

Denudation of Taiwan Island since the Pliocene Epoch

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ABSTRACT

The average denudation rate of the Central Range of Taiwan Island has been increasing since the Pliocene Epoch. Today it is at least 1,365 mg/cm²yr, which is probably the highest known value in the world.

INTRODUCTION

The reversal of the downthrust of the colliding Eurasia and Philippine Sea plates occurs near the area east of Taiwan Island (Wu, 1970; Lee and Hilde, 1975, unpub. data); therefore, Taiwan Island has been very active in a tectonic sense since early in its formation (mainly the present Central Range) during the Paleocene Epoch. As will be shown by the present study, the acceleration of the denudation rate since Pliocene time attests to the rapid upward movement of Taiwan Island.

PRESENT DENUDATION RATE OF TAIWAN ISLAND

The present-day physical denudation rate (hereafter, PDR) at each observational station located in the upstream drainage areas of Taiwan was calculated from extensive data of suspended-particle loadings on rivers throughout the island (Comm. Water Resource Control, 1973). Similarly, the chemical denudation rate (CDR) of upstream drainage areas at more than 30 stations was also estimated by using the bimonthly chemical data (Hsü, 1964) and the water-flow data (Comm. Water Resource Control, 1970) for the rivers. Figures 1A and 1B show the values of the PDR and the CDR, respectively.

$$\text{PDR} = \sum_{i=1}^{365} a \cdot Q_i^{b+1} / A$$

and

$$\text{CDR} = (Q_T \cdot \sum_{i=1}^n Q_i \cdot C_i) / (A \cdot \sum_{i=1}^n Q_i),$$

where Q_i = water-flow rate in cubic metres per day; a and b = empirical constants from the relation $C_i = a \cdot Q_i^b$ in which C_i = concentration of suspended particles for the case of PDR and total dissolved salts for the case of CDR; Q_T = annual water-flow rate; and n = number of observations. The calculated PDR values should be considered as minima, because the coarser sand grains and pebbles transported near and (or) on the river beds were not included in the measurements. The calculated CDR values, on the other hand, represent the maxima, because in the calculation, one-half of bicarbonate ions in river waters was assumed to have been entirely derived from the dissolution of carbonate rocks and the remainder from the air. (In the case of chemical weathering of silicate minerals, all bicarbonate ions in river waters were directly or indirectly—for example, oxidation of organic materials—supplied by the air and should not be considered as components derived from weathered rocks.)

The dashed line in Figure 1A represents the 600-mg/cm²yr contour of the PDR. The area to the right of the dashed line has an average PDR of about 1,300 mg/cm²yr, and the area to the left, about 325 mg/cm²yr. The great change in the PDR can be explained by the change in relief and (or) in the bedrock geology. For example, in the Central Range of Taiwan (that is, the area of the pre-Miocene formations, enclosed by the dotted line in Fig. 1A), the relief and the relief ratio are extremely high (the highest peak is 3,997 m, and the relief ratio is no less than one-tenth) and so are the PDR values. One exception is the upstream area of river 1 and the area between rivers 2 and 3 (locations in Fig. 1A) where the bedrock consists mainly of compact formations of Eocene and Oligocene age. Outside the Central Range, the drainage area between rivers 4 and 5 is the only location with a comparably high PDR, although the

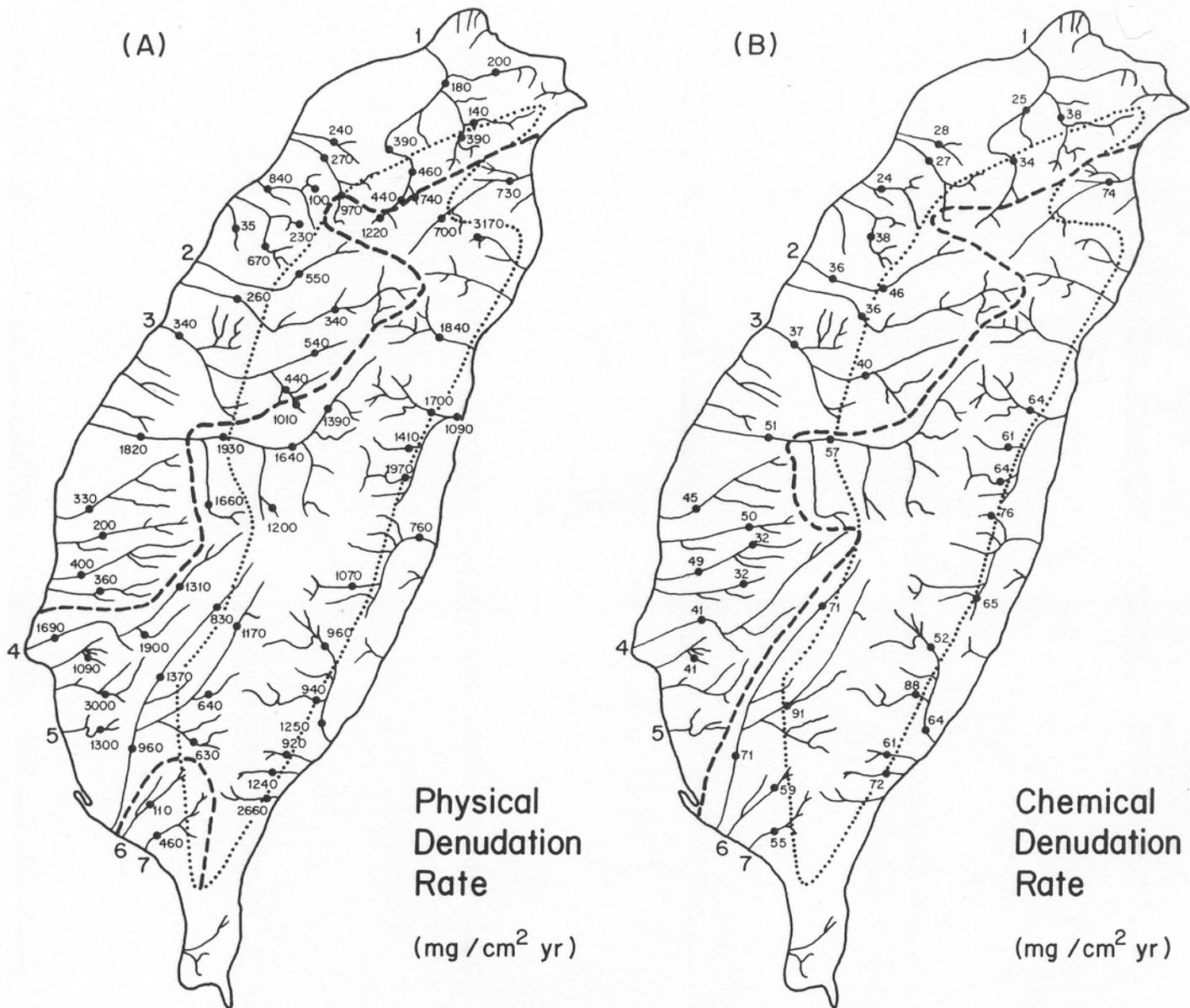


Figure 1. Physical denudation rates (A) and chemical denudation rates (B) of upstream drainage areas at each station. Values in milligrams per square centimetre per year. Dashed lines represent boundary between low and high denudation rates; area within dotted line represents Central Range.

relief ratio is relatively lower. Most of the bedrock in this area consists of loosely bound siltstone and mudstone of late Miocene and Pliocene ages.

In comparison with the average PDR for the Asian continent (30 mg/cm²yr; Garrels and Mackenzie, 1971) for the Yellow River drainage of China (290 mg/cm²yr; Comm. Water Resource Control, 1973) and for the Alpine Rhine (115 mg/cm²yr; Li and Erni, 1974), the average PDR for Taiwan Island is extremely high. The average PDR for the Central Range (1,300 mg/cm²yr) is probably the highest known physical denudation rate in the world. At this high rate of denudation, the Central Range could be leveled within half a million years, if the orogeny ceases.

The dashed line in Figure 1B is the 50-mg/cm²yr contour of the CDR. The area to the right of this contour has an average

CDR of about 65 mg/cm²yr, and the area to the left, about 38 mg/cm²yr. The contrast is not as pronounced as in the case of the PDR. For comparison, the average CDR is only about 3 mg/cm²yr for the Asian continent (Garrels and Mackenzie, 1971) and 18 mg/cm²yr for the Alpine Rhine (Li and Erni, 1974).

The areas of high and low chemical denudation rates in general correspond well to the areas of high and low physical denudation rates (the high and low values are relative to the dashed line in Figs. 1A and 1B). However, the CDR is low in the drainage area between rivers 4 and 5, whereas the PDR is high. Another minor exception is the drainage area of rivers 6 and 7 where the PDR is low but the CDR is high; this situation possibly indicates some large carbonate outcrops in the area. In the regions with low values of both PDR and CDR, the ratio of

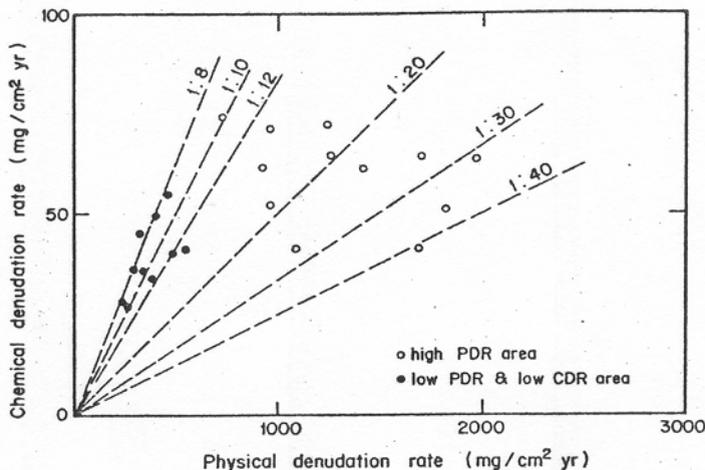


Figure 2. Ratio of chemical denudation rate to physical denudation rate at various stations.

PDR to CDR clusters around 10 ± 2 (Fig. 2), which is similar to the average for the Asian continent (Garrels and Mackenzie, 1971). The PDR/CDR ratio ranges from 10 to 40 (Fig. 2) in regions with high PDR values.

DISCUSSION

Integrating the thickness contours of the Pleistocene Toukoshan formation and the Pliocene formation deposited in the basin west of the Central Range down to a 500-m contour line as given by Chou (1973) and taking the mean density of sedimentary rocks to be 2.5 g/cm^3 allow the mass of the deposited Pleistocene and Pliocene sediment to be estimated at about $7.0 \times 10^{19} \text{ g}$ and $8.5 \times 10^{19} \text{ g}$, respectively. According to Chou (1973), the main source area for the sediment was the Central Range.

If it is assumed that (1) an equal amount of sediment was also discharged to the Pacific Ocean on the east side of the Central Range; (2) only a relatively small amount of the Pleistocene and Pliocene formations has been removed by erosion; (3) 1 to 2 m.y. were required for the deposition of the Pleistocene Toukoshan formation, and 10 m.y. were required for deposition of the Pliocene formation; and (4) the area of the Central Range since Pliocene time was about the same as it is today (that is, $18 \times 10^{13} \text{ cm}^2$), then the average physical denudation rate of the Central Range during the Pliocene and the Pleistocene would be $96 \text{ mg/cm}^2\text{yr}$ and $385 \text{ to } 770 \text{ mg/cm}^2\text{yr}$, respectively. In comparison with the present-day minimum value of $1,300 \text{ mg/cm}^2\text{yr}$ (some human effects cannot be excluded altogether, although most of the population and the agricultural activities are concentrated in the coastal plains around the island), it is apparent that the denudation rate of the Central Range has been accelerating since the Pliocene. This implies that the Central Range has been rising rapidly; such movement is also indicated by the uplifted coastal terraces of several stages and by the raised beach deposits and coral reefs found at the northern and southern ends of Taiwan today (Chou, 1973).

According to the work of Lin (1969) and the data compiled by Bonilla (1975), the minimum uplift rate of the recent coastal terraces (less than 9,000 yr old) around the island ranges from

2 mm/yr to 6.4 mm/yr and averages about 4 mm/yr. On the other hand, the average denudation rate (physical plus chemical) outside the area with high physical denudation rates (Fig. 1) is about 1.5 mm/yr (if it is assumed that the density of the formations is about 2.5 g/cm^3). Therefore, the actual average uplift rate of the coastal terraces (minimum uplift rate plus denudation rate) may be about 5.5 mm/yr. If the uplift rate of 5.5 mm/yr also applies to the Central Range, the height of the Central Range would not change much today, since the average denudation rate of the Central Range is also about 5.5 mm/yr (if it is assumed that the density of rock is about 2.5 g/cm^3).

One can conclude that the high denudation rate of the Central Range today is a direct consequence of the rapid upward movement of Taiwan Island, but the rapid denudation of the Central Range, in turn, aids the further uplift of the island by an isostatic adjustment.

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