Journal of the Minnesota Academy of Science

Volume 23 | Number 1 Article 13

4-1955

The Effect of Land Reduction on Sea Level and Continental Area

Fred Boos Jr.
Macalester College

may have been a tamarack forest at this time.

Later, the climate became increasingly warmer and drier. The tamaracks of Upper Cold Spring Terrace succumbed and migrated to Lower Cold Spring Terrace—a last-ditch position. However, even this favorable position is being lost: the peat is being filled with alluvium, or drained by erosion; the climate favors the hardier deciduous treets and grasses; wind storms topple the shallow-rooted tamaracks—and soon there will be no living tamarack relics in the Rockville-Cold Spring area to dramatically bring to the observer's attention that here the coniferous forest once flourished in the successive plant communities that are following the ice masses northward.

LITERATURE CITED

ALLISON, IRA S. 1932. The Geology and Water Resources of Northwestern Minnesota. Minn. Geol. Surv. Bull. 22, Minneapolis.

COOPER, W. S. 1935. The History of the Upper Mississippi River in Late Wisconsin and Postglacial Time. Minn. Geol. Surv. Bull. 26, Minneapolis.

HARRAR, E. S. 1947. "Larch," Encyclopaedia Britannica 13:722. University of Chicago, Illinois.

LEIGHTON, M. M. 1933. The Naming of Subdivisions of the Wisconsin Glacial Age. Science, N. S., 77:168.

ROSENDAHL, C. O., AND BUTTERS, F. K. 1928. Trees and Shrubs of Minnesota. University of Minnesota Press, Minneapolis.

WEAVER, J. E., and CLEMENTS, F. E. 1929. Plant Ecology. McGraw-Hill Book Company, Inc., New York.

WILMARTH, M. G. 1925. The Geologic Time Classification of the United States Geological Survey Compared with Other Classifications. Accompanied by the Original Definitions of Era, Period, and Epoch Terms. U. S. Geol. Survey, Bull. 769, 138 pages.

WILMARTH, M. G. 1938. Lexicon of Geologic Names of the United States (Including Alaska). U. S. Geol. Survey, Bull. 896, 2 Vols., 2396 pages.

WRIGHT, H. E. JR., et al. 1954. Friends of the Pleistocene—Field Trip, Central Minnesota. (Typewritten Guide), University of Minnesota, Minneapolis.

THE EFFECT OF LAND REDUCTION ON SEA LEVEL AND CONTINENTAL AREA

FRED BOOS, JR.
Macalester College, St. Paul

INTRODUCTION

Because lands were raised to exceptional height in late geologic time, the earth today possesses a relatively high relief in comparison with the average relief of the past. Repeatedly during long intervals of the earth's history the continents existed as low partially inundated plains. Accordingly, it is at least not unreasonable to suppose that the earth will experience a time of continental reduction in the immediate geologic future. If such is the case, then large volumes of soil and rock will effectively be stripped from the continents and carried to the sea. The natural result of such a transfer of material would be increased sea level rise and loss of land area due to sea invasion. If it is assumed that diastrophism and vulcanism are to remain quiescent during the next geologic epoch, it is possible to calculate the sea level rise and land loss due to sea invasion that would be produced by a given amount of continental reduction. In this paper it is assumed that diastrophism and vulcanism are completely inoperative, and that gradation is the sole agent of change.

METHODS

The first step was to adopt a simplified earth profile, one which would facilitate calculation and, at the same time, provide a fairly accurate representation of the earth's surface. The profile selected (see Fig. 1 and Fig. 2) is adopted from the study by Erwin Kossinna (1921).

Each of the altitude zones shown in Fig. 2 represents a definite volume of land material. If all the material of one of these zones were transported to the ocean, sea level would rise in order to compensate for the volume of water displaced. As a first approximation, sea level (s) would rise an amount given by

$$s = \frac{V}{A} \tag{1}$$

where V represents the volume of material in the given land zone and A represents the combined ocean area.

While it is easy to determine the overall land volume of a given zone in Fig. 1, one cannot be sure that all the material of the zone will be deposited in the sea. Alluvial fans, talus piles, river levies and deltas, glacial moraines, and sand dunes are all examples of eroded material deposited before reaching the sea. At the same time these continental deposits are being formed, much material is eroded from the lower zones and added to that carried from the upper zones. At high altitudes it is likely that the amount eroded greatly exceeds the amount deposited; along coastal planes, on the other hand, deposition may occasionally overbalance erosion as, for example, in a river delta area. It is probably correct to say that, on the average, all the altitude zones with the possible exception of the coastal zone are being reduced, and that the higher the altitude of the zone the faster is the rate of reduction.

FIGURE 1. THE PROFILE OF THE EARTH

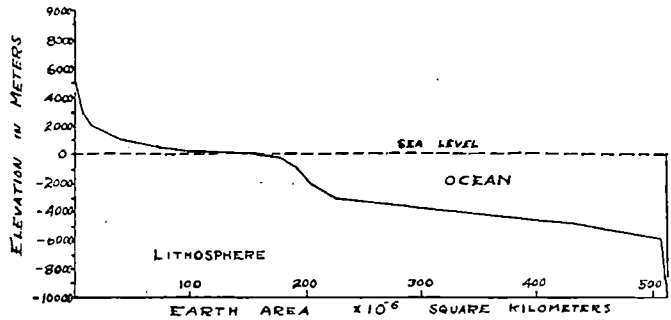
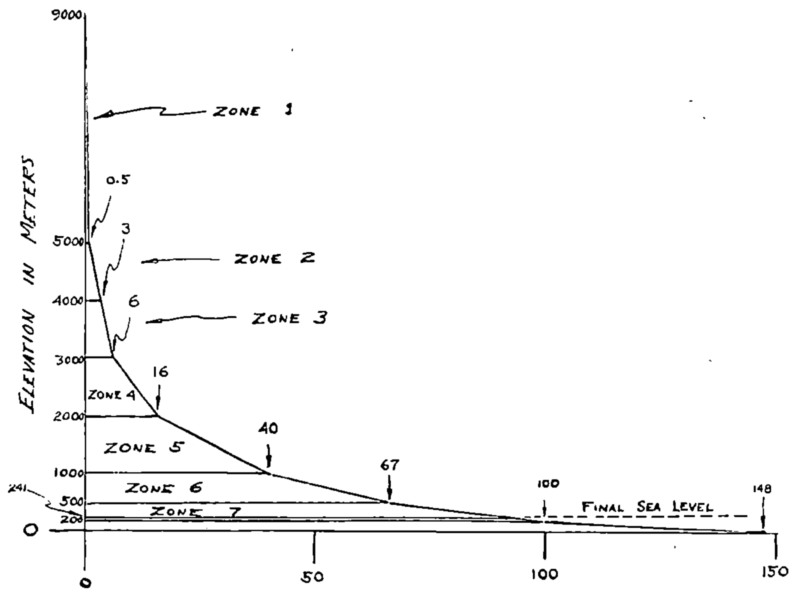


FIGURE 2. LAND ELEVATION ZONES



As a working hypothesis we will assume that the highest zone of Fig. 2 disappears before significant volume change has occurred in the lower zones. Thus the zones of Fig. 2 are eroded in order and the eroded material is in effect carried directly to the sea.

SOLUBILITY, WEATHERING AND POROSITY

In order to make an accurate determination of sea level rise, one should consider such factors as (1) *effective* loss of eroded material due to ocean solubility, (2) volume changes that accompany the weathering-deposition cycle, (3) effective loss of water replacement potential due to porosity.

(1) *Solubility.* Although about thirty or forty percent of eroded material carried to the sea by rivers is carried in solution, very little of this remains dissolved after thorough mixing in the sea. Complex physical, chemical and biological processes act to precipitate the major portion of this solute. Calcium carbonate, which comprises over 50% of the dissolved material carried by rivers is probably precipitated at the same rate at which it is being added—*i.e.*, the amount dissolved in the ocean remains constant. If this were not the case, then the oceans today would contain far more calcium and carbonate than they do.

Sodium chloride, which comprises over 80% of the material dissolved in the sea, amounts to less than 3% of igneous rock and about 1% of sedimentary rock (Sverdrup *et al.*, 1942). Thus, the net gain of sodium chloride to the sea, when igneous rock is weathered and sedimentary rock produced, is less than 2% in spite of the fact that sodium and chlorine constitute the major portion of the material dissolved in sea water. The reasonable conclusion is that very little of weathered igneous rock remains in solution after mixing. Goldschmidt (1933) estimated that the mass of sedimentary deposits are 97% of the mass of the original igneous rocks weathered. Thus, by this solubility consideration, igneous rock is potentially 97% effective in displacing sea water and causing sea level to rise.

Sedimentary rock, because it is usually a product of the seas, should be nearly 100% effective in this regard.

(2) *Weathering.* Clark and Washington (1924) estimate that igneous rock increases in volume a little less than 10% when it is chemically weathered due to the absorption of carbon dioxide, water and oxygen. This indicates that igneous rock has a water displacement potential of about 107% [*i.e.*, 100% — 3% (solubility) + 10% (weathering)]. Part of this volume increase is due to combination with land water, and cannot be considered as contributing to the water displacement potential.

Sedimentary rock does not, in general, exhibit this marked volume increase due to chemical weathering. The average chemical composition of new sediments being formed is approximately equal to the average composition of the sediments eroded.

According to Goldschmidt (1937) the earth contains 4.5 liters of land ice for every 268.45 liters of sea water. If we assume that the volume of the sea is equal to 1.37×10^9 cubic kilometers (Kossinna, 1921) then the volume of land ice is approximately 2.3×10^7 cubic kilometers. If we assume that ice undergoes a 10% volume decrease when it is physically weathered, then we may determine the error involved if this volume decrease is neglected. If all land ice were to melt then sea level rise as calculated by equation (1) would be

$$s = \frac{2.3 \times 10^7 \text{ cubic kilometers}}{3.62 \times 10^8 \text{ square kilometers}} \cong 64 \text{ meters}$$

The error involved would be about 10% of this value or approximately 6 meters.

This discrepancy amounts to less than 3% of the total sea level rise produced by complete land reduction (see Table 1).

(3) *Porosity*. Land materials vary widely in porosity, ranging from less than 1% for granites, schists and gneisses to approximately 50% for chalk, clay and soils (Meinzer, 1923). If these pore spaces are filled with gaseous substance, and if the gases escape during the weathering-erosion-deposition process, then the eroded material will not be 100% influential in producing sea level rise. Pore spaces filled with solid or liquid substance will generally be influential. Below the water table one would expect the "effective" porosity to be much reduced because pore spaces would tend to fill with water. Above the water table the effective porosity could approach "true" porosity if the climate were dry enough.

If one assumes that all land areas were covered by a *dry* 50% porous material to a depth of 60 meters, then the sea level rise produced by transporting this layer to the ocean would be approximately 10 meters compared with a 20 meter rise if the layers were nonporous.

> If we assume that land area is equal to one unit, then total ocean area is equal to three units, and the effective volume of pore space is equal to (50%) (60 meters) (1) = 30 meters x (the new unit); then by equation (1), we have a sea level rise
>
> $$s = \frac{V}{A} = \frac{30 \text{ meters} \times (\text{the new unit})}{3 \text{ (new units)}} = 10 \text{ meters}$$

Ten meters amounts to less than 5% of the total sea level rise produced by land reduction (see Table 1).

Below the water table the "effective" porosity is very slight due to the fact that (1) land material is probably composed of over 20% nearly non porous crystalline rock, (2) shale, which has a porosity less than five percent, comprises about 80% of all sedimentary rock (Clark and Washington, 1924), and (3) many of the pore spaces that do exist are filled with water.

A complete and accurate analysis of the influence of the three factors discussed above would obviously require detailed data concerning the physical and chemical quality of subsurface as well as surface land material, plus a complete understanding of the weathering-erosion-deposition cycle. While such an analysis would be extremely difficulty, the discussion does indicate that if the three factors were ignored, the error involved would not be excessive—certainly less than 10% and possibly less than 5%.

For this reason we shall assume in this discussion (1) that the zones of Figure 2 are removed by erosion in order, (2) that the material removed is in effect carried directly to the sea, and (3) that the over all volume of any given land zone is 100% effective is displacing sea water and causing sea level rise. Thus, sea level rise produced by the erosion of a given zone will be given by equation (1) where V represents the volume of the zone and A represents the area of the ocean at the time of erosion.

LAND REDUCTION. If zone one of figure 2 is eroded and the material of the zone transported to the sea, then sea level rise (s) is

$$s = \frac{V}{A} = \frac{10^6 \text{ km.}^3}{3.62 \times 10^8 \text{ km}^2} = 2.8 \text{ meters} \qquad (2)$$

The value 10^6 km.^{3} represents the volume of zone one and 3.62 x 10^8 km.^{2} represents the present area of the sea (see Table 1).

Because the slope of shore area is 200 meters of rise per 48 x 10^6 km. of land area (see Fig. 2), the amount of sea invasion (a) is given by

$$a = \frac{(2.8 \text{ meters})\ (48 \times 10^6 \text{ km.}^2)}{200 \text{ meters}} = 0.6\ 10^6 \text{ km.}^2 \qquad (3)$$

The new ocean area is equal to the old ocean area plus the area of sea transgression

$$(362 \times 10^6 + 0.6 \times 10^6 \text{ km.}^2 \cong 363 \times 10^6 \text{ km.}^2 \qquad (4)$$

This procedure may be repeated for each of the zones of figure two. The results of the calculations are tabulated in Table 1.

In order to obtain the correct value of sea level rise, it is necessary to use an average value for ocean area during erosion—i.e., a value intermediate between area before and after zone reduction. When considering zone five, for example, sea level rise calculated using initial (i.e., prior to erosion) ocean area is

$$s_5 = \frac{V_5}{A_{4,5}} = \frac{28 \times 10^6 \text{ km.}^3}{374 \times 10^6 \text{ km.}^2} = 75 \text{ meters} \qquad (5)$$

and

$$s_1 + s_2 + s_3 + s_4 + s_5 = 50 + 75 = 125 \text{ meters} \qquad (6)$$

According to the procedure of equation (3) the area of sea invasion is

$$a_1+a_2+a_3+a_4+a_5=\frac{(125\text{m.})\ (48\text{x}10^6\text{km.}^2)}{200\text{ m.}}=30\text{x}10^6\text{km.}^2 \quad (7)$$

The new sea area is equal to ocean area prior to the reduction of zone one plus the total area of sea transgression

$$(362 + 30)\ \text{x}\ 10^6\ \text{km.}^2 = 392\ \text{x}\ 10^6\ \text{km.}^2 \quad (8)$$

Recalculation according to equation (1) using a value of ocean area intermediate between the ocean area prior and post to the erosion of zone five yields

$$s_5 = \frac{28\ \text{x}\ 10^6\ \text{km.}^3}{\left[\frac{374\ +\ 392}{2}\right]\ \text{x}\ 10^6\ \text{km.}^2} = 73\ \text{meters} \quad (9)$$

$$s_1 + s_2 + s_3 + s_4 + s_5 = 123\ \text{meters} \quad (10)$$

These values are correct to the nearest meter and differ from those values obtained in equations (4) and (5) by two meters. Recalculation in order to improve the value of sea invasion yields

$$a_1+a_2+a_3+a_4+a_5=\frac{(123)\ (48\text{x}10^6\text{km.}^2)}{200}=30\text{x}10^6\text{km.}^2 \quad (11)$$

This value is identical to the nearest 10^6 km.^{2}, with the original result obtained in equation (6) so that this calculation produces no improvement.

Because the slope of the shore area is 300 meters rise in 33 x 10^6 km.^{2} when land area becomes less than 100 x 10^6 km.^{2}, and sea level rise exceeds 200 meters (see Fig. 2), slightly different numbers are used to calculate the area of sea transgression. Because total sea level rise surpasses 200 meters by 41 meters (see Table 1), sea invasion beyond the 100 x 10 km. land area mark, is

$$a = \frac{(41\text{ m.})\ (33\ \text{x}\ 10^6\ \text{km.}^2)}{300\text{ m.}} = 5\ \text{x}\ 10^6\ \text{km.}^2 \quad (12)$$

The final land area as shown in Table 1 is

$$100\ \text{x}\ 10^6\ \text{km.}^2 - 5\ \text{x}\ 10^6\ \text{km.}^2 = 95\ \text{x}\ 10^6\ \text{km.}^2 \quad (13)$$

TABLE 1.

Zone Eroded	Volume of Zone x 10^6 Km.^{3}	Sea Level Rise Meters	Accumulative Sea Level Rise Meters	New Land Area x 10^6 Km.^{2}	New Sea Area x 10^6 Km.^{2}
0	—	—	—	148	362
1	1.0	3	3	147	363
2	1.75	5	8	146	364
3	4.50	12	20	143	367
4	11.0	30	50	136	374
5	28.0	73	123	118	392
6	26.75	67	190	102	408
7	21.0	51	241	95	415

SUMMARY

Table 1 indicates that if the continents are reduced to incipient inundation, sea level will rise approximately 241 meters, and will flood about 53 x 10^6 km.^{2} of land area, or a little over one-third of the present land area. The discussions indicate that the probable error is less than 10% and possibly less than 5%.

LITERATURE CITED

CLARK, FRANK W. AND HENRY S. WASHINGTON. 1924. The Composition of the Earth's Crust. U. S. Geological Survey, Professional Paper 127, Washington, Government Printing Office.

GOLDSCHMIDT, V. M. 1937. The Principles of Distribution of Chemical Elements in Minerals and Rocks. Chemical Society Journal, pp. 655-73, London.

KOSSINNA, ERWIN. 1921. Der Tiefen des Weltmeers. Berlin Univ., Naturwiss. Reihe, Heft 9, 70 pages.

MEINZER, OSCAR EDWARD. 1923. The Occurrence of Ground Water in the United States. U. S. Geological Survey, Washington, Government Printing Office.

SVERDRUP, H. U., MARTIN W. JOHNSON, AND RICHARD H. FLEMING. 1942. The Oceans. Prentice-Hall, Inc., New York.

TRADITIONAL AND ECOLOGICAL ASPECTS OF THE QUARTER SECTION

HILDEGARD BINDER JOHNSON
Macalester College, St. Paul

ABSTRACT

The philosophical background of the rectangular land survey of the United States and its "geometric spirit" can be traced back to Descartes. An investigation of the legislative history of the "Ordinance for ascertaining the mode of disposing of lands in the western territory" reveals that the rational and geometric land division ignored the natural differences of the land and a mathematical impossibility as well: Square townships, sections and quarter sections were to be governed by the true meridians as the law decreed, but it is impossible because of the convergence of the meridians.

Legislation subsequent to the Ordinance made possible the purchase of tracts smaller than a section. After 1832, the "forty," that is, a quarter of a quarter section, could be obtained by first transfer of government land to private ownership. Nothing, after 1832, has basically modified the survey or the mode of first transfer.

A detailed study of the original surveyors' lists and their land descriptions and of the original book of Land Office Record Deeds at Winona, Minnesota, during 1855, shows that the pioneers