumulating around the continental margin, with no means of being returned to the sialic continent. The geological cycle simply does not work here. The same applies to Australia, and to Africa except possibly the Mediterranean margin. Atlantic coasts of Europe and the Americas are the same. The Arctic Ocean is bounded by passive margins.

In some areas the offshore sediments have been well studied, and support the view that sediments have simply accumulated at the continental margin. The eastern coast of the U.S.A. goes back to the Cretaceous (Poag and Sevon, 1989), as does the Scandinavian margin (Lidmar Bergström *et al.*, 2000). On some continents the rifts that were formed in the first stage of fragmentation of Gondwana or Pangea are preserved as salt basins. They are disturbed by salt tectonics, but have not been thrust onto or under the continent.



**Fig. 8.5.** The distribution of island arcs. The arrows show direction of possible subduction. Only oceanic plates can be subducted, and back arc basins prevent continental sediment reaching the trenches outside the arcs. The arrows are diagrammatic only. The actual direction of plate movement may be oblique and even tangential to the arc, as in the Aleutian Arc.

b) Limited impact at active continental margins. Active continental margins are in reality limited to the west coasts of the American continents. Even here the total length of coast may be a false measure of the amount of possible subduction, because there is no trench along part of North America. The main problem is that in both North and South America the major continental watershed is close to the west coast (fig. 8.4). Most of the drainage is to the passive margins of the Atlantic or the Arctic, where subduction is not possible. So even here most sediment goes to a site where restoration to the continents is not possible.

c) Limited impact at island arcs. Many island arcs are backed by spreading sites of the back-arc basins. These will trap continental sediment and prevent it getting to the trenches. Back-arc basins do not have a role in re-cycling: there is no trench, Benioff Zone, or any other indication of subduction. The outer side of most of the West Pacific arcs (fig. 8.5) can have only a minor role in re-cycling continental material, as they can only subduct oceanic basalt plates and the trivial amount of material derived from the islands of the arc itself. Otherwise they are subducting only oceanic basalt plate. The same applies to other arcs. The Indonesian arcs are neither backed by, nor facing any major sediment source, so their role in re-cycling is small. The largest arc, the Sumatra-Java Arc, is not backed by a large continent, so has little role in global cycling. The Caribbean, Scotia, and Mid-American arcs are similar.

d) The goodness of the fit in continental reconstructions. Another relevant point is the fit of the continents, when reassembled into Gondwana or Pangaea, which is often remarkably good. Carey's (1958) closure of the Atlantic was within half a degree over  $45^\circ$  of latitude. The only overlaps were the huge fans off the Amazon and the Congo, representing the few places where sediment is not stored on the continental shelf. The goodness of fit confirms what is generally believed anyway, that the passive margins have not been deformed by subduction or any other tectonic event moving material from offshore.

## 8.4. QUANTIFICATION OF THE MATERIAL CYCLE: RATES OF UPLIFT AND EROSION

The re-cycling of materials in Earth history is the subject of quantitative study, much used by geochemists, but to a lesser extent in other areas of geology. The rates are very relevant to any discussion of the conservation of continents.

### 8.4.1. Erosion rates

Much quantitative work has been done on rates of erosion, deposition rates of sediments, and uplift rates of continental areas. With all their problems, the calculated rates provide a basis for speculating on what is needed in the conservation of continents. For discussions of the rates and the way they are measured see Young and Saunders (1986), Ollier (1982), and Selby (1985).

Many units have been used for measurement of rates, and for comparison many authors use the *Bubnoff Unit (B)*, which is 1 mm/Kyr, or 1 m/Myr.

At the present day erosion rates are obtained by soil conservation observations, by rates of fill of reservoirs, by direct measurement on hillslopes, and numerous other methods. On geological time scales estimates of erosion may be made from the volume of sediment in a sedimentary basin, the length of time involved, and the area of catchment for the basin. The last is the most difficult factor, and generally makes the calculation impossible or very crude. Using such techniques Gilluly *et al.* (1970) found that the erosion rate in the Rocky Mountains region in the Lower Cretaceous was 183 B. The Ventura Anticline area, also in the Lower Cretaceous, had an erosion rate of 1.524 B. The Eastern U.S.A. in Triassic times was low and arid and had a surface lowering rate of 25 B.

Detailed consideration of erosion rates suggests that relief is the main factor, rather than climate, vegetation cover, or other factors (see table 8.I).

**Table 8.I.** Rates of erosion relevant to global cycles.

Schumm (1977) suggests the following averages:	
Plains	72 B
Mountains	915 B
Young (1969) suggests the following:	
Normal relief	46 B
Steep relief	500 B
Garrels and Mackenzie (1971) provided figures by continent:	
North America	47 B
South America	33 B
Asia	133 B
Africa	16 B
Europe	25 B
Australia	12 B
Several authors have made estimates of the world average rate of erosion, including:	
Judson and Ritter (1964)	24 B
Corbel (1959)	30 B
Holeman (1968)	69 B
Stoddart (1969)	35 B

Another approach is to estimate the total amount of sediment added to the world's oceans from the continents, which is said to be  $9.6 \times 10^9$  t/yr, of which  $9.3 \times 10^9$  t is brought by rivers. This gives a world figure of 24 B. Given the roughness of the calculations and the varied assumptions involved, these are remarkably similar figures.

Even at the lower estimated rates, say 25 B, erosion rates are such that the entire Earth landmass could be reduced to sea level in about 25 Myr. But this has not happened. Why?

## 8.4.2. Uplift rates

Uplift rates are measured today by repeated survey systems. Old uplift rates can be determined by the height of marine rocks of known age a.s.l., and a whole range of other techniques. Uplift rates generally turn out to be two to ten times faster than erosion rates. In an early attempt to quantify rates, Schumm (1963) pointed out the disparity between erosion rates and uplift rates, but was unable to provide an explanation. It is possible that the reason is that we have experienced exceptional uplift in the past 5 Myr or so (Ollier and Pain, 2000, 2001). It is commonly assumed that folding and mountain building go together, but this need not be true. Mountains occur not only on folded rocks, but on horizontal rocks, granite, and lava flows. Ollier and Pain (2000) assembled evidence that most mountains are the products of uplift of a plain to form a plateau, which may or may not be extensively dissected. The age of a mountain or mountain range is then the age of plateau uplift, not the last age of folding of rock. On this basis, a table of time of uplift of mountains and plateaus from around the world shows a preponderance of uplift in the last few million years. This uplift of mountains in the past few million years appears to be a global phenomenon. It affects so-called Alpine mountains, mountains on passive continental margins, and in deep continental interiors. The period of uplift is known as the Neotectonic Period (Morner, 1993; Ollier and Pain, 2000).

We might note in passing that the Wilson cycle, a theoretical concept related to the opening and closing of ocean basins and the break up and re-amalgamation of continents, would have a time span measured in hundreds of Myr. The present time of seafloor spreading has lasted at least 200 Myr, and if we allow the same for closure we get about 400 Myr. This is vastly different to the erosion flux rate, and indeed permits only one event in the Phanerozoic.

## 8.5. CONCLUSIONS

On the global scale, sediments are deposited in places where they cannot be converted to continent, and erosion should have flattened the continents long ago at present rates. Most supposed subduction sites, at island arcs or active continental margins, are located where they receive little sediment and can only subduct basaltic ocean plates. Some incredible coincidences are required to recycle basalt of the oceanic basins, and new elements remain unaccounted for. We are left with the problem that the geological cycle is not working now. Did it ever work in the past? Either the cycle concept is not valid, or we need a new model for global tectonics.

The data presented here is not only a challenge to plate tectonics. I can think of no model of global tectonics – fixist, shrinking, expanding or pulsating Earth, surge tectonics, wrench tectonics or others – that can account for the problems of conservation of continents, and the cycling of oceanic basalt. I feel it is incumbent on those who postulate hypotheses of global tectonics to have at least a first approximation to the geological cycle. Plate tectonics and other hypotheses of global tectonics do not acknowledge that they fail to deal with one of the most fundamental ideas of geological science.

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