Tectonophysics

Thermal Structure and Evolution of the Earth I
Emerald (HI)
Monday 0830 h
Frank Richter (Univ. of California), Presiding

T1

THERMAL HISTORY OF THE EARTH: ONE GEOLOGISTS' VIEW

Kevin Burke (Department of Geological Sciences, State University of New York at Albany, Albany, NY 12222)
W.S.F. Kidd (same)

Archean and Proterozoic greenstone belts closely resemble in structure and rock type Phanerozoic island arcs and Phanerozoic and Proterozoic suture zones. The close resemblance between these four environments is interpreted as meaning that all represent products of the Wilson cycle of the opening and closing of oceans and this leads to the inference that plate-tectonic processes were active during the first half of earth history much as they are today. Distinctive characters of greenstone belts are that they contain ultramafic komatiites and that they are typically more closely spaced than later suture zones. These characters are attributed to the earth's being hotter 2.5 Ga ago. Ultra-thick sequences and an absence of shallow water sediments reported from greenstone belts are myths. Although the world 2.5 Ga ago was hotter than now, basal continental crust (~35 km deep) did not generally melt and this indicates that the greater heat being generated in the mantle did not escape by conduction through continental crust. Because rocks and structures of greenstone belts indicate that the Wilson cycle was operating in the Archean we suggest that the extra heat escaped by making and aging more ocean floor than now - that is by more plate tectonics.

It seems likely that plate activity has lessened generally on earth as heat generation has declined. The extent of Phanerozoic continental flooding seems consistent with this view, but episodes of extensive flooding, for example, 80 m.y. ago, may indicate unexpected surges in heat release.

T2

THERMAL HISTORY OF THE EARTH: ANOTHER GEOLOGISTS VIEW

R.B. Hargraves,(Dept. of Geological and Geophysical Sciences, Princeton University, Princeton, New Jersey 08544)

Doctrinaire uniformitarianism encourages interpretation of the inorganic geologic record in terms of the recent Earth, or minor variations of it, and many geoscientists agree that "there is no vestige of a beginning" in the oldest terrestrial rocks (∿3.8by). Yet there was a beginning, about 4.6 by ago, and it is inconceivable that the features of the earth then closely resembled those of today. Unquestionably, the earth has changed in terms of heat flux. The nature, style and duration of the associated morphological and dynamic evolution, however, is the subject of much current debate.

Given the important role of interpretation in reading the record of earth history, especially where it is incomplete, I argue that overemphasis on uniformitarianism hinders the search for (or recognition of) evidence of change, and discourages active interest in plausible alternative processes or styles. For me, the possibility that the available geologic record of the earth stores evidence of significant changes in appearance and operating style, adds spice to Precambrian studies.

T3

HEAT FLOW IN THE MESOZOIC AND CENOZOIC

Donald L. Sprague
Henry N. Pollack (both at Dept. of Geology and Mineralogy, University of Michigan, Ann Arbor, Michigan 48109 U.S.A.

Heat flow vs. tectonic age relationships for oceans and continents are used to estimate variation in the global heat flux over the past 180 My. The age distribution of the oceanic crust at times in the past is obtained from the present age distribution and a survival probability function. The survival probability of an element of oceanic crust depends on the area of crust accreted subsequently. The model can be constrained by the following present-day parameters: heat flux, oceanic crustal accretion rate, mean age of oceanic crust, and mean age of subducting lithosphere. Heat flow, accretion rates, and ocean basin volume are calculated as a function of time. The age distribution of continental crust is determined from the present age distribution and calculated oceanic accretion rates. The generation of young orogenic areas on continents is related to the pace of sea-floor spreading. We suggest that the global heat flux, presently 75 mW/m^2, has fluctuated in the range 65-90 mW/m^2 over the past 180 My. The mean age of the ocean floor, presently 65 My has ranged between 56 and 86 My, accounting for most of the variation in heat flow.

T4

THE EVOLUTION OF PRECAMBRIAN METAMORPHISM

Jeffrey A. Grambling (Dept. Geological Sciences, Princeton University; present address, School of Geology, University of Oklahoma, Norman, OK (Sponsor: Bernie B. Bernard)

A self-consistent set of Precambrian P-T estimates has been compiled by comparing published descriptions of metamorphic mineral assemblages to currently available phase-stability data. Pressures and temperatures indicate that geothermal gradients have decreased through time. A second secular trend, illustrated by the mean depth of erosion (d), shows that older areas tend to be less deeply eroded than younger areas.

Age	Geothermal Grad.	Mean	(max.) d
>3.0 Ga	42-61°C/km	15 km.	(27)
2.5-3.0 Ga	35-68	16	(30)
1.5-2.5 Ga	32-58	18	(22)
1.0-1.5 Ga	30-42	19	(27)

There are rare exceptions to these trends. Several Precambrian localities contain assemblages indicating depths of up to 30 km. Invariably, these were metamorphosed under geothermal gradients substantially lower (24-26°C/km) than those shown above.

Whereas the majority of Precambrian geothermal gradients from rocks of a single age fall within a limited range, Phanerozoic (0-600Ma) gradients clearly do not. P-T estimates from Phanerozoic metamorphic rocks yield gradients from 8 to 60°C/km. This contrast suggests a corresponding contrast in the causes of the metamorphic events. It is commonly accepted that Phanerozoic metamorphism has occurred along convergent plate margins; Precambrian metamorphism may have not. If the two secular trends reflect development of average continental crust, then they may indicate a gradual cooling of the earth and thickening of the crust. The near-30 km localities may preserve evidence of unusually thick crust developed in areas of low heat flow. On the other hand, if the high gradients resulted from regional thermal perturbations, then localities containing 27-30 km assemblages and accompanying low geothermal gradients could represent "normal" Precambrian crustal thickness and heat flow.

T5

Pb EVOLUTION IN THE MANTLE

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D. Unruh

The solid/liquid distribution coefficients of Pb for most basaltic minerals appear to be about 10-50 times higher than those of U, but are still less than 1. Therefore, tholeiites which are derived from the LIL-depleted low velocity zone (LVZ) should have less radiogenic Pb and Sr and radiogenic Nd, whereas alkali basalts derived from the less-depleted mantle should have more radiogenic Pb and Sr but less radiogenic Nd. That is, Pb and Sr isotopes should be positively correlated but both Pb and Sr should be inversely correlated with Nd isotopes.

A positive correlation between Pb and Nd isotopic compositions has been observed in Hawaiian basalts, but this correlation is interpreted to be the result of source-mixing. Thus, the interpretation, based on the ^{207}Pb-^{206}Pb relationships, that the Hawaiian basalt-source region differentiated ∿1.6 b.y. (10^9y) ago is probably incorrect.

Oceanic basalt sources have experienced a net enrichment in U relative to Pb [the ^{207}Pb-^{206}Pb data yield negative (future) model ages]. However, mantle-evolution models involving two or more stages of Pb evolution with continuously increasing $^{238}U/^{204}Pb$ (μ) ratios may not be correct. The μ ratio in the mantle could have increased to ∿21 in the less-depleted zone due to removal of Pb from the mantle, either by volatilization, or by segregation into the core. The μ ratio of the low-velocity zone has subsequently decreased as a result of partial melting and extraction of U/Pb-enriched melts.

T6

MANTLE DEPLETION AND THE AGE OF THE CRUST

D. J. DePaolo (Department of Earth and Space Sciences, University of California, Los Angeles, CA 90024)

Transport equations describing relative radiogenic isotope evolution for long-lived radioactive elements (λ^{-1}>>age of the earth) have been derived for a model of crust extraction from a uniform depleting mantle reservoir with crustal recycling. These equations can be integrated for arbitrary crustal growth histories and recycling rates. Using this model, the Nd isotopic composition of mid-ocean ridge (MOR) basalt, rare-earth abundance estimates for continental crust, and a chondritic earth model for refractory lithophile elements, a balance can be made between mantle depletion/mass and crustal enrichment for key trace elements. The controlling parameter is mean crustal age (<T>). For plausible values of <T> (2±0.5 Æ), the maximum possible mass of MOR-type mantle is 30% of the total mantle. Combining this estimate with considerations of mantle structure deduced from Nd and Sr isotope variations in modern basalts (Wasserburg and DePaolo, Proc. Nat. Acad. Sci., 1979) results in a two-layer mantle model with the upper mantle (to ∿700 km depth) depleted in incompatible elements and the lower mantle retaining its primitive composition. This result allows a self-consistent model for the distribution of heat-producing elements in the earth to be constructed, independent of heat flow observations. It is assumed that the crustal enrichment is approximately equal for Rb, U, Th, K, which gives K∿100 ppm in the earth. In this model 75% of the earth's present radioactive heat production (total production ≡ 31 mWm^{-2} surface heat flow) is in the lower mantle, ≲5% is in the upper mantle and 20% is in the crust. A major uncertainty is the radioactive content and extent of subcontinental lithospheric mantle. A requirement of this model is that MOR basalt must represent <5% partial melt of the upper mantle rather than 20-30%. The low Th/U of MORB is unaccounted for in this model.

T7

ND-ISOTOPES AND NOBLE GASES IN THE MANTLE: EVIDENCE FOR PRIMEVAL, UNMELTED LAYER(S) IN THE EARTH'S MANTLE

Asish R. Basu (Dept. of Geological Sciences University of Rochester, Rochester, N. Y. 14627)

It is proposed here from two lines of evidence that the Earth has retained within its mantle unmelted a primeval layer or layers since its accretion from chondritic matter some 4.56 billion years ago.

First, Nd-isotopes provide important information about the source region of the alkalic ultrabasic kimberlites, the only rock-type known to be derived from ~200 kms in the mantle. The initial 143Nd/144Nd ratios of kimberlites ranging in age from 90 million years to 1300 million years from South Africa, India, and the U.S.A. are identical to those ratios in the basaltic achondrite, Juvinas, which represents the bulk chondritic earth in rare earth elements. This correlation strongly indicates the existence of primeval mantle beneath these continents. Further, carbonatite and melilite basalt from the Cape Verde islands in the Atlantic Ocean show identical chondritic signature in their 143Nd/144Nd ratios, indicating the presence of primeval layer also in the suboceanic mantle.

The second line of evidence is from the analyses of the noble gases, He, Ne, Ar, Kr, and Xe in various mantle-derived rocks and minerals. The elemental abundance patterns of the noble gases in the mantle is similar to the "planetary" pattern as defined by carbonaceous chondrites. The high 3He/4He ratio of 10^{-5} and an atmospheric, low 40Ar/36Ar ratio in the mantle indicate that primordial noble gases are still retained in parts of the mantle.

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