Erosion, transport & deposition

Streams act as giant conveyer belts to transport the products of chemical weathering on the continents to the oceans.

Sediment transport in a stream has three components

- suspended load — water is muddy after a storm
- bed load — dragged or tumbled along the stream bottom
- dissolved load — solids in solution

The dissolved load is the easiest to measure because the solutes are well mixed throughout the water — we shall discuss this later

Bedload transport is the hardest to measure. Even suspended load transport is not easy because must sample entire cross-sectional area of stream.

Example: Fig 4.47 — the Danube.

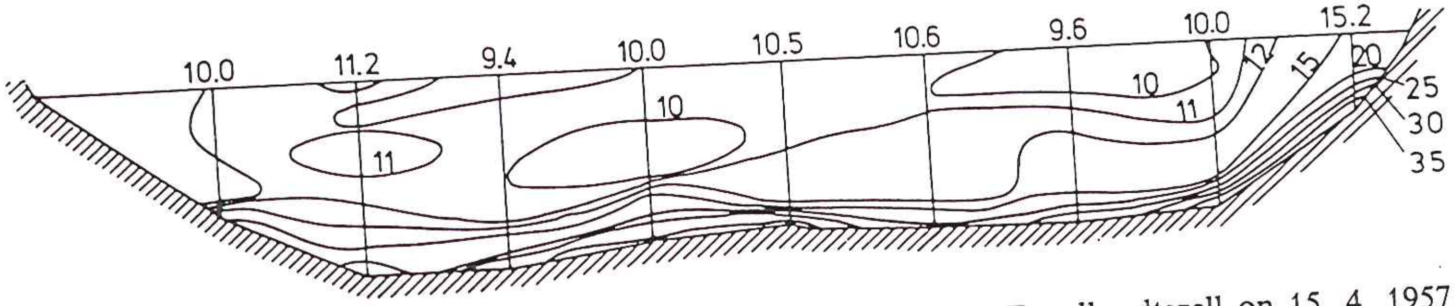


Fig. 4.47. Distribution of suspended load in $g\,m^{-3}$ in Danube at Engelhardtszell on 15. 4. 1957. (From data of Donaukraftwerke Jochenstein AG)

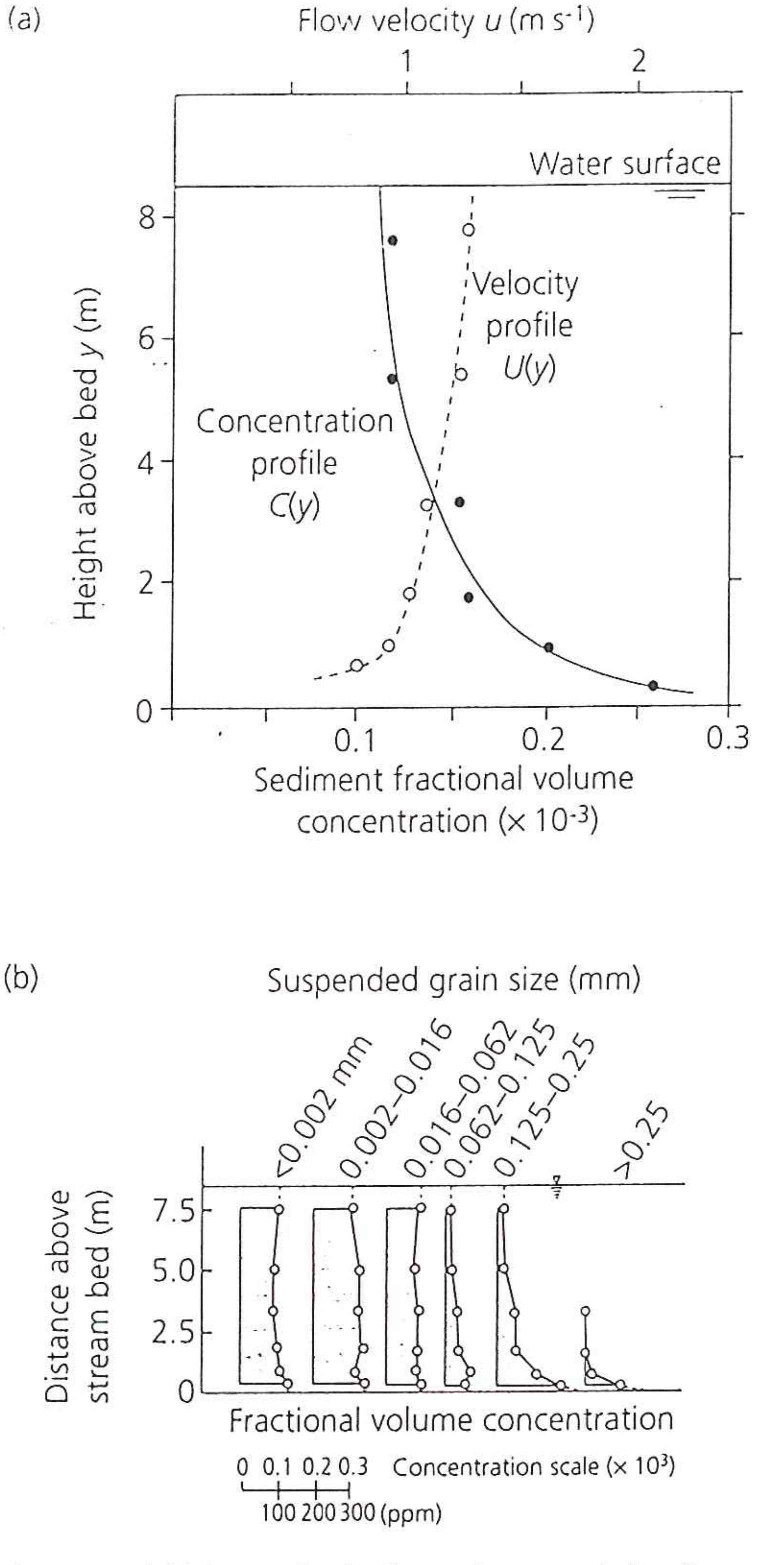


Fig. 5.12 (a) Meaured velocity and suspended sediment concentration profiles in the Mississippi River at St Louis, Missouri, on 24 April 1956. (b) Sediment concentration profiles for a range of grain size intervals. After Colby (1963) [27].

The amount of suspended sediment is greater near the base because of settling.

Not surprisingly, there are tremendous variations in the three loads with time, associated with storms.

Example – the 1941 flood on the San Juan River near Bluff, Utah

Figure A shows the variation in suspended load transport (tons of sediment per day) and discharge (cubic feet per second)

The suspended load and discharge both went up, then down

The maximum discharge was ~ 50,000

$$5 \cdot 10^4 \frac{ft^3}{sec} \times 62.4 \frac{lb}{ft^3} \times \frac{1}{2200} \frac{tons}{lb} \times 86400 \frac{se}{d}$$

$$= 1.2 \cdot 10^8 \text{ tons of } H_2O/\text{day}$$

The suspended load then was 10^7 tons/(d

The "water" was a slurry 8% mud by weight

10^8 tons H_2O / day maximum flow

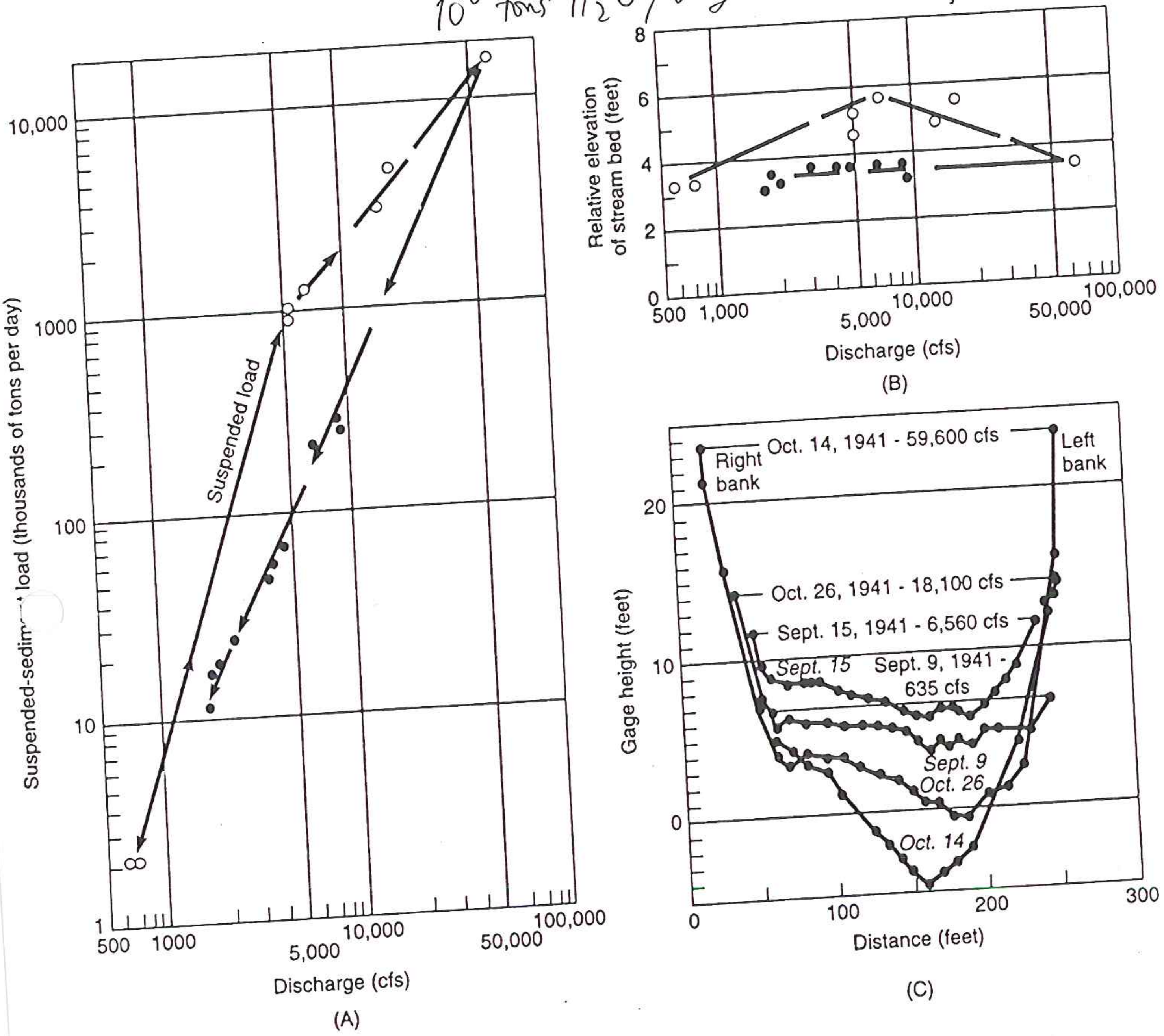
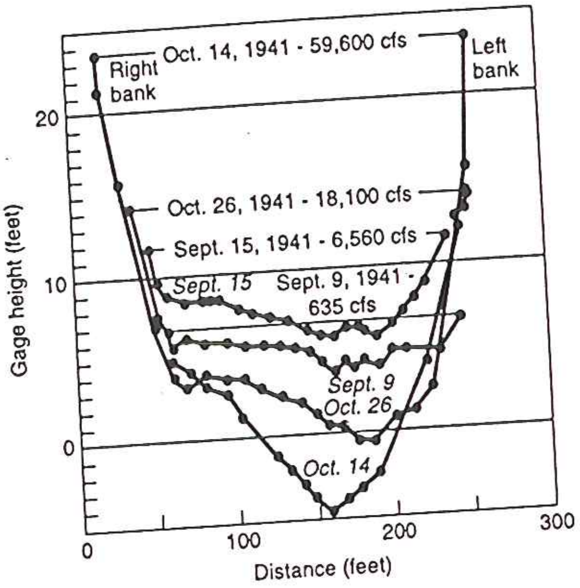
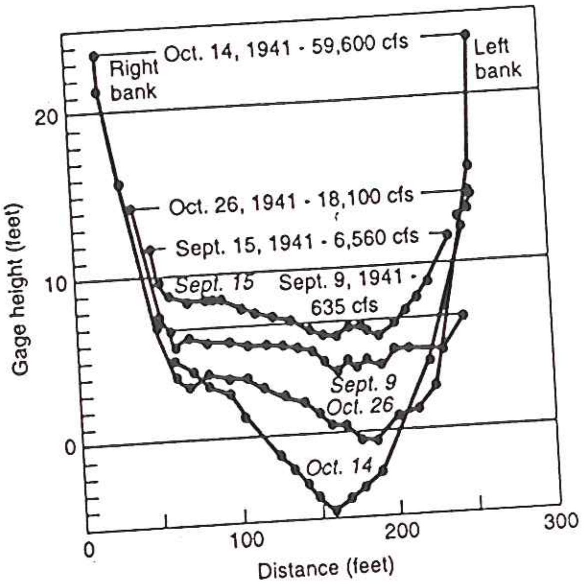


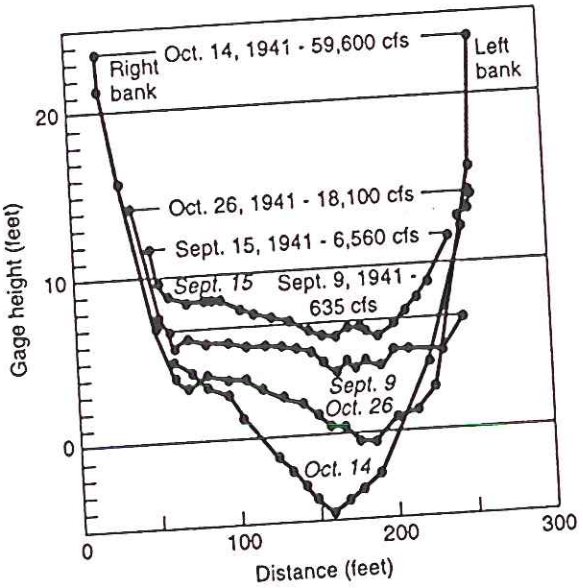
FIGURE 6.14

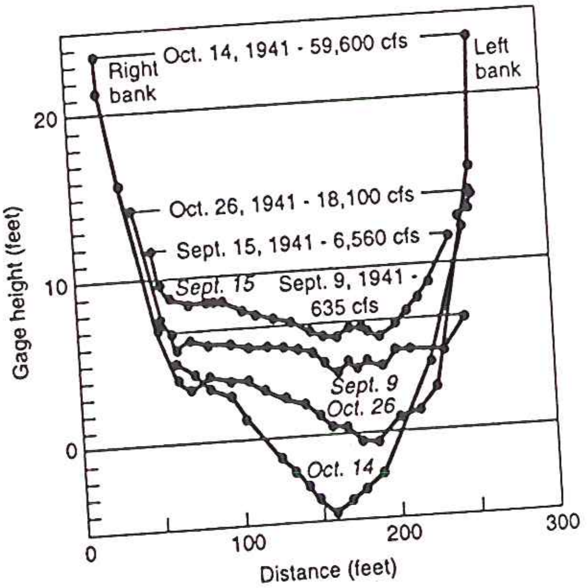
Changes in (A) suspended load, (B) streambed elevation, and (C) water-surface elevation with discharge during September–December 1941 flood of the San Juan River near Bluff, Utah.

(Leopold and Maddock 1953)


Gage height (feet)
20
10
0
Right bank
Oct. 14, 1941 - 59,600 cfs
Left bank
Oct. 26, 1941 - 18,100 cfs
Sept. 15, 1941 - 6,560 cfs
Sept. 15
Sept. 9, 1941 - 635 cfs
Sept. 9
Oct. 26
Oct. 14
0
100
200
300
Distance (feet)


Gage height (feet)
20
10
0
Right bank
Oct. 14, 1941 - 59,600 cfs
Left bank
Oct. 26, 1941 - 18,100 cfs
Sept. 15, 1941 - 6,560 cfs
Sept. 15
Sept. 9, 1941 - 635 cfs
Sept. 9
Oct. 26
Oct. 14
0
100
200
300
Distance (feet)


Gage height (feet)
20
10
0
Right bank
Oct. 14, 1941 - 59,600 cfs
Left bank
Oct. 26, 1941 - 18,100 cfs
Sept. 15, 1941 - 6,560 cfs
Sept. 15
Sept. 9, 1941 - 635 cfs
Sept. 9
Oct. 26
Oct. 14
0
100
200
300
Distance (feet)


Gage height (feet)
20
10
0
Right bank
Oct. 14, 1941 - 59,600 cfs
Left bank
Oct. 26, 1941 - 18,100 cfs
Sept. 15, 1941 - 6,560 cfs
Sept. 15
Sept. 9, 1941 - 635 cfs
Sept. 9
Oct. 26
Oct. 14
0
100
200
300
Distance (feet)

The cross sections show the variation in water-surface elevation and the position [illegible] of the channel bed with time

Sept 9 – 15 : stream level rises, sedimentatio
Sept 15 – Oct 14 : increase in discharge,
scouring of channel
stream ~ 30 feet deep
Oct 14 – Oct 26 : stream level falls,
sedimentation continues

This type of variability is typical of all streams everywhere. Makes it very difficult to get an accurate accounting of sediment transport budgets.

Note, however, that during this dynamic rise and fall, accompanied by both sedimentation and scouring, there is a close relation between sediment transport S and stream discharge Q

$$S \approx \text{const}\ Q^{1.5}$$

Such empirical relations have been developed for many other streams.

Examples:

- figure from Suppe $S \approx \text{const } Q^2$
- Fig. 3.27, Tanana River, Alaska

$$S \approx \text{const.} \, Q^{2.7}$$

In this case the bed load transport has been measured separately

bedload flux $B \approx 0.03 \, S$
3% of suspended load flux

whether a stream scours its bottom or deposits its suspended load on its bottom depends on both the water velocity v and the sediment size d

Discuss figure from John — also in Judson & Richardson

Also Fig. 13.4 in Press & Siever

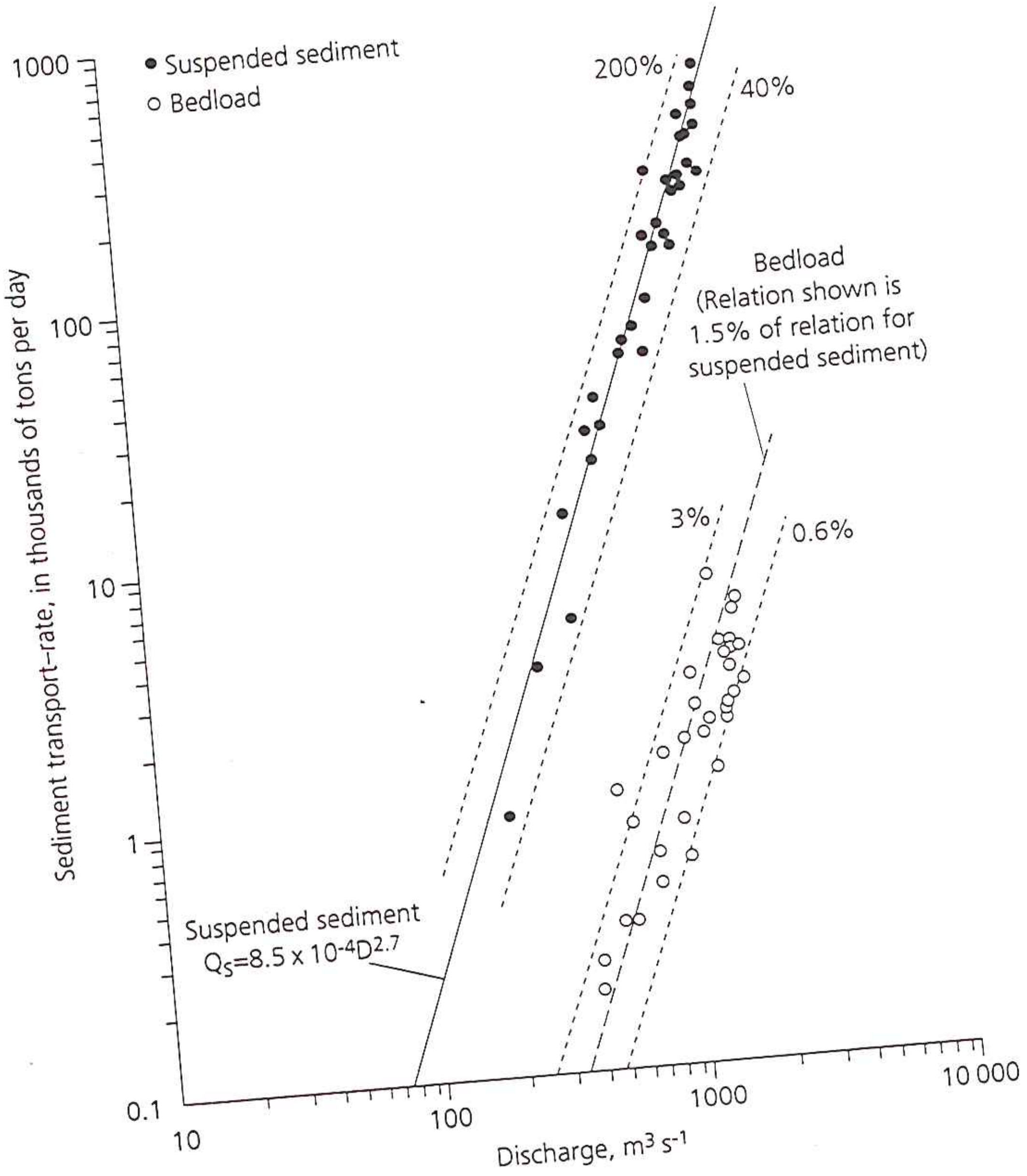
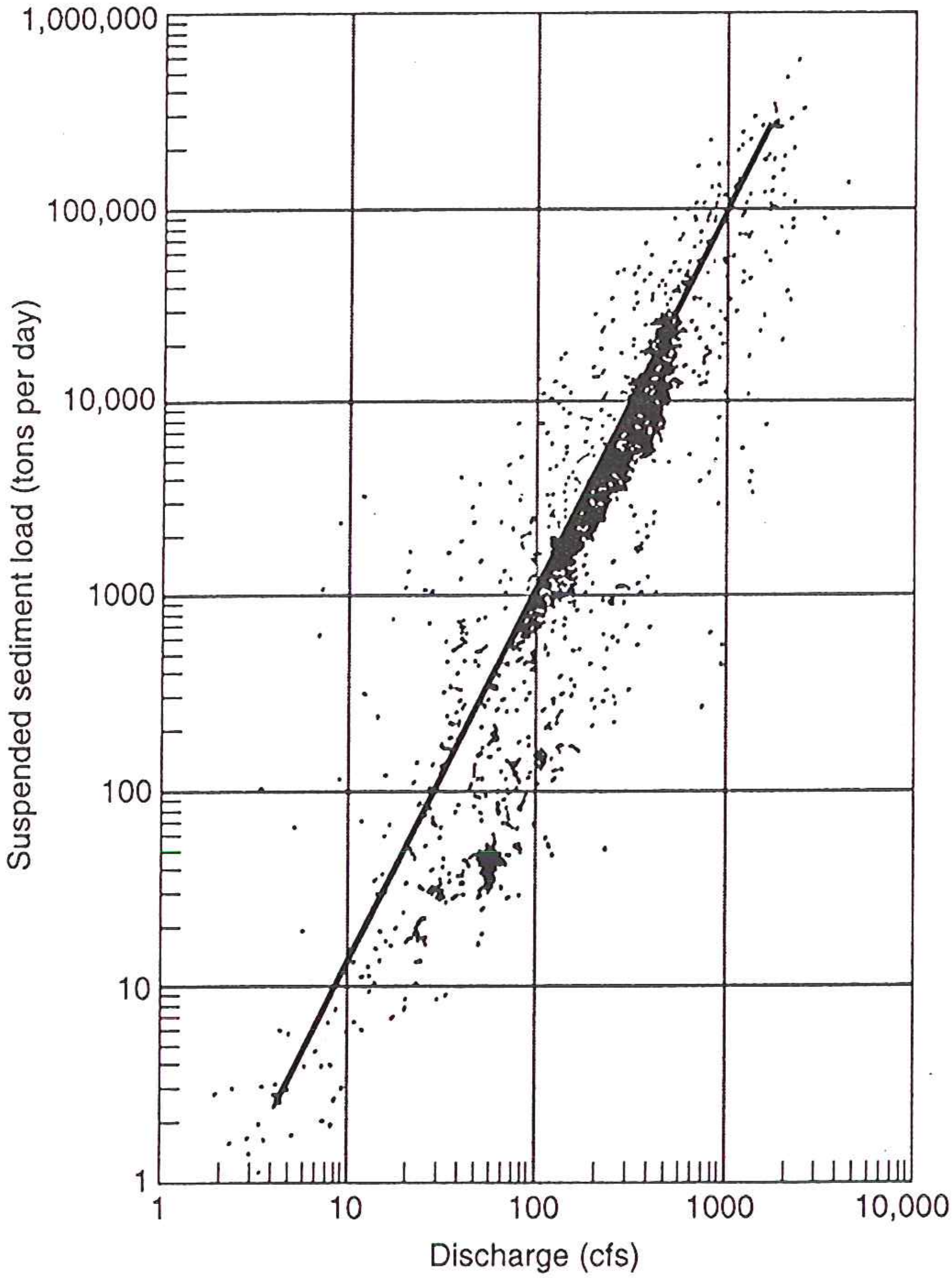
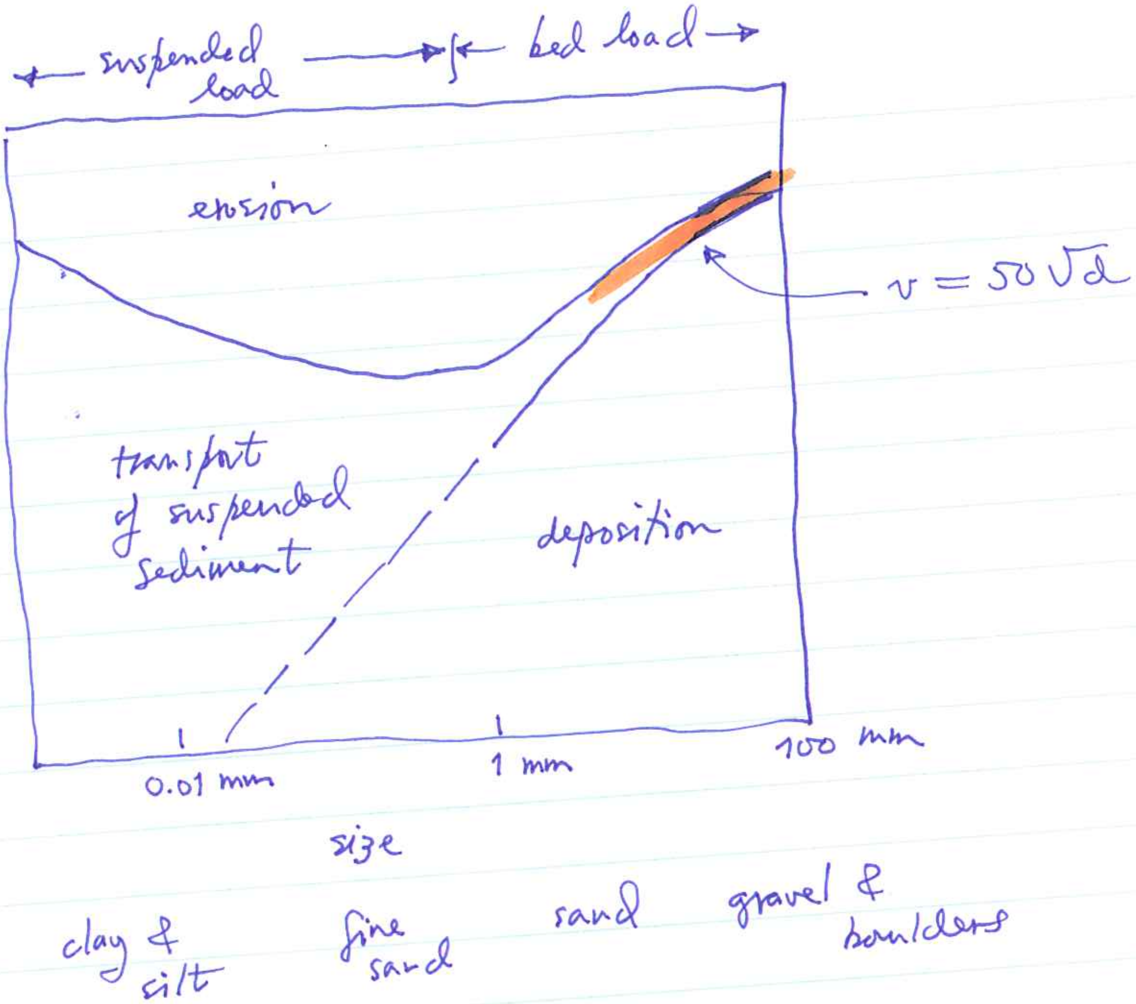


Fig. 3.27 Example of a sediment rating curve for bedload and suspended load transport rate as a function of discharge, Tanana River close to Fairbanks, Alaska. Data from Burrows *et al.* (1979) [34].

Sediment flux $\approx$ const (discharge)^2





These relationships are completely empirica
Obtained from analyses of sediment transport, deposition and erosion in flume studies. • Flume figure

The upper right corner of this diagram can be understood on the basis of a highly simplified analysis of a particle resting on the stream bed.

The drag force exerte by stream (in turbulent regime) is

$$F_{drag} = C_{drag} \underbrace{\frac{\pi}{4} d^2}_{\substack{\text{cross-}\\ \text{sectional}\\ \text{area}\\ \text{presented}\\ \text{to flow}}} \cdot \frac{1}{2} \rho_w v^2$$

To move the particle along the bottom this force must exceed the frictional resistance to sliding

$$F_{resist} = \mu \underbrace{(\rho - \rho_w) g \frac{\pi}{6} d^3}_{\text{buoyant mass}}$$

$\frac{\pi}{6} d^3$: volume

μ: coeff. of friction, dimensionless, of order 1

Equating and solving for the critical scouring velocity:

$$\boxed{v = \sqrt{\frac{4 g \mu (\rho - \rho_w)}{3 C_{drag} \rho_w} d}}$$

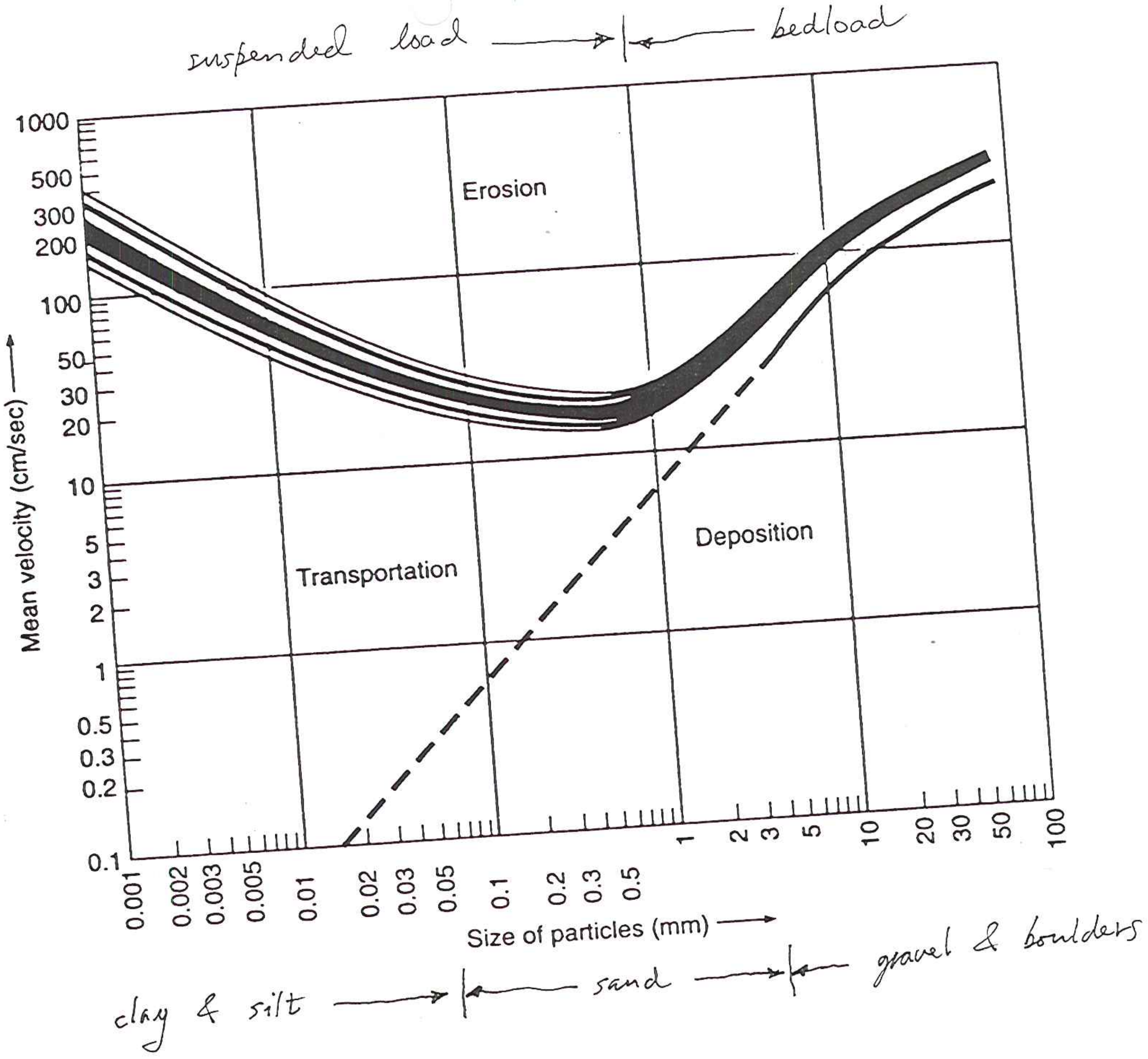
Setting $\mu \approx C_{drag} \approx 1$, $\rho = 2700\ kg/m^3$

$\rho_w = 1000\ kg/m^3$

$g = 9.8\ km/sec^2$

We find:

$$\boxed{v\,(cm/sec) \cong 50 \sqrt{d\,(cm)}}$$


suspended load
bedload
Erosion
Transportation
Deposition
Mean velocity (cm/sec)
1000
500
300
200
100
50
30
20
10
5
3
2
1
0.5
0.3
0.2
0.1
Size of particles (mm)
0.001
0.002
0.003
0.005
0.01
0.02
0.03
0.05
0.1
0.2
0.3
0.5
1
2
3
5
10
20
30
50
100
clay & silt
sand
gravel & boulders

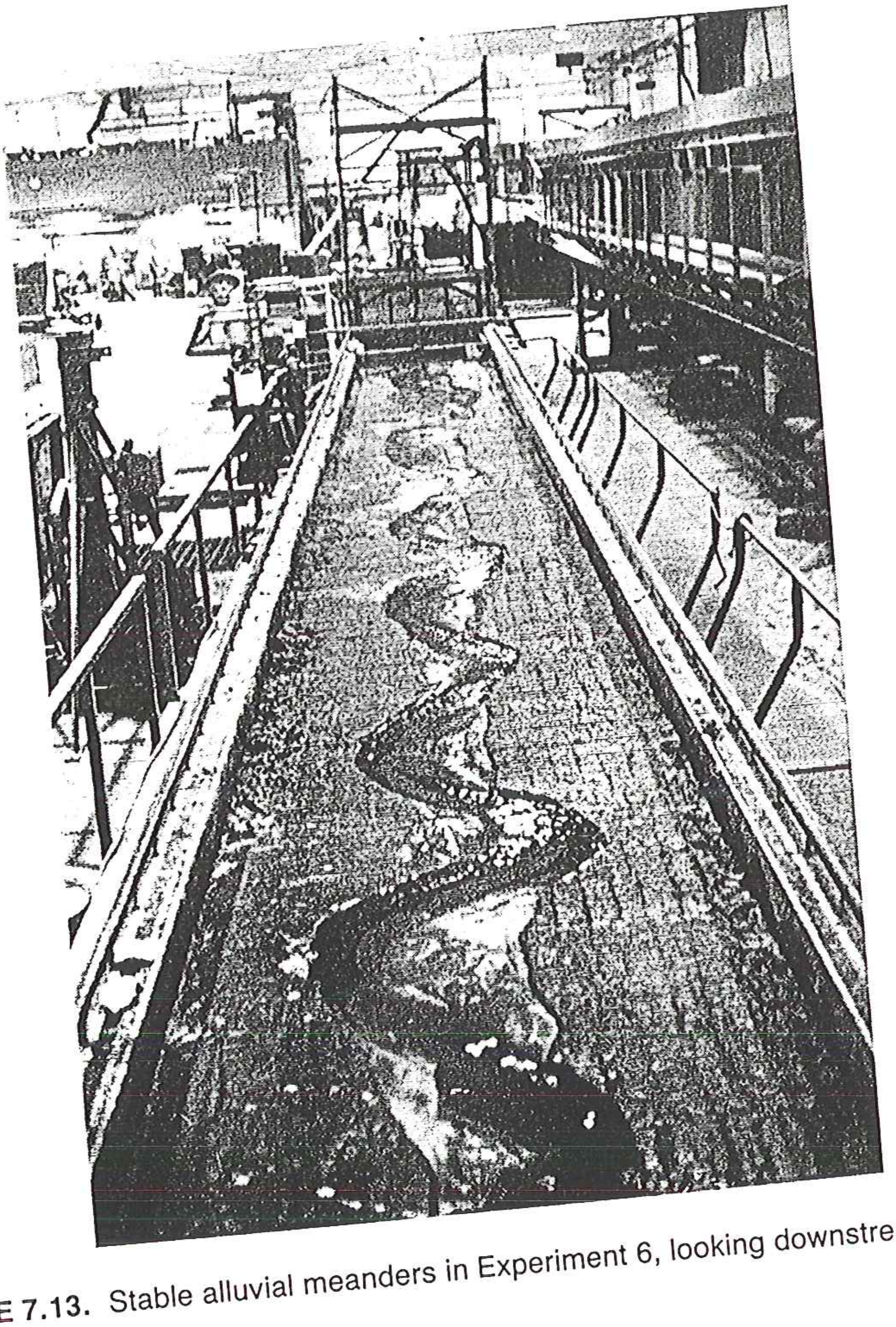


FIGURE 7.13. Stable alluvial meanders in Experiment 6, looking downstream (from Gardner, 1973).

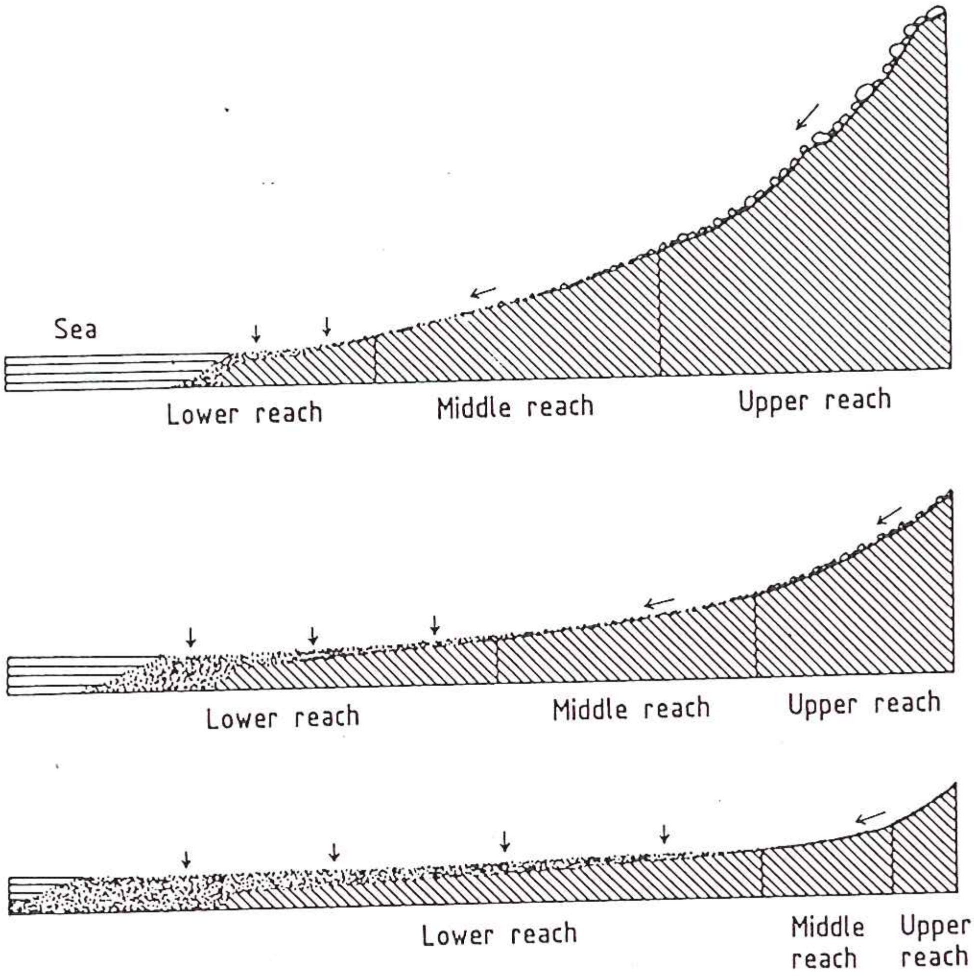


Fig. 5.18. Stages of denudation. (Redrawn after Wagner 1960)

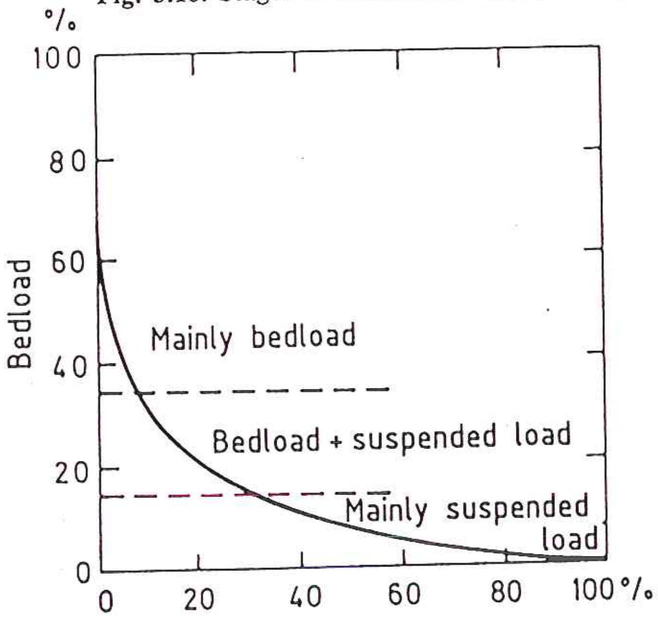


Fig. 5.19. Hypothetical relation between bedload transport and silt/clay portion in % of total solids. (After Schumm 1963)

This plots nicely on the observed boundary.

This part of the curve where the erosion & deposition curves merge is the province of bedload transport.

The remainder of the diagram pertains to the suspended load.

think of mudballs, clods, versus non-cohesive nature of sand.

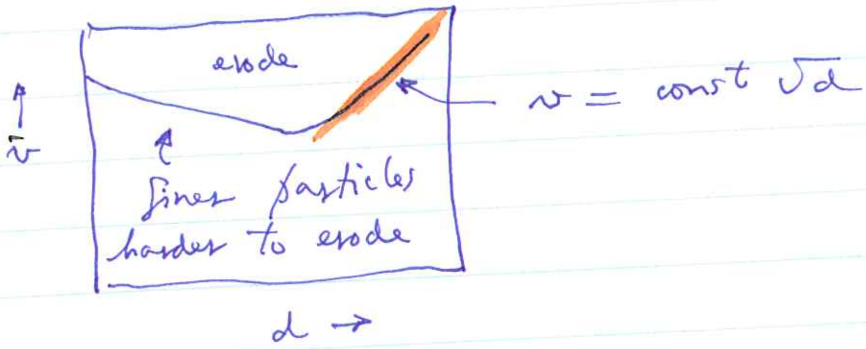
It is observed empirically that fine silt is less susceptible to erosion than fine sand — this a consequence of its greater cohesion

See p
7.5
for
expla

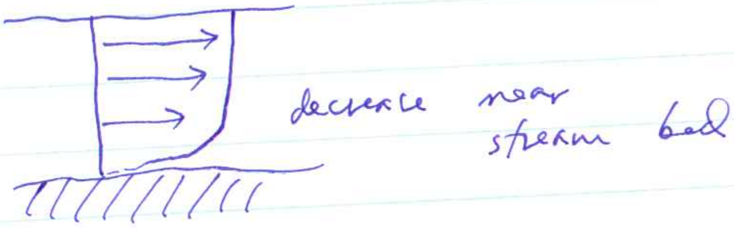
The boundary between suspended transport and deposition is dashed because it does not depend only on $\bar{v}$. The suspended particles are always settling out — boundary depends on water depth and how far you want to transport them.

At a bend in a river, a water particle of mass m experi
a centrifugal force

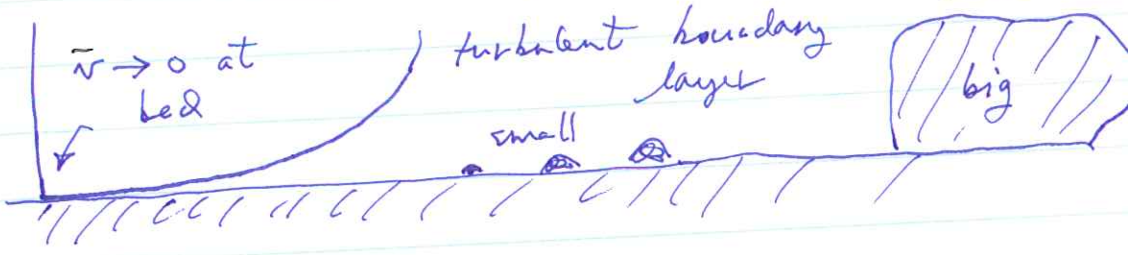
Here is a probable reason for



Recall that the velocity profile in a stream looks like this:

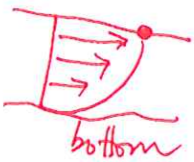


A magnified view near stream bed looks like this — a viscous fluid adheres to solids

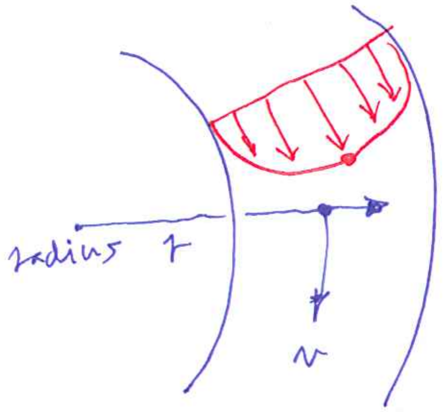


Small particles do not protrude above this turbulent boundary layer. The velocity they experience is << the free-stream veloci

Figs. 5.18 & 5.19 shows tendency for bed load transport upper reach, suspended lower reach

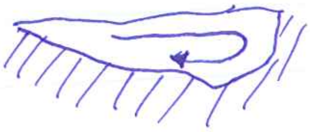


dot • denotes fastest water



$$F_{cent} = m \frac{v^2}{r}$$

Since the surface water is moving faster it is deflected more — it moves to the bank and cuts into it. To conserve water there must be a return flow



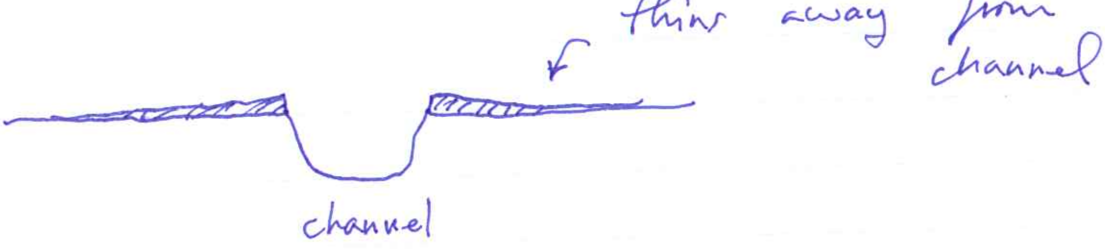
This is the origin of meanders and point bars, also oxbow lake

The motion of rivers within their floodplains is extremely dynamic
Example — age map of floodplain of Little Missouri River in North Dakota — determined by tree-ring dating of bank cottonwood trees!

Meandering of rivers such as Colorado cutting into sandstone bedrock can lead to development of natural bridges.

Another reason for stream meandering.

During large storms a stream occupies its floodplains. It deposits suspended sediment there



After many instances of this, the cross section looks like this:

The channel is on a ridge.

This is an unstable situation

As a result, there is a strong tendency for streams to change their channels.

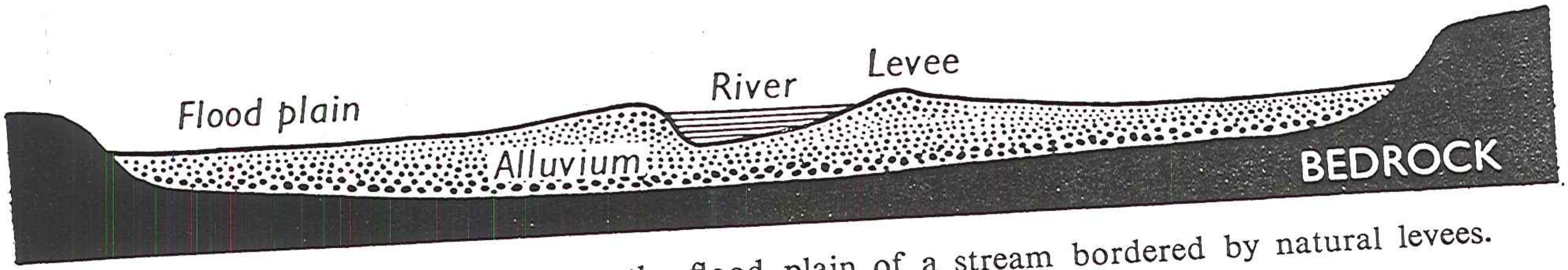


FIG. 389 Schematic section across the flood plain of a stream bordered by natural levees. Vertical scale greatly exaggerated

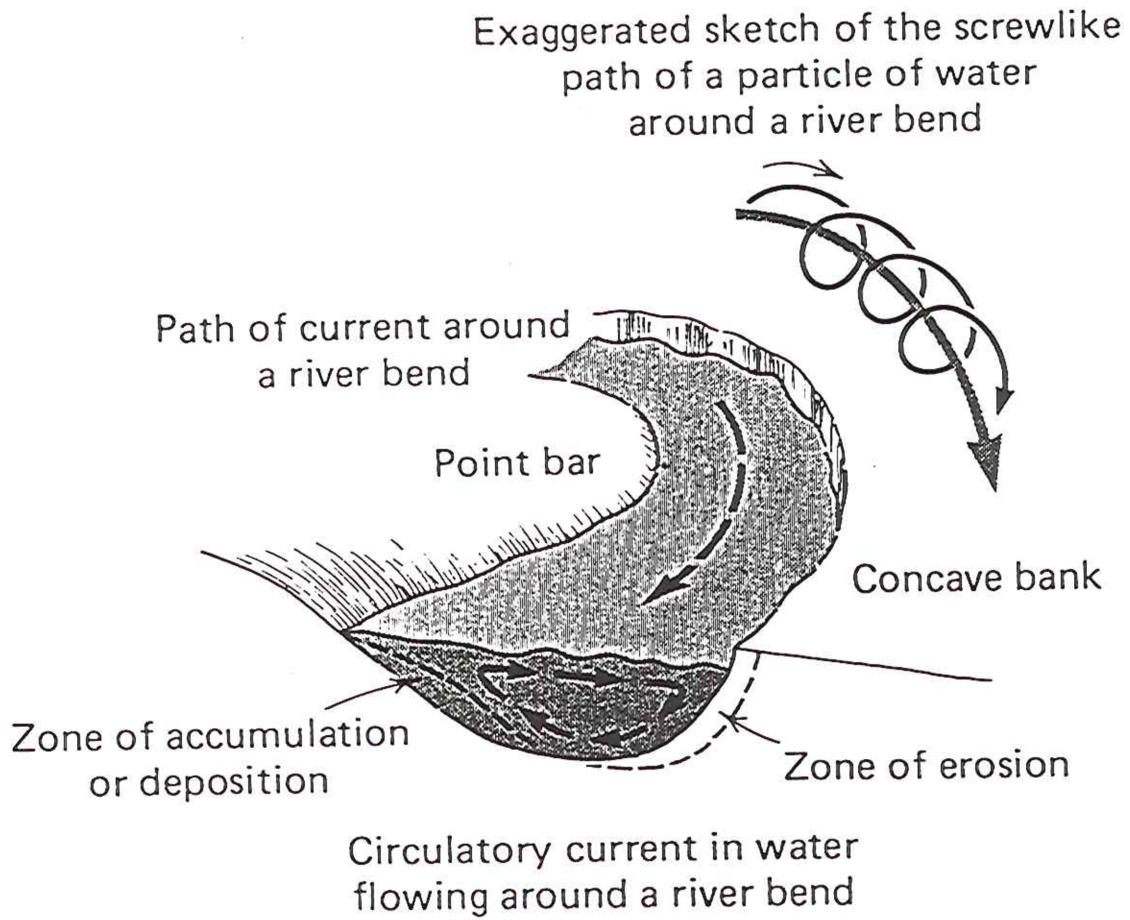


Figure 24
Effect of a curved channel on water flow. (U.S.G.S.)

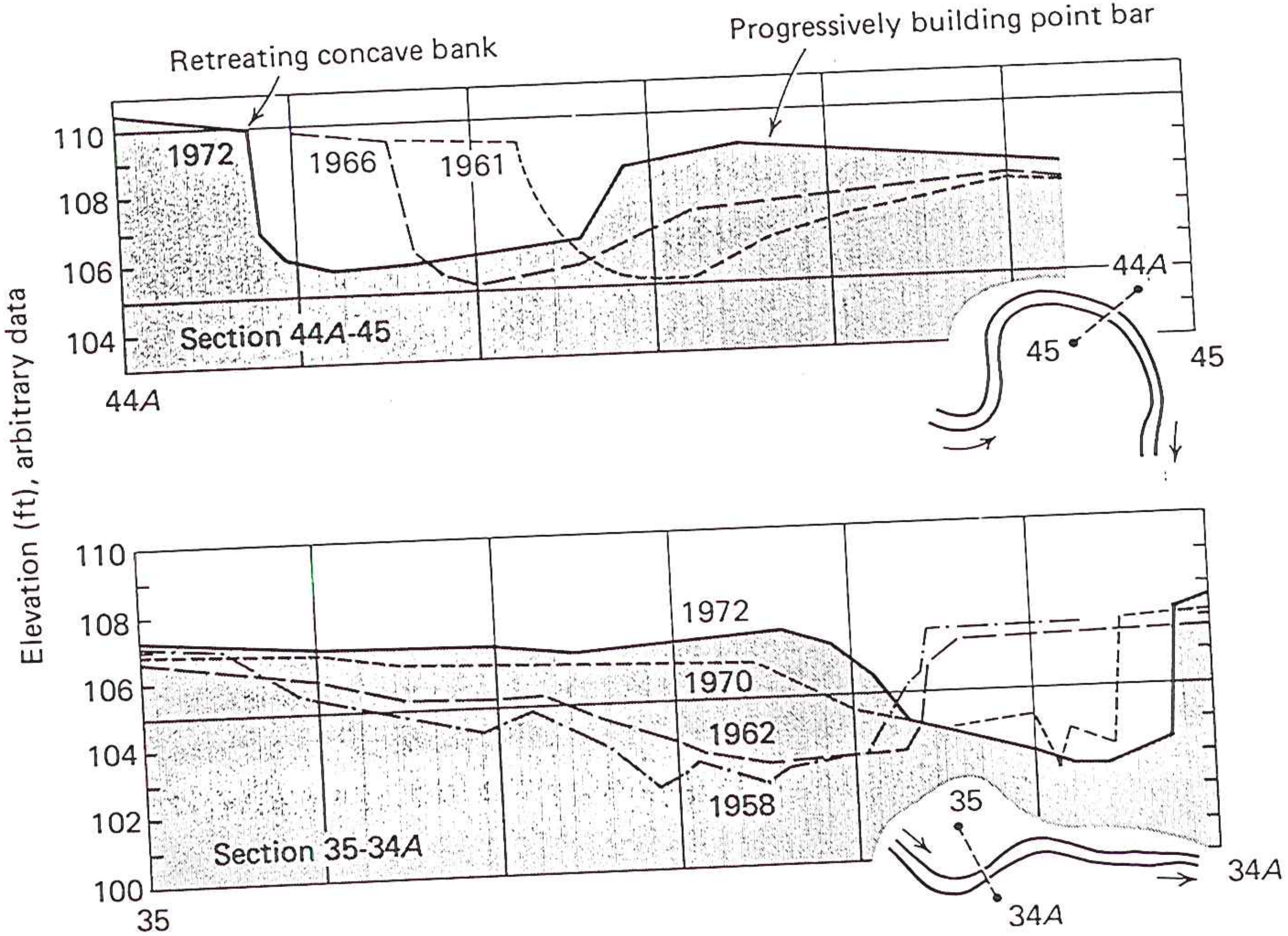


Figure 28
Data obtained from successive resurveys of Watts Branch near Rockville, Maryland, show lateral migration of a river channel by the building of a point bar into the stream and the concurrent erosion of the opposite bank. The continuation of such point bar building results in the development of a flood plain. Diagrams in lower right indicate position of the cross section relative to channel bends. (From Leopold, *Bull. Geol. Soc. America*, June 1973.)

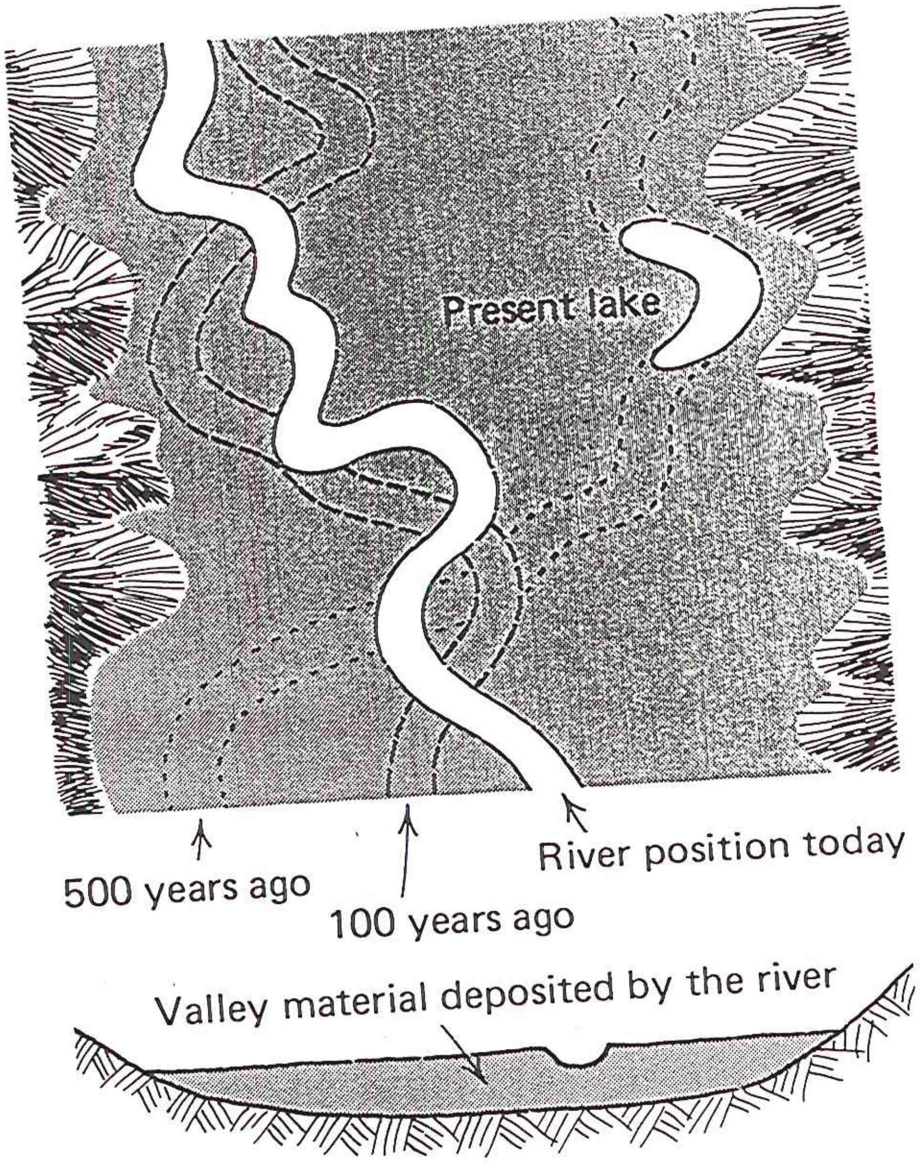


Figure 26
Present and past courses of a reach, or length, of river. (U.S.G.S.)

Figure 29
Meander bend of Buffalo Creek, near Gardenville, New York. House in foreground stands on a terrace several feet higher than the flood plain. The flood plain level is the forested area within the bend in the center of the photograph. The sandy area without vegetation on the convex bank is newly deposited material of a building point bar. (Photograph by G. S. Smith, United States Soil Conservation Service.)

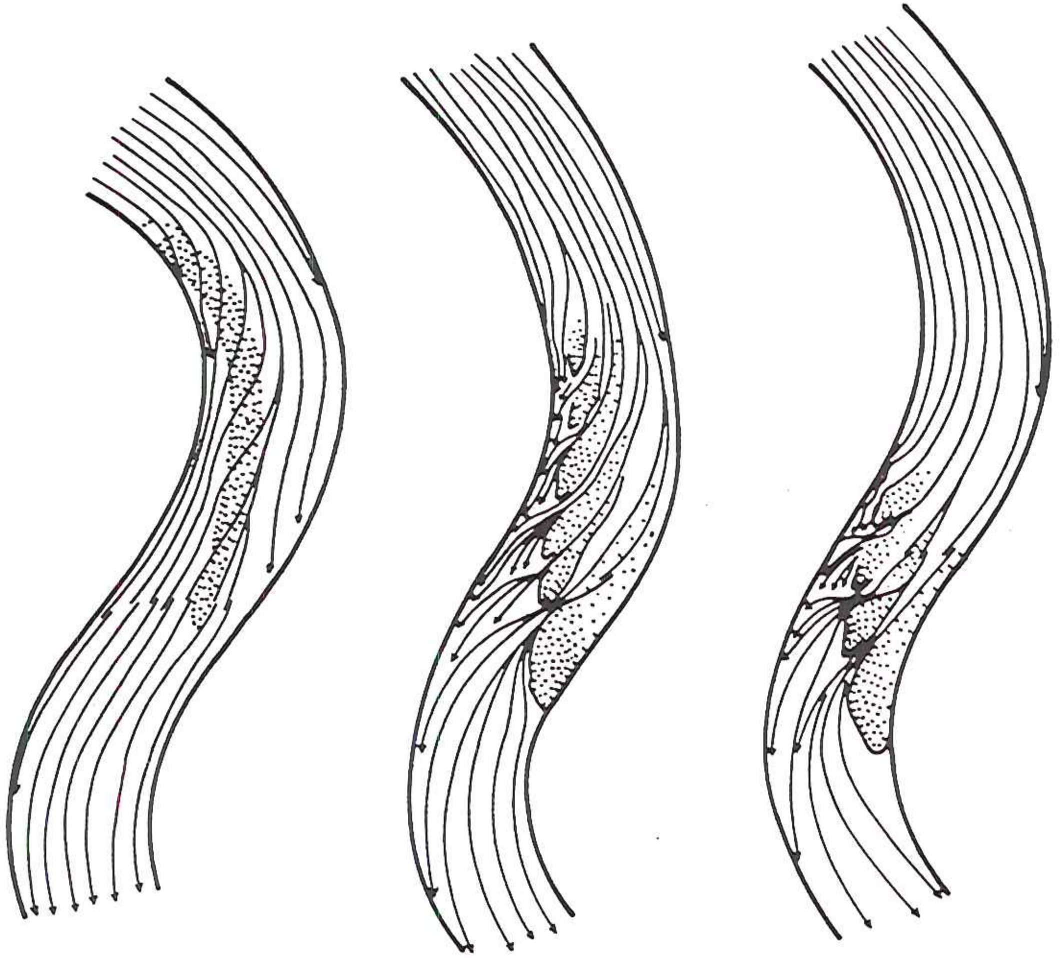


Fig. 5.7. Development of a gravel bar below a river bend. (After Krigström 1962)

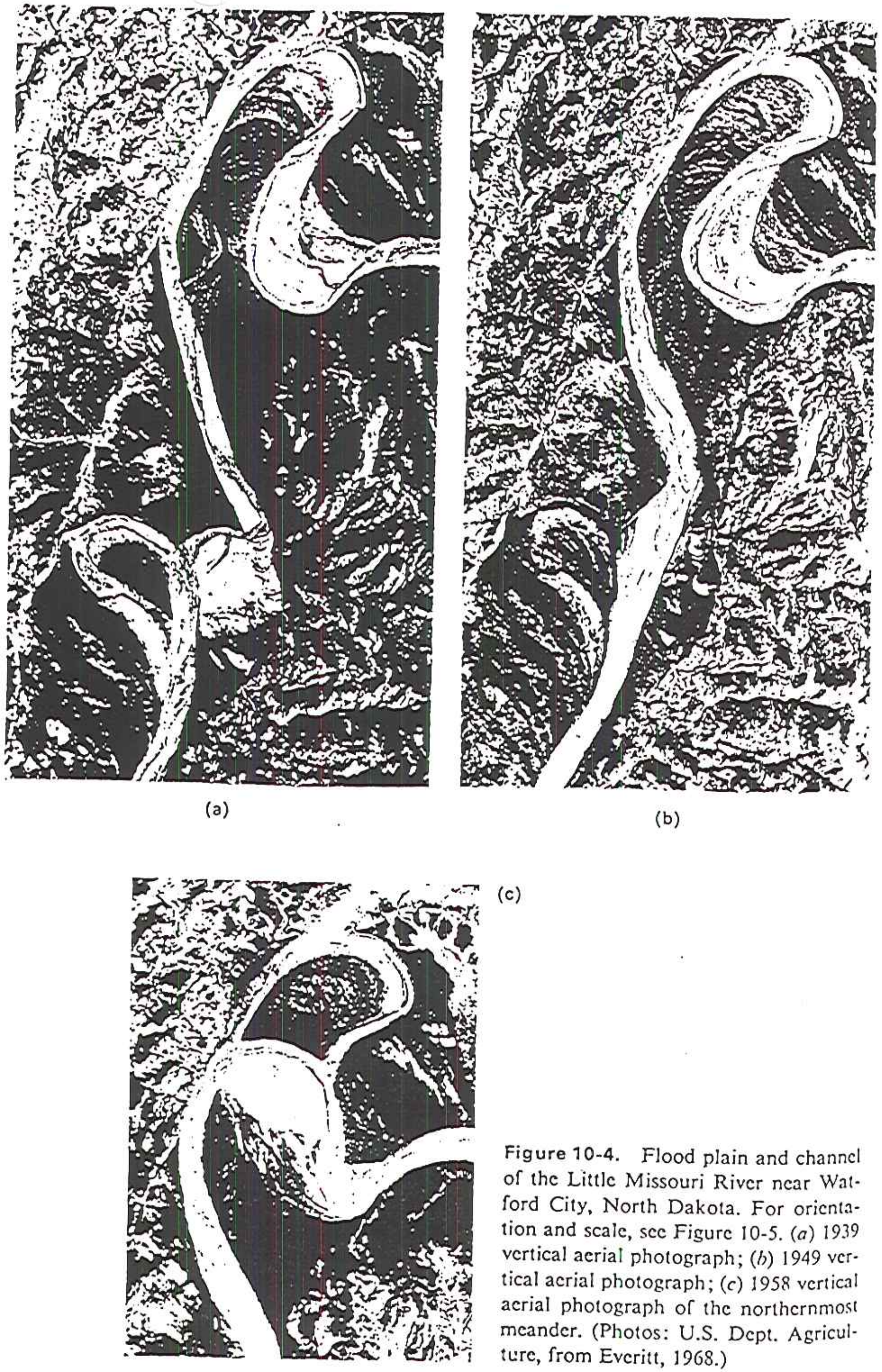


Figure 10-4. Flood plain and channel of the Little Missouri River near Watford City, North Dakota. For orientation and scale, see Figure 10-5. (*a*) 1939 vertical aerial photograph; (*b*) 1949 vertical aerial photograph; (*c*) 1958 vertical aerial photograph of the northernmost meander. (Photos: U.S. Dept. Agriculture, from Everitt, 1968.)

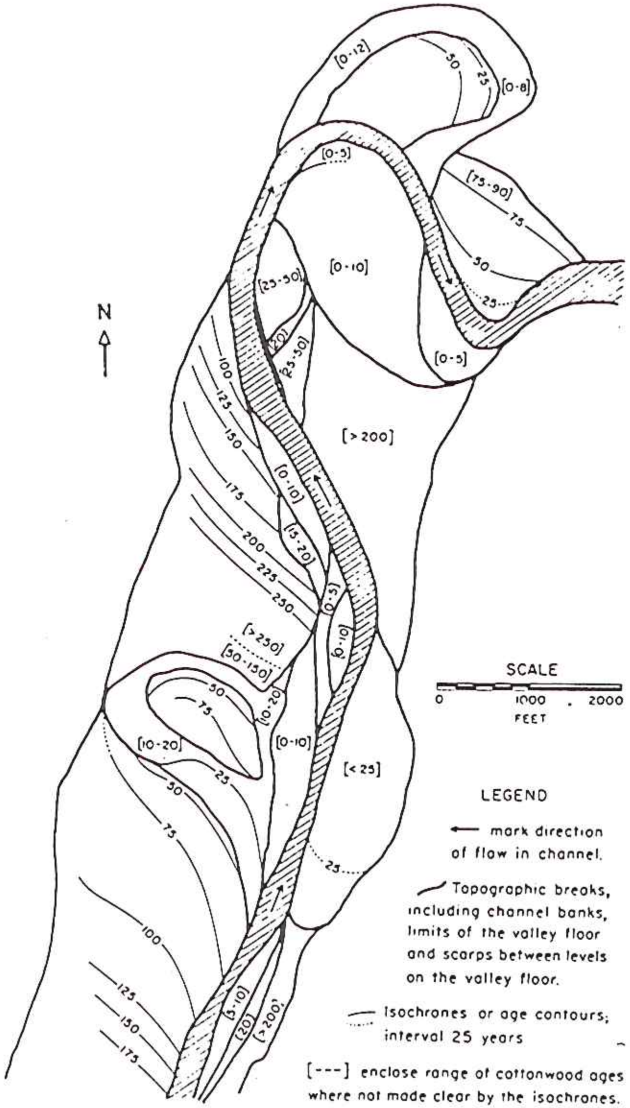
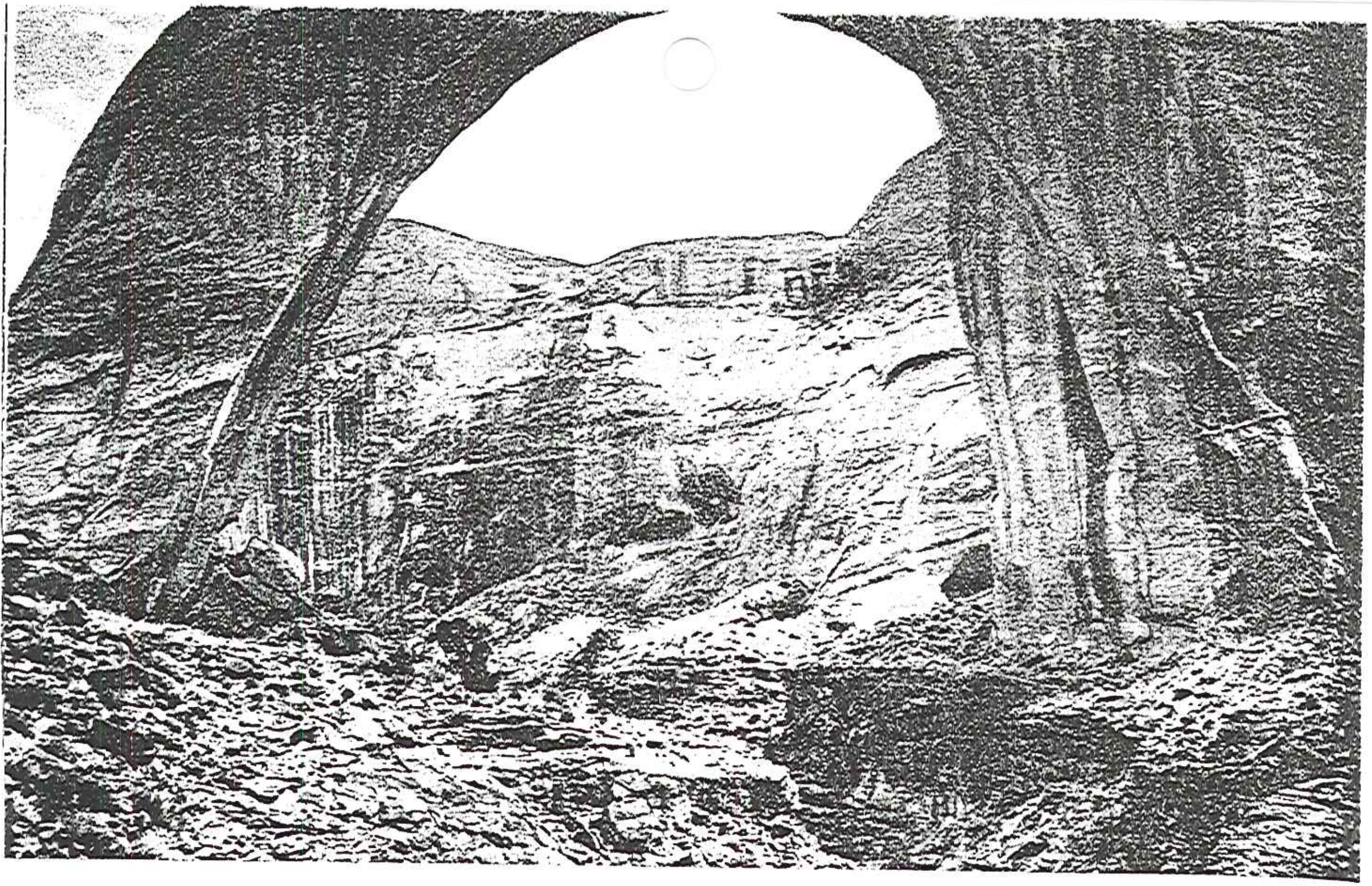


Figure 10-5. Age map of the flood plain of the Little Missouri River near Watford City, North Dakota, based on ages of cottonwood trees. (Everitt, 1968.)

Figure 27
The meandering gorge of the Colorado River at the Loop, below Moab, Utah. The channel has cut downward more than 1,000 feet since the Colorado Plateau area began to rise more than 1 million years ago. (U.S.G.S.)



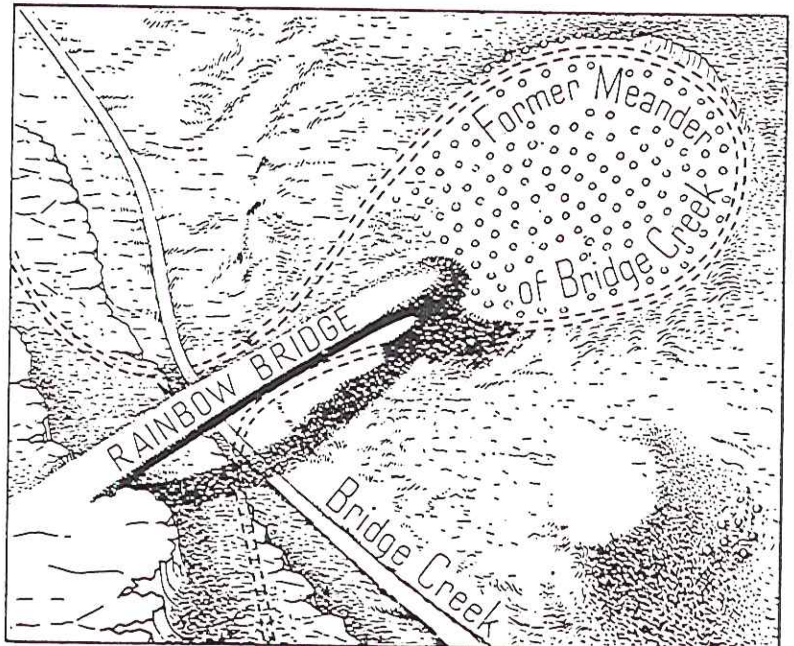


FIG. 428 Rainbow Bridge, Bridge Creek, Utah. See Figs 429 and 430 (*Ewing Galloway*)

FIG. 429 Diagram illustrating the mode of origin of Rainbow Bridge

The dissolved load, as noted earlier, is the easiest to measure.

Collect a sample (anywhere) and analyze chemically. Have to be careful when you measure [dilution after storms Fig 3.28

Main dissolved species are:

Ca^{2+}, HCO_3^-, SO_4^{2-}, Na^+, Cl^-, Mg^{2+}, K^+

Source of these ions is the ground water and interflow into streams. These are the soluble products of weathering that are removed by streams. Fig. 5.7

Table 5.5 (Berner & Berner) shows the concentrations of a number of major elements in rocks, soils, and river suspended and dissolved loads.

Al, Fe, Si, P very insoluble – almost entirely transported as suspended particles

Ca^{2+} and Na^+ are both more than half dissolved. Mg is 60% particulate 40% dissolved.

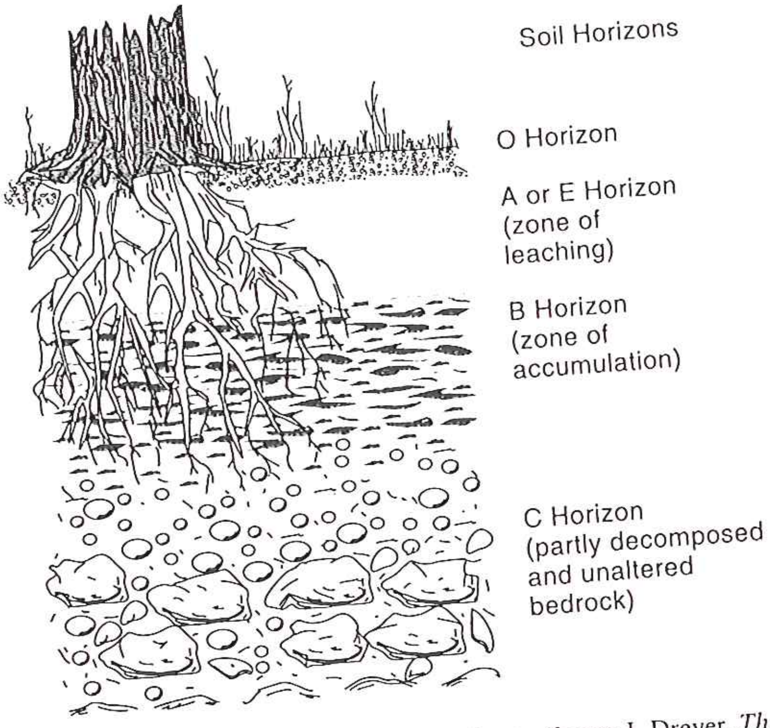


Figure 4.6. Soil horizons formed in a temperate humid climate (James I. Drever, *The Geochemistry of Natural Waters,* 2e, © 1992, p. 145. Reprinted by permission of Prentice Hall, Englewood Cliffs, New Jersey.)

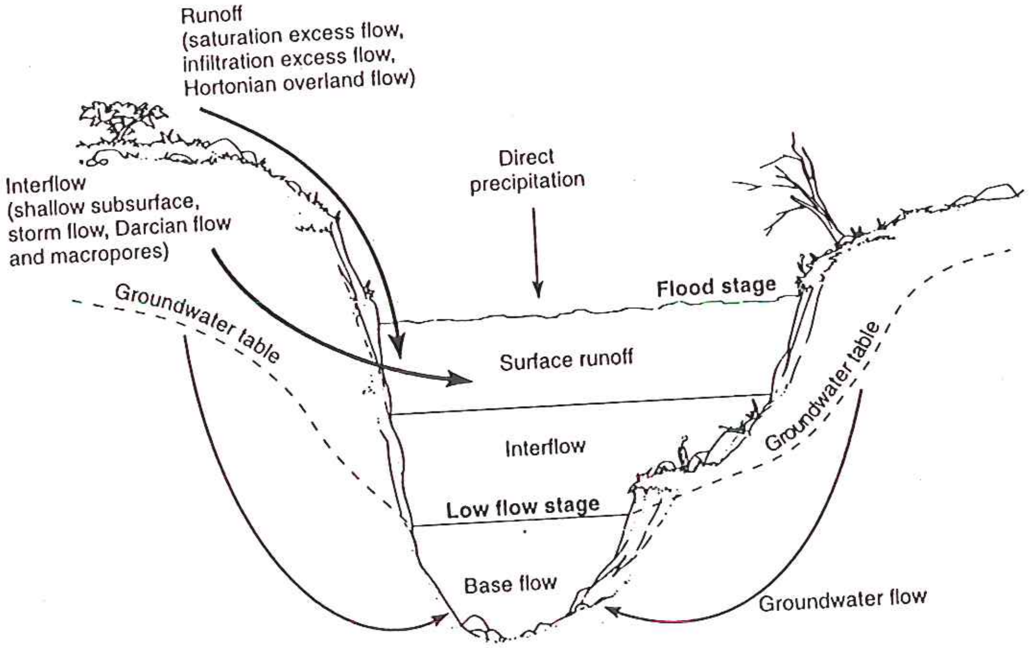


FIGURE 5.7

Schematic of stream channel showing major kinds of water contributions. Arrival of water from any given precipitation event is progressively delayed from runoff to interflow to groundwater flow.

(Based on Kochel 1992)

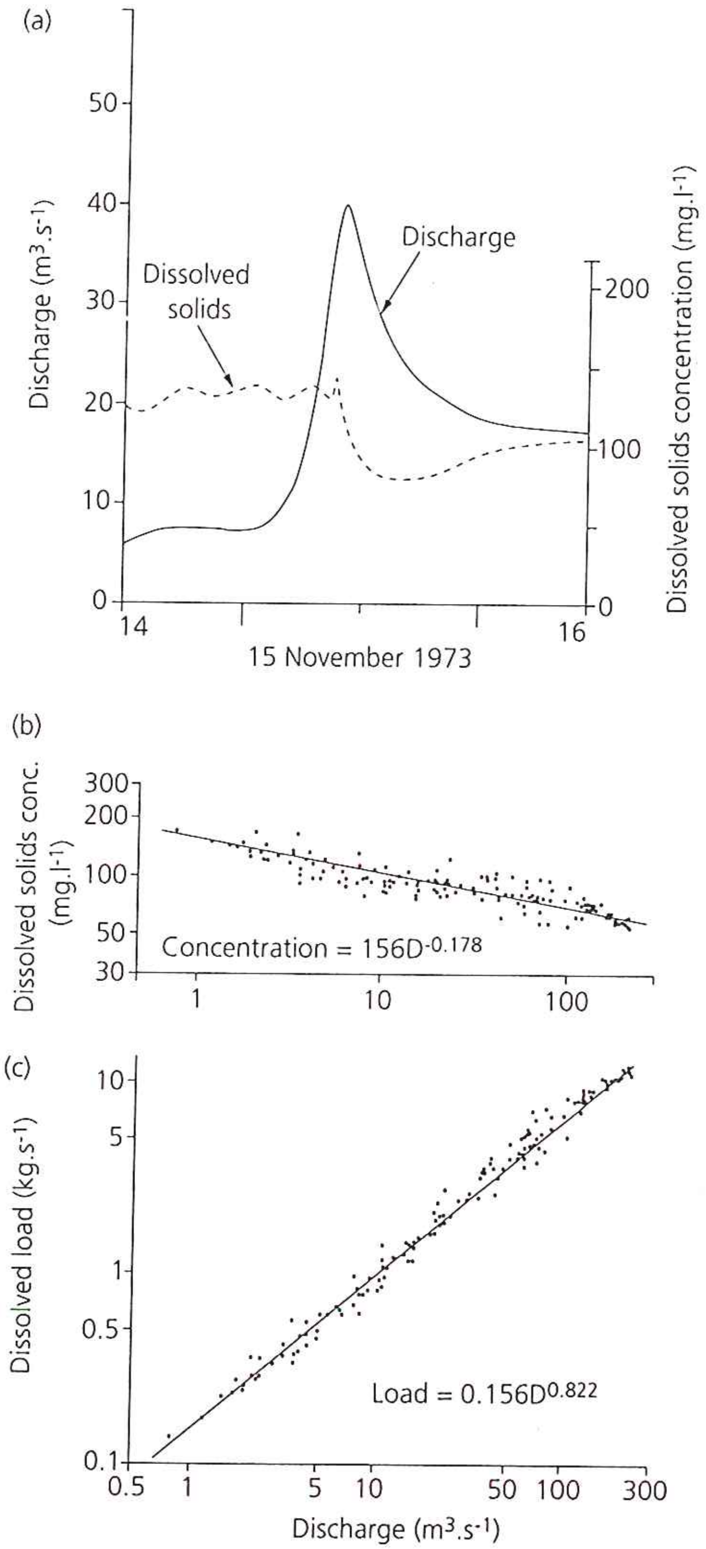


Fig. 3.28 Solute load response to a flood event in a small English river (River Exe at Thorverton). Drop in dissolved solids concentration during peak flood discharges (a) results in the inverse relation between solute concentration and discharge shown in (b), despite the fact that the total dissolved load has a positive relation in the rating curve shown in (c). After Walling (1984) [35].

Source of these ions – see Table 5.11

Ca^{++} and HCO_3^- : <u>carbonate rocks</u> (limestone)

$CaCO_3 + \underset{\text{carbonic acid}}{H_2CO_3} \rightarrow Ca^{++} + 2HCO_3^-$

formation of caves, etc

not a major element in ⊕

Na^+ and Cl^- : solution of <u>evaporite</u>

$NaCl \rightarrow Na^+ + Cl^-$

Mg^{++} : both from weathering of silicates and <u>dolomite</u>

$\underbrace{CaMg(CO_3)_2}_{\text{dolomite}} + 2H_2CO_3 \rightarrow Ca^{++} + Mg^{++} + 4HCO_3^-$

The <u>sediment</u> budget is summarized in Berner Table 5.1

Suspended & dissolved sediment flux of 20 largest rivers

units : Tg/yr = 10^{12} grams of sediment/y
= 10^6 tons/y

Rule of thumb : dissolved load ≈ $\frac{1}{3}$ x tota

≈ $\frac{1}{2}$ x suspen

i.e., the average load is $\frac{2}{3}$ suspended + $\frac{1}{3}$ dissolved

TABLE 5.5 Concentrations of Major Elements in Continental Rocks and Soils and in River Dissolved and Particulate Matter

	Continents		Rivers				Element Weight Ratio	
Element	Surficial Rock Concentration (mg/g)	Soil Concentration (mg/g)	Particulate Concentration (mg/g)	Dissolved Concentration (mg/l)	Particulate Load (10^6 tons/yr)	Dissolved Load (10^6 tons/yr)	River Particulate/ Rock	Particulate/ (Particulate + Dissolved)
Al	69.3	71.0	94.0	0.05	1457	2	1.35	0.999
Ca	45.0	35.0	21.5	13.40	333	501	0.48	0.40
Fe	35.9	40.0	48.0	0.04	744	1.5	1.33	0.998
K	24.4	14.0	20.0	1.30	310	49	0.82	0.86
Mg	16.4	5.0	11.8	3.35	183	125	0.72	0.59
Na	14.2	5.0	7.1	5.15	110	193	0.50	0.36
Si	275.0	330.0	285.0	4.85	4418	181	1.04	0.96
P	0.61	0.8	1.15	0.025	18	1.0	1.89	0.96

Note: Elements with no gaseous phase only. Particulate and dissolved loads based, respectively, on the total loads, 15.5 × 10^9 tons solids/yr and 37,400 km^3 water/yr.

Sources: After Martin and Meybeck 1979; Martin and Whitfield 1981; Meybeck 1979, 1982.

TABLE 5.11 Sources of Major Elements in World River Water (in Percent of Actual Concentrations)

		Weathering			
Element	Atmos. Cyclic Salt	Carbonates	Silicates	Evaporites[a]	Pollution[b]
Ca^{++}	0.1	65	18	8	9
HCO_3^-	<<1	61[c]	37[c]	0	2
Na^+	8	0	22	42	28
Cl^-	13	0	0	57	30
SO_4^{--}	2[d]	0	0	22[d]	54
Mg^{++}	2	36	54	<<1	8
K^+	1	0	87	5	7
H_4SiO_4	<<1	0	99+	0	0

[a] Also includes NaCl from shales and thermal springs.

[b] Values taken from Meybeck (1979) except sulfate, which is based on calculation given in the text.

[c] For carbonates, 34% from calcite and dolomite and 27% from soil CO_2; for silicates, all 37% from soil CO_2; thus, total HCO_3^- from soil (atmospheric) $CO_2 = 64\%$ (See also Table 5.13).

[d] Other sources of river SO_4^{--}; natural biogenic emissions to atmosphere delivered to land in rain, 3%; volcanism, 8%; pyrite weathering, 11%.

TABLE 5.1 Major Rivers that Flow to the Sea, Listed in Order of Discharge

River	Location	Annual Discharge: Water (km³/yr)	Annual Discharge: Dissolved Solids (Tg/yr)	Annual Discharge: Suspended Solids (Tg/yr)	Dissolved/ Suspended Ratio	Drainage Area (10^6 km²)
1. Amazon	S. America	6300	275	1200	0.23	6.15
2. Zaire (Congo)	Africa	1250	41	43	0.95	3.82
3. Orinoco	S. America	1100	32	150	0.21	0.99
4. Yangtze (Chiang)	Asia (China)	900	247	478	0.53	1.94
5. Brahmaputra	Asia	603	61	540	0.11	0.58
6. Mississippi	N. America	580	125	210 (400)	0.60	3.27
7. Yenisei	Asia (Russia)	560	68	13	5.2	2.58
8. Lena	Asia (Russia)	525	49	18	2.7	2.49
9. Mekong	Asia (Vietnam)	470	57	160	0.36	0.79
10. Ganges	Asia	450	75	520	0.14	0.975
11. St. Lawrence	N. America	447	45	4	11.3	1.03
12. Parana	S. America	429	16	79	0.20	2.6
13. Irrawaddy	Asia (Burma)	428	92	265	0.35	0.43
15. Mackenzie	N. America	306	64	42	1.5	1.81
17. Columbia	N. America	251	35	10 (15)	3.5	0.67
20. Indus	Asia (India)	238	79	59 (250)	1.3	0.975
Red (Hungho)	Asia (Vietnam)	123	?	130	?	0.12
Huanghe (Yellow)	Asia (China)	59	22	1100	0.02	0.77

Note: Tributaries are excluded. Tg = 10^6 tons = 10^{12} g.

Sources: Water and suspended solids from Milliman and Meade (1983) and Milliman and Syvitski (1992). Dissolved solids calculated from Table 5.7 and Pinet and Souriau (1988) (for the Irrawaddy). Suspended load values in parentheses indicate pre-dam values.

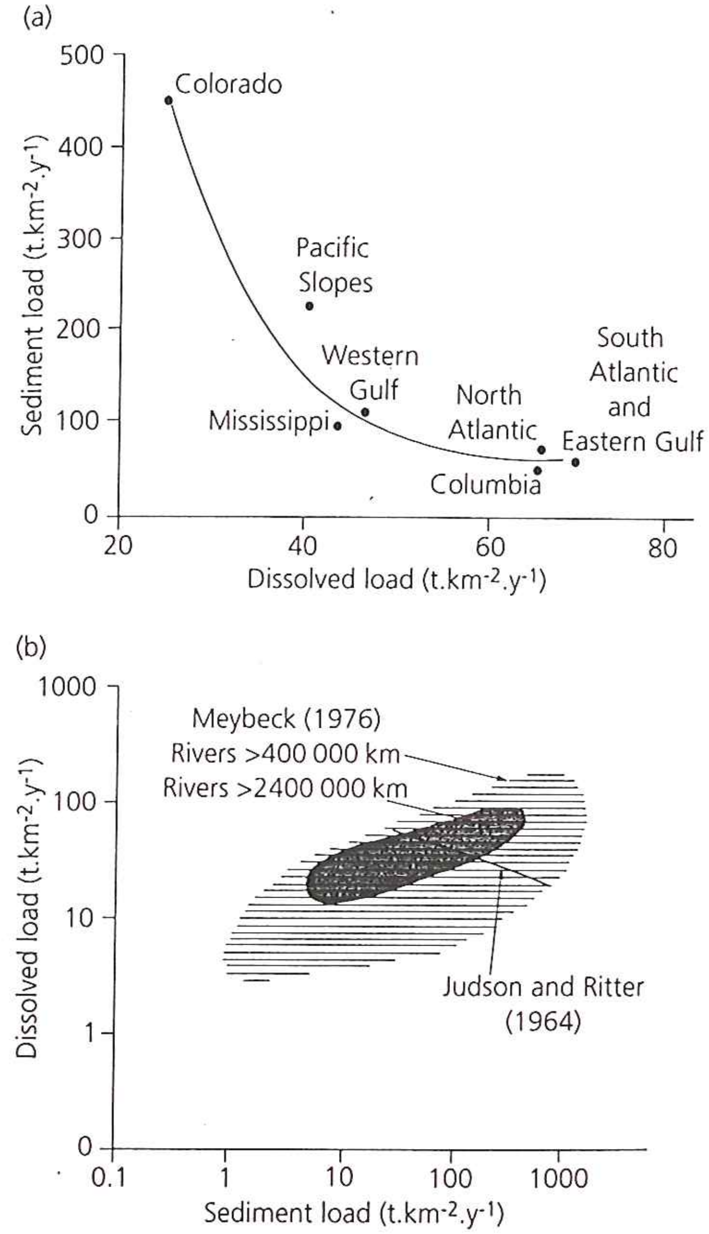


Fig. 3.25 Relationships between the dissolved and suspended sediment components of the total river load in US rivers (a) after Judson & Ritter (1964) [32] and (b) based on world-wide data (after Meybeck (1976) [30]).

Very rough rule of thumb:

dissolved load $\approx \frac{1}{2}$ suspended load

$\approx \frac{1}{3}$ total load

$$\boxed{\text{Total load} \approx \tfrac{2}{3}\text{ suspended} + \tfrac{1}{3}\text{ dissolved}}$$

However, not all of the dissolved load is derived from continental rocks

- 65% of HCO_3^- from dissolved atmospheric CO_2 (Table 5.13)
- also natural rainwater has some dissolved minerals
- pollution sources, e.g., road salt

Best estimate of <u>total</u> chemical erosion rate by all the world's rivers (Berner & Berner) — due to solution of continental rocks.

~~Also, subtract pollution sources to get this result~~

~~Chemical erosion rate = 26 tons/km^2/yr~~

Roughly speaking, <u>half</u> of the dissolved load [illegible] is derived from continental rocks, half from ions in rainwater and solution of atmospheric CO_2 in pore spaces

~~Perhaps better to say that ~1/3 derived from continental rocks, 2/3 from ions in rainwater & atmosphere and pollution sources~~

~~world-wide chemical erosion rate ~ 25 tons/km^2/yr~~

~~$\dot{e}_{chemical} \approx 0.01$ km/Myr $\approx$ [illegible] $\frac{1}{10}$ total~~

~~$\approx \frac{1}{9}\, \dot{e}_{suspended}$~~

TABLE 5.13 Sources of Rock Weathering-Derived HCO_3^- in World Average River Water

Weathering Source	Percent of Total HCO_3^- from Soil CO_2	Percent of Total HCO_3^- from Carbonate Minerals
Calcite + Dolomite	27	34
Ca-silicates	13	—
Mg-silicates	15	—
Na-silicates	6	—
K-silicates	3	—
Total	64	34

Note: For method of calculation, see text. (An additional 2% of total HCO_3^- is added by pollution; see Table 5.11.)

EROSION RATES OF MAJOR RIVER BASINS OF THE WORLD

(listed in order of water discharge)

	total erosion/area Tg/10^6km^2	dissolved/area Tg/10^6km^2
Amazon	240	45
Zaïre (Congo)	22	11
Orinoco	184	32
Yangtze (Chiang)	373	127
Bramaputra	1036	105
Mississippi	161	38
Yensei	31	26
Lena	27	20
Mekong	275	72
Ganges	610	77
St. Lawrence	48	44
Parana	37	6
Irrawaddy	830	214
Mackenzie	59	35
Columbia	75	52
Indus	337	81
Huanghe (Yellow)	1457	29

TABLE 5.1 Major Rivers that Flow to the Sea, Listed in Order of Discharge

River	Location	Annual Discharge Water (km³/yr)	Dissolved Solids (Tg/yr)	Suspended Solids (Tg/yr)	Dissolved/ Suspended Ratio	Drainage Area (10^6 km²)
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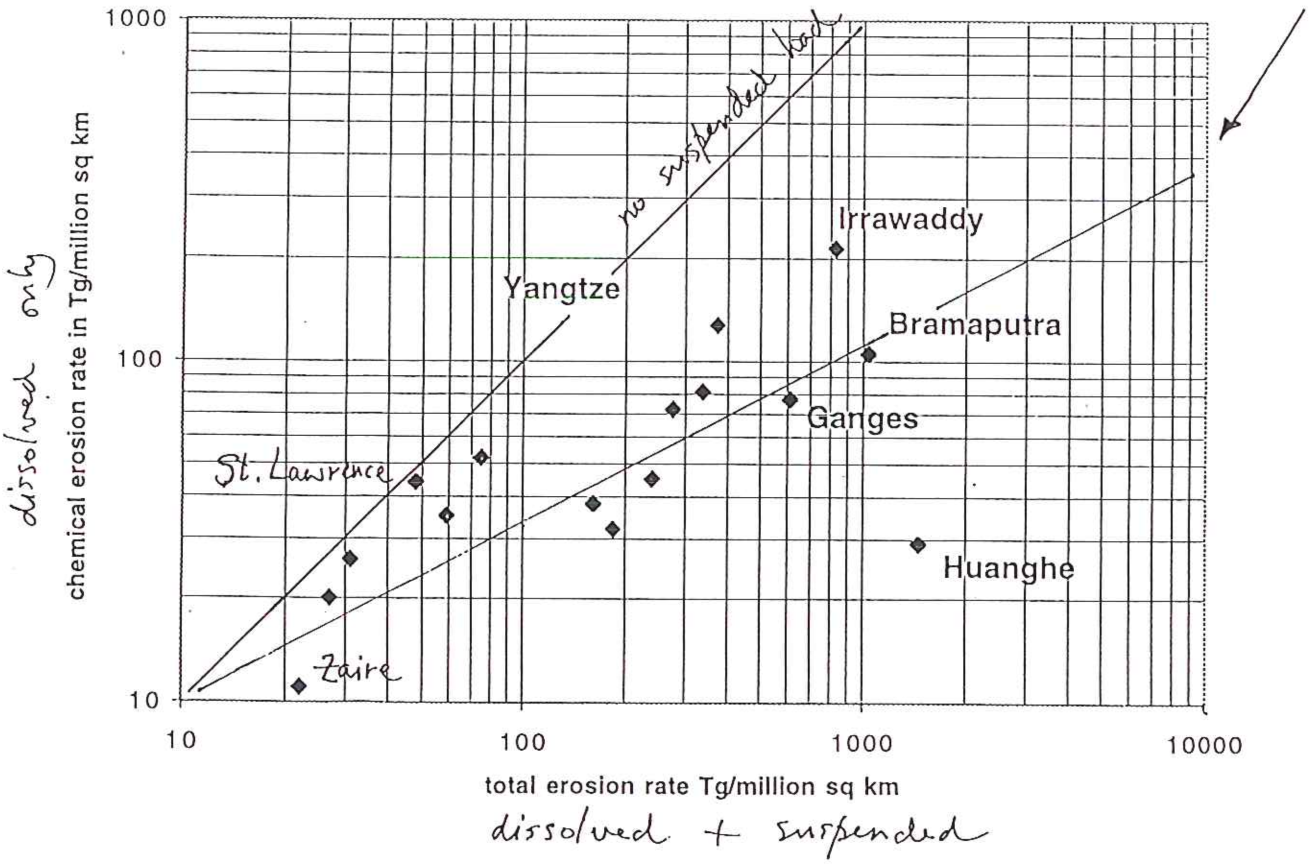
Note: Tributaries are excluded. Tg = 10^6 tons = 10^{12} g.

Sources: Water and suspended solids from Milliman and Meade (1983) and Milliman and Syvitski (1992). Dissolved solids calculated from Table 5.7 and Pinet and Souriau (1988) (for the Irrawaddy). Suspended load values in parentheses indicate pre-dam values.

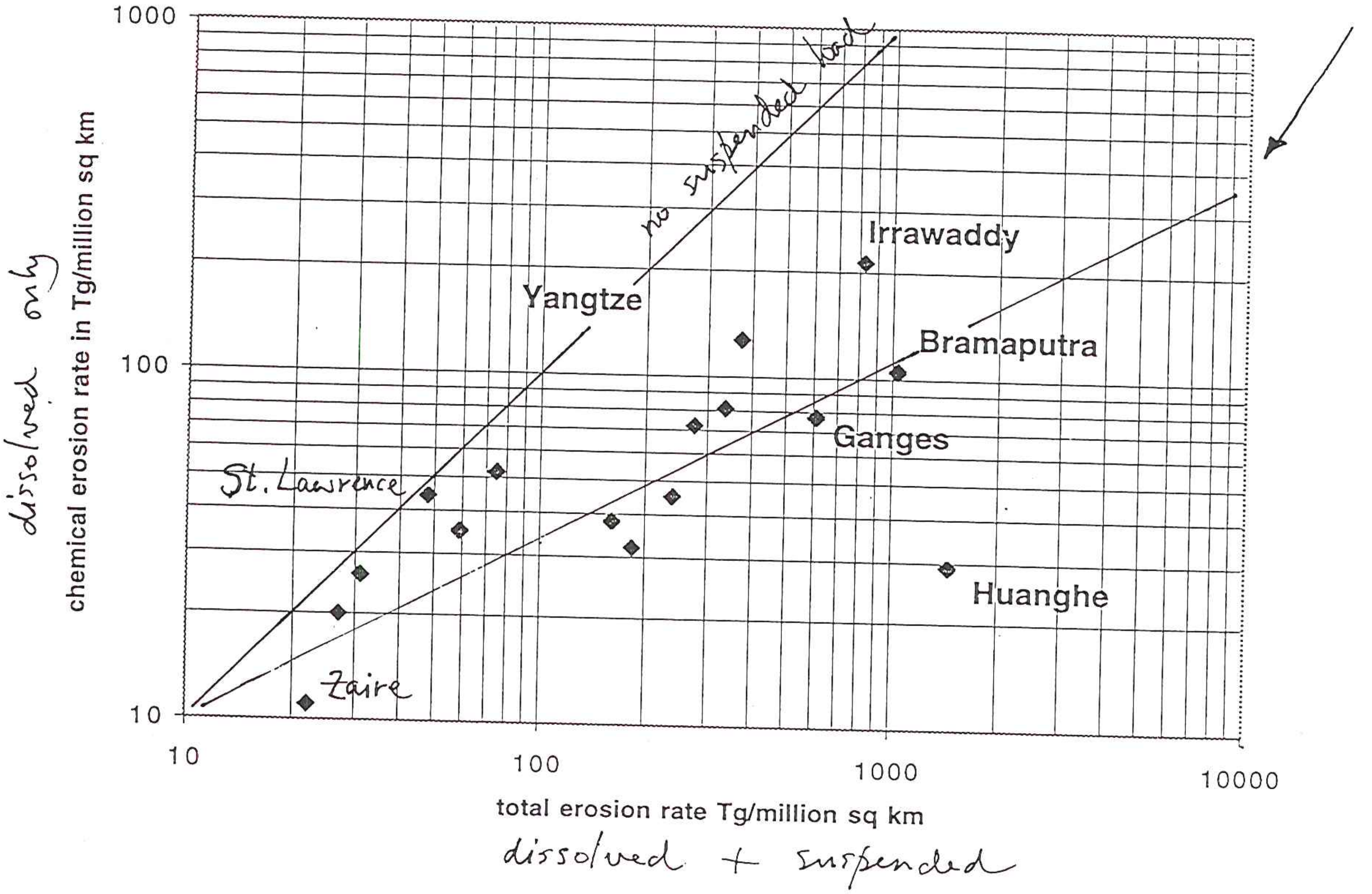
total load = $\frac{2}{3}$ suspended + $\frac{1}{3}$ dissolved

Erosion rates of major river basins of world



total li d =
$\frac{2}{3}$ suspended
+ $\frac{1}{3}$ dissolved

Erosion rates of major river basins of world



The total land area drained is also given.

Table 5.2 adds up the sediment fluxes on a continent-by-continent basis

A total of $20,000 \times 10^6$ tons/year by all rivers

$$\boxed{2 \cdot 10^{10} \text{ tons/yr} = 20 \text{ Pg/yr}}$$

petagrams

A few Pacific Ocean islands (Japan, Indonesia, Taiwan, Philippines, New Guinea, New ~~the~~ Zealand) contribute almost half of this.

If we divide the total sediment flux by the total drainage area, we get the ~~world-wide average erosion rate~~ so-called sediment yield

$$226 \ \frac{\text{tons}}{\text{km}^2 \text{ yr}}$$

this is suspended load only

~~adding the dissolved load~~

~~suspended 226~~
~~chemical 26~~
~~total 252 tons/km² yr total erosion rate~~

~~$\frac{9}{10}$ suspended + $\frac{1}{10}$ dissolved~~

11.5

Total dissolved load ≈ $\frac{1}{2}$ × suspended load

Dissolved load derived from continental rocks = $\frac{1}{2} \times \frac{1}{2} = 25\%$ of suspended load

In addition, the bedload is typically 1/10 × suspended load, so...

Total sediment yield =

$$226 \frac{\text{tons}}{\text{km}^2\,\text{yr}} \left(\underset{\substack{\nearrow\\ \text{suspended}}}{1} + \underset{\substack{\uparrow\\ \text{dissolved}}}{0.25} + \underset{\substack{\uparrow\\ \text{bed load}}}{0.10} \right)$$

$= 300 \text{ tons}/\text{km}^2\,\text{yr}$

Let us convert this to an erosion or denudation rate

note: we want the source rock density here

$$300 \frac{\text{tons}}{\text{km}^2\,\text{yr}} \times 1000 \frac{\text{kg}}{\text{ton}} \times \frac{1}{2700} \frac{\text{m}^3}{\text{kg}}$$

$$\times \frac{1}{10^6} \frac{\text{km}^2}{\text{m}^2} \times 10^3 \frac{\text{mm}}{\text{m}} = 0.1 \frac{\text{mm}}{\text{yr}}$$

world-wide average erosion rate

$$\langle \dot{e} \rangle = 0.1 \frac{\text{mm}}{\text{yr}} = 0.1 \frac{\text{km}}{\text{Myr}}$$

$\dot{e}_{\text{New Zealand \& al}} = 1.2$ km/Myr

The rate in the six oceanic islands is 12 times this — we shall investigate the factors that control the erosion rate in the next lecture.

Rate in North America is 3.4 times lower than world average

$$\dot{e}_{\text{North America}} = 0.03 \frac{\text{km}}{\text{Myr}}$$

conterminous US rate about the same

S. Alps NZ
9 km/My
Taiwan 5 km/M

Note: this does not represent the <u>total</u> rate of soil erosion which may be of interest to farmers & conservationists

Estimated that total amount of sediment eroded in conterminous US is

$5 \cdot 10^9$ tons/yr ← makes sense – ½ the NAM value in Tabl 5.2

But only about $5 \cdot 10^8$ tons/yr or 10% of this is discharged to the oceans (more than $3 \cdot 10^8$ tons/yr by the Mississippi)

Is this a homework problem

One last thing – total sediment supply to oceans in all world's rivers is

$$20 \cdot 10^9 \left(1 + \underset{\text{dissolved}}{\overset{0.25}{\cancel{0.5}}} + \underset{\text{bedload}}{0.1}\right) = \overset{2.7}{\cancel{3.2}} \cdot 10^{10} \ \frac{\text{tons}}{\text{yr}}$$

(counting pollution, etc.)

Total flow of water is 36,000 km³/yr
$= 3.6 \cdot 10^{13}$ tons H_2O/yr

Average concentration of suspended + dissolved sediments in river water is thus

$$\text{weight \%} = \frac{\overset{2.7}{\cancel{3.2}} \cdot 10^{10}}{3.6 \cdot 10^{13}} \sim 10^{-3} \sim \frac{1 \text{ mg solids}}{1 \text{ gm } H_2O}$$

TABLE 5.2 Suspended Sediment Carried by Rivers to the Ocean (in Metric Tons)

Continent	Drainage Area Contributing Sediment to Ocean (10^6 km^2)	Sediment Discharge (10^6 tons/yr)	Sediment Yield (tons/km^2/yr)	Mean Continental Elevation (km)
North America	15.4	1020	66	0.72
Central America[a]	2.1	442	210	—
South America	17.9	1788	97	0.59
Europe	4.61	230	50	0.34
Eurasian Arctic	11.17	84	8	~0.2
Asia	16.88	6349	380	0.96
Africa	15.34	530	35	0.75
Australia	2.2	62	28	0.34
Pacific & Indian Ocean Islands[b]	3.0	9000[c]	3000[c]	~1.0
World total	88.6	20,000[d]	226[d]	

[a] Includes Mexico.

[b] Japan, Indonesia, Taiwan, Phillipines, New Guinea, and New Zealand (Oceania).

[c] From Milliman and Syvitski (1992).

[d] From Milliman and Syvitski (1992). Data reflect greater sediment discharge from South America, the Alps-Caucusus Mountains, and northwest Africa, in addition to Oceania.

Sources: After Milliman and Meade (1983) and Milliman and Syvitski (1992), elevations from Fairbridge (1968).