UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

# Latitudinal distribution of land and shelf and absorbed solar radiation during the Phanerozoic

Judith Totman Parrish[1]

Open-File Report 85-31



[1] Address: Branch of Oil and Gas Resources, U.S. Geological Survey, Denver

CONTENTS



TABLES



ILLUSTRATIONS

## INTRODUCTION

The latitudinal distribution of organisms and of paleoclimatically significant rocks, such as coal and evaporites, is of interest to paleoclimatologists, because variations in distribution along north-south trends may be indicative of gradients in climatic parameters such as rainfall and temperature. Paleoclimatologists and paleontologists occasionally are concerned with the relationship of their data to land area or shelf area (for example, Schopf and others, 1978). This report contains data on the area of land and continental shelf (continental crust covered by the sea) for ten-degree latitudinal belts for fourteen geologic ages during the Phanerozoic. In addition, calculations of absorbed solar radiation are presented (ASR; essentially heat) for each time interval, which is dependent on the distribution of land and sea at each latitude. Changes in heat absorbed at the Earth's surface may partially explain major paleoclimatic changes.

## METHODS

The land and shelf areas were measured from the global paleogeographic maps of Scotese and others (1979) and Ziegler and others (1983), which represent 14 geologic ages of the Phanerozoic, listed in table 1; the measurements are presented in table 2. The maps are Lambert equal-area projections; therefore, areas were measured directly using a planimeter. The methods of constructing the maps are described in the original publications and will not be repeated here except for the following points:

(1) No attempt was made to restore allochthonous terranes to their original positions, which are rarely known anyway. Furthermore, the terranes were omitted from maps that represent times older than the oldest rocks known from those terranes.

(2) Palinspastic reconstructions were included in reconstructions of the Mesozoic and Tertiary paleogeography of the Mediterranean area, Zagros Thrust Belt, and northern India, but for no other regions.

ASR was calculated as described in Barron and others (1980). The equation is: $ASR = \sum_{i=1}^{18} (Q_i[1-a_{T_i}])$, where $Q_i$ is the incoming solar radiation for each ten-degree latitudinal belt and $a_T$ is the total albedo (reflectivity) of the Earth's surface within that belt. Various assumptions can be made about albedo with regard to surface characteristics, such as cover by snow, ice, or plants. Albedo also varies with latitude for water and ice. Water is more reflective at high latitudes, where the angle of incidence of sunlight is small, than at low latitudes and sea ice is less reflective than land ice. Values for albedo used in this study for various substrates at different latitudes (table 3) were taken from Barron and others (1980), and a number of different cases, with different assumptions about albedo for each time period, were calculated.

ASR is also dependent on the incoming solar radiation (Q). Incoming solar radiation is believed to have changed through time in accordance with the sun's stellar evolution cycle. The best-accepted solar evolution model is that described in Sagan and Mullen (1972), and states that the sun's luminosity has increased monotonically from 75% of its present value since 4.5 billion years ago. Luminosity values appropriate for each time interval, extrapolated between that value and present solar luminosity, were used for the calculations of ASR. The present luminosity values for ten-degree latitude belts and the percent of present luminosity determined for each time interval are listed in table 4.

## RESULTS

Changes in land and shelf area through time are summarized in figure 1. The shelf-area curve may be taken as a sea-level curve, with the following conditions:

(1) The connected points represent specific geologic ages that are not necessarily representative of highstands and lowstands of sea level

(2) Because palinspastic reconstruction was not attempted for many regions, the total area of continental crust (land + shelf area) for each time interval may be increasingly underestimated from the Tertiary to the early Paleozoic. However, the increase in total area of continental crust through time is only partly apparent; owing to accretion, an actual increase also took place.

Two peaks in shelf area occurred in the Wenlock (Late Silurian) and Cenomanian (middle Cretaceous).

Variations in ASR through time are presented in figures 2 and 3, which illustrate the results for different assumptions about albedo. The calculated values are presented in tables 5 and 6. figure 3 incorporates the most "realistic" assumptions for each time period, which are detailed in table 6. As with the shelf-area curve, the ASR curve represents the changes between specific time intervals and may not be representative of actual maximum or minimum values.

ASR generally mirrors sea level changes, especially when snow and ice and deserts are ignored. This is to be expected because between 60° north and south, approximately 87% of the Earth's surface, reflectivity of water is less than that of land. In all cases, the inclusion of deserts and high-latitude snow and ice cover results in minimum values of ASR because of the reflectivity of those substrates. The effects of snow and ice on ASR versus the effects of deserts depends on the land area covered by each of those substrates but, in general, deserts reduce ASR more than does snow and ice cover (table 5).

## DISCUSSION

The data suggest that sea level may be a major control on climate and, also, that deserts are more important than snow and ice cover.

These are both conclusions arrived at by Barron and others (1980). Of course, the character of the Earth's surface is determined by a network of climatic processes that include feedback mechanisms that might, for example, reduce desert area while increasing ice cover. In addition, clouds have a high albedo, and their contribution is not calculable with the technique outlined here; indeed, clouds have proved an intractable problem in even the most sophisticated climate models. Nevertheless, calculations of ASR can provide some insights of the effects of paleogeographic change. To demonstrate this point, calculations of ASR for two paleogeographic conditions during the Ashgill (latest Ordovician) are included in table 6 and figure 3. At the beginning of the Ashgill, sea level was high, in accordance with sea level throughout the Ordovician. At the culmination of the terminal Ashgillian glaciation, however, sea level dropped drastically, nearly to the shelf break in North America (Sheehan, 1973). By generalizing exposed land-surface area at the terminal Ashgill to include all continental crust to the shelf break, and including the condition that the regression would have exposed vast carbonate platforms having a high albedo (in the Ordovician, the land surface would not have been colonized by plants), an extremely low value of ASR is obtained. This raises the possibility that the severity of the Late Ordovician glaciation was intensified by feedback from the progressive decrease of ASR not only as more ice formed but also as more highly reflective land was exposed. The same argument might be applied to the Permian glaciation, which was roughly coeval with the deposition of widespread desert sediments and evaporites, both of which are highly reflective. It must be emphasized, however, that cause and effect in climatic change are very delicate and that other processes, such as changes in orbital parameters (Hays and others, 1976), are equally important.

## REFERENCES CITED

Barron, E.J., Sloan, J.L., and Harrison, C.G.A., 1980, Potential significance of land-sea distribution and surface albedo variations as a climatic forcing factor; 180 million years to the present: Palaeogeography, Palaeoclimatology, Palaeoecology v. 30, p. 17-40.

Hays, J.D., Imbrie, J., and Shackleton, N.J., 1976, Variations in the Earth's orbit: pacemaker of the Ice Ages: Science v. 194, p. 1121-1132.

Sagan, C., and Mullen, G., 1972, Earth and Mars: evolution of atmospheres and surface temperatures: Science v. 177, p. 52-56.

Schopf, T.J.M., Fisher, J.B., and Smith, C.A.F., III, 1978, Is the marine latitudinal diversity gradient merely another example of the species-area curve? IN Battaglia, B., and Beardmore, J.A., eds., Marine Organisms: Genetics, Ecology, and Evolution. New York, Plenum Publishing Company, p. 365-386.

Scotese, C.R., Bambach, R.K., Barton, C., Van der Voo, R., and Ziegler, A.M., 1979, Paleozoic base maps: Journal of Geology v. 87, p. 217-277.
Sheehan, P. M., 1973, The relation of Late Ordovician glaciation to the Ordovician-Silurian changeover in North American brachiopod faunas. Lethaia v. 6, p. 147-154.
Ziegler, A.M., Scotese, C.R., and Barrett, S.F., 1983, Mesozoic and Cenozoic paleogeographic maps. IN Brosche, P., and Sündermann, J., eds., Tidal Friction and the Earth's Rotation, II. Berlin, Springer-Verlag, p. 240-252.

Table 1. Geologic ages represented by global paleogeographic maps used for the land and shelf measurements (Scotese and others, 1979; Ziegler and others, 1983).

| Period | Series | Age |
|---|---|---|
| Cambrian | Late | Franconian |
| Ordovician | Early-Late | Llandeilo-Caradoc |
| Silurian | Late | Wenlock |
| Devonian | Early | Emsian |
| Mississippian | Early | Visean |
| Pennsylvanian | Late | Westphalian C-D |
| Permian | Late | Kazanian |
| Triassic | Early | Induan |
| Jurassic | Early | Pliensbachian |
| Jurassic | Late | Volgian |
| Cretaceous | early Late | Cenomanian |
| Cretaceous | late Late | Maestrichtian |
| Tertiary | Eocene | Lutetian |
| Tertiary | Miocene | Vindobonian |

Table 2. Areas, in $10^6$ $km^2$ of land and continental shelf for 14 geologic ages in the Phanerozoic, broken down by 10°-latitude belts. Measurements were made from the maps published in Scotese and others (1979--Paleozoic) and Ziegler and others (1983--Mesozoic and Cenozoic). * = estimated values.

FRANCONIAN (Late Cambrian)

| Latitude | Shelf | Land |
|---|---|---|
| 80-90°N | 0 | 0 |
| 70-80 | 0 | 0 |
| 60-70 | 0 | 0 |
| 50-60 | 0 | 0 |
| 40-50 | 3 | 0.06* |
| 30-40 | 5.3 | 1.4 |
| 20-30 | 4.6 | 6.1 |
| 10-20 | 4.8 | 10 |
| 0-10N | 7.7 | 17 |
| 0-10°S | 8.1 | 18 |
| 10-20 | 7.3 | 14 |
| 20-30 | 4.8 | 8.9 |
| 30-40 | 4 | 7.7 |
| 40-50 | 5.6 | 3.8 |
| 50-60 | 1.3 | 0.4 |
| 60-70 | 0 | 0 |
| 70-80 | 0 | 0 |
| 80-90S | 0 | 0 |
| Total | 56.5 | 87.4 |

LLANDEILO-CARADOC (late Early and early Late Ordovician)

| Latitude | Shelf | Land |
|---|---|---|
| 80-90°N | 0 | 0 |
| 70-80 | 0 | 0 |
| 60-70 | 0 | 0 |
| 50-60 | 0 | 0 |
| 40-50 | 1.3 | 0.3 |
| 30-40 | 4 | 0.1 |
| 20-30 | 2.5 | 0.4 |
| 10-20 | 5.2 | 2.9 |
| 0-10N | 9.1 | 6.5 |
| 0-10S | 7.6 | 10 |
| 10-20 | 8.1 | 11 |
| 20-30 | 4.8 | 11 |
| 30-40 | 3.1 | 9.4 |
| 40-50 | 3.8 | 7.3 |
| 50-60 | 3.8 | 7.3 |
| 60-70 | 6.2 | 5.1 |
| 70-80 | 5.2 | 1.4 |
| 80-90S | 1.2 | 0 |
| Total | 65.9 | 72.7 |

Table 2 continued.

WENLOCK (Late Silurian)

| Latitude | Shelf | Land |
|---|---|---|
| 80-90°N | 0 | 0 |
| 70-80 | 0 | 0 |
| 60-70 | 0 | 0 |
| 50-60 | 0 | 0 |
| 40-50 | 0.8 | 1 |
| 30-40 | 2.1 | 1.4 |
| 20-30 | 5.3 | 0.3 |
| 10-20 | 4.7 | 0.7 |
| 0-10N | 5.5 | 6.1 |
| 0-10S | 9.2 | 4.1 |
| 10-20 | 7.3 | 3.1 |
| 20-30 | 4.1 | 3.4 |
| 30-40 | 8 | 3.8 |
| 40-50 | 14 | 6.6 |
| 50-60 | 4.5 | 14 |
| 60-70 | 3 | 14 |
| 70-80 | 0.6 | 11 |
| 80-90S | 0 | 4.2 |
| Total | 69.1 | 73.7 |

EMSIAN (Early Devonian)

| Latitude | Shelf | Land |
|---|---|---|
| 80-90°N | 0 | 0 |
| 70-80 | 0 | 0 |
| 60-70 | 0.1 | 0 |
| 50-60 | 1 | 1.2 |
| 40-50 | 2.5 | 2.4 |
| 30-40 | 4 | 3.4 |
| 20-30 | 1.9 | 7.6 |
| 10-20 | 5 | 8.9 |
| 0-10N | 4.9 | 7.8 |
| 0-10S | 4.5 | 2.5 |
| 10-20 | 1.6 | 2.4 |
| 20-30 | 8 | 3.5 |
| 30-40 | 11 | 5.7 |
| 40-50 | 4.7 | 13 |
| 50-60 | 2.7 | 14 |
| 60-70 | 3.8 | 9.7 |
| 70-80 | 3.8 | 7.7 |
| 80-90S | 0.5 | 2.9 |
| Total | 60.0 | 92.7 |

Table 2 continued.

VISEAN (Early Carboniferous)

| Latitude | Shelf | Land |
|---|---|---|
| 80-90°N | 0 | 0 |
| 70-80 | 0.9 | 1.4 |
| 60-70 | 1 | 2.4 |
| 50-60 | 2.2 | 1.9 |
| 40-50 | 1.8 | 1 |
| 30-40 | 4.1 | 5.8 |
| 20-30 | 3.8 | 6.5 |
| 10-20 | 3.4 | 7 |
| 0-10N | 4.4 | 6.5 |
| 0-10S | 4.2 | 1.6 |
| 10-20 | 7.1 | 2.4 |
| 20-30 | 7.7 | 10 |
| 30-40 | 3.7 | 15 |
| 40-50 | 0.3 | 17 |
| 50-60 | 0.2 | 14 |
| 60-70 | 0.4 | 11 |
| 70-80 | 2.3 | 6 |
| 80-90S | 0.7 | 2 |
| Total | 48.2 | 111.5 |

WESTPHALIAN C-D (Late Carboniferous)

| Latitude | Shelf | Land |
|---|---|---|
| 80-90°N | 0 | 0 |
| 70-80 | 0.4 | 0.3 |
| 60-70 | 0.6 | 2.2 |
| 50-60 | 1.6 | 3.8 |
| 40-50 | 2.9 | 3.8 |
| 30-40 | 6.6 | 4.4 |
| 20-30 | 4.7 | 6.4 |
| 10-20 | 4.6 | 8.1 |
| 0-10N | 2.5 | 8 |
| 0-10S | 2.4 | 7 |
| 10-20 | 2.4 | 6.5 |
| 20-30 | 3.7 | 4.9 |
| 30-40 | 5.8 | 8 |
| 40-50 | 3.1 | 14 |
| 50-60 | 2.2 | 18 |
| 60-70 | 0.5 | 18 |
| 70-80 | 0 | 11 |
| 80-90S | 0 | 4.1 |
| Total | 44.0 | 128.5 |

Table 2 continued.

KAZANIAN (Late Permian)

| Latitude | Shelf | Land |
|---|---|---|
| 80-90°N | 0 | 0.4 |
| 70-80 | 0.6 | 2.8 |
| 60-70 | 0.7 | 5 |
| 50-60 | 1.5 | 5.2 |
| 40-50 | 6.6 | 4.6 |
| 30-40 | 4.4 | 6.6 |
| 20-30 | 2.9 | 8.6 |
| 10-20 | 1.4 | 7.4 |
| 0-10N | 1.5 | 6.8 |
| 0-10S | 1.4 | 6.3 |
| 10-20 | 1.6 | 8 |
| 20-30 | 2.9 | 9.8 |
| 30-40 | 4.5 | 9.3 |
| 40-50 | 2.5 | 13 |
| 50-60 | 2.3 | 13 |
| 60-70 | 0.7 | 12 |
| 70-80 | 1.1 | 9.2 |
| 80-90S | 0 | 3.9 |
| Total | 36.6 | 131.9 |

INDUAN (earliest Triassic)

| Latitude | Shelf | Land |
|---|---|---|
| 80-90°N | 1.5 | 0.2 |
| 70-80 | 2.3 | 1.4 |
| 60-70 | 2.4 | 3.4 |
| 50-60 | 2.8 | 6.1 |
| 40-50 | 2.5 | 11.2 |
| 30-40 | 2.6 | 13.2 |
| 20-30 | 6.8 | 9.5 |
| 10-20 | 4.2 | 8.4 |
| 0-10N | 2.2 | 10.0 |
| 0-10S | 1.9 | 9.5 |
| 10-20 | 1.7 | 10.3 |
| 20-30 | 2.0 | 10.0 |
| 30-40 | 3.5 | 8.6 |
| 40-50 | 3.5 | 10.9 |
| 50-60 | 1.1 | 12.4 |
| 60-70 | 0.9 | 9.2 |
| 70-80 | 0.7 | 5.4 |
| 80-90S | 0.6 | 2.0 |
| Total | 43.2 | 141.7 |

Table 2 continued.

PLIENSBACHIAN (Early Jurassic)

| Latitude | Shelf | Land |
|---|---|---|
| 80-90°N | 2.2 | 1.1 |
| 70-80 | 2.8 | 4.7 |
| 60-70 | 1.9 | 7.6 |
| 50-60 | 1.9 | 12.4 |
| 40-50 | 0.9 | 14.7 |
| 30-40 | 3.9 | 12.4 |
| 20-30 | 4.2 | 8.8 |
| 10-20 | 3.8 | 6.3 |
| 0-10N | 2.6 | 7.7 |
| 0-10S | 1.4 | 10.1 |
| 10-20 | 1.5 | 9.8 |
| 20-30 | 2.1 | 8.2 |
| 30-40 | 2.6 | 8.9 |
| 40-50 | 1.7 | 12.1 |
| 50-60 | 0.8 | 11.4 |
| 60-70 | 0.6 | 7.6 |
| 70-80 | 0.7 | 3.1 |
| 80-90S | 0 | 0 |
| Total | 35.6 | 146.9 |

VOLGIAN (latest Jurassic)

| Latitude | Shelf | Land |
|---|---|---|
| 80-90°N | 2.1 | 0.7 |
| 70-80 | 3.4 | 1.8 |
| 60-70 | 3.2 | 4.0 |
| 50-60 | 4.7 | 8.4 |
| 40-50 | 3.0 | 12.5 |
| 30-40 | 2.8 | 14.8 |
| 20-30 | 6.8 | 12.5 |
| 10-20 | 6.1 | 3.6 |
| 0-10N | 4.1 | 6.6 |
| 0-10S | 2.3 | 9.1 |
| 10-20 | 2.0 | 9.6 |
| 20-30 | 2.5 | 8.4 |
| 30-40 | 4.3 | 10.4 |
| 40-50 | 1.2 | 12.8 |
| 50-60 | 0.2 | 11.7 |
| 60-70 | 0.8 | 7.2 |
| 70-80 | 1.31 | 3.3 |
| 80-90S | 0.4 | 0.3 |
| Total | 51.2 | 137.7 |

Table 2 continued.

CENOMANIAN (middle Cretaceous)

| Latitude | Shelf | Land |
|---|---|---|
| 80-90°N | 1.2 | 0.8 |
| 70-80 | 2.2 | 4.4 |
| 60-70 | 2.6 | 7.4 |
| 50-60 | 3.8 | 10.2 |
| 40-50 | 3.2 | 13.7 |
| 30-40 | 6.7 | 11.5 |
| 20-30 | 6.3 | 6.4 |
| 10-20 | 5.9 | 4.1 |
| 0-10N | 5.5 | 6.2 |
| 0-10S | 2.8 | 11.3 |
| 10-20 | 1.6 | 9.4 |
| 20-30 | 1.4 | 6.9 |
| 30-40 | 4.3 | 6.7 |
| 40-50 | 3.1 | 9.5 |
| 50-60 | 2.4 | 5.1 |
| 60-70 | 2.0 | 5.6 |
| 70-80 | 0.4 | 5.4 |
| 80-90S | 0.1* | 2.8 |
| Total | 55.5 | 127.4 |

MAESTRICHTIAN (latest Cretaceous)

| Latitude | Shelf | Land |
|---|---|---|
| 80-90°N | 0.6 | 1.1 |
| 70-80 | 1.8 | 7.3 |
| 60-70 | 2.7 | 9.5 |
| 50-60 | 3.6 | 12.0 |
| 40-50 | 5.3 | 8.4 |
| 30-40 | 7.2 | 8.4 |
| 20-30 | 4.9 | 8.5 |
| 10-20 | 5.5 | 4.4 |
| 0-10N | 5.6 | 7.7 |
| 0-10S | 4.2 | 8.7 |
| 10-20 | 2.7 | 10.9 |
| 20-30 | 2.1 | 8.2 |
| 30-40 | 2.4 | 6.4 |
| 40-50 | 2.7 | 4.7 |
| 50-60 | 1.2 | 4.4 |
| 60-70 | 1.4 | 4.5 |
| 70-80 | 1.9 | 5.6 |
| 80-90S | 0 | 3.8 |
| Total | 55.8 | 124.5 |

Table 2 continued.

LUTETIAN (middle Eocene)

| Latitude | Shelf | Land |
|---|---|---|
| 80-90°N | 0.7 | 0 |
| 70-80 | 3.9 | 6.7 |
| 60-70 | 1.9 | 14.7 |
| 50-60 | 3.7 | 14.0 |
| 40-50 | 5.4 | 12.5 |
| 30-40 | 4.6 | 11.4 |
| 20-30 | 5.8 | 8.3 |
| 10-20 | 5.1 | 9.0 |
| 0-10N | 3.9 | 12.7 |
| 0-10S | 1.7 | 11.1 |
| 10-20 | 0.9 | 7.4 |
| 20-30 | 0.7 | 6.0 |
| 30-40 | 2.2 | 4.1 |
| 40-50 | 2.0 | 3.4 |
| 50-60 | 1.4 | 4.6 |
| 60-70 | 2.2 | 2.2 |
| 70-80 | 0.7 | 7.2 |
| 80-90S | <0.1* | 2.9 |
| Total | 46.9 | 138.2 |

VINDOBONIAN (middle Miocene)

| Latitude | Shelf | Land |
|---|---|---|
| 80-90°N | 0.5 | 0.1* |
| 70-80 | 3.1 | 6.6 |
| 60-70 | 1.8 | 13.8 |
| 50-60 | 2.0 | 15.1 |
| 40-50 | 3.6 | 15.1 |
| 30-40 | 5.4 | 12.9 |
| 20-30 | 5.0 | 11.8 |
| 10-20 | 2.6 | 12.4 |
| 0-10N | 2.7 | 11.8 |
| 0-10S | 2.7 | 9.7 |
| 10-20 | 2.1 | 8.7 |
| 20-30 | 1.3 | 9.6 |
| 30-40 | 1.6 | 7.1 |
| 40-50 | 1.7 | 1.6 |
| 50-60 | 0.8 | 0.2 |
| 60-70 | 1.3 | 1.8 |
| 70-80 | 2.0 | 6.2 |
| 80-90S | <0.1* | 2.9 |
| Total | 40.3 | 147.4 |

Table 3. Albedo of land and sea by latitude and cover (from Barron and others, 1980). A = land with snow and ice cover (high latitudes) or deserts (low latitudes); B = sea; C = sea ice. A and C are presented for the latitudes to which they were applied in Table 5 (for the snow and ice and desert cases). General value for land for calculations in Tables 5 and 6 is average for modern plant cover, a = 0.15. The desert values (0.25) was used for all land area in the calculations in Table 6 for Cambrian through Devonian, that is, before the existence of extensive terrestrial flora.

| Latitude | A | B | C |
|---|---|---|---|
| 80-90° | 0.65 | 0.15 | 0.35 |
| 70-80 | 0.65 | 0.15 | 0.35 |
| 60-70 | | 0.15 | |
| 50-60 | | 0.13 | |
| 40-50 | | 0.10 | |
| 30-40 | | 0.08 | |
| 20-30 | 0.25 | 0.06 | |
| 10-20 | 0.25 | 0.06 | |
| 0-10 | | 0.06 | |

Table 4. Present solar luminosity values (Q) by latitude and percent of present solar luminosity for each time period, extrapolated from 75% of modern value at 4.5 billion years before present (Sagan and Mullen, 1972).

| Latitude | Q |
|---|---|
| 80-90 | 0.05 |
| 70-80 | 0.17 |
| 60-70 | 0.31 |
| 50-60 | 0.51 |
| 40-50 | 0.74 |
| 30-40 | 0.97 |
| 20-30 | 1.17 |
| 10-20 | 1.33 |
| 0-10 | 1.41 |

| Time | % Q |
|---|---|
| Franconian | 96.96 |
| Llandeilo-Caradoc | 97.33 |
| Ashgill | 97.48 |
| Wenlock | 97.58 |
| Emsian | 97.75 |
| Visean | 98.06 |
| Westphalian C-D | 98.25 |
| Kazanian | 98.59 |
| Induan | 98.65 |
| Pliensbachian | 99.10 |
| Volgian | 99.24 |
| Cenomanian | 99.45 |
| Maestrichtian | 99.61 |
| Lutetian | 99.76 |
| Vindobonian | 99.93 |

Table 5. Calculations of absorbed solar radiation. A = without snow and ice or deserts; B = with snow and ice cover >70°; C = with deserts 10-20°; D = with deserts 10-30° and snow and ice >70°. All calculations were made with extrapolated solar luminosity values (Table 4).

| Time | A | B | C | D |
|---|---|---|---|---|
| Franconian | 11.662 | 11.576 | 11.430 | 11.344 |
| Llandeilo-Caradoc | 11.784 | 11.692 | 11.630 | 11.538 |
| Wenlock | 11.884 | 11.735 | 11.838 | 11.689 |
| Emsian | 11.854 | 11.722 | 11.723 | 11.591 |
| Visean | 11.862 | 11.737 | 11.710 | 11.585 |
| Westphalian C-D | 11.881 | 11.727 | 11.729 | 11.575 |
| Kazanian | 11.901 | 11.747 | 11.700 | 11.546 |
| Induan | 11.855 | 11.729 | 11.627 | 11.501 |
| Pliensbachian | 11.920 | 11.793 | 11.723 | 11.596 |
| Volgian | 11.944 | 11.871 | 11.742 | 11.671 |
| Cenomanian | 12.003 | 11.859 | 11.839 | 11.697 |
| Maestrichtian | 12.020 | 11.856 | 11.834 | 11.670 |
| Lutetian | 12.022 | 11.861 | 11.835 | 11.676 |
| Vindobonian | 12.008 | 11.852 | 11.782 | 11.596 |

Table 6. Calculations of absorbed solar radiation using "realistic" values for albedo of each latitudinal belt and extrapolated solar luminosity values for each time period. The albedo values are based on assumptions or observations about the probable characteristics of the Earth's surface, such as glacial cover (see notes at end of table).

| Latitude | Є[1,2] | ϴ[1,2] | $Ash_t$[1,2] | $Ash_r$[1,2] | S[1,2] | D[1,2] | M[5,6] | P̶[5,6] | P[5,6] |
|---|---|---|---|---|---|---|---|---|---|
| 80-90N | 0.041 | 0.042 | 0.042 | 0.042 | 0.042 | 0.042 | 0.032 | 0.032 | 0.030 |
| 70-80 | 0.140 | 0.140 | 0.141 | 0.141 | 0.141 | 0.141 | 0.103 | 0.107 | 0.097 |
| 60-70 | 0.256 | 0.257 | 0.257 | 0.257 | 0.257 | 0.258 | 0.258 | 0.259 | 0.260 |
| 50-60 | 0.430 | 0.432 | 0.432 | 0.432 | 0.433 | 0.431 | 0.435 | 0.434 | 0.436 |
| 40-50 | 0.646 | 0.647 | 0.649 | 0.649 | 0.647 | 0.642 | 0.652 | 0.650 | 0.651 |
| 30-40 | 0.859 | 0.868 | 0.867 | 0.867 | 0.864 | 0.856 | 0.864 | 0.869 | 0.867 |
| 20-30 | 1.034 | 1.068 | 1.061 | 1.051 | 1.071 | 1.036 | 1.063 | 1.065 | 1.062 |
| 10-20 | 1.154 | 1.199 | 1.216 | 1.186 | 1.215 | 1.170 | 1.162 | 1.157 | 1.168 |
| 0-10N | 1.186 | 1.251 | 1.286 | 1.221[4] | 1.257 | 1.248 | 1.281 | 1.281 | 1.287 |
| 0-10S | 1.181 | 1.232 | 1.263 | 1.181[4] | 1.270 | 1.280 | 1.294 | 1.283 | 1.289 |
| 10-20 | 1.132 | 1.152 | 1.186 | 1.131 | 1.203 | 1.207 | 1.204 | 1.171 | 1.160 |
| 20-30 | 1.019 | 1.010 | 1.044 | 1.017 | 1.054 | 1.056 | 1.053 | 1.068 | 1.059 |
| 30-40 | 0.831 | 0.827 | 0.846 | 0.824 | 0.853 | 0.846 | 0.847 | 0.862 | 0.862 |
| 40-50 | 0.633 | 0.623 | 0.615 | 0.598 | 0.626 | 0.605 | 0.634 | 0.606[8] | 0.642 |
| 50-60 | 0.429 | 0.414 | 0.406 | 0.400 | 0.400 | 0.401 | 0.430 | 0.400[9] | 0.433 |
| 60-70 | 0.256 | 0.249 | 0.238 | 0.234 | 0.234 | 0.241 | 0.214[7] | 0.223[10] | 0.260 |
| 70-80 | 0.140 | 0.140 | 0.141[3] | 0.060[5] | 0.141 | 0.141[3] | 0.084 | 0.058 | 0.072 |
| 80-90S | 0.041 | 0.042 | 0.042[3] | 0.017[5] | 0.042 | 0.042[3] | 0.024 | 0.017 | 0.017 |
| Total | 11.408 | 11.593 | 11.732 | 11.308 | 11.750 | 11.643 | 11.634 | 11.542 | 11.652 |

Table 6 continued.

| Latitude | Tr[3,11] | Early J[3,12] | Late J[3,13]* |
|---|---|---|---|
| 80-90N | 0.042 | 0.043 | 0.043 |
| 70-80 | 0.143 | 0.143 | 0.144 |
| 60-70 | 0.260 | 0.261 | 0.262 |
| 50-60 | 0.433 | 0.435 | 0.437 |
| 40-50 | 0.644 | 0.645 | 0.646 |
| 30-40 | 0.864 | 0.868 | 0.779 |
| 20-30 | 1.001 | 1.055 | 0.987 |
| 10-20 | 1.141 | 1.197 | 1.232 |
| 0-10N | 1.280 | 1.284 | 1.295 |
| 0-10S | 1.278 | 1.291 | 1.288 |
| 10-20 | 1.157 | 1.220 | 1.156 |
| 20-30 | 1.119 | 1.066 | 1.021 |
| 30-40 | 0.857 | 0.861 | 0.867 |
| 40-50 | 0.643 | 0.642 | 0.645 |
| 50-60 | 0.435 | 0.434 | 0.436 |
| 60-70 | 0.260 | 0.261 | 0.262 |
| 70-80 | 0.143 | 0.143 | 0.144 |
| 80-90S | 0.042 | 0.043 | 0.043 |
| Total | 11.742 | 11.892 | 11.687 |

Table 6 continued.

$Ash_t$ and $Ash_r$ are, respectively, values for the highest sea level prior to the Ashgillian (latest Ordovician) continental glaciation and the maximum regression during the glaciation.

*"realistic" values for the Cretaceous and Tertiary are from Table 5 as follows: Cretaceous and Lutetian--deserts, no snow and ice; Vindobonian--deserts, snow and ice.

Assumptions:

[1]no sea ice in polar oceans
[2]land albedo 70°N-70°S = 0.25 (no land plants)
[3]no snow and ice >70°
[4]high albedo (0.35) for 1/3 of land area (exposed carbonate platform)
[5]ice and snow >70°
[6]deserts 10-20° (albedo = 0.35)
[7]1/2 of land 60-70° covered with ice, albedo = 0.65
[8]1/5 of land 40-50° covered with ice, albedo = 0.65
[9]1/6 of land 50-60° covered with ice, albedo = 0.65
[10]1/4 of land 60-70° covered with ice, albedo = 0.65
[11]deserts 10-30° (albedo = 0.35)
[12]deserts 1/20 of sea fraction 10-30°N (evaporites, albedo = 0.350)
[13]deserts 20-40°N, 10-30°S (albedo = 0.35)

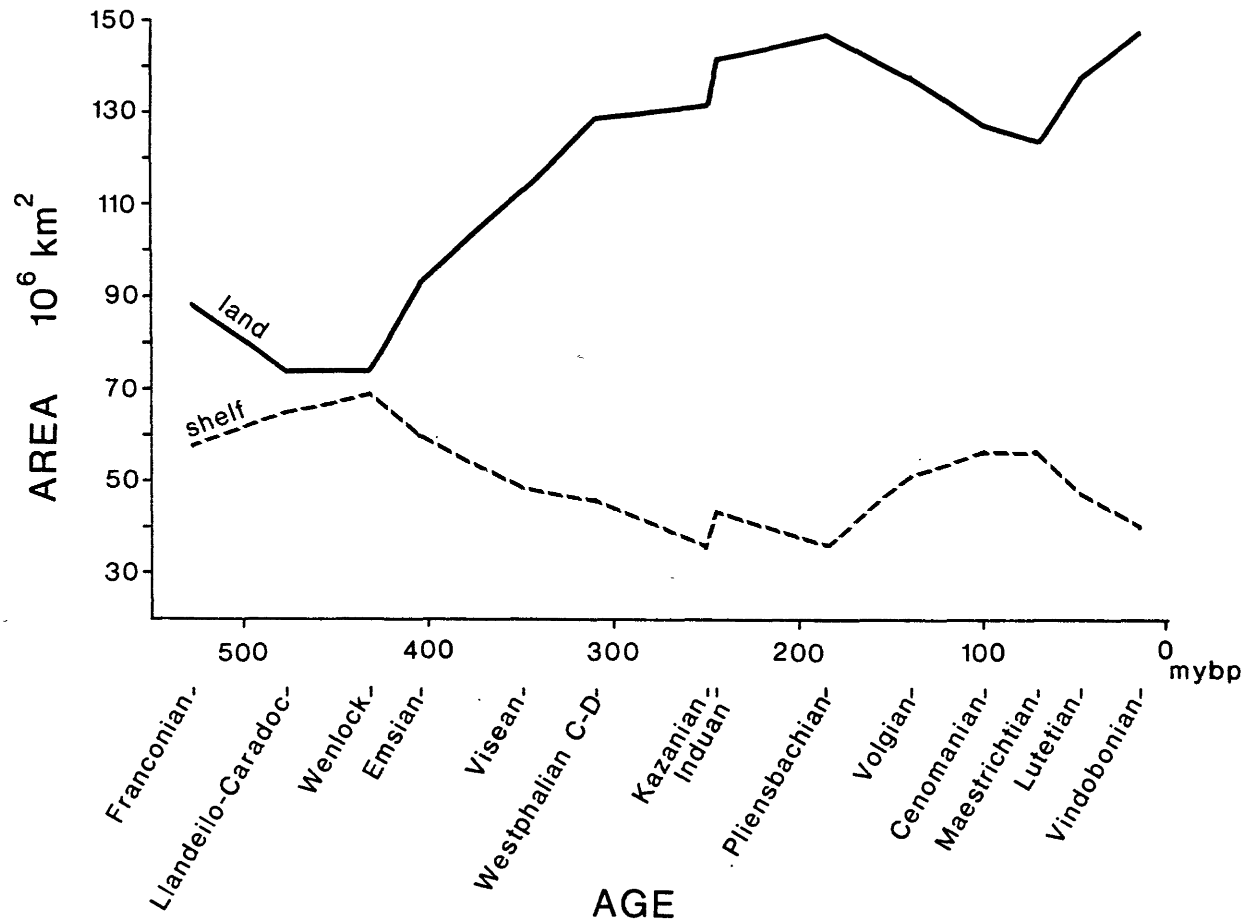


Figure 1. Changes in areas of land and continental shelf through the Phanerozoic.

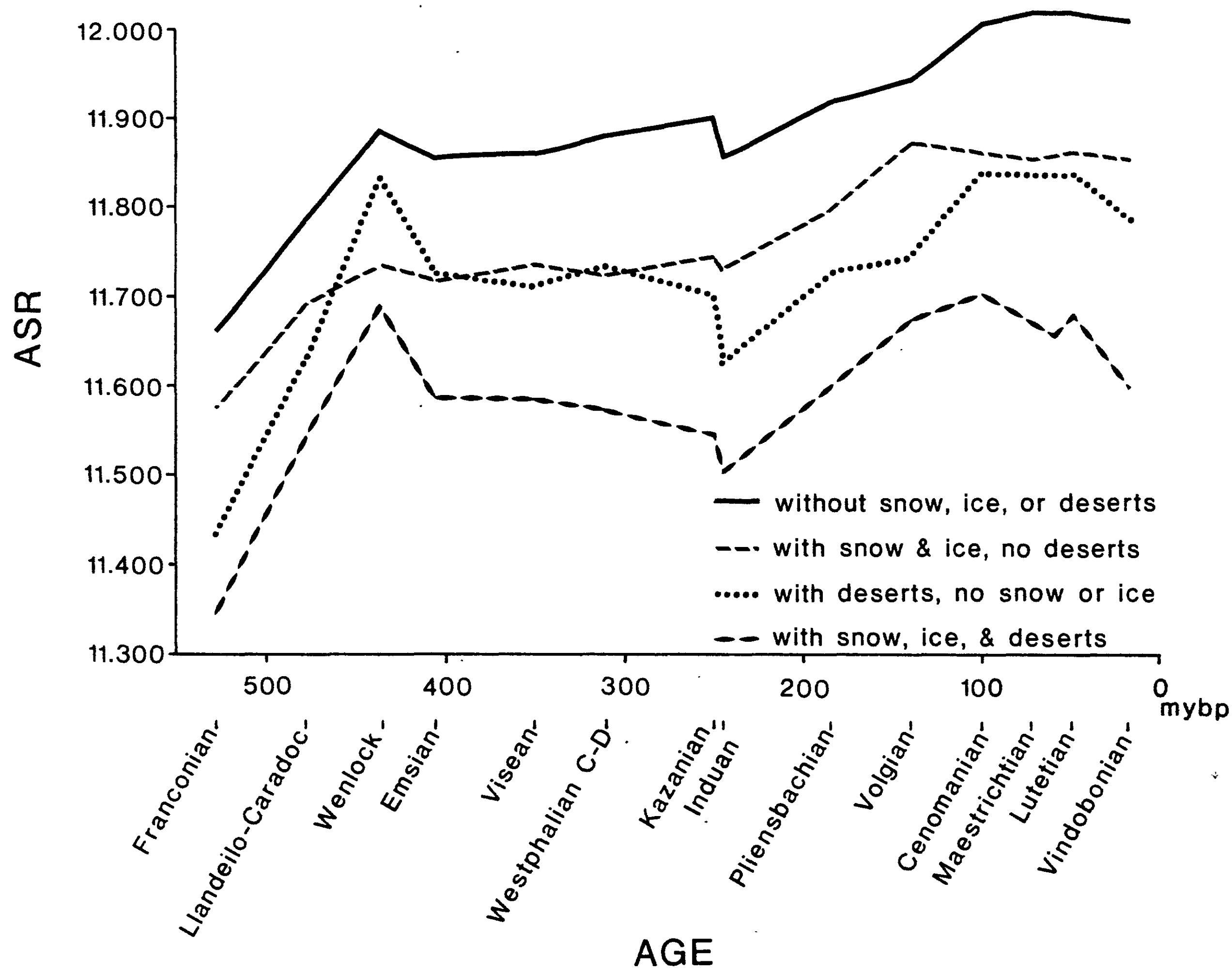


Figure 2. Absorbed solar radiation through the Phanerozoic with various assumptions about the distribution of snow and ice and deserts (see Table 5).

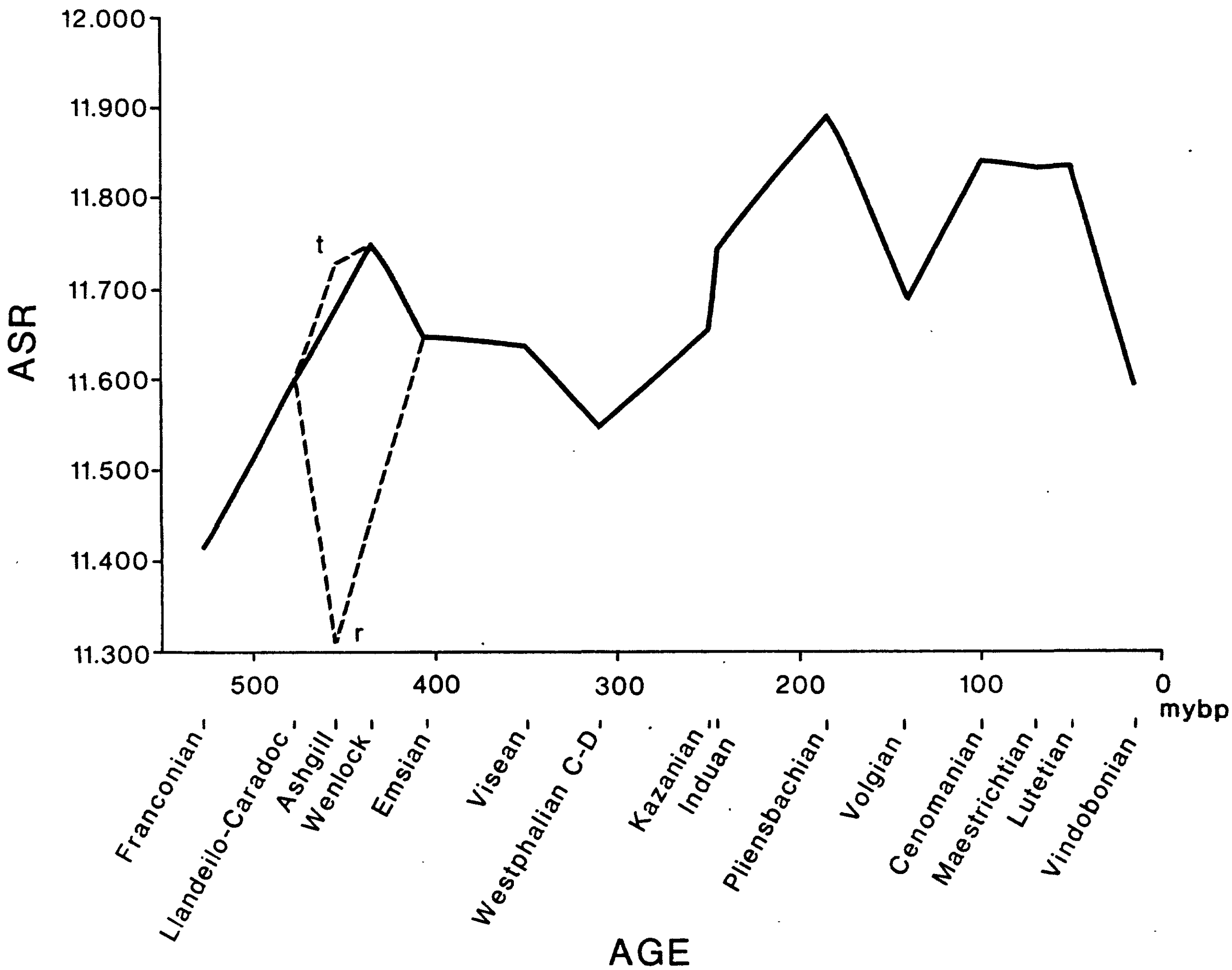


Figure 3. Absorbed solar radiation through the Phanerozoic with "realistic" assumptions about surface reflectivity for each time period (see Table 6). Dashed line indicates the Ashgill values. t = maximum transgression, r = maximum regression.