The Sea's Missing Salt: A Dilemma for Evolutionists

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Abstract

The known and conjectured processes which deliver and remove dissolved sodium (Na^+) to and from the ocean are inventoried. Only 27% of the present Na^+ delivered to the ocean can be accounted for by known removal processes. This indicates that the Na^+ concentration of the ocean is not today in "steady state" as supposed by evolutionists, but is increasing with time. The present rate of increase (about 3×10^{11} kg/yr) cannot be accommodated into evolutionary models assuming cyclic or episodic removal of input Na^+ and a 3-billion-year-old ocean. The enormous imbalance shows that the sea should contain much more salt than it does today if the evolutionary model were true. A differential equation containing minimum input rates and maximum output rates allows a maximum age of the ocean of 62 million years to be calculated. The data can be accommodated well into a creationist model.

Keywords

Sodium, Ocean, Salt, Inputs, Outputs, Evolutionary Earth Models, Ocean's Age, Creationist Model

Introduction

Sodium is the most common dissolved metal in the ocean. It exists in seawater as a positively charged ion. Sodium ions (Na^+) form the primary salt of the sea along with negatively charged chloride ions (Cl^-). The extreme solubility is caused by the cation's small size (ionic radius is 0.97Å) and small charge (single positive charge), which allows Na^+ ions to escape most geochemical processes which remove larger ions with the same or greater charge.

The worldwide delivery of Na^+ to the ocean by rivers has been recognized by scientists for hundreds of years. Almost 300 years ago Edmund Halley (1715) recognized that salt cannot easily leave the ocean and suggested that the age of the ocean might be established from knowledge of how much salt enters it year by year from rivers. Nearly 100 years ago John Joly (1899) measured the amount of Na^+ dissolved in river water and estimated with extraordinary accuracy the global yearly input of Na^+ to the ocean. Joly said it would take 80 to 90 million years for the sea to accumulate its present amount of Na^+, if it did so at a constant rate and had none in the beginning. That calculation was accepted by many scientists as giving the age of the earth.

By 1930 radioactive dating methods had been developed which indicated that the age of the earth was longer than anyone had anticipated. Many scientists became convinced that the earth and the ocean are billions of years old. These scientists could no longer endorse Joly's method which they recognized "… leads to the spuriously low geochemical age" Livingstone (1963). F. W. Clarke (1924), V. M. Goldschmidt (1933), and W. W. Rubey (1951) were among many who conjectured that Na^+ is removed from the ocean about as fast as it enters, causing the amount of Na^+ in the ocean to remain roughly constant with time. C. B. Gregor (1988, p. 13) reaffirmed their belief recently,

> If magma kept the crust built up against the ravages of erosion and the waste products accumulated in the sea, at present rates of influx the ocean basins should long ago have been choked with sediment and salt…. salt must somehow leave the ocean.

Those who endorse a 4.5 billion year old earth agree that Joly's 80 to 90 million years is not the age, but the "residence time" for Na^+, that is, the average length of time the ion would survive in the ocean before being removed.

The interpretation that the ocean is in "steady state" with respect to Na^+ was brought to creationists'

attention again by Howard J. Van Till, Davis A. Young & Clarence Menninga in *Science Held Hostage* (1988). They endorse radioactive isotope dating and insist that evolutionists are correct when they suppose that the rate of addition of Na^+ to the ocean is balanced by removal processes of equal magnitude. The residence time for Na^+, they assert, provides no means for establishing an age for the ocean. They affirm, "The 4.5 billion year chronology of earth history is in no way weakened or disqualified by an appeal to the salt content of the terrestrial oceans" (Van Till, Young, & Menninga, 1988, p. 91). But where is the empirical evidence supporting the steady state model? Is there sufficient reason, apart from evolutionary assumption, to dismiss Joly's geochemical age for the ocean? Van Till, Young, & Menninga do not present the evidence, but simply endorse the model supposed by earlier evolutionists.

The steady-state hypothesis cannot be tested directly, because, even if the ocean is not in steady state, the change in Na^+ concentration of seawater during recent times would be too small to be measurable. But there is an indirect test for the hypothesis; we can compare measured input rates with all known or conjectured output rates. If outputs are considerably lower than inputs at present, then the sea cannot be in steady state. If that condition is likely to have persisted for the history of the ocean, there is strong reason to doubt that the sea is billions of years old. Thus, we will examine input and output rates carefully.

Figure 1 illustrates inputs and outputs. We define the system in question as being the seawater in the ocean basins, not including water trapped in sea-floor sediments. First, we list all the known or conjectured inputs and outputs and try to quantify them with the latest data from the scientific literature. Then, we specify their past behavior in the evolutionary model. Next, we calculate the maximum possible age of the ocean on the basis of the evolutionary model, in order to show the inconsistency of that model. Last, we indicate the concordance of the data with a creation model, and offer a challenge to evolutionists and old-earth creationists.
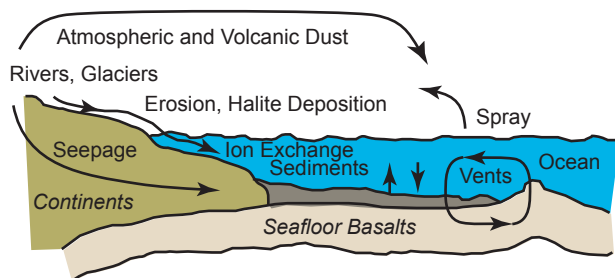

Figure 1. Diagram illustrating the ocean's major inputs and outputs of Na^+.

Present Inputs of Na^+ to the Ocean

Let us define A_i as the mass per unit time of Na^+ delivered to the ocean by the ith source. What follows is a compilation of 11 major natural Na^+ inputs to the ocean. Most considerations of the Na^+ cycle for the oceans only take account of the first three inputs listed (rivers), but we list in Table 1 and below eight additional sources which cannot be neglected.

The most thoroughly investigated process delivering Na^+ to the ocean is rivers. The most recent global survey by the French geochemist Michel Meybeck gives both the total discharge and average Na^+ concentration of rivers. The total river discharge to the ocean is 3.74×10^{16} L/yr, and the globally averaged Na^+ concentration of rivers after man-made pollution is removed is 5.15 mg/L (Meybeck, 1979, Tables 1 and 5). These numbers allow the global river input of natural dissolved Na^+ to the ocean to be calculated as 1.92×10^{11} kg/yr (Meybeck, 1979, Table 6). According to Meybeck, there are three major sources for Na^+ in river water: (a) sea spray, (b) chemical weathering of silicate minerals, and (c) solution of chloride minerals.

Table 1. Inputs of Na^+ to the world ocean. Units are in 10^{10} kg/yr. Present inputs are listed in column headed A_i. Minimum past inputs are listed in column headed A_{imin}. Models for estimating A_{imin} are denoted "M" for "Modern Earth Model" and "C" for "Cretaceous Earth Model."

	Na^+ Input Process	A_i	A_{imin}	Model
1.	Rivers: Sea spray	5.5	5.0	C
2.	Rivers: Silicate weathering	6.2	6.2	M
3.	Rivers: Chloride solution	7.5	7.5	M
4.	Ocean floor sediments	11.5	6.21	C
5.	Glacial silicates	3.9	0.0	C
6.	Atmospheric and volcanic dust	0.14	0.14	M
7.	Marine coastal erosion	0.077	0.074	C
8.	Glacier ice	0.12	0.0	C
9.	Volcanic aerosols	0.093	0.093	M
10.	Ground water of continents	9.6	9.3	C
11.	Hydrothermal vents	1.1	1.1	M
		$A_p = 45.7$	$A_{min} = 35.6$	

A_1. Rivers: Sea Spray Component

Spray from ocean waves causes droplets of seawater to evaporate leaving halite aerosol in the atmosphere. A large part of the aerosol is deposited by rain and snow on the continents. The component of Na^+ in river water derived from sea spray was estimated by study of the Na^+ concentrations of

numerous rain samples and the total discharge of rivers to the ocean. According to Meybeck (1979, Table 6), sea-spray-derived Na^+ in river water is 5.5×10^{10} kg/yr, which is 29% of the total yearly river flux of Na^+. Thus, $A_1 = 5.5 \times 10^{10}$ kg/yr.

A_2. Rivers: Silicate Weathering Component

Chemical weathering of the continents released Na^+ from silicate minerals (especially feldspars and clays) the major part of which finds its way to rivers and enters the ocean. Analysis of the mineral breakdown of dissolved ions in river water by Meybeck (1987) indicates that 32% of the total Na^+ is derived from weathering of continental silicate minerals. Thus, $A_2 = 6.2 \times 10^{10}$ kg/yr.

A_3. Rivers: Chloride Solution Component

A small area of the continents (approximately 1.3% of area) has outcrops of chloride and sulfate minerals the principal mineral of which is halite (NaCl). These are extremely soluble in water. Using the mineral breakdown analysis of dissolved ions in river water, Meybeck (1987) calculated that 39% of modern river Na^+ is derived from solution of chlorides. Thus, $A_3 = 7.5 \times 10^{10}$ kg/yr. The sum $A_1 + A_2 + A_3 = 1.92 \times 10^{11}$ kg/yr, which is the total global river flux of Na^+.

A_4. Ocean Floor Sediments

Detailed studies of the Na^+ concentrations of pore waters of ocean floor sediments by Sayles (1979) show that their pore waters are enriched in Na^+ relative to sea water. The increase in Na^+ of pore waters with depth within ocean sediments describes a concentration gradient which requires diffusion of Na^+ from ocean sediments into the ocean. Pore waters of ocean sediments show decreasing concentrations of K^+ and Mg^{+2} with depth. This data requires sediments to absorb K^+ and Mg^{+2} from seawater (Sayles, 1979).

A good explanation offered for this data is that most Na^+ is released from clays during prolonged burial as K^+ or Mg^{+2} is absorbed in its place. K^+ would be absorbed during prolonged burial of clays because it has larger ionic radius than Na^+. Similarly, Mg^{+2} would be absorbed by clays during prolonged burial because of its divalent charge, twice that of Na^+.

The ocean sediment pore water data for the Atlantic Ocean assembled by Sayles is representative of other oceans allowing the global Na^+ flux out of ocean sediments to be calculated. The estimate of Sayles (1979) is slightly adjusted for charge balance and yields $A_4 = 1.15 \times 10^{11}$ kg/yr (Drever, Li, & Maynard, 1988, Table 1.4, column 3). This large input to the ocean is 60% of the total river input.

A_5. Finely Pulverized Glacial Silicates

Glaciers produce very finely ground rock flour and, as illustrated by Antarctica and Greenland, add the minutely pulverized material directly to the ocean. This fine rock flour is dominated by silicate minerals which weather rapidly when added to the ocean. Schultz & Turekian (1965) describe the silica enriched deep ocean waters surrounding Antarctica and the evidence that about 1.4×10^{12} kg (64%) of the continent's glacial-marine sediments dissolve in sea water before being buried on the sea floor. If we assume that the glacial-marine sediment of Antarctica has 2.4% by weight Na^+ (the composition of the "average igneous rock"), the dissolved silicates add 3.4×10^{10} kg of Na^+ to the ocean each year. The continent of Antarctica comprises 86% of our planet's continentally glaciated area and indicates that the global glacial-marine Na^+ flux is $A_5 = 3.9 \times 10^{10}$ kg/yr. This is 20% of the total river input.

A_6. Atmospheric and Volcanic Dust

A considerable quantity of the dust removed from the continents by wind is added to the ocean. The fine dust is largely silicate minerals, a major part of which dissolve in the sea. According to Garrels & Mackenzie (1971), 5×10^{10} kg of atmospheric dust are added yearly to the ocean basins. This is equivalent to an average of 140 kg of dust/km^2 of ocean each year, and agrees with dust fluxes collected over the ocean (Pye, 1987). Mackenzie & Wollast (1977) add to this total 4×10^{10} kg of volcanic dust each year. Assuming that atmospheric and volcanic dust is 2.4% by weight Na^+ and that 64% of it dissolves, $A_6 = 1.4 \times 10^9$ kg/yr. This is 1% of the total river input.

A_7. Marine Coastal Erosion

The direct attack of ocean waves along the coast erodes considerable amounts of sand, silt, and clay. Most of the finest particles produced are silicates which have not been rinsed by the fresh water of rivers and remain very reactive with the ocean. According to Garrels & Mackenzie (1971), 2.3×10^{11} kg of material is added to the ocean yearly by marine erosion. Assuming that this debris is 0.67% by weight Na^+ (the concentration in the "average sedimentary rock") and that 50% of it dissolves in the ocean, $A_7 = 7.7 \times 10^8$ kg/yr of Na^+ from marine erosion. This is less than 1% of the total river input.

A_8. Glacier Ice

Snow has small quantities of Na^+ derived from halite aerosols of the atmosphere. Melting of glacier ice directly in the sea adds small quantities of Na^+

to the sea. Meybeck (1979, Table 6) lists this value, $A_8=1.2\times10^9$ kg/yr. This is less than 1% of the total river input.

A_9. Volcanic Aerosols

Dissolved in the steam that continental volcanoes deliver to the earth's surface are small quantities of Na^+. Meybeck (1979, Table 6) calculated the mass delivered from airborne volcanic aerosols to the ocean. He obtained $A_9=9.3\times10^8$. This is less than 1% of the total river input.

A_{10}. Ground Water Seepage

Geologists have suspected for more than 100 years that water seeps through the continents and issues forth on the floor of the ocean. This was not proven until recently when drilling of sediments of the continental shelves revealed fresh water moving seaward through the sedimentary layers. The dissolved solids of ground waters can be measured in parts per thousand (ppt) and vary significantly from as fresh as rain water (0.0001 ppt) to extremely saline brine (over 250 ppt). For this reason we have great difficulty in estimating their average Na^+ content.

Most near surface ground waters have more dissolved solids than river waters (rivers average 0.13 ppt). Deep ground waters often are saline brines as an example from the southeastern United States illustrates. Strata at depth within the Florida-Bahama Platform are filled with dense brine (over 200 ppt) that seeps from the platform onto the floors of the Atlantic Ocean and the Gulf of Mexico (Paull & Neumann, 1987). According to Paull & Neumann, major brine seepage causes significant solution of limestone and is believed to be a major cause of the steep slopes at the margins of the platform. The salty brine has actually been sampled in locations where it issues onto the sea floor, and appears to be derived from solution of rock salt (halite) and gypsum within strata under Florida.

The quantity of ground water seepage into the ocean on a global scale can be estimated from the quantity of global yearly rainfall minus global evaporation as compared to global river runoff. Global river runoff is about 10% less than global rainfall minus evaporation (Garrels & Mackenzie, 1971). This missing water from the continents (approximately 3.7×10^{15} L/yr) is believed to be the total ground water seepage from the continents. An average Na^+ concentration for this seepage would allow the Na^+ flux to the ocean to be calculated. However, we know this average imperfectly. If we assume that the average ground water has 26 mg/L of Na^+ (5 times the concentration of average river water), the global Na^+ flux is $A_{10}=9.6\times10^{10}$ kg/yr from ground water seepage.

This rough estimate represents 50% of the total river input. If further research should increase the global average Na^+ content of the ground water, the flux of this very significant source would increase.

A_{11}. Sea-floor Hydrothermal Vents

Fifteen years of intense investigations of hot springs on the deep ocean floor have led geochemists to the understanding that large quantities of ocean water are circulated through a significant fracture system in hot sea-floor rocks. Some of the springs have water hotter than 350°C containing significantly more total dissolved solids than seawater. This indicates seawater alters sea-floor basalt by a complex series of metamorphic reactions. According to Seyfried (1987) metasomatism dissolves Na^+ from basalt below 350°C but fixes Na^+ in mineral phases above 350°C.

Two classes of sea-floor hydrothermal vents are recognized by Wolery & Sleep (1988); axial and off-axial hydrothermal vents. The axial hydrothermal vents occur along the axes of mid-ocean ridges where active rift faulting has brought the hottest basalts near the ocean floor. These springs are dominated by water hotter than 250°C. The off-axial vents are located on the flanks of the mid-ocean ridges away from the recent rift faulting. These springs are dominated by water from 80 to 250°C, which is cooler than the axial springs. Using data on latent heat and heat flow from mid-ocean ridges, Wolery & Sleep (1988, p. 91) estimate the upper limit of water flux on a global scale through mid-ocean ridges: 2.3×10^{13} kg/yr. They believe that 17% of the water flows through axial vents and 83% flows through off-axial vents. Chemical compositions of vent waters allowed Wolery & Sleep (1988, Table 3.5) to estimate that the off-axial vents add 1.1×10^{10} kg of Na^+ each year to the ocean.

Estimation of the global contribution of Na^+ by way of the axial vents is complicated by the difficulty in measuring the actual vent temperature and calculating the rock to water ratio in these springs. Furthermore, two dozen measurements of axial springs may not be representative of the global flow. Twenty axial springs from the Pacific Ocean have an average Na^+ concentration of 502 mmol/kg, showing an enrichment of 38 mmol/kg above normal seawater (Von Damm, 1988). Therefore, the axial spring data indicate that axial hot springs in the Pacific and Atlantic Oceans are enriched by 42 mmol/kg in Na^+. Using the global water flux for axial vents of 3.8×10^{12} kg (Wolery & Sleep, 1988, p. 91), the global Na^+ flux from axial vents is 3.7×10^9 kg of Na^+ added to the ocean each year.

Addition of the calculated Na^+ inputs from off-axial

and axial hydrothermal springs gives the global hydrothermal vent flux: $A_{11}=1.5\times10^{10}$ kg/yr. This is 8% of the total river input.

Present Outputs of Na$^+$ from the Ocean

Let us define B_i as the mass per unit time of Na$^+$ taken out of the ocean by the ith sink. What follows below and in Table 2 is a compilation of the seven known or conjectured natural Na$^+$ outputs from the ocean. These outputs are those from the exhaustive list of Holland (1978, Table 5.14).

Table 2. Outputs of Na$^+$ from the ocean. Units are in 10^{10} kg/yr. Present outputs are listed in column headed B_i. Maximum past outputs are listed in column headed B_{imax}. Models for estimating B_{imax} are denoted "M" for "Modern Earth Model," "P" for "Pleistocene Earth Model," "C" for "Cretaceous Earth Model," and "S" for time averaged salt deposits of the Permian System.

i	Na$^+$ Output Process	B_i	B_{imax}	Model
1.	Sea spray	6.0	6.7	P
2.	Cation exchange	3.5	5.2	P
3.	Burial of pore water	2.2	3.9	P
4.	Halite deposition	<0.004	4.0	S
5.	Alteration of basalt	0.44	0.62	C
6.	Albite formation	0.0	0.0	M
7.	Zeolite formation	0.08	0.2	P
		B_p=12.2	B_{max}=20.6	

B$_1$. Sea Spray

Waves of the sea, especially breaking waves along the shore, produce air bubbles in the water. Collapse of these bubbles shoots into the air droplets of seawater which evaporate to form microscopic crystals of halite. Crystals of halite are carried with other aerosols by the winds from the ocean to the continents. A major quantity of these aerosols form condensation nuclei for clouds, some are scrubbed from the atmosphere by rain, and a small fraction falls out dry onto the earth. Analyses of numerous rain water samples from five continents by Meybeck (1979, p. 242) indicate that average rainwater has 0.55 mg/L of Na$^+$. This average rain value is probably in excess of the actual average because recent studies show that Asia, the continent with the greatest rainfall, averages less than 0.4 mg/L (Petrenchuk, 1980; Petrenchuk & Selezneva, 1970). Furthermore, 2,000 m of ice core from Antarctica, the earth's longest duration aerosol record, averages less than 0.1 mg/L (De Andelis, Barkov & Petrov, 1987). Using the value for global precipitation over the continents of 1.10×10^{17} L/yr (Berner & Berner, 1987) and Meybeck's generous value of 0.55 mg/L of Na$^+$ in average rainfall, we obtain the mass of sea spray deposits of Na$^+$ on the

continents: $B_1=6.0\times10^{10}$ kg/yr. This output is 31% of the total river input.

B$_2$. Ion Exchange

Clays exhibit significant cation exchange ability especially in response to changes in the chemical environment. River-borne clays have their cation exchange sites dominated by Ca^{+2} because of the relatively high proportion of Ca^{+2} to Na$^+$ in river water. However, at the mouth of rivers upon entering the ocean these clays encounter seawater which has a significantly higher proportion of Na$^+$ relative to Ca^{+2}. As a result river-borne clays release Ca^{+2} from their cation exchange sites and absorb Na$^+$. The ability of river-borne clays to absorb seawater Na$^+$ is limited by the concentration of Ca^{+2} on the cation exchange sites.

Sayles & Mangelsdorf (1979) have studied the cation exchange characteristics of clays of the Amazon River, the world's largest river. Analysis of the river-borne clay of the Amazon showed that the cation exchange process occurs very rapidly as the clays enter the ocean. At the most frequently encountered discharge and sediment levels of the Amazon, Sayles & Mangelsorf (1979) estimate that 20% of the river-borne Na$^+$ is absorbed as clays enter the ocean. This was confirmed by laboratory experiments on the cation exchange abilities of river-borne clay (Sayles & Mangelsdorf, 1977). Using this data, Drever et al., (1988 Table 1.3, column 3) estimated the global uptake of Na$^+$ by river-borne clays at $B_2=3.5\times10^{10}$ kg/yr. This output is 18% of the total river input.

B$_3$. Burial of Pore Water

Sediments contain open spaces between their grains which in the ocean are filled with pore fluids. Thus, there is some seawater lost each year from the ocean simply by the permanent burial of pore water with the accumulated of sediments. Drever et al. (1988, p. 27) used the mass of ocean sediment added to the ocean and accumulated on the sea floor annually (2×10^{13} kg/yr) and the average final porosity (30%) to estimate the quantity of seawater removed. From the quantity of seawater removed they calculate the flux of Na$^+$ removed yearly by burial of pore water: $B_3=2.2\times10^{10}$ kg/yr. This output is 11% of the total river input.

B$_4$. Halite Deposition

Many have assumed that the major pathway for Na$^+$ removal from today's ocean is the deposition of the mineral halite. However, the major halite deposits accumulate currently from concentrated river water on the continents, not from the ocean. Modern marine sedimentary deposits are nearly

devoid of halite. Recent marine salt flats and coastal lagoons occur along the Persian Gulf, along the Gulf of California, and on the west coast of Australia, but they have very meager deposits of halite. When halite is deposited in marine salt flats and coastal lagoons, freshening of the brine after deposition often redissolves the halite. Solution of halite in seawater occurs because seawater is very undersaturated in both Na^+ and Cl^-. In fact seawater could contain 20 times its present concentration of Na^+ before deposition of halite would occur. Thus, modern sedimentary conditions seem to prevent large, permanent accumulation of halite in marine environments. The world inventory of modern marine halite deposits must be accumulating today at a rate of less than 1×10^8 kg/yr. Thus, the flux of Na^+ in modern marine halite deposition is: $B_4 < 4 \times 10^7$ kg/yr. Today's oceanic output of Na^+ as halite is trivial when compared to the modern river input.

B_5. Low Temperature Alteration of Sea Floor Basalt

The coolest basalts which form the uppermost rock of the ocean floor also circulate seawater but the temperatures of these fluids usually remain below 60°C. At this lower temperature the basalt is weathered to form clay minerals. Drilling of the upper 600 m of oceanic basalt showed 5 to 15% weathering of basalt to form very pervasive clays (Muehlenbachs, 1980). The primary clay is saponite, a Na^+-containing mineral of the smectite (montmorillonite) group. Therefore, Na^+ from low-temperature seawater reactions with the basalt must remove Na^+ from seawater. The quantity of clays in basalt was reported by Wolery & Sleep (1988, Table 3.2) to require removal of about 4.4×10^9 kg/yr of Na^+. Thus, removal of Na^+ by low temperature alteration of basalt is $B_5 = 4.4 \times 10^9$ kg/yr. This output is 2% of the total river output.

B_6. Albite Formation

Sea floor basalts above 350°C contain fluids which exchange Na^+ for Ca^{+2} (Seyfried, 1987). This metasomatic process, which occurs beneath the ocean, transforms calcium-rich feldspar (anorthite) to Na^+-rich feldspars (albite). Evidence of the process is seen in chlorite-grade metamorphism from basalts dredged from the sea floor. However, as discussed earlier in the input section, the axial hydrothermal vents, even many of those which emit water over 350°C, generally show enrichment, not depletion, of Na^+ (Campbell et al., 1988; Von Damm, 1988). The suggestion by Holland (1978, Table 5.14, p. 232) that albite formation is an effective sink for oceanic Na^+ is not supported by the most recent data. It appears that the seawater as it is heated from ocean temperature to 350°C gains as much or more Na^+ from low temperature solution of Na^+ in basalt as is removed above 350°C. Thus, there does not appear to be any significant removal of Na^+ from the seawater by the formation of albite. The Na^+ used in albite formation appears to come from within the ocean crust. It is concluded that albite formation removes essentially no Na^+ from the ocean. Therefore, $B_6 = 0$ kg/yr.

B_7. Zeolite Formation

Minerals of the zeolite group are strong absorbers of alkalies (Na^+, K^+) from seawater and are found in small amounts in ocean sediments. Phillipsite and clinoptilolite, Na^+-rich members of the zeolite group, form from alteration of volcanic ash. According to Mackenzie & Wollast (1977) about 4×10^{10} kg of volcanic ash are added to the ocean yearly. If fully one-half of this volcanic ash (averaging 3% by weight Na^+) is converted to phillipsite (averaging 7% by weight Na^+), 8×10^8 kg/yr of Na^+ would be removed from seawater. Thus, a generous allowance for zeolite formation suggests $B_7 = 8 \times 10^8$ kg/yr of Na^+ removal. Holland (1978, p. 186) recognizes the removal of seawater Na^+ by zeolites, but admits the quantity is minor. The output of Na^+ calculated for zeolites is less than 1% of the total river input.

Evolutionary Earth Models

Constraints on the minimum inputs and maximum outputs for Na^+ can be established by examining three different earth models. These are (a) the Pleistocene Earth Model, (b) the Cretaceous Earth Model, and (c) the Modern Earth Model. These models have been elaborated by evolutionists and are employed here to evaluate the limits of Na^+ variation in the history of earth's dynamic systems.

The Pleistocene Earth Model (abbreviated "Model P") was generated by geologic evidences of widespread continental glaciation. It supposes that the earth experienced an "ice age" (Flint, 1971). A large area of northern Europe, Asia, and North America was covered by continental glaciers when global mean temperature was about 10°C. Compared to today's earth, sea level was lower, about 5% greater area of continents was exposed, and there was greater length of coastline. Total global rainfall was greater than today, and, because of higher river discharge, more elevated continents, and much reduced desert areas, global erosion was more rapid than today (Flint). Volcanism was extensive judging from the size and abundance of Pleistocene calderas, but rift faulting at mid-ocean ridges was occurring near today's rate (Berner, Lasaga, & Garrels, 1983).

The Cretaceous Earth Model (abbreviated "Model C") is based on fossil flora and fauna from Cretaceous strata indicating that warm climate extended into polar latitudes (Barron, Thompson, & Schneider, 1981). There are supposed to have been no glaciers and global mean temperature may have exceeded 20°C (Berner et al., 1983). Higher sea level would have caused the area of Cretaceous continents to be 95% of today's continents (Tardy, N'Kounkou, & Probst, 1989, Table 7). Global rainfall and global continental drainage by rivers may have been 25% greater than today's (Tardy et al., 1989, Table 7), but because of the reduced elevation of the continents, less continental area, and more extensive soil development, the rate of erosion and sedimentation was about 54% of today's (Tardy et al., 1989, Table 7). Cretaceous sea-floor spreading has been supposed to have occurred at 1.4 times today's rate (Berner et al.). Perhaps, because of more volatiles released by accelerated tectonics on the sea floor, there was four times the present level of atmospheric CO_2 (Berner et al.). Chemical weathering would have been greater than today because of increased soil humidity and acidity (Berner et al.).

The Modern Earth Model (abbreviated "Model M") is based on our recent earth which is available for our direct study. Today's earth has 15°C global mean temperature and, because of modern continental glaciers, more closely resembles Model P than Model C. An important distinctive of our modern earth is its aridity. Desert areas characterize large portions of our continents which have reduced river discharge.

Minimum Past Na⁺ Inputs According to Evolutionary Models

We seek to determine minimum past input rates, A_{imin}, for each of the 11 processes delivering Na⁺ to the ocean. We can use our earth models to make this evaluation for the purpose of discerning whether evolutionary explanations for the earth's ocean allow the ocean's Na⁺ content to remain in steady state. Minimum values for 11 Na⁺ input processes (A_{imin}) are listed in Table 1. For the sake of calculation, we assume the steady state condition where the ocean's Na⁺ concentration does not change with time.

The flux of river Na⁺ from wash out of sea spray aerosol depends on the length of shoreline, area on continents, energy of waves, and concentration of Na⁺ in seawater. Assuming the steady-state model (past Na⁺ concentration of seawater equivalent to today's), we obtain the minimum sea spray river flux using Model C. Because Cretaceous coastlines would be 97% of today's length and continental area for aerosol to wash out would be 95% of today's, $A_{1min} = 0.97 \times 0.95 \times A_1$.

In a similar fashion past minimum global fluxes can be estimated for inputs A_2 through A_{11}. The rate of release of Na⁺ to rivers by silicate weathering (input A_2) is primarily dependent on soil acidity and soil humidity (Berner & Barron, 1984). Soil acid, which is produced primarily from CO_2 generated by organic decay, is the most effective agent for release of Na⁺ from silicate minerals. High soil humidity is the factor which increases organic activity in soils, and, in addition, makes possible the leaching of Na⁺ from soils to rivers. Thus, it can be argued that Model M with modern, more arid and alkaline soils would produce the minimum global flux of silicate-derived Na⁺ to the oceans through rivers. Models P and C have more humid and acidic soils than Model M. The area of modern deserts (where low Na⁺ solution from silicates occurs) in Model M more than offsets the increased area covered by glaciers (where low solution of Na⁺ occurred) in Model P. Indeed, it is difficult to imagine an earth model where less Na⁺ is delivered by rivers to the ocean from weathering of silicates. Therefore, $A_{2min} = A_2$.

The flux of Na⁺ through rivers from solution of chlorides on the continent is related to global precipitation and to area of exposed chloride deposits on the continents. All earth models suppose about the same area of exposed continental chlorides, so Model M, the model with the most arid climate, would have the lowest solution rate. Thus, $A_{3min} = A_3$.

The expulsion of Na⁺ from ocean sediments (A_4) is directly related to the rate of sedimentation, the lowest sedimentation rate producing the lowest input of Na⁺ from buried sea-floor clays. The lowest sedimentation rate is for Model C, evaluated at 54% of Model M by Tardy et al. (1989). Thus, $A_{4min} = 0.54 \times A_4$. For inputs of Na⁺ by marine erosion (A_7) and ground water (A_{10}), Model C gives the minimum Na⁺ inputs because marine erosion and ground water fluxes are related most strongly to the length of shorelines. Length of Cretaceous shorelines would be about 97% that of modern shorelines. Thus, $A_{7min} = 0.97 \times A_7$ and $A_{10min} = 0.97 \times A_{10}$. Sea-floor spreading has been regarded by evolutionists to be slowing down with time (Berner et al., 1983). Therefore, the lowest output of Na⁺ from sea-floor hydrothermal vents is today's: $A_{11min} = A_{11}$.

Maximum Past Na⁺ Outputs According to Evolutionary Models

We can also evaluate the past outputs of Na⁺ from the ocean and estimate each B_{imax}, the maximum output values for each output process. These are listed in Table 2. The quantity of Na⁺ removed from the ocean by the sea spray process (B_1) is, as stated before, related to length of shoreline, area of the continents, energy of waves, and concentration of Na⁺ in seawater as each sea spray droplet formed. Evolutionists have

supposed the Na^+ concentration of seawater and salt spray droplets have remained roughly constant over hundreds of millions of years. Thus, Model P with the most shoreline, the greatest continental area, and the greatest wave energy produces the greatest sea spray flux. A 2,000 m deep ice core from Antarctica (De Andelis et al., 1987) contains old ice left over from the Pleistocene. That ice, however, does not contain a significantly higher Na^+ aerosol content than recent ice deposited on Antarctica. Thus, past maximum rates of removal of Na^+ by sea spray are only slightly greater than modern rates. A generous allowance gives a good value, $B_{1max} = 6.7 \times 10^{10}$ kg/yr.

Approximately 1.5 times the present river sediment load would be carried to the oceans with Model P (Tardy et al., 1989). This largest global load of sediment in an evolutionary model would allow the largest Na^+ exchange from seawater to river sediments and bury the most pore water within ocean sediments. Thus, it can be estimated that $B_{2max} = 5.2 \times 10^{10}$ kg/yr and $B_{3max} = 3.9 \times 10^{10}$ kg/yr. The most Na^+ removal by alteration of ocean floor basalt would occur in Model C where sea floor is supposed to form 1.4 times faster than today. The value of $B_{5max} = 0.62 \times 10^{10}$ is estimated.

Evolutionists have claimed that the process of halite deposition (B_4) is much different today than in the past. They admit that modern marine halite deposits are of trivial volume, but attribute ancient massive halite deposits to short, irregularly occurring episodes. Drever et al. (1988, p. 51) speak for many evolutionists who believe: "… such events appear to be well able to absorb the river excess over long periods of time …".

Na^+ in earth's halite deposits is a relatively small sink for Na^+, as can be appreciated by "time averaging" it over the supposed duration of the deposits. The present inventory of rock salt in the earth's strata contains about 4.4×10^{18} kg of Na^+ (Hosler's estimate of global salt inventory, as cited in Holland, 1984) which is 30% of the mass of Na^+ in the ocean. Dividing the present mass of Na^+ in global rock salt (4.4×10^{18} kg) by the supposed duration of the Phanerozoic deposits (6×10^8 yr) gives an average rate of Na^+ removal for the Phanerozoic of 7.3×10^9 kg/yr. This flux is an order of magnitude less than the sea spray output process (B_{1max}) and cannot serve to balance during long time intervals any of the major input processes (A_{1min}, A_{2min}, A_{3min}, or A_{10min}). Furthermore, it is extremely unlikely that the "time averaged" halite output contains a significant error. No major quantity of halite in the earth's crust could have escaped our detection. Because halite is dominantly a basinal deposit on continents, it is unlikely that any major quantity has been extracted by subduction from the crust into the mantle.

We can estimate B_{4max} by an analysis of halite deposits of the Permian system. The Permian contains the world's thickest and most extensive marine halite deposits. Of the 4.4×10^{18} kg of Na^+ in the earth's rock salt, 1.0×10^{18} kg (23%) resides in Permian rock salt (Zharkov, 1981). Assuming that 50% of the Permian halite strata have survived erosion (a good estimate based on the continental exposure of Permian basinal deposits), the original Permian Na^+ mass would be 2×10^{18} kg. The "time averaged" maximum rate of removal of Na^+ by halite deposition is estimated in reference to the supposed 50 million year duration of the Permian period. The maximum rate of Na^+ removal by marine halite deposition (B_{4max}) is 4.0×10^{10} kg/yr (Hosler et al., 1980). The rate is only 67% of the present river input of Na^+ derived weathering silicates (A_2). Even more interesting is the observation that B_{4max} is about half the present river flux derived from solution of continental chloride minerals (A_3).

Past halite deposition (B_{4max}) is not the major process that has been supposed: it ranks third behind past sea spray (B_{1max}) and cation exchange (B_{2max}). Halite in the earth has not been the major sink for Na^+ generated by supposed hundreds of millions of years of continental weathering.

Significance of the Imbalance

Data that have been assembled in summary form in Tables 1 and 2 show the enormous imbalance of Na^+ inputs compared to outputs. A_p, the total of the eleven present Na^+ inputs, is 4.57×10^{11} kg/yr, whereas B_p, the total of the seven present outputs, is only 1.22×10^{11} kg/yr. The present output to input ratio ($x_p = 0.27$) shows that only 27% of Na^+ going into today's ocean can be accounted for by known output processes. If the steady state model is correct, x_p should be equal to 1.0, not 0.27! It is extremely unlikely that one major or several minor Na^+ output processes, comprising 3.35×10^{11} kg/yr of Na^+, have eluded our detection. That the Na^+ imbalance exists in the ocean is further corroborated by consideration of Cl^-, the primary anion which balances the charge of input Na^+. According to Drever et al., (1988, p. 37), Cl^- is also being added to the ocean at a much faster rate than it is being removed. Thus, we have strong evidence that the ocean is not presently in steady state condition.

If the inputs of Na^+ were constant in time and there were no outputs, the time τ it would take to bring the mass of Na^+ in the ocean from zero to today's amount M_p would be:

$$\tau = \frac{M_p}{\Sigma A_i} = \frac{M_p}{A_p} \qquad (1)$$

In a similar fashion the maximum time required to bring the ocean to its present Na^+ level can be calculated assuming the slowest possible Na^+ input processes:

$$\tau_{max} = \frac{M_p}{\Sigma A_{imin}} = \frac{M_p}{A_{min}} \qquad (2)$$

Evolutionists call τ the residence time of Na^+, implying that τ is the average time a Na^+ ion spends in the ocean. However, as already demonstrated, the present oceans are not in steady state, so τ cannot be the residence time for Na^+. For clarity of concepts, we call τ the "filling time". Estimates of the Na^+ filling time (residence time) in the literature over the last century have varied between 260 Myr (Livingstone, 1963) and 26 Myr (Billo, 1989), generally getting smaller with time as more Na^+ inputs have been identified and measured more accurately.

Before a filling time (τ) can be calculated, M_p, the present mass of Na^+ in the ocean needs to be determined. The ocean's concentration of Na^+ today is 10,760 mg/kg (Holland, 1978, Table 5.1). The mass of the oceans is 1.37×10^{21} kg (Berner & Berner, 1987), allowing the Na^+ mass in the ocean to be calculated: $M_p = 1.47 \times 10^{19}$ kg. The total of the 11 A_is listed in the "present inputs" section is $A_p = 4.57 \times 10^{11}$ kg/yr. Substituting the last two values in equation 1 gives a filling time of 32.2 Myr. Because the input fluxes were estimated conservatively, we can say: $\tau < 32.2$ Myr. The maximum filling time calculated using equation 2 gives $\tau_{max} = 41.3$ Myr. Because the minimum input fluxes were estimated very conservatively, we can say $\tau_{max} < 41.3$ Myr.

Estimating the Ocean's Age

It is important to understand that τ is not the age of the ocean. To get an age estimate, we need to account for three other factors: (a) the output rates, (b) the past behavior of the input and outputs, and (c) the initial amount of Na^+. Let us consider first the effect of output rates. The three major outputs are aerosol removal by sea spray (B_1), cation exchange with river clays (B_2), and burial of pore water in ocean sediments B_3). Together these three removal paths account for 96% of the present Na^+ removal from the ocean (see Table 2). However, the rates of Na^+ removal of each of these three processes are dependent on the concentration of Na^+ in seawater. Lower rates of removal for the three processes would be expected in the past when seawater had a lower concentration of Na^+. Thus, these output rates cannot be constant through time, but must be proportional to $[Na^+](t)$, and Na^+ concentration of the ocean at some past time t, and also proportional to $M(t)$, the mass of Na^+ in the ocean at time t. We can express the rates as $B_i(t) = b_i M(t)$, where each coefficient b_i is a proportionality constant.

Next, let us consider outputs. If the sea has been increasing its Na^+ content continually, then today's three major outputs (B_1, B_2, and B_3) must have been

smaller in the past. Thus, one cannot simply subtract today's output rates from the input rates and use a form of equation 1 to get the age. Instead, we must solve a differential equation giving the rate of change of $M(t)$ in terms of the input rates A_i and the output rates $B_i(t)$ (Lasaga, 1980):

$$\frac{dM}{dt} = \Sigma A_i - \Sigma B_i = A_t - \beta M(t) \qquad (3)$$

where we have defined $\beta = \Sigma b_i$ and $A_t = \Sigma A_i$. If A_t and β are constant with time, the solution of Equation 3 is:

$$M(t) = \frac{A_t}{\beta} - \left(\frac{A_t}{\beta} - M_o \right) \exp(-\beta t) \qquad (4)$$

as one can verify by substitution. Here M_o is the initial mass of Na^+ in the sea. We can solve this equation for the time T it would take the mass of Na^+ in the ocean to reach the present level, M_p:

$$T = \frac{1}{\beta} \ln\left(\frac{A_t - \beta M_o}{A_t - \beta M_p} \right) = \frac{\tau}{x} \ln\left[\frac{1 - (M_o x / M_p)}{1 - x} \right] \qquad (5)$$

where τ is the fillup time of Equation 1 and x is the output-to-input ratio:

$$x = \frac{\Sigma B_i}{\Sigma A_i} = \frac{B_t}{A_t} \qquad 0 < x < 1 \qquad (6)$$

Equation 5 would give the age of the ocean if A_t and β had been constant, conditions which undoubtedly do not apply. However, we will use Equation 5 in the following discussion to establish a *maximum* age for the ocean. We can say by the evolutionary models discussed previously that A_t, the sum of the Na^+ inputs at any time t in the past, has always been greater than or equal to $A_{min} = 3.56 \times 10^{11}$ kg/yr, the sum of the 11 past minimum input rates for the processes in Table 1. Similarly, we can say that B_t, the sum of the Na^+ outputs at any time t in the past, has always been less than or equal to $B_{max} = 2.06 \times 10^{11}$ kg/yr, the sum of the seven past maximum output rates for the processes in Table 2. The ratio of these two values, B_{max}/A_{min}, gives us a maximum value, x_{max}, for the output-to-input ratio:

$$x = \frac{B_t}{A_t} \le \frac{B_{max}}{A_{min}} = \frac{2.06 \times 10^{11}}{3.56 \times 10^{11}} = 0.58\, x_{max} \qquad (7)$$

To make our age estimate as large as possible for the benefit of the evolutionary model, we set the initial Na^+ mass $M_o = 0$, even though the creationist model would suggest otherwise. Then, we insert x_{max} from Equation 7 and τ_{max} from Equation 2 into Equation 5 to get an expression for the absolute upper limit for the age of the ocean:

$$T \le -\frac{\tau_{max}}{x_{max}} \ln(1 - x_{max}) = \tau_{max}\left(1 + \frac{x_{max}}{2} + \frac{x_{max}^2}{3} + \cdots \right) \qquad (8)$$

Using $\tau_{max}=41.3\,$Myr and $x_{max}=0.58$ in equation 8 gives $T\leq62\,$Myr.

Outline of a Creationist Model

To get a maximum age for the ocean according to an evolutionary model, we had to assume zero initial Na^+ in the sea, but there is no reason for the creationist model to make such an assumption. On the contrary, there may be good biological reasons to expect God to have created the original ocean with significant salinity. In the maximum age calculation we also assumed an evolutionary model with no catastrophic additions of Na^+ to the ocean. The Genesis Flood, however, would have added highly saline subterranean waters to the oceans (the "fountains of the great deep," Genesis 7:11). Furthermore, Na^+ would have been released by reactions with hot basalt spreading out from the resulting mid-ocean ridges, reactions with volcanic ash and basalt, and the massive runoff of waters from the continents (Genesis 8:3–5). For thousands of years after the Flood, the climate would have been hotter and wetter than today, causing enhanced amounts of Na^+ solution. Extensive post-Flood volcanoes would have deposited enormous quantities of volcanic ash which would have weathered and delivered Na^+ to the oceans at a much higher rate than today. Thus, the creationist model implies (a) that the initial level of Na^+ in the ocean was a substantial fraction of today's level, (b) that there was a significant burst of input Na^+ during the Genesis Flood, and (c) the Na^+ input rate was at higher levels than today for thousands of years.

Conclusion

Equation 8 reduces the entire controversy down to one question: What is the value of x_{max}? Evolutionists and old-earth creationists must assert that the ocean is in a steady state condition, meaning that input and output rates have been about equal throughout geologic time, on the average. By that view, they assert that $x_{max}=1$. This means that T would be infinite, and we could say nothing about the age of the ocean from its Na^+ content.

However, data we have been able to compile from our knowledge of the earth, indicate that the present output of Na^+ from the sea is only one-quarter the present rate of input ($x_p=0.27$). Furthermore, taking into account plausible evolutionary earth models with maximum outputs and minimum inputs we still cannot solve the dilemma. Our most generous output and input models give $x_{max}=0.58$. This means (a) that the evolutionary steady-state model is inconsistent with the data, and (b) that the ocean is much younger than the 3 billion year age evolutionists commonly suppose. The data and equation 8 limit the ocean's age to less than 62 million years.

The significance of this result is (a) the evolutionary timescale of geologic events associated with the ocean is grossly wrong in an absolute sense (though not necessarily in a relative sense), (b) the corresponding radiometric dating methods are grossly wrong (probably because of assumptions implicit in the methods), and (c) biologic evolution, which is alleged to have started in the ocean and had most of its history there, has not had time to occur.

Our result is an upper limit on the age of the ocean. It does not mean that the true age is anywhere near 62 Myr. According to the creationist model, most of the Na^+ in the ocean is there as a result of creation and the Genesis Flood, not as a result of Na^+ input due to geologic processes sustained over a billion years. This leaves room for the possibility that the sea is less than 10,000 years old. Our conclusion from the Na^+ data is that the sea is less than 62 million years old. This is at least 50 times younger than the age evolutionists require it to be.

We challenge evolutionists and old-earth creationists to report quantitative data supporting a steady state ocean. Those who propose that continental weathering and rivers have been delivering Na^+ to the ocean for 3 billion years need to explain the sea's missing salt. We urge Van Till, Young, & Menninga to justify their assertion: "The 4.5 billion year chronology of earth history is in no way weakened or disqualified by an appeal to the salt content of the terrestrial oceans" (Van Till et al., 1988, p. 91).

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Discussion

The world that we live in is God's world. We are reminded by many passages of Scripture, and especially by Psalm 19:1 that "The heavens are telling the glory of God; the skies proclaim the work of his hands." Therefore, we must give serious consideration to what we learn about God's world through scientific study of that world. From within that perspective, I submit the following comments:

1. Our knowledge and understanding of God's world is less than perfect and less than complete. We

have not yet learned in detail all of the processes involving sodium in the ocean environment. Any improvements in our understanding are welcome.

2. The authors speak of the inability to account for all of the factors which affect sodium concentration in the oceans as a "dilemma" for those who think that the earth is old. However, even if the residence time of sodium in the oceans is less than the 260 million years reported in much of the recent literature, we must remember that the residence time of sodium in the oceans is not the same as the age of the earth. After all, the residence time of aluminum in the oceans is only 100 years, and that is not viewed as a dilemma.

3. While short residence times for various elements in ocean water are no dilemma for those who think the earth is old, long residence times for some elements in ocean water decidedly presents a dilemma to those who think that the earth is young.

4. Sodium is not the only element with a residence time in the oceans which is longer than several thousand years. The residence time for potassium is 11 million years, for magnesium is 45 million years, for silver is 2 million years, and for uranium is 500,000 years. Are all of those long residence times in error? Can all of them be reduced to several thousand years by good data and proper calculations?

5. According to their own calculations, the authors have determined a "filling time" of the oceans of 32.2 million years. Are the authors willing to accept that number as a minimum age of the earth?

6. After gathering a considerable amount of data, and after performing several calculations and logical analyses, the authors suggest that the scientific study they have done isn't worth anything, after all. They suggest that God might have made the oceans recently, with a great deal of sodium (and other elements) already dissolved in the water. If that is the attitude one wishes to adopt, what is the justification for doing the scientific study? A paper which is only one or two sentences in length would suffice to reach the same result.

7. It is God's world that we are studying by scientific methods. It is God's handiwork that we are learning about through those studies. God deserves to be praised and honoured—and believed—for what we have been able to learn about his world. If our careful study of God's world brings us false or unreliable information, then what can it mean for the Psalmist to sing, "The heavens are telling the glory of God; the skies proclaim the work of his hands."?

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Closure

We had hoped Dr. Menninga would respond to our challenge "to report quantitative data supporting a steady state ocean," but his review contains no such data. An erroneous assumption underlies all of his remarks. It appears implicity in his points 2 through 4, and explicitly in point 5: he assumes that residence times are minimum ages for the ocean, that is, that the ocean must be older than any given residence time. He does not explain his reasoning, but it must be something like this: (a) If there were not initial sodium (for example) in the ocean, and (2) if the input of sodium has always been no greater than the present rate, then it would take more than 32 million years (our residence time for sodium) to get the present amount of sodium in the ocean. In other words, Dr. Menninga assumes a uniformitarian view of the origin of sodium in the ocean; he feels that all the sodium in the sea got there by today's processes at essentially today's rates.

The flaw in Dr Menninga's reasoning is in his two uniformitarian "if" conditions; he has no logical basis for assuming either is true. The creationist model we described provides a specific counter-example: Menninga cannot logically exclude the possibilities that (a) God created the ocean with some initial sodium, and (b) the sodium input during the Flood was much higher than it is today, a very natural consequence of such an event. (See Figure A). This shows that Menninga's assumptions are not generally valid, so residence times are not minimum ages. Our specific replies follow:

1. "Our knowledge … is less than perfect."

This is basically an appeal to unknown factors to support his view. "Improvements in our understanding are welcome." Since our paper is the only one which has collected all the diverse data on sodium inputs (including seven previously unrecognized ones) and outputs, it should have improved Dr. Menninga's understanding.

2a. "Inability to account for all of the factors."

It is not we who profess such an inability, we wrote that we have accounted for all of the major factors. For over half a century, many evolutionists have been diligently searching for sodium outputs, so we think it likely that all of the major ones have been found. The dilemma for evolutionists is not in accounting, but in facing up to the bottom line of the ledger: The sea is young.

2b. "Residence time … is not the same as age."

We agree; we never said otherwise. Dr. Menninga evidently overlooked our statement stressing that point: "It is important to understand that t [the residence time] is not the age of the ocean." Apparently he also overlooked our main point, which we emphasized numerous times in the paper:

we have determined a maximum limit on the age, not the age itself. Equation (8) specifies this limit, which depends not only on the residence time but also on the maximum output-to-input ratio, xmax.

2c. Aluminum's small residence time is not a dilemma for old-earthers.

Hence, he implies sodium's residence time should not present a dilemma, either. But it is not the residence time which makes the dilemma; it is the imbalance between sodium inputs and outputs. We can see this by contrasting what Equation 8 says about aluminum and sodium. The data for aluminum gives $x_{max}=1$; using this in Equation 8 tells us that the x_{max} of the ocean is equal to or less than infinity. For the data we report concerning sodium, Equation 8 tells us that the ocean is less than 62 million years old. Both statements are true, but the one based on sodium is more stringent, and that is the one which places evolutionists in a dilemma.

3. "Long residence times … present a dilemma to [young-earthers]."

This would be true only if residence times were minimum ages, an idea we disproved in our introductory remarks above.

4. Can [various large residence times] be reduced to thousands of years?

Since residence times are not minimum ages, we are under no obligation to perform such a shrinkage.

5. "Are the authors willing to accept [their 32 million year sodium residence time] as a minimum age?"

No. We can be persuaded by valid reasoning, but not by mere repetition of the same error which underlies the previous points.

6. "The authors suggest [their analysis] isn't worth anything."

This suggestion comes from Dr. Menninga, not from us. "What is the justification for the study?" The reason for our study is the pursuit of truth. In the best tradition of science, the study rigorously tests a hypothesis (the evolutionary view of the ocean), and it outlines a testable alternative hypothesis, our creationist model. For reasons he does not specify, Menninga disdains our model, but if he had paid close attention to its implications, he might have recognized the flaws in his own argument.

7. "God's world brings us false or unreliable information."

Dr. Menninga's reaction to our paper suggests that it is he who regards information from the natural world as unreliable. He is avoiding a straightforward understanding of the sodium data, because it does not fit into his preconceptions of an old earth. "God's world … deserves to be … believed." So why doesn't Dr. Menninga believe it?

Conclusion

Dr. Menninga has staked a great deal upon his assumption that residence times represent minimum ages; it is probably one reason he does not respond to our challenge. He failed to see that our analysis and alternative model expose the logical fallacies behind his assumptions and collapse his case. He also misunderstood the thrust of the paper. Our main purpose was not to reduce the residence time of sodium, but to quantify the gross imbalance between sodium inputs and outputs and to clarify its implications. His response fails to make crucial distinctions between four different concepts: residence time, maximum age, minimum age, and true age. His decided preference for the term "residence time" instead of the more neutral term "filling time" clouds the central issue: Is ocean sodium in a steady state?

Dr. Menninga's repeated references to God and the Bible seem inconsistent with his aversion to our creationist model. After all, the two main features of the model came directly from Scripture: (a) a recent creation, and (b) a worldwide Flood whose natural consequence would be a massive influx of sodium into the ocean. We were aware that Menninga and his colleagues resist a straightforward understanding of the Bible with regard to the youth of the earth. Evidently, they similarly resist the biblical account of the Flood.

We are genuinely disappointed that Dr. Menninga did not overcome his uniformitarian presuppositions enough to follow our reasoning clearly. We did not expect agreement, but we did expect understanding. Therefore, we call upon Dr. Clarence Menninga and his colleagues, Drs. Davis Young and Howard Van Till, to re-examine their presuppositions, read our paper more carefully, and respond to our challenge; report quantitative data supporting a steady-state ocean. If they cannot provide such data, then they should cease denying what we are asserting: that all present knowledge about sodium in the sea indicates that the ocean is young.
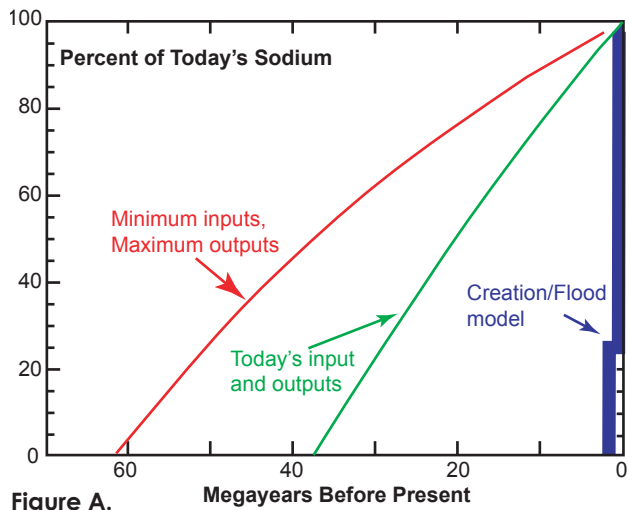

Figure A.