(NASA-CR-164272) CONTRIBUTIONS TO A THERMODYNAMIC MODEL OF EARTH SYSTEMS ON RIVERS Final Report (General Technical Services, Inc.) 16 p HC A02/MF A01 CSCL 08F

N81-23506

Unclas

G3/42 15006

FEBRUARY 1981

FINAL REPORT

CONTRIBUTIONS TO A THERMODYNAMIC MODEL OF EARTH SYSTEMS

On Rivers

by

A. S. Iberall, S. Z. Cardon

prepared under

Contract No. NASW-3378

by

GENERAL TECHNICAL SERVICES, INC.

Upper Darby, Pa. 19082

for

NATIONAL AERONAUTICS

AND

SPACE ADMINISTRATION

Washington, D.C.

February 1981

FINAL REPORT

CONTRIBUTIONS TO A THERMODYNAMIC MODEL OF EARTH SYSTEMS

On Rivers

by
A.S. Iberall, S.Z. Cardon

prepared under
Contract No. NASW-3378
by
GENERAL TECHNICAL SERVICES, INC.
Upper Darby, Pa. 19082

for
NATIONAL AERONAUTICS
AND
SPACE ADMINISTRATION
Washington, D.C.

Abstract

This study began on the premise that it was necessary to obtain a uniform basis of modelling six earth systems - lithosphere, hydrosphere, atmosphere, geochemical sphere, biochemical sphere, and modern societal man - for rational management and policy making regarding earth resources. Modelling of rivers (as a component of the hydrological cycle) and of civilizations was begun. When it was recommended that effort be concentrated on rivers, a model for the chemical (e.g. ground water) erosion and physical (e.g. bed load, including sedimentation) erosion of the land was developed. The rudiments of the relation between a regulated sea level (for the past 2500 million years) and the episodic rise and erosion of continents was examined to obtain some notion of the process scalings. Major process scales of about 200 years, 100,000 years, 3 My, 40 My,300 My were estimated. It was suggested that a program targeted at ecological management would have to become familiar with processes at the first four scales (i.e. from glaciation to the horizontal movement of continents). The study returns to the initial premise. In order to understand and manage earth biology (life, <u>and</u> modern man), it is necessary minimally to pursue systems' biogeology at a considerable number of process space and time scales via their irreversible thermodynamic couplings.

Table of Contents

Sedimentation Revisited

Erosion Data

"The rate of erosion (of land) varies enormously, but the global rate is such that a mass equal to that of all the land above 200m is transported every 20 million years". (1). Elder continues, noting that the gross removal of matter from the land is largely dominated by two processes - chemical and mechanical. We have touched on the 'chemical' erosion by ground waters. Now we wish to return to the mechanical. He gives a rough estimate of about 30 tons per km^2 per year for chemical removal, on a continental scale, independent of altitude (i.e. as ground water erosion), and about 100 tons per km^2 per year for mechanical removal, approximately linear with altitude. We would like to test the latter statement.

If we turn to U.S.G.S. Water Supply Papers (2), we find suspended sediment data on the following basin systems

- Lower Mississippi Rivers Basins
- Western Gulf of Mexico Basins
- North Atlantic Slope Basins
- South Atlantic Slope Basins
- S. Atlantic and E. Gulf of Mexico Basins
- Ohio River Basin
- Cumberland and Tennessee River Basins
- St. Lawrence River Basin

Since the lower Mississippi River Basin data covers the largest single segment of drainage area, we will elaborate on its data.

Lower Mississippi River Basin (at St. Louis, Mo.)
Drainage area: 701,000 sq. mi.
Suspended solids data (1948-1857):

Maximum sediment mass rate (M) - 7,010,000 tons per day (5/5)
Minimum sediment mass rate - 4,340 tons per day (2/3)
Total yearly sediment rate - 417,000,000 tons per year
Yearly mean sediment rate - 1,140,000 tons per day
Specific sediment removal rate (M/A) - 230 tons per km^2 per year
Maximum discharge rate (Q) - 780,000 cfs (6/21)
Minimum discharge rate - 42,000 cfs (2/3)
Total yearly discharge - 96,600,000 cfs-days
Yearly mean discharge rate - 265,000 cfs
Maximum (mean) concentration (Δc) - 6,420 ppm (6/7)
Minimum concentration - 38 ppm (2/2 - 2/3)
Yearly mean concentration - 1,550 ppm
Particle size (median percentage finer than indicated size):

.002mm - 40%	.062mm - 81%
.004mm - 50%	.125mm - 88%
.008mm - 55%	.250mm - 97%
.016mm - 64%	.500mm - 99%
.031mm - 75%	

The particle distribution is basically log normal, (a normal distribution in the logarithm of particle size). It is an interesting comparison to make with airborne particles. Size distribution of ash particles in the stratosphere from eruptions of Mount St. Helen's recently appeared in Science (3). The log normal character of that distribution is clearly represented. Of interest is that the airborne particle range covers about 0.1-2μm (20 to 1), whereas the water dynamics covers a range of about 0.1 to 500μm (in this case 5,000 to 1).

We have introduced the dynamics of a bed load saltation-type law of atmospheres for river flow, including a brief introduction to the process by which the river acquires its suspended solids 'bed load' ((4), particularly the 4th and final report). At this point we would simply say that for large continental masses, on which a wide range of river velocities appear (unfortunately these water quality papers do not include the detailed velocity data, some such data have to be acquired from other sources), one may expect large range competences to transport material of a broad spectrum of sizes. Thus the Elder notion of near constant erosion (rather a distribution range for near constant erosion) has considerable validity.

More specifically, as these tabulated water quality data indicate, the transport expectation of rivers, which tend to exhibit velocities in the 1 to 10 fps range, is to move bed (including suspended load) material in the range 1μm to fraction mm size by hydrodynamic field forces within the boundary layer, but including more complex transport of larger size gravel (e.g. 0.1-2.5 inch), cobbles (2.5-10 inch), boulders (10-160 inch).

Additional discussion of these sediments movement issues may be found in (5). This reference indicates quite clearly the tendency of a large system (e.g. the Mississippi River) to tend to diminish the average size (and the maximum size) particles which are moved as one moves downstream in the larger system. The movement of sediment thus is not solely a direct transport toward the ocean margins, but a considerable redistribution of material and reformation of river valley shape (resculpting) as part of the longer term erosion of a land mass. The landscape is resculpted as an early step in its removal.

We have examined these Mississippi Basin data for some additional distribution characteristics. Thus, for example, on a logarithmic scale of discharge flow rates versus calendar time, we have counted the number of 'crossings' per discharge flow level. This has revealed that on a log scale we find two normal distributions, i.e. one for a low level sedimentation flux ranging from about 3,000 tons per day to 300,000 tons per day for the period mid-October to mid-February (autumn - winter), and a high level sedimentation flux ranging from about 100,000 tons per day to 10,000,000 tons per day for the period mid-February to mid-October (spring - summer). The related concentration range distributions are about 30-1,000 ppm, and 500-5,000 ppm. The much less fluctuating discharge rate is a modest 60,000-100,000 cfs winter range, and a 100,000-800,000 spring-summer range.

In the following table we have abstracted the sedimentation data from (2), concentrating on the sheaf of variables that may relate to the specific sedimentation rate.

Sedimentation M and River Flow Q in U.S.A. Basins

Data Source: USGS Water Supply Papers (2).

Area sq. mi.	Max. M t/d	Min. M t/d	Total M t/y	Specific M/A t/y km^2	Max. Q cfs	Min. Q cfs	Total Q cfs-days	Mean $\overline{Q}$ cfs	Basin Exit
									L. Miss. R. Basin
7.0(5)	7.0(6)	4.3(3)	4.2(8)	230	7.8(5)	4.2(4)	9.7(7)	2.7(5)	St. Louis
5.3(2)	11.9(3)	0.5	2.8(4)	20	2.2(2)	1.7	2.9(3)	7.9	Loma Parda
5.2(2)	2.0(5)	0	4.0(5)	300	2.0(3)	0	9.0(3)	25	Baeyeros
19.3(3)	3.7(6)	0	6.4(6)	130	13.8(3)	4	7.2(4)	2.0(2)	Amarillo
2.3(3)	6.3(5)	0	3.3(6)	550	14.7(3)	0	10.8(4)	3.0(2)	Carter
									W. Gulf Mex. Basin
8.0(3)	5.7(5)	0	15.9(5)	77	3.7(3)	0	2.3(4)	63	Aspermont
4.0(3)	4.1(4)	0	2.3(5)	22	3.0(3)	0	3.2(4)	88	Ft. Griffin
15.8(3)	3.9(5)	0	10.2(5)	25	2.9(3)	0	2.8(4)	77	Robert Lee
15.6(3)	7.6(4)	0	6.8(5)	17	18.3(3)	0	2.0(5)	5.5(2)	Three Rivers
10.4(3)	5.1(4)	10	14.4(3)	.5	6.1(2)	1.8(2)	12.4(4)	3.4(2)	Embudo
2.2(3)	10.2(4)	0.5	3.1(5)	55	11.4(2)	1.1	7.0(4)	1.9(2)	Abiquiu
3.2(3)	8.4(4)	0	5.8(5)	70	11.3(2)	0	7.3(4)	2.0(2)	Chamita
14.3(3)	18.4(4)	16	9.0(5)	24	17.5(2)	153	2.0(5)	5.5(2)	San Ildefonso
6.4(2)	3.6(5)	0	2.6(5)	160	4.1(2)	0	14.9(2)	4.1	Domingo
10.4(2)	16.7(4)	0	7.9(5)	290	8.7(2)	0	7.0(3)	19	Bernalillo
17.3(3)	3.2(5)	2	17.0(5)	38	2.1(3)	3	14.2(4)	3.9(2)	Bernalillo

Area sq. mi.	Max. M t/d	Min. M t/d	Total M t/y	Specific M/A t/y km^2	Max. Q cfs	Min. Q cfs	Total Q cfs-days	Mean $\bar{Q}$ cfs	Basin Exit
19.2(3)	2.4(5)	0	8.6(5)	17	15.4(2)	0	8.6(4)	2.4(2)	Bernardo
4.2(2)	15.5(4)	0	7.5(5)	690	2.8(2)	0	16.4(2)	4.5	Cabezon
13.9(2)	7.4(5)	0	14.4(5)	400	10.7(2)	0	6.4(3)	18	Guadalupe
2.6(3)	7.9(4)	0	2.3(5)	34	4.5(2)	0	2.5(3)	6.8	Correo
5.2(3)	10.9(5)	0	4.1(6)	300	18.5(2)	0	11.7(3)	32	Rio Puerco
5.9(3)	9.6(5)	0	4.6(6)	300	18.3(2)	0	11.6(3)	32	Bernardo
13.8(2)	3.7(5)	0	2.5(6)	700	8.5(2)	0	6.1(3)	17	San Acacia
2.7(4)	15.7(5)	0	5.3(6)	76	2.0(3)	0	9.1(4)	2.5(2)	San Acacia
2.8(4)	3.7(5)	0	10.5(5)	14	14.3(2)	0	6.0(4)	1.6(2)	San Marcial
4.0(3)	4.5(5)	5	7.8(5)	75	18.9(2)	35	4.4(4)	1.2(2)	Puerto de Luna
15.3(3)	11.6(4)	0.5	5.8(5)	15	14.5(2)	1.0	7.0(4)	1.9(2)	Artesia
									<u>N. Atl. Basin</u>
98	6.7(3)	0.2	8.6(3)	34	10.9(2)	27	7.2(4)	2.0(2)	Broad Brook
3.5(3)	3.0(5)	0.8	9.0(5)	100	6.9(4)	88	2.7(6)	7.4(3)	Cohoes
6.8(3)	11.9(4)	11	7.6(5)	43	12.1(4)	4.0(3)	5.3(6)	1.5(4)	Trenton
3.6(2)	9.0(4)	0	16.4(3)	18	5.3(3)	2.1(2)	2.6(5)	7.1(2)	Berne
18.9(2)	6.5(5)	2	2.5(5)	51	[illegible].2(4)	7.7(2)	11.3(5)	3.1(3)	Manayunk
3.1(2)	2.1(4)	0.5	3.2(4)	39	2.4(3)	136	15.2(4)	4.2(2)	Wilmington
12.2	19.4(2)	0	4.2(3)	1[illegible]0	6.3(2)	0.5	7.2(3)	20	Mainesburg

Area sq. mi.	Max. M t/d	Min. M t/d	Total M t/y	Specific M/A t/y km²	Max. Q cfs	Min. Q cfs	Total Q cfs-days	Mean $\bar{Q}$ cfs	Basin Exit
10.2	7.7(2)	0	3.6(3)	140	3.6(2)	0.2	6.7(3)	18	Mainesburg
2.7(2)	6.3(3)	1	3.5(4)	50	3.1(3)	130	15.5(4)	4.2(2)	Milesburg
3.4(2)	2.3(3)	0.5	2.8(4)	32	3.3(3)	140	16.9(4)	4.6(2)	Blanchard
3.4(3)	12.8(4)	0	2.8(5)	32	3.3(4)	6.2(2)	16.6(5)	4.5(3)	Newport
15.0	5.1(2)	0.05	11.9(2)	31	5.3(2)	4.3	7.2([illegible])	20	Loysville
16.3(2)	18.3(4)	1	4.9(3)	1.2	4.8(3)	3.0(2)	2.8(5)	7.7(2)	Front Royal
7.7(2)	2.5(3)	0.5	7.2(3)	3.6	3.4(3)	105	11.9(4)	3.3(2)	Stratsburg
6.2(2)	2.3(4)	0.5	4.5(4)	28	4.4(3)	38	14.3(4)	3.9(2)	Remington
									S. Atl. Basin
4.7(2)	2.3(4)	0.5	17.8(3)	15	18.2(2)	38	8.2(4)	2.2(2)	Colpepper
2.1(3)	7.6(4)	1	4.1(4)	7.6	14.0(3)	2.8(2)	4.8(5)	1.3(3)	Buchanan
4.6(3)	17.0(4)	2.0	12.2(4)	10	18.5(3)	4.6(2)	9.1(5)	2.5(3)	Scottsville
18.0(2)	14.1(4)	4	15.7(4)	34	9.0(3)	2.0(2)	3.3(5)	9.1(2)	Altavista
3.0(3)	7.2(4)	13	19.4(4)	25	14.1(3)	3.0(2)	5.5(5)	1.5(3)	Randolph
2.6(3)	7.7(4)	11	4.6(5)	68	16.0(3)	2.4(2)	6.3(5)	1.7(3)	Paces
									Ohio R. Basin
6.0(3)	4.6(4)	3	11.7(5)	75	2.5(4)	6.2(2)	3.0(6)	8.2(3)	Dresden
5.1(3)	11.2(4)	1	13.8(5)	100	3.1(4)	3.4(2)	16.6(5)	4.5(3)	Higby
51	11.0(2)	.05	6.1(3)	46	5.7(2)	1.7	15.9(3)	44	Selma
29	2.4(2)	.05	13.5(2)	18	2.1(2)	1.4	8.7(3)	24	Pitchin

Area sq. mi.	Max. M t/d	Min. M t/d	Total M t/y	Specific M/A t/y km²	Max. Q cfs	Min. Q cfs	Total Q cfs-days	Mean $\bar{Q}$ cfs	Basin Exit
129	13.6(3)	.05	12.6(3)	38	11.5(2)	11	4.1(4)	1.1(2)	Oldtown
26	6.5(2)	0	2.1(3)	31	3.1(2)	1.2	9.6(3)	26	Cedarville
64	19.3(2)	.05	9.7(3)	59	9.6(2)	4.6	2.3(4)	63	Wilberforce
2.2(2)	5.3(4)	.05	15.6(4)	270	4.9(3)	4.2	9.1(4)	2.5(2)	Roachester
2.3(3)	2.2(5)	0.5	2.3(6)	390	3.1(4)	72	13.6(5)	3.7(3)	McKinneysburg
5.4(3)	2.2(5)	1	3.4(6)	240	7.2(4)	154	2.9(6)	7.9(3)	Frankfort
32	6.5(3)	0	2.8(4)	340	12.3(2)	0	12.0(3)	33	Waterford
12.3(2)	10.3(4)	0	8.9(5)	280	2.1(4)	12	5.1(5)	1.4(3)	Shepardsville
17.9(2)	15.3(4)	0.5	7.4(5)	160	3.6(4)	111	10.6(5)	2.9(3)	Munfordsville
16.8(2)	9.1(4)	0.5	5.4(5)	120	3.6(4)	69	8.6(5)	2.4(3)	Bowling Green
500	2.4(4)	0.5	2.9(5)	220	8.5(3)	18	2.4(5)	6.6(2)	Rough
2.6(2)	13.7(2)	0	16.9(3)	25	3.9(3)	0	9.6(4)	2.6(2)	Olney
									<u>Cumb. and Tenn. Basin</u>
16.1(2)	6.8(4)	0.5	6.0(5)	140	2.9(4)	42	11.0(5)	3(3)	Williamsburg
.67	45	(.01)	--	--	(25)	(.06)	--	--	Parkers Lake
									<u>St. Lawrence R. Basin</u>
6.3(3)	16.1(4)	0.5	19.8(5)	120	4.3(4)	110	19.3(5)	5.3(3)	Waterville
4.3(2)	2.8(4)	.05	10.2(4)	94	8.2(3)	4.8	15.2(4)	42	Woodville
12.5(2)	4.7(4)	.05	3.3(5)	100	14.2(3)	17	3.5(5)	9.6(2)	Fremont
7.1(2)	3.4(4)	0.5	3.2(5)	170	7.9(3)	76	3.1(5)	8.5(2)	Independence

Area sq. mi.	Max. M t/d	Min. M t/d	Total M t/y	Specific M/A t/y km²	Max. Q cfs	Min. Q cfs	Total Q cfs-days	Mean $\bar{Q}$ cfs	Basin Exit
									S. Atl. Basin
2.3(3)	10.8(4)	3	10.2(5)	170	2.[illegible](4)	7.9(2)	10.4(5)	2.8(3)	Yadkin College
									Ohio R. Basin
9.4(2)	14.0(3)	0.5	11.4(4)	47	7.5(3)	48	2.5(5)	6.8(2)	Athens
2.4(2)	5.4(3)	.05	6.1(4)	100	5.7(3)	1.3	11.6(4)	32	Greenup
8.1(2)	7.1(4)	0.5	3.3(5)	160	17.3(3)	23	3.1(5)	8.5(2)	Bourneville

Note: The bracketed numbers each denote a power of ten multiplier.

Although these data are selected from only one continent, the North American, and relate mostly to a temperatate climate, and thus neglect data from tropical land masses and ice inundated land masses, hopefully they present some of the expected range of basin erosion.

We have taken these data and examined the specific erosion rate M/A against the range variables of flow, Q minimum, mean, and maximum. There appears to be no significant correlation. (A wide range in Q, e.g. as measured by the mean to maximum interval range in Q, or perhaps twice that logarithmic interval for the range minimum to maximum, suggests that the river has a velocity variation which is an appreciable fraction of the interval 1-10 fps). Over a discharge flow range of rivers of $1\text{-}10^5$ cfs, with rivers whose individual range is perhaps 1 to 4 decades wide, their specific erosion rate seems to be independent of either the discharge rate or the discharge range.

We have therefore regarded the specific erosion rate to be represented by an almost 'independent' distribution function. Plotting the value M/A cumulatively over the experimentally observed range of 0.5 to 1,000 tons per year per km^2 (by decades), we have found a log normal distribution whose mean is about 80 tons per year per km^2 with a standard deviation of about 0.8 decade (i.e. 1.6 to 1, thus 50-130 is the central range for one standard deviation). The total range is about 12-400 tons per year per km^2. Thus Elder's statement is quite essentially correct.

Discussion

Technical efforts to deal with the dynamics of erosion are to be found in (4,5) and references therein. We believe that the following discussion may touch on some salient ideas which would augment any such analytic issues.

The existence of rainfall and its runoff on and under the earth's surface assures the creation of sedimentation deposits in the ocean margins and the erosion of continents at a geological time scale. However such rainfall also assures that there will be a near - continuum of processes by which that erosion takes place. It is the consequences of an inexhorable trickling under gravity force in the presence of a spectrum of atomic species.

Whereas in an earlier study, we had tentatively inferred that a dominant slow process for ground waters (one slow enough to fit geological time) was ion exchange, it seems clearer now that many more processes take place, beginning from a very slow solubilizing process which includes physical erosion for poorly soluble materials within the ground ((6), second report) and winding up as much more rapid mechanical abrasion by surface waters which self-generate (by its carving competence) a stream with abrasive competence in the 1-10 fps range. There is no doubt that other processes may augment the common range, e.g. surface winds, cracking by freezing, rheological properties of earth, but the 'standard' processess seem to be competent to produce nearly most of the common range of erosion. Thus Elder's global summary for continental processes is fair - 100 tons per year per km^2 for mechanical sedimentation movement (our estimate from the U.S.A. 80 tons), 30 tons per year per km^2 for chemical 'solubility' movement.

A note is desirable on the latter number: The approximate run-off for rivers is roughly about 6 inches of rainfall per year. This corresponds to a discharge efflux of 5.4 x 10^6 cfy per km^2. If we were to elect an average chemical concentration of 350 ppm, this would correspond to about 60 tons per year per km^2. Nitrate, for example, with a concentration of the order of 1 ppm would contribute about 0.12 tons per year per km^2. If we adopt Livingstone's summary (6,7) of about 120 ppm for the mean composition of river waters of the world, we would reduce the estimate to 20 tons per year per km^2. However if we actually take Livingstone's runoff data for each of the continents, as tabulated below, we find an average of about 34 tons per year per km^2. Thus Elder's estimate is essentially precise.

Continental Data on Chemical Denudation

Source: Livingstone (7)

Continent	Area 10^3 mi^2	Runoff 10^3 cfs	Dissolved solids-ppm	Specific Denud. tons/yr-km^2
North Am.	8,172	5,100	142	33.7
Europe	4,211	2,796	182	46.1
Asia	17,985	12,431	142	37.4
Africa	11,500	6,604	121	26.5
Australia	2,970	354	59	26.8
South Am.	7,551	8,962	69	31.2
				34 mean

From the point of view of simple nonhistorical processes, this is/as much as one might say about river processes. However such a status would leave very weak connectivity to the remainder of earth processes, particularly biological (or actually biochemical). Thus, although it is beyond the scope that we have been asked to limit ourselves to, we might attempt a few conjectures that might be relevant to earth resources studies, whether geological or biological.

With an average thickness of continental crust of about 30km (see third quarterly report (6)), and with an average height of land above sea level of about 5km, land surfaces become featureless in about 10^8 years. Because of isostatic buoyancy, about 5.6km has to be removed for each km of continental height. As Elder shows, these 'facts' can be encompassed by elementary theory in the following way. The removal of 130 tons per km^2 per year (taking an average of 2.8 gm/cm^3) corresponds to an exponential time constant of about 1.2 x 10^8 years. However if we take into account the elastic rebound due to isostacy the time constant would be about 6.8 x 10^8 years.

($H\Delta\rho$, the density buoyancy of a continental slab of total height H supported by a magma of density ρ, is equilibrated by the density buoyancy of the continent above sea level $h\rho$ (its height is h) and by the buoyancy of the continental segment under the ocean $d(\rho-\rho_w)$ (d is the ocean depth). Assuming the ocean depth to be constant, and the erosion rate to be proportional to the height h of continent above sea level

$$\frac{dh}{dt} = -\frac{h}{\tau}$$

$$\Delta\rho \frac{dH}{dt} = \rho \frac{dh}{dt}$$

These two relations permit making the estimates.)

These numbers provide some notion of the global time-scale of sediment production relevant to erosion and to a consequent change in buoyancy. But, as Elder and Wood (see (6)) point out, there are more rapid areal rearrangements of the crust as a whole (plate tectonics) which prevent the embarrassing excess of sediment and accounts for the more nearly constant depth of the ocean.

This highlights the significance of the Exxon sea level data (6) in which one finds relatively rapid million year changes in level of a few hundred meters in sea level for the past 7 million years. Thus small plate adjustments at some such more rapid process (more rapid than 10^8 years) is a more dominant process than slow land erosion.

In more detail, in (6) we identified a number of adjustment processes; i.e. a 200-400 year adjustment of glacio-isostatic origin, the one (changing to 3-4) million year process or processes which may be associated with plate rolling (or subduction) or thrust faulting, or to midocean ridge spreading all due to sediment weight, and then there may be the longer horizontal plate movements at the 30-40 million year scaling.

Do one or more of these scales interact with the biological scales? We would surmise that the answer is yes, but that the issues are not significantly decided in the rivers.

We would surmise, possibly differing from the thrust given to the theme of ocean biochemistry in our second quarterly report (6) that the interaction of sedimentation and water has to be treated as a systems' process, wherein its long term scalings have to be uncovered. We sense that there are three systems' scalings that have to be treated - one for the deep ocean system, one for continental margins, and one for the run-off system on the land. As far as the run-off system on land is concerned, we do not believe that there is a great deal of process dynamics besides that associated with the high frequency biological oxygen demand and the fitting of species niches, and the much slower process of species adaption. More interesting global biochemistry is associated with the other two regions (except for global catastrophes, of wiping out biological species by extraterrestrial collisions, as recent theorizing has brought to the fore).

Thus we sense, once again, that a narrow focus on the hydrological cycle on the land masses is not sufficient to uncover all of the important and interesting earth processes. Instead, once again, it suggests the need to couple the six interacting systems we initially proposed and started to develop. The added factor that we have learned and highlighted in this program is a sharper idea of the pertinent time scales.

Thus, for example, in examining the recommendations put forth in (8), we can agree with their Recommendation 7 that "theory includ[ing] extensive quantitative modelling of the global cycles of the earth's major elements" is desirable for a useful theory of global ecology, but we cannot agree with Recommendation 12 which would restrict the response to major events of the Pleistocene (glacial) record.

Such restriction would concentrate on an inordinate amount of Pleistocene record detailing and still miss the major factors influencing cyclic factors important to biology. Such a scale has to extend to the epoch relevant to current continental formation, e.g. the 30-40 million year process cycles.

Economic geologists who are really also concerned with biogeological processes of even longer scales may feel excluded from such a range of concerns, but that simply neglects a longer scale story on the more fundamental relation between phylogenetic processes and geological processes.

The biochemistry on earth (as a physical process) must basically be founded on evolutionary biology, interacting with historical geological processes. This provides, as we have suggested, a number of the relevant time scales for a biogeologically oriented ecological study.

References

1. Elder, J., The Bowels of the Earth, Oxford U. Press, London, 1976.

2. Quality of Surface Waters of the United States, U.S.G.S. Water-Supply Papers, No. 1199, 1951; 1450, 1956; 1520, 1957. U.S. Govt. Print., Off., D.C.

3. Farlow, N., etal "Size Distributions and Minerology of Ash Particles in the Stratosphere from Eruptions of Mount St. Helens", Science 211, 832, 1981.

4. Iberall, A., Cardon, S., "The Physical Description of the Hydrology of a Large Land Mass Pertinent to Water Supply and Pollution Control", 4 Qtrly reports to DWSPC, Public Health Service, Dept. HEW, Contract SAph 78640, 1961-1962.

5. Leopold, L., Wolman, M., Miller, J., Fluvial Processes in Geomorphology, Freeman, San Francisco, 1964.

6. Iberall, A., Cardon, S., "Contributions to a Thermodynamic Model of Earth Systems", 3 Qtrly reports to NASA-Hq., May, Aug., Nov., 1980.

7. Livingstone, D., "Chemical Composition of Rivers and Lakes", Geo. Surv. Prof. Paper 440-G, U.S. Govt. Print. Off., 1963.

8. Botkin, D., "Life from a Planetary Perspective", Report to NASA Hdqts., NASW-3392, Nov., 1980.