Geochemical Reservoirs and Transfer Processes

Ocn 623
Dr. Michael J. Mottl
Dept. Of Oceanography

Three Basic Questions

• 1. Why does Earth have oceans?
• 2. Why does Earth have dry land?
• 3. Why are the seas salty?
Why do we have dry land?

- **Land** with a mean elevation of +840 m (29% of Earth surface area).
- **Ocean floor** with mean depth of -3800 m (71% of Earth surface area).

*If Earth were smooth, depth of oceans would be 2450 m over the entire globe!*

Earth’s solid surface has two levels representing *oceanic* and *continental* crust.

Venus’s has only one!

Loss of H₂O probably prevented *plate tectonics* on Venus, including formation of continents!

*Earth has dry land because it has oceans!*
Three Basic Questions

• 1. Why does Earth have oceans?

• 2. Why does Earth have dry land?

• 3. Why are the seas salty?

Chemical differentiation produced by Earth surface processes

Igneous rocks plot near the center of the tetrahedron.

Sedimentary minerals and rocks represent physical and chemical dispersal of the igneous components by weathering, transport, and deposition.
Implications
1. All sedimentary and metamorphic rocks in the crust derive ultimately from igneous rocks.
2. Na$^+$ and K$^+$ end up mainly in seawater rather than in sedimentary minerals or rocks.

$\text{Na}^+$ in the oceans can be used to estimate the total mass of igneous rock that has weathered to form sediments and sedimentary rocks (?).

Clarke (1908): 1st edition of Data of Geochemistry:
avg. igneous rock = avg. sedimentary rock + seawater
(avg. igneous rock has ~2.5 wt.% more Na$_2$O than does avg. sedimentary rock)

Goldschmidt (1933): 1st Geochemistry textbook:
$600 \text{ g avg. ign rock} + 1 \text{ kg volatiles} = 600 \text{ g avg. sed rock} + 1 \text{ kg seawater}$

Geochemical Mass Balances

Two types:

1. Balance between reactants (igneous rocks and volcanic gases) and products (sediments, sedimentary rock, and seawater).

These early attempts neglected to consider cyclical processes adequately: e.g., conversion of sediments into high-grade metamorphic and, ultimately, igneous rocks by melting. Na$^+$ in seawater thus represents only the “standing crop” of sediments and sedimentary rocks.

2. Geochemical cycles and the balancing of inputs with outputs from various reservoirs, esp. seawater.
Cycling of material among Earth reservoirs throughout Geologic time

Goal of Geochemistry

To understand how the Earth works as a chemical system, i.e.,

To identify and quantify those processes which transfer Earth materials from one reservoir to another:

1. Identify and characterize reservoirs.
2. Identify mass transport processes and quantify their rates.
3. Identify and quantify relationships among transport processes and reservoir characteristics, i.e., feedback mechanisms.

Reservoir: a largely isolated part of a larger system, which is relatively homogeneous internally and distinct from adjoining reservoirs based on its composition and/or physical properties

In practice, the choice of reservoir boundaries depends on the problem to be solved and the availability of data!

Types of reservoirs:
1. Accumulative
2. Steady state
3. Non-steady state, non-accumulative
Accumulative Reservoirs

For a particular component:

Barth (1952): “characteristic time” = time required to accumulate an observed amount, at the estimated mean input rate

If characteristic time exceeds age of Earth, either values are wrong or reservoir is non-accumulative.

Example: filling of ocean basins with sediment

Historically, the oceans have been considered to be accumulative for all materials carried by rivers to the sea: water, sediment, dissolved salts!

Sir Edmund Halley (1715)

- suggested that the age of the oceans could be estimated by measuring the increase in Na\(^+\) with time.
- bemoaned the fact that the Romans had not left us with a record of the concentration of Na\(^+\) in seawater of their time!
John Joly (1898)

mass of Na in oceans
annual river input of Na

\[ \text{mass of Na in oceans} = \frac{1.5 \times 10^{22} \text{ g}}{3.2 \times 10^{14} \text{ g/yr}} = 48 \times 10^6 \text{ yrs} \]

Corrected for atmospheric recycling: 58 x 10^6 yrs
(Joly’s value: 80-90 x 10^6 yrs)

\[ = \text{Residence time} \]

(of Na\(^+\) in the oceans, wrt the river input, corrected for atmospheric recycling)

Residence time is important because it is an approximate measure of the response time of a system to perturbation.

Steady-State Reservoirs

For a particular component:

Its concentration does not change with time, because its total rate of input is equal to its total rate of output.

Residence time = total amount/ rate of input or output;
called “period of passage” by Barth (1952)

Steady-state conditions are often assumed, but always require proof. Steady state is most likely to prevail over time periods comparable to the residence time, but not over much shorter or much longer periods.
Fig. 3-1. Processes (circles) and reservoirs (boxes) affecting the oxygen content of the atmosphere. (From Walker, 1974. Copyright 1974 by the American Journal of Science. New Haven, Conn. Used by permission of the publisher.)
Fig. 19a & 19b. The chemical composition of igneous rocks forms equilibria using the ternary diagram shown. Diagram A, any horizontal or vertical line gives a constant: molar amount of alkali, silica, calcic oxide or iron and magnesium. Thus, the less volatile species in a matrix are represented by points close to the base of the column; molar oxides rich in these elements are represented by points near the top of the column. The contents of the rocks contain the more volatile oxide species, so that rocks which contain the less volatile oxide species are represented by points in the upper right, whereas those containing the more volatile oxide species are represented by points in the lower left. The columns of the column are divided into the following sections: the upper right comprises rocks with more than 50% of their weight in oxides of iron and magnesium, the lower left comprises rocks with less than 50%. The subcolumns are divided into the following sections: the lower right comprises rocks with more than 50% of their weight in oxides of iron and magnesium, the lower left comprises rocks with less than 50%.