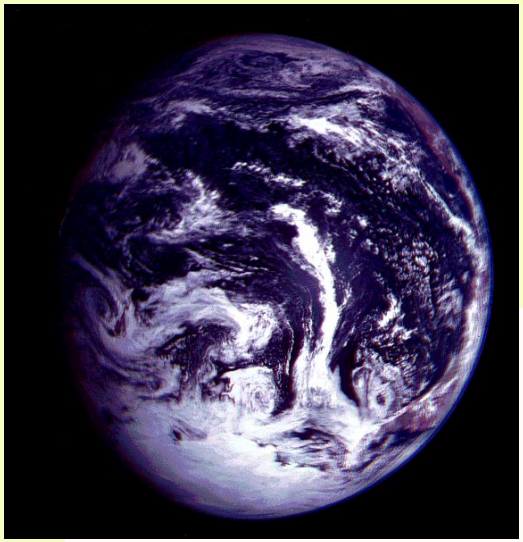

Water, water, everywhere!

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Whole Earth geohydrologic cycle, from the clouds to the core: The distribution of water in the dynamic Earth system

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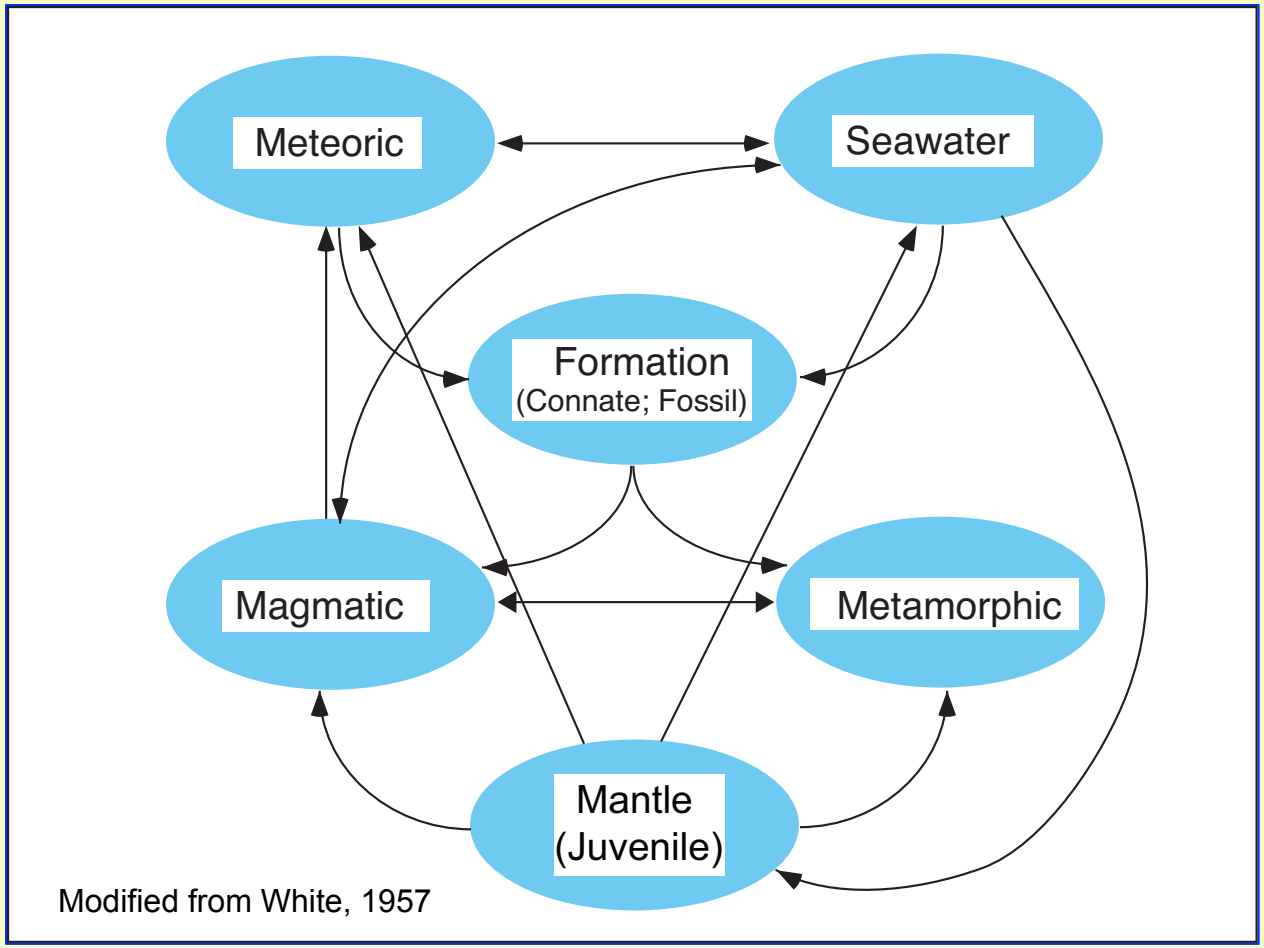
Don White of the U.S. Geological Survey was one of the pioneers in characterizing the various natural water sources, and in 1957 he summarized his findings in a classic paper in the *Bulletin of the Geological Society of America* that included a highly-cited diagram showing different water reservoirs on Earth.



Modified from White, 1957

During the latter half of the 20th century, a recognition that fluids are cycled into the deep Earth emerged, and that these fluids significantly influence the chemical and rheological evolution of the deep crust and mantle.

Quantifying the reservoirs and fluxes of the most volatile and soluble phases of the earth is one of the major tasks of modern geochemistry. As well as playing a leading role in influencing the stability and changes of the environment, fluids are significant in the mechanics of the lithosphere and influence deep electrical properties and the propagation of seismic waves. Deep recycling of fluids is more important than previously recognized .....

W.S. Fyfe (1987)

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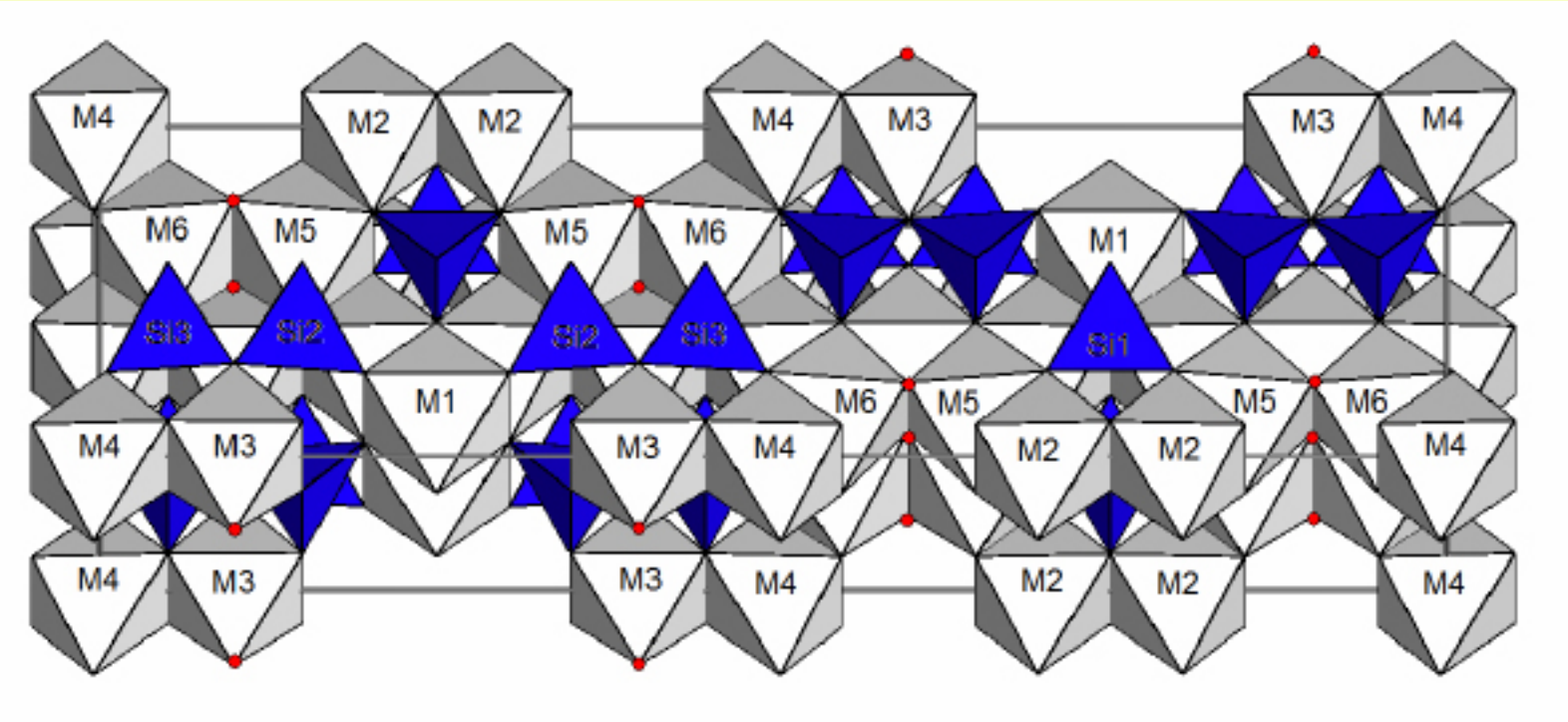
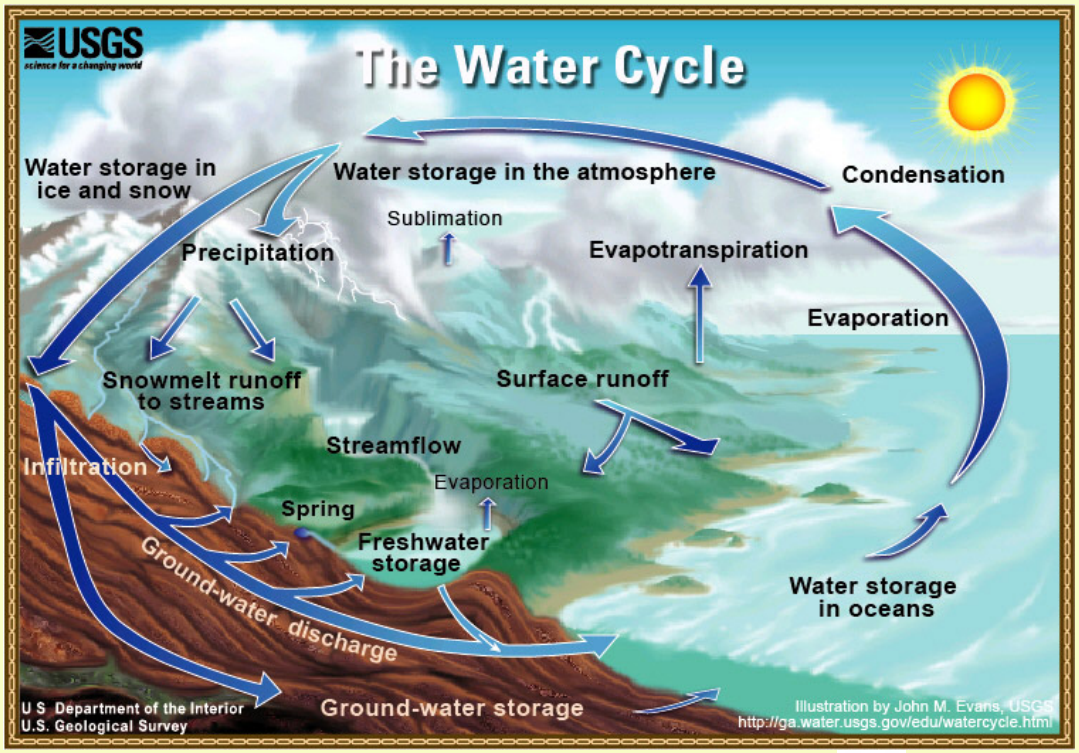
Joe Smyth's study of wadsleyite that showed that the upper part of the transition zone could contain as much water as the world's oceans led to the development of an entirely new branch of mineralogy related to NAMs.

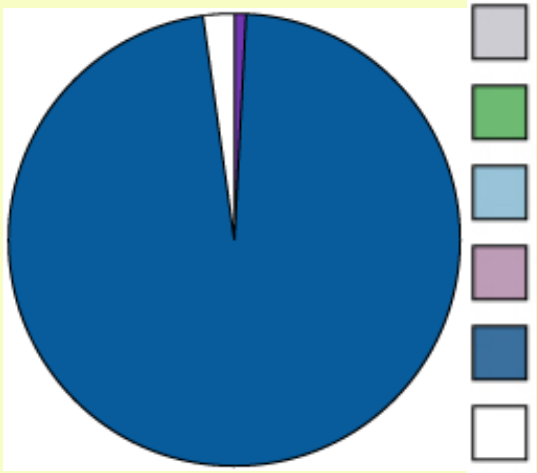


Smyth (1994) A crystallographic model for hydrous wadsleyite (β-Mg_2SiO_4): an ocean in the earth's interior?

The Earth's hydrologic cycle circa 1970

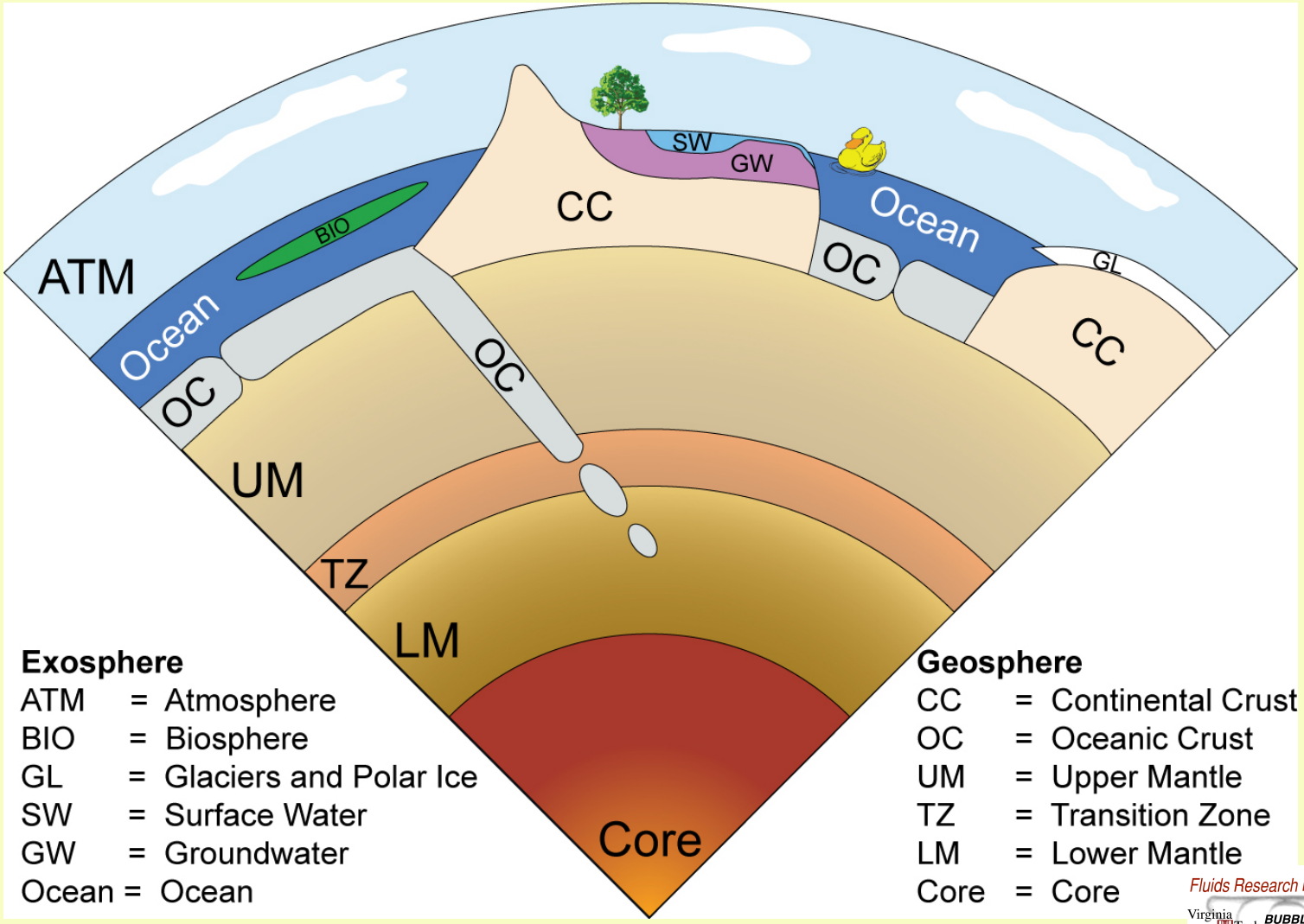


The conventional hydrologic cycle describes the near-surface water reservoirs and the movement of water between these reservoirs. The oceans contain the largest proportion of water in the near-surface environment, and water from all reservoirs is eventually cycled through the atmosphere.



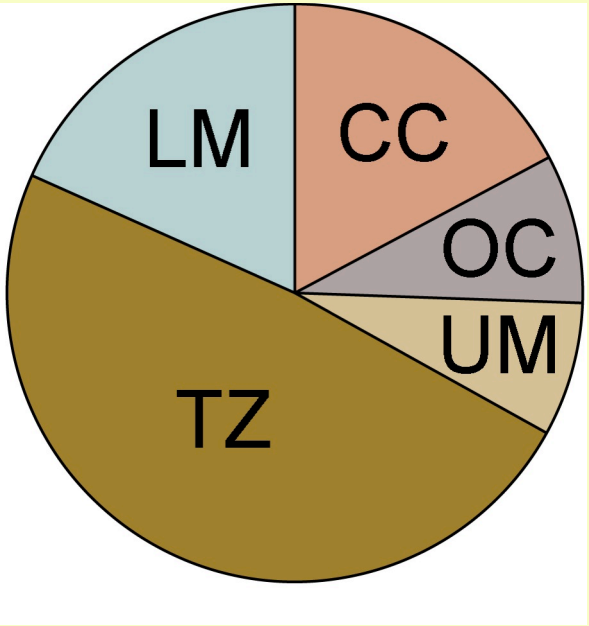
= exosphere

The modern hydrologic cycle that has been developed in the last half century includes the reservoirs within the solid earth



Geohydrologic Cycle

How much water is there and where is it?



	Reservoir Size (kg)
Atmosphere	1.3E+16
Biosphere	4.667E+15
Surface Water	2.065E+17
Groundwater	1.053E+19
Oceans	1.37E+21
Glaciers & Polar Ice	3.3245E+19
Continental Crust	2.8E+20
Oceanic Crust	1.38E+20
Upper Mantle	1.2E+20
Transition Zone	7.9E+20
Lower Mantle	3.0E+20

Essentially all water in the geosphere occurs in hydrous minerals, or dissolved in magmas, or as trace components in NAMs.

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Geohydrologic Cycle

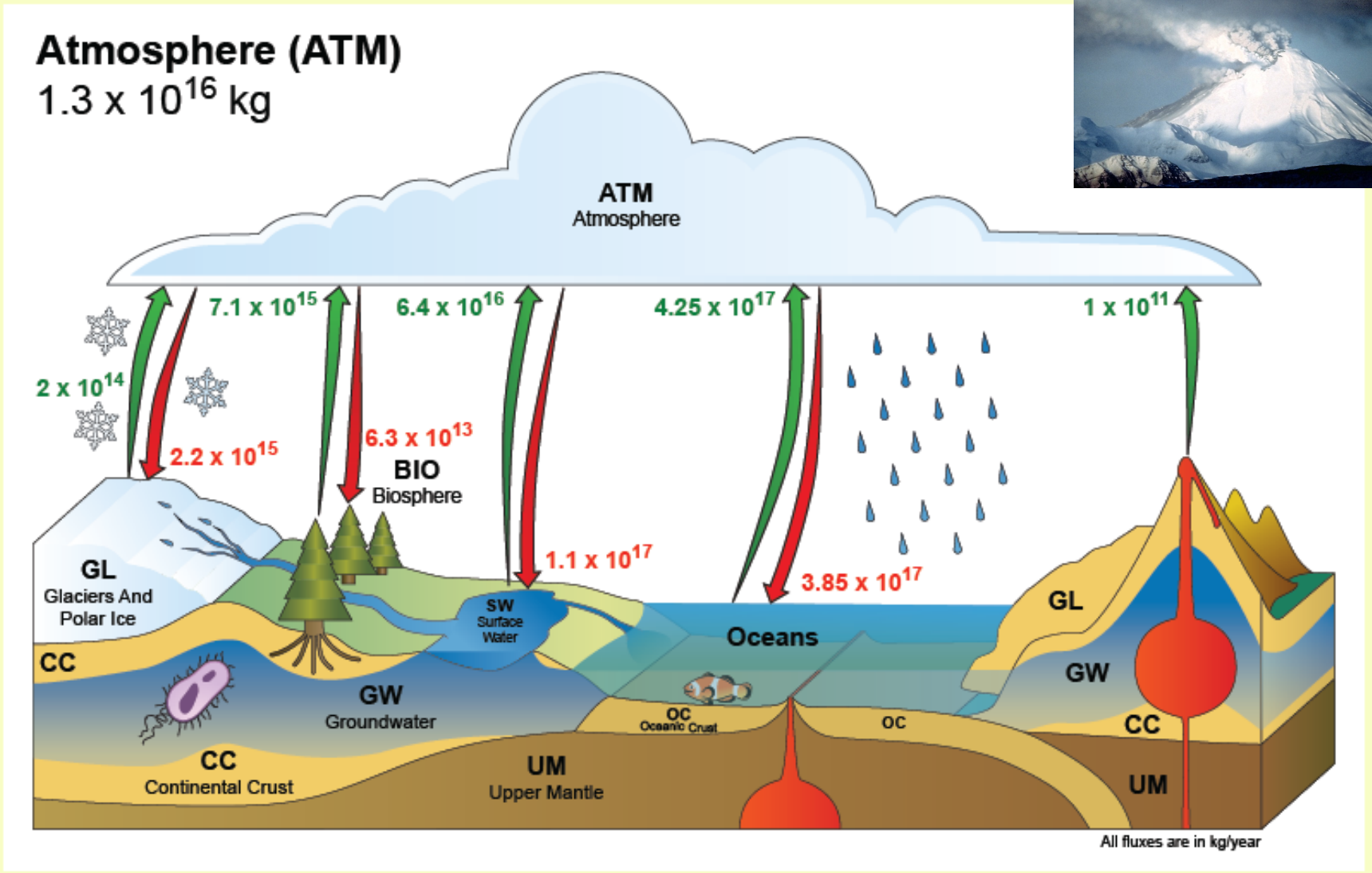
Fluxes between reservoirs in the geohydrologic cycle have been quantified assuming a balanced model

TABLE 2. FLUXES IN THE GEOHYDROLOGIC CYCLE

Reservoir	Amount of H_2O in reservoir (kg x 10^{17})	Percentage of total H_2O	ATM	BIO	Oceans	SW	GW	GL	CC	OC	UM	TZ	LM	Total Out*
Atmosphere (ATM)	0.13	0.0004		63	385000	110000		2200						497000
Biosphere (BIO)	0.047	0.0002	7100		230	90	1							7400
Oceans	13700	45	425000	230			260	15000		1.6				441000
Surface water (SW)	2.07	0.01	64000	7100	36000		15000		0.1					122000
Groundwater (GW)	105	0.35		1	2500	13000								15300
Glaciers & Polar Ice (GL)	332	1.09	200		17000									17200
Continental Crust (CC)	2800	9.2	0.1				0.18			0.12				0.4
Oceanic Crust (OC)	1380	4.5			1.3						0.38	0.07	0.05	1.8
Upper Mantle (UM)	1200	3.9			0.11				0.3	0.12				0.5
Transition Zone (TZ)	7900	26.0									0.120			0.12
Lower Mantle (LM)	3000	9.9										0.05		0.05
Total H_2O in Earth	30419	100												
Total In*			496000	7400	441000	122000	15300	17200	0.4	1.8	0.5	0.12	0.05	

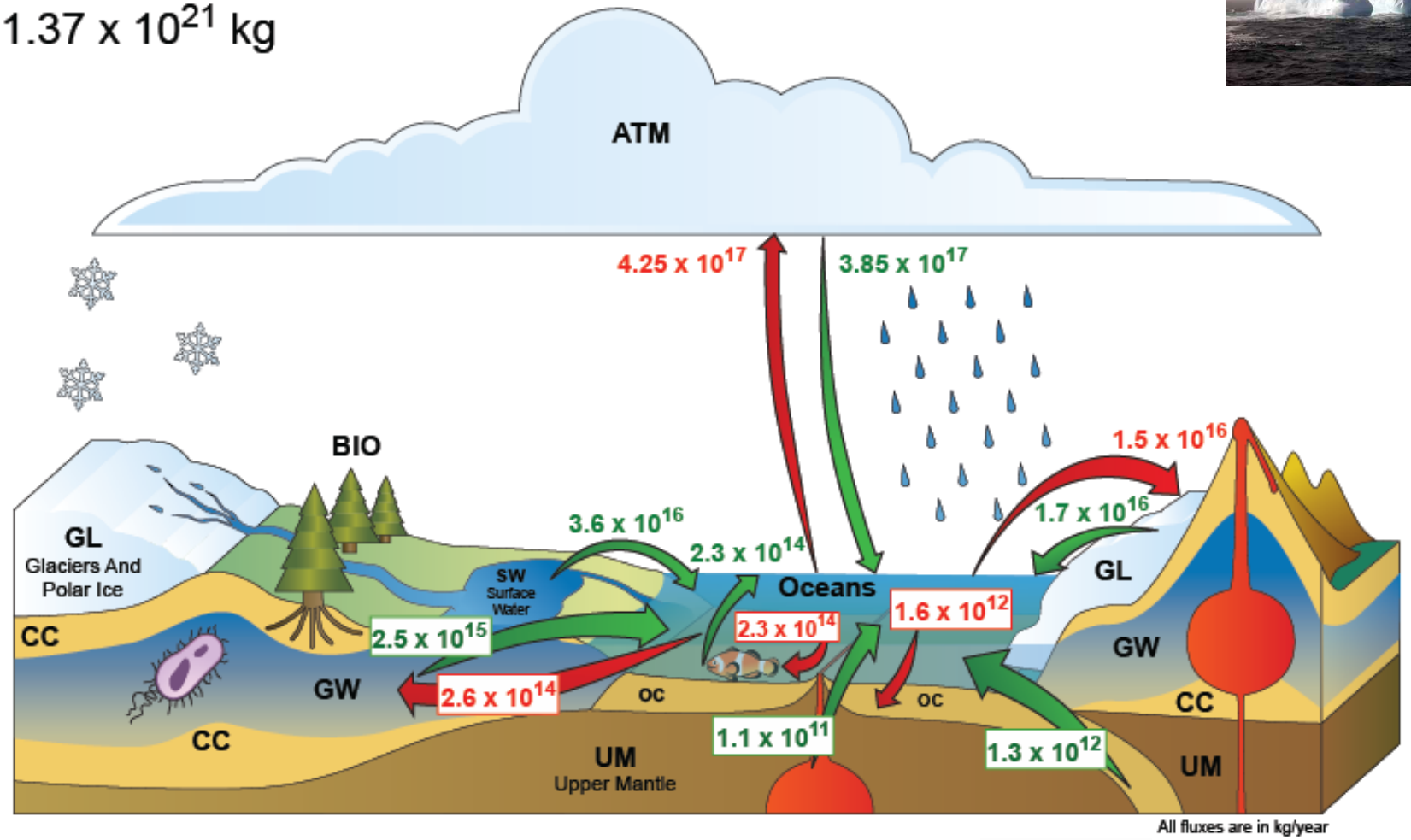
All fluxes in kg/yr x 10^{12}.
* Slight differences between "Total In" and "Total Out" are the result of rounding errors.

Geohydrologic Cycle

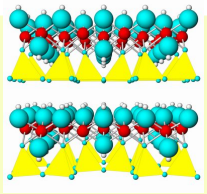


Earth's surface to top of stratosphere

Geohydrologic Cycle



Saline water in 5 oceans and major seas connected to oceans



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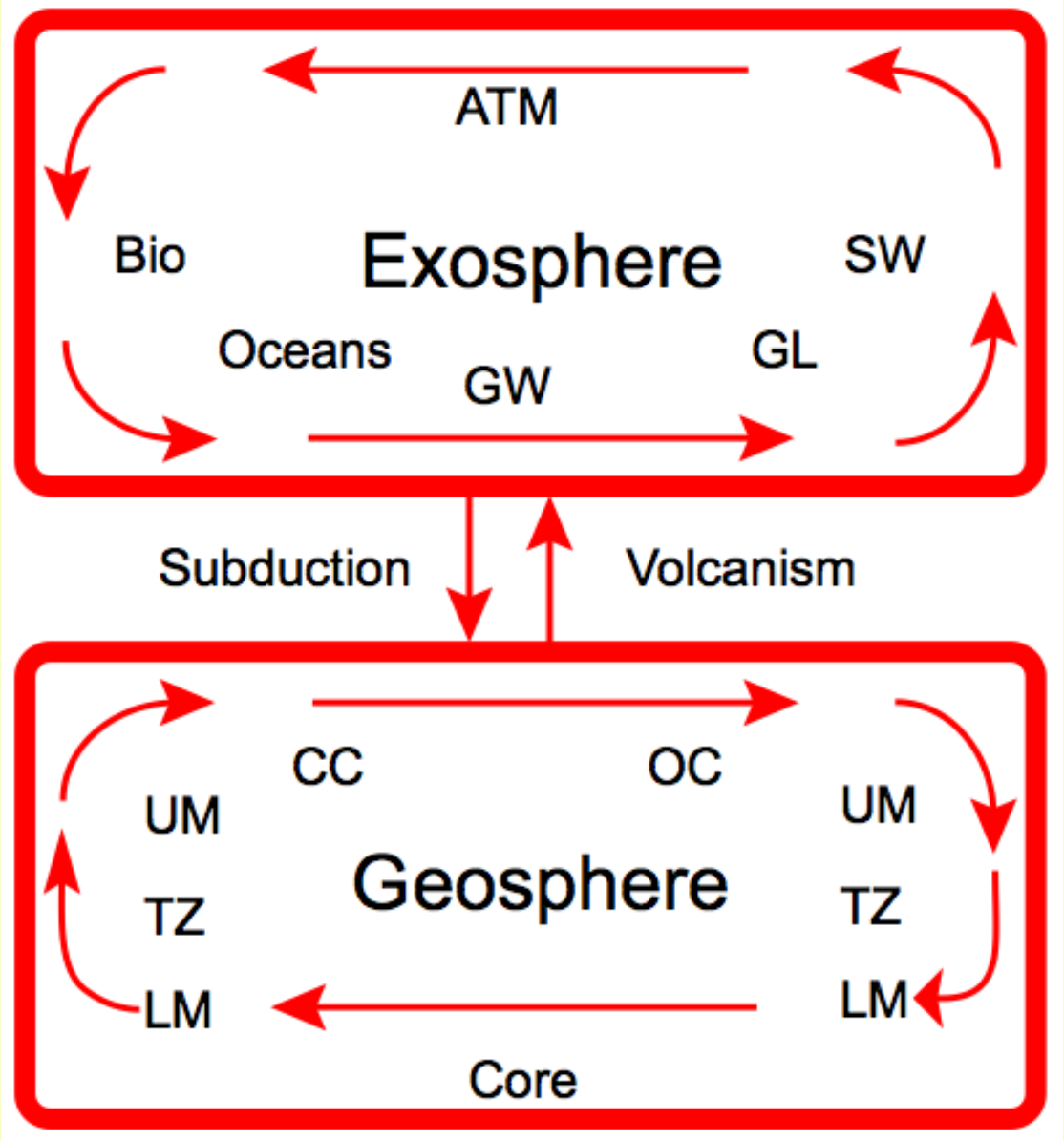
Geohydrologic Cycle



Exosphere:

Atmosphere (ATM)
Biosphere (BIO)
Ocean
Surface Water (SW)
Groundwater (GW)
Glaciers and Polar Ice (GL)

Geosphere:

Continental Crust (CC)
Oceanic Crust (OC)
Upper Mantle (UM)
Transition Zone (TZ)
Lower Mantle (LM)
Core

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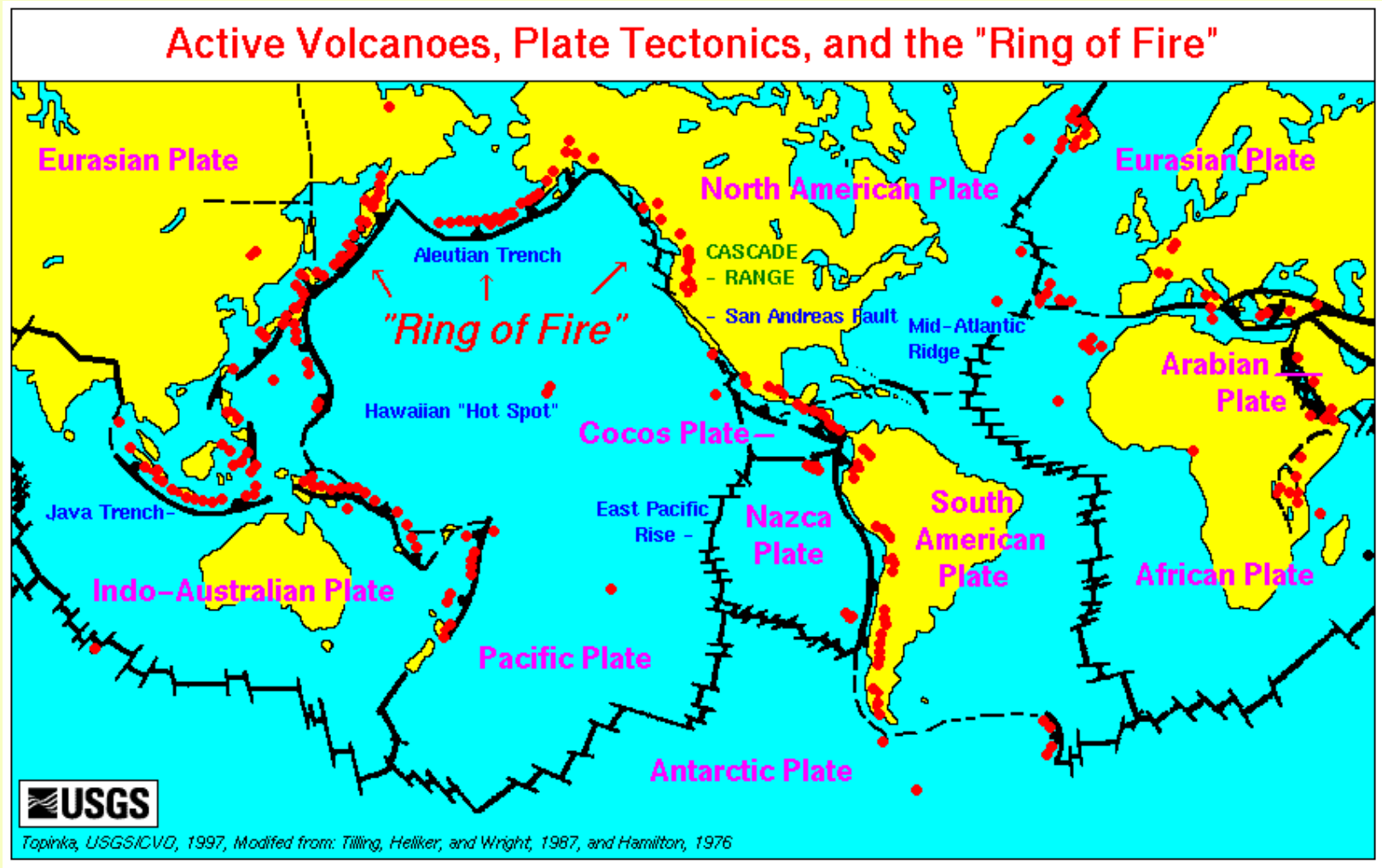
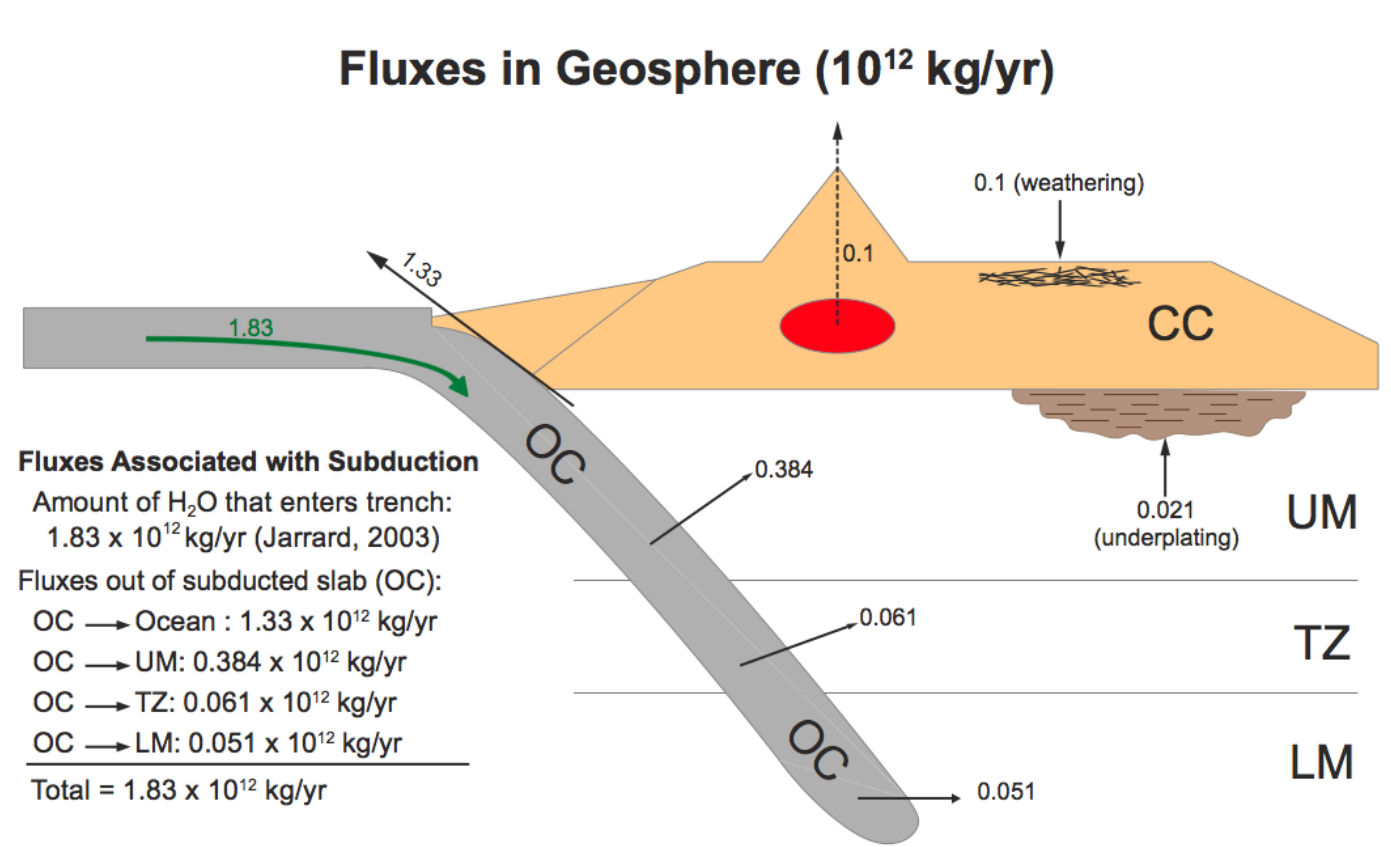
Water is cycled from the exosphere into the geosphere at subduction zones, and water is returned from the geosphere to the exosphere at mid-ocean ridges and arc volcanoes.



Summary of fluxes into subduction zones



- Most water (73%) that enters trench is returned to oceans by updip flow
- About 11% of subducted water is lost to arc magmas
- About 10% of subducted water is incorporated into minerals in the upper mantle
- About 6% of subducted water is transported into the transition zone and lower mantle

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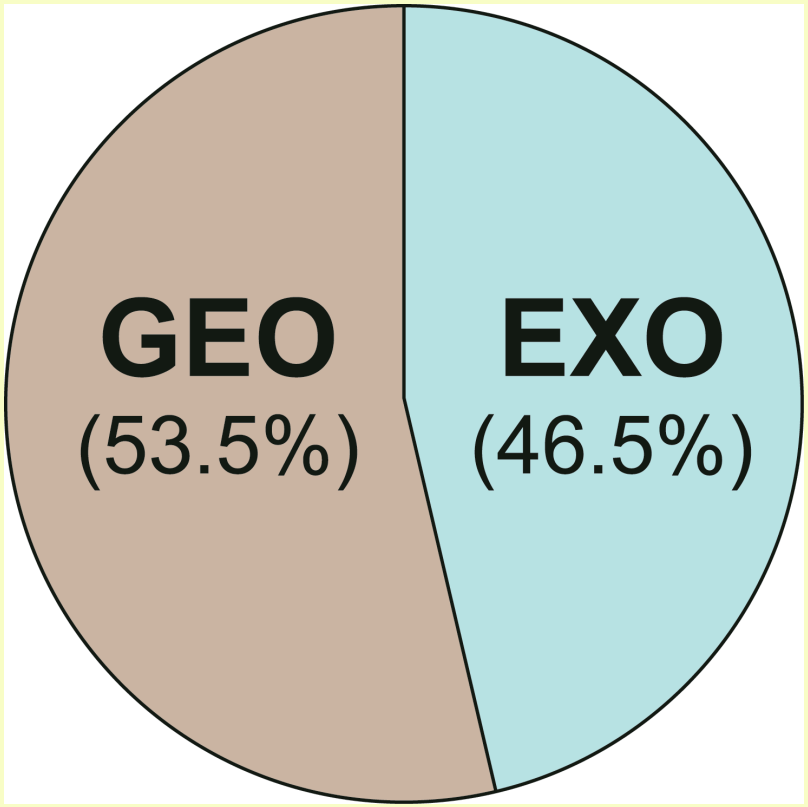
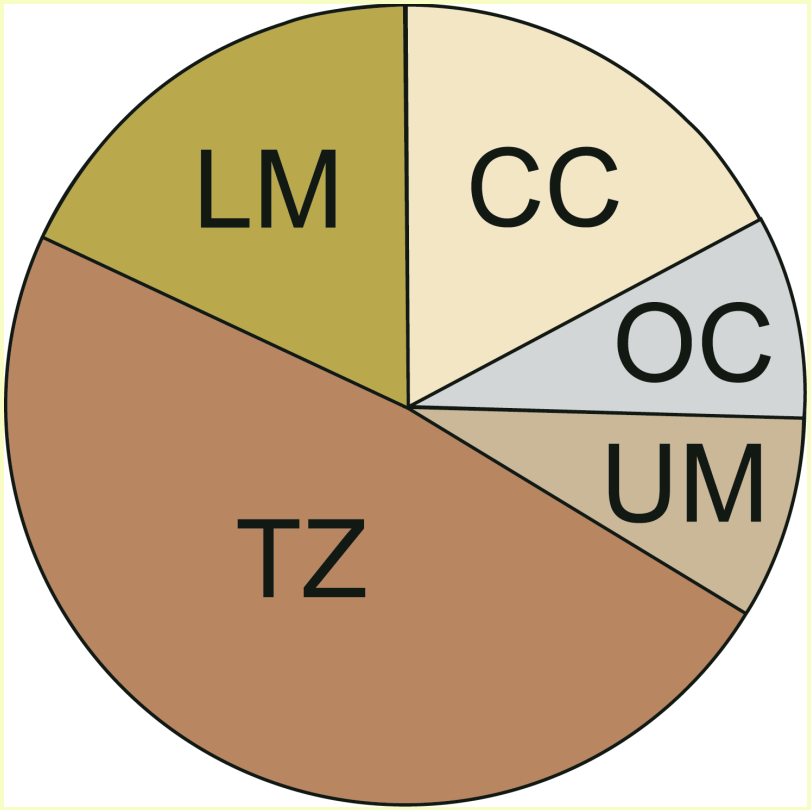
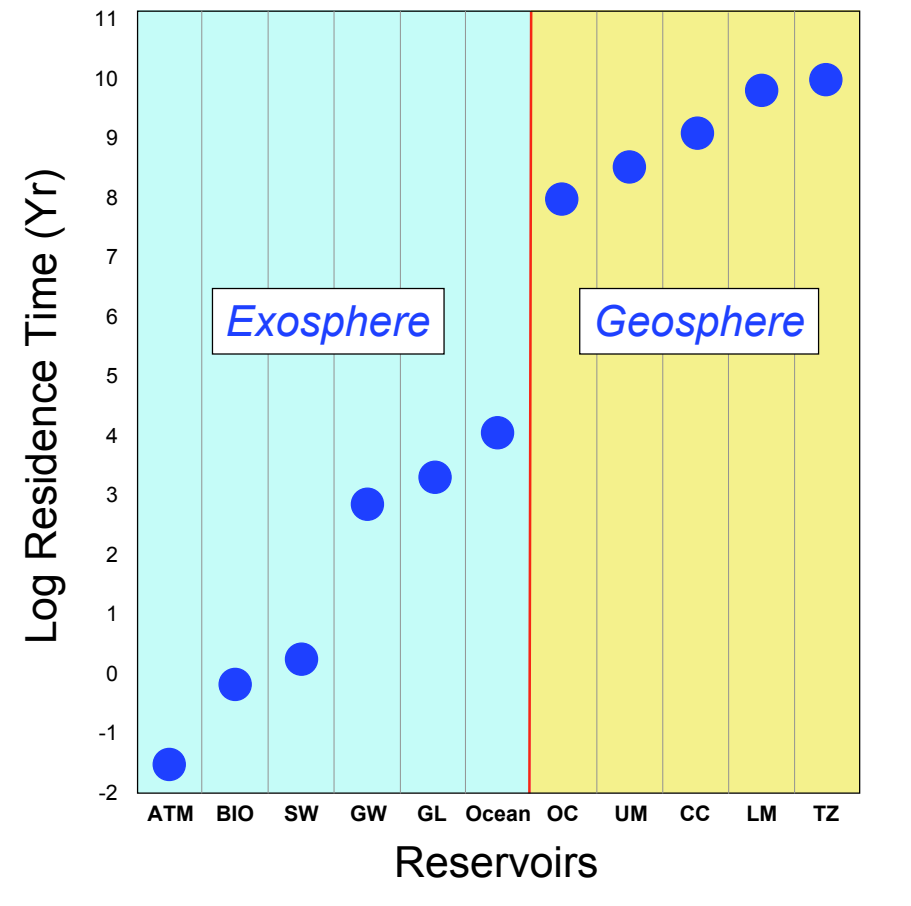
Geohydrologic Cycle

What proportion of the Earth's water is in the Geosphere?





How long does water reside in different reservoirs?



Residence Times - yrs

Atmosphere	2.62E-02
Biosphere	6.29E-01
Surface Water	1.68E+00
Groundwater	6.75E+02
Oceans	3.11E+03
Glaciers & Polar Ice	1.93E+03
Continental Crust	6.86E+08
Oceanic Crust	7.54E+07
Upper Mantle	1.23E+08
Transition Zone	7.72E+08
Lower Mantle	4.82E+9
Core	1.37E+15

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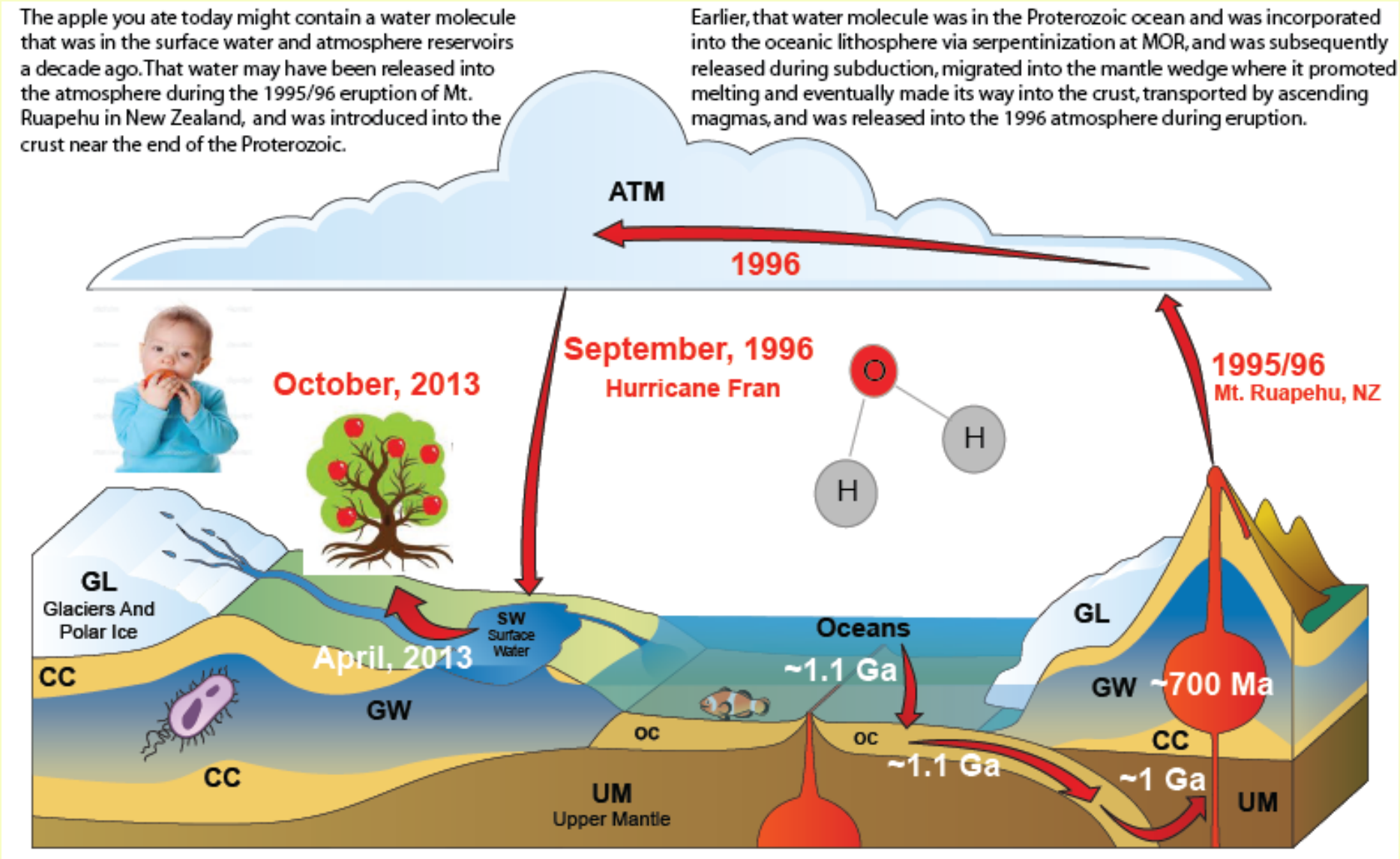
The earth is a dynamic system, and many materials, including water, have been continuously cycled through its many reservoirs during its ~4.5 Ga history.



We all live on this water planet which we have mistakenly chosen to call Earth. [Anonymous]

Earth and Moon from Mariner 10 Spacecraft

We offer our gratitude and special thanks to Pat Bickford for his leadership and advice as we prepared this chapter. We also thank the many reviewers and others who have provided data, advice and suggestions as we developed the whole-Earth geohydrologic cycle model.

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