Temporal variations in tempestite thickness may be a geologic record of CO_2

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ABSTRACT

Storm-bed (tempestite) thickness reflects, in part, storm intensity, which is related to the amount of atmospheric CO_2. Thus, variations in tempestite thickness through geologic time may record fluctuations of CO_2. Geologic criteria other than storm-bed data have been used to define specific intervals of time when the atmosphere was CO_2 enriched (greenhouse phases) and CO_2 depleted (icehouse phases). If tempestite thickness, storm intensity, and CO_2 are causally linked, greenhouse phases should correspond to deposits of thick tempestites (more intense storms), and icehouse phases should be characterized by comparatively thin tempestites (less intense storms). Tempestite thickness data provide a test of the greenhouse-icehouse model, and initial results suggest general agreement with the independently derived climate (CO_2) curve for the latest Precambrian through Phanerozoic.

INTRODUCTION

A. G. Fischer (1984) proposed two Phanerozoic supercycles of mantle convection to explain temporal patterns of eustasy, continental movement, plutonism, and sedimentation. Each supercycle comprises two phases defined by fluctuations of atmospheric CO_2: a CO_2-enriched "greenhouse" phase and a CO_2-depleted "icehouse" phase (Fig. 1, top). The maximum intensity that can be attained by tropical cyclones (the most intense storms) is postulated to increase with increased atmospheric CO_2 (Emanuel, 1987). Storm intensity is recorded in tempestites deposited in subaqueous environments (e.g., Aigner and Reineck, 1982; Aigner, 1985; Brett et al., 1986). Therefore, it should be possible to detect fluctuations in maximum storm intensity through time and thereby determine the history of CO_2 fluctuations. The most convenient measure of storm intensity preserved in the geologic record is storm-bed thickness. Intense storms produce thicker tempestite beds than less intense storms (other factors being equal). In this paper, we propose a test of Fischer's climate model by using tempestite maximum-thickness data.

TEST OF THE MODEL

It is predicted that the maximum thickness of storm beds will be relatively low during icehouse phases, and in particular during times when ice sheets were present (reduced maximum storm intensity). Maximum thickness will be comparatively high during greenhouse phases (increased maximum storm intensity). Fischer's model comprises three major icehouse phases (latest Precambrian through Middle Cambrian, Late Devonian through Middle Triassic, and late Cenozoic) and two major greenhouse phases (Late Cambrian through Middle Devonian, but with glaciation near the Ordovician/Silurian boundary, and Late Triassic through early Cenozoic; Fig. 1, top). Fischer's climate (CO_2) curve shows a low in the latest Precambrian (our time interval 1), a rise in the Early to Middle Cambrian (2) that continues through the Late Cambrian and reaches a high in the Ordovician (3), a sharp drop near the Ordovician/Silurian boundary (4), a high during the Silurian-Devonian (5), a decrease in the Late Devonian and early Carboniferous (6) to a low in the late Carboniferous and Permian (7), a rise in the Early to Middle Triassic (8) that continues through the Late Triassic and Jurassic (9) to a high in the Cretaceous (10), and a decrease in the early Cenozoic (11) that continues through the late Cenozoic (12).

Our test of Fischer's model is based on maximum tempestite bed thicknesses in latest Precambrian and Phanerozoic geologic units, compiled from the literature. This test is difficult to apply at present. The storm origin proposed for some beds remains uncertain (see discussions in Marsaglia and Klein, 1983; Duke, 1985, 1987; Klein and Marsaglia, 1987). Tempestites and their thicknesses are not routinely reported, and individual sedimentation events are not always distinguished from amalgamated beds that probably represent multiple storms. Tempestite thickness decreases with increasing water depth along a proximal-distal environmental gradient (Aigner and Reineck, 1982; Brett et al., 1986). We used only beds considered to be individual sedimentation episodes. To control for variations in tempestite thickness due to differences among depositional environments, we considered data from only clastic and mixed clastic-carbonate marine shelves. We attempted to control for proximal-distal thickness variations by including only storm beds that were described as distal and that most likely represent individual events separated by background deposition. Individual tempestites in the mid-shelf environment are characterized by an erosional base, are cross- or planar-laminated, and are capped by fine-grained sand and/or shale (background sediments). Proximal or shoreface

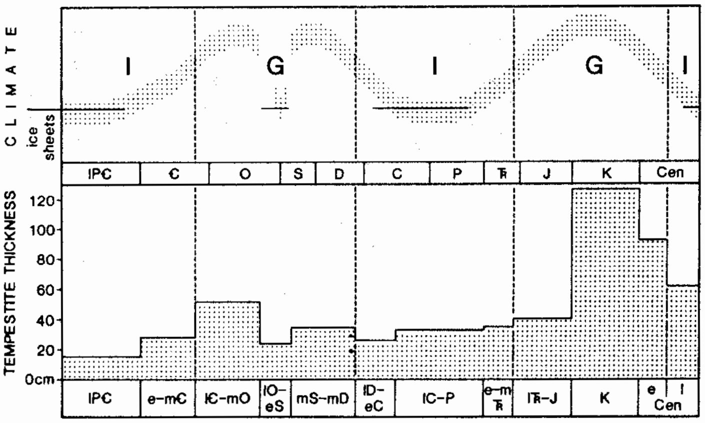

Figure 1. Top: Fischer's (1984) climate (CO_2) curve for latest Precambrian and Phanerozoic. I = icehouse phase when CO_2 reaches minimum; G = greenhouse phase when CO_2 reaches maximum. Bottom: Histogram of tempestite thickness for 12 geologic time intervals (averages of maximum thicknesses reported in literature sources for each interval, n = 84). 1—lPЄ = latest Precambrian (n = 6; average = 16 cm; range 3–50 cm); 2—e-mЄ = Early-Middle Cambrian (n = 3; average = 28 cm; range 15–50 cm); 3—lЄ-mO = Late Cambrian–Middle Ordovician (n = 13; average = 51 cm; range 5–100 cm); 4-10—eS = Late Ordovician-Early Silurian (n = 11; average = 24 cm; range 5–60 cm); 5—mS-mD = Middle Silurian- Middle Devonian (n = 9; average = 34 cm; range 10–133 cm); 6—lD-eC = Late Devonian-early Carboniferous (n = 10; average = 26 cm; range 5–50 cm); 7—lC-P = late Carboniferous–Permian (n = 4; average = 33 cm; range 1–60 cm); 8—e-mŦ = Early Middle Triassic (n = 2; both 35 cm); 9—l Ŧ-J = Late Triassic–Jurassic (n = 3; average = 40 cm; range 30–50 cm); 10—K = Cretaceous (n = 8; average = 127 cm; range 40–216 cm); 11—eCen = early Cenozoic (n = 4; average = 93 cm; range 80–100 cm); 12—lCen = late Cenozoic (n = 11; average = 62 cm; range 5–250 cm).

Cordilleran orogenesis, the middle Cretaceous "Columbian orogeny." The details of the proposed tectonic history are not well constrained, particularly with regard to the unfolding of the oroclinal "Z" formed by the Cretaceous metamorphic belts. Nonetheless, the basic hypothesis provides an explanation for the seemingly irreconcilable evidence for extension concurrent with collision-related compression, and is actualistic because it is based on a neotectonic analog. Moreover, the hypothesis is testable in three ways.

1. The hypothesis predicts that extensional tectonics should be recognizable throughout the southern Brooks Range, Ruby terrane, and Yukon-Tanana terrane, yet extension has only been documented in one area in the Brooks Range (Gottschalk and Oldow, 1988) and in one area in the Yukon-Tanana terrane (Pavlis et al., 1988a). Inspection of reconnaissance maps of the Yukon-Tanana terrane and the Ruby terrane suggests that other extensional structures exist, although different modes of extension may be present. A particularly significant test would be offered by structural-metamorphic studies of the major metamorphic belts of northern Alaska (Yukon-Tanana, Ruby, and the southern Brooks Range). In these areas, a characteristic feature is that the latest major metamorphic fabric is essentially flat on a regional scale. This fabric has typically been ascribed to major overriding by thrust sheets, yet seismic reflection data indicate that regional flat fabrics are typical of the middle and lower crust of many extensional terranes (e.g., Serpa and de Voogd, 1987). Thus, a similar origin should be considered for the latest, low-angle fabric of the northern Alaska metamorphic belts.

2. The model predicts that the Yukon-Koyukuk basin system of west-central Alaska could represent a major extensional basin system (Fig. 2, top). The stratigraphic succession from a Jurassic-Cretaceous arc system to a major basinal setting with thick sediment accumulations (Patton, 1973) is seemingly analogous to an advanced stage of back-arc rifting with nearly complete continental breakup. Indeed, the Carpathian arc (Royden et al., 1983) may be a close analog, and future studies need to consider this analogy.

3. A great variety of metamorphic facies series has been recognized in northern Alaska, ranging from blueschists and eclogites of the Brooks Range (Armstrong et al., 1986) and Yukon-Tanana terrane (e.g., Foster et al., 1987; Hansen, 1988) to regional low-*P*, high-*T* belts (e.g., see Foster et al., 1987). Detailed studies of the pressure-temperature-time history of these metamorphic belts are clearly needed because theoretical models indicate that extensional terranes have distinctive *P-T-t* signatures (e.g., Thompson and England, 1984).

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