

Seismic Stratigraphy and Global Changes of Sea Level, Part 4: Global Cycles of Relative Changes of Sea Level.¹

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Abstract Cycles of relative change of sea level on a global scale are evident throughout Phanerozoic time. The evidence is based on the facts that many regional cycles determined on different continental margins are simultaneous, and that the relative magnitudes of the changes generally are similar. Because global cycles are records of geotectonic, glacial, and other large-scale processes, they reflect major events of Phanerozoic history.

A global cycle of relative change of sea level is an interval of geologic time during which a relative rise and fall of mean sea level takes place on a global scale. A global cycle may be determined from a modal average of correlative regional cycles derived from seismic stratigraphic studies.

On a global cycle curve for Phanerozoic time, three major orders of cycles are superimposed on the sea-level curve. Cycles of first, second, and third order have durations of 200 to 300 million, 10 to 80 million, and 1 to 10 million years, respectively. Two cycles of the first order, over 14 of the second order, and approximately 80 of the third order are present in the Phanerozoic, not counting late Paleozoic cyclothems. Third-order cycles for the pre-Jurassic and Cretaceous are not shown. Sea-level changes from Cambrian through Early Triassic are not as well documented globally as are those from Late Triassic through Holocene.

Relative changes of sea level from Late Triassic to the present are reasonably well documented with respect to the ages, durations, and relative amplitudes of the second- and third-order cycles, but the amplitudes of the eustatic changes of sea level are only approximations. Our best estimate is that sea level reached a high point near the end of the Campanian (Late Cretaceous) about 350 m above present sea level, and had low points during the Early Jurassic, middle Oligocene, and late Miocene about 150, 250, and 200 m, respectively, below present sea level.

Interregional unconformities are related to cycles of global highstands and lowstands of sea level, as are the facies and general patterns of distribution of many depositional sequences. Geotectonic and glacial phenomena are the most likely causes of the sea-level cycles.

Major applications of the global cycle chart include (1) improved stratigraphic and structural analyses within a basin, (2) estimation of the geologic age of strata prior to drilling, and (3) development of a global system of geochronology.

INTRODUCTION

Cycles of relative change of sea level on a global scale are evident throughout Phanerozoic time. The evidence is based on the fact that many regional cycles determined on different continental margins are simultaneous and that the relative magnitudes of the changes generally are similar. Concepts and methods of determination of rela-

tive changes of sea level and regional cycles were given previously (Part 3, Vail et al, this volume). In this paper are presented charts of global cycles, the methods for constructing the charts from a modal average of correlative regional cycles based on seismic stratigraphy, and our estimates of the actual magnitudes of the sea-level changes.

Because the global cycles are records of geotectonic, glacial, and other large-scale processes, they reflect major events of Phanerozoic history. The timing and relative importance of these events are indicated by charts of the cycles. Such a composite record offers a means of subdividing Phanerozoic time into significant geochronologic units based on a single criterion.

Fairbridge (1961) summarized the historical development of concepts of sea-level change on a global scale, including the classic works of Haug (1900), Suess (1906), Stille (1924), Grabau (1940), Umbgrove (1942), Kuenen (1940, 1954, 1955), Arkell (1956), and others. These pioneer investigations laid the foundation for later work including ours. However, some developments have confused "transgressions and regressions" of the shoreline with "rises and falls" of sea level. Grabau (1924) recognized this problem. The charts we present in this paper show relative and eustatic rises and falls of sea level on a global scale, and differ from charts that show transgressions and regressions of the shoreline.

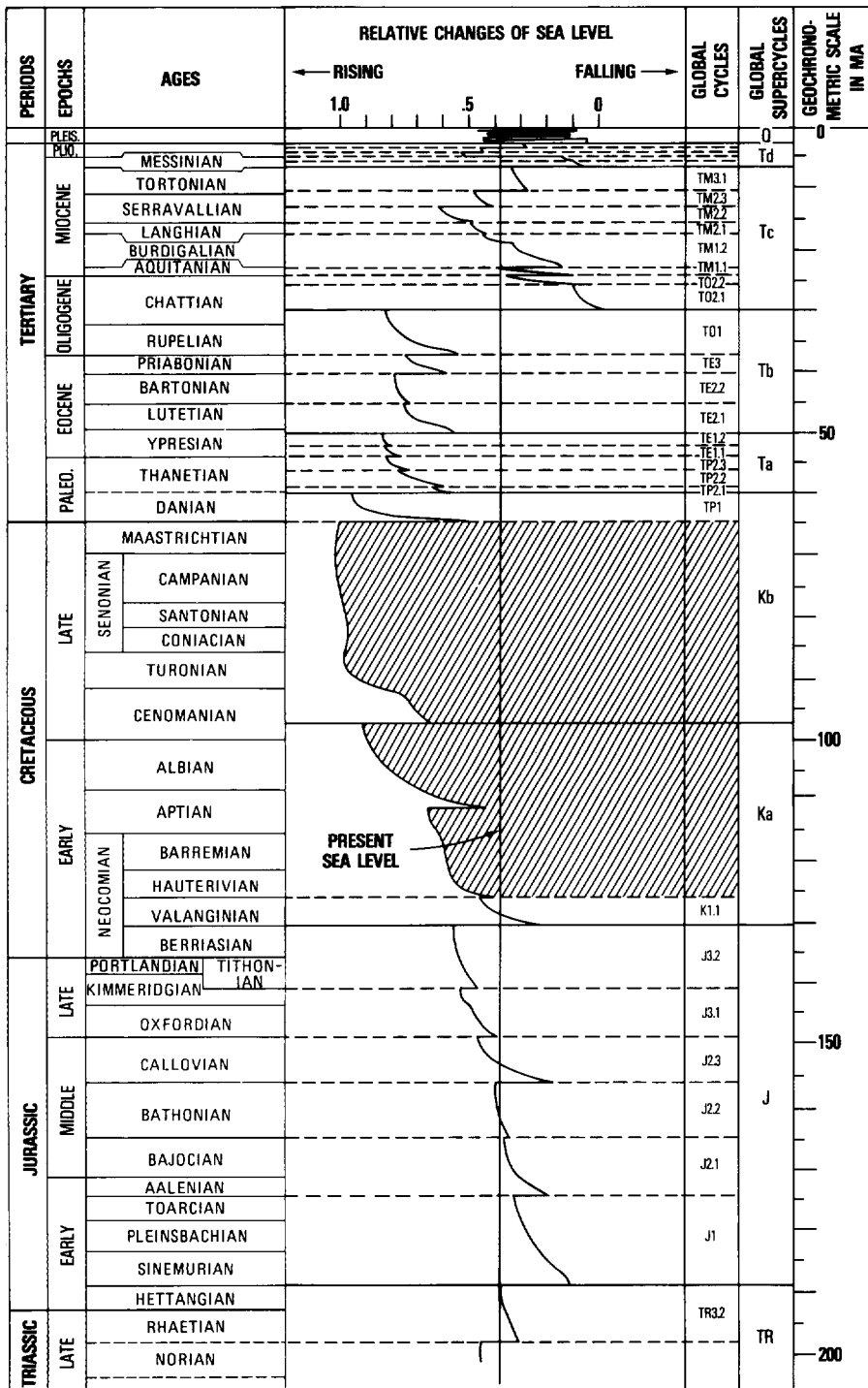
GLOBAL CYCLES

Figures 1 through 3 are charts of relative changes of sea level on a global scale. The vertical axis of each chart is scaled in millions of years (Ma, after Van Hinte, 1976 a, b), with standard periods and epochs plotted alongside. The horizontal axis shows relative positions of sea level and is scaled from 1.0 to 0.0, with 1.0 being the maximum relative highstand (65 Ma) and 0.0 being the minimum relative lowstand (30 Ma). Relative rises of sea level are plotted toward the left, and relative falls toward the right. The present position of sea level is extended through

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Jurassic-Cretaceous time scale after Van Hinte 1976 a, b

FIG. 2—Global cycles of relative change of sea level during Jurassic-Tertiary time. Cretaceous cycles (hatched area) have not been released for publication.

Phanerozoic time as a vertical reference line, although it rarely can be related to measurement of ancient changes of sea level.

A *global cycle* of relative change of sea level is an interval of geologic time during which a relative rise and fall of sea level takes place on a global scale. Intermittent stillstands (and therefore paracycles) may occur in any part of the cycle, but tend to predominate after the major part of the rise has taken place and before the fall begins.

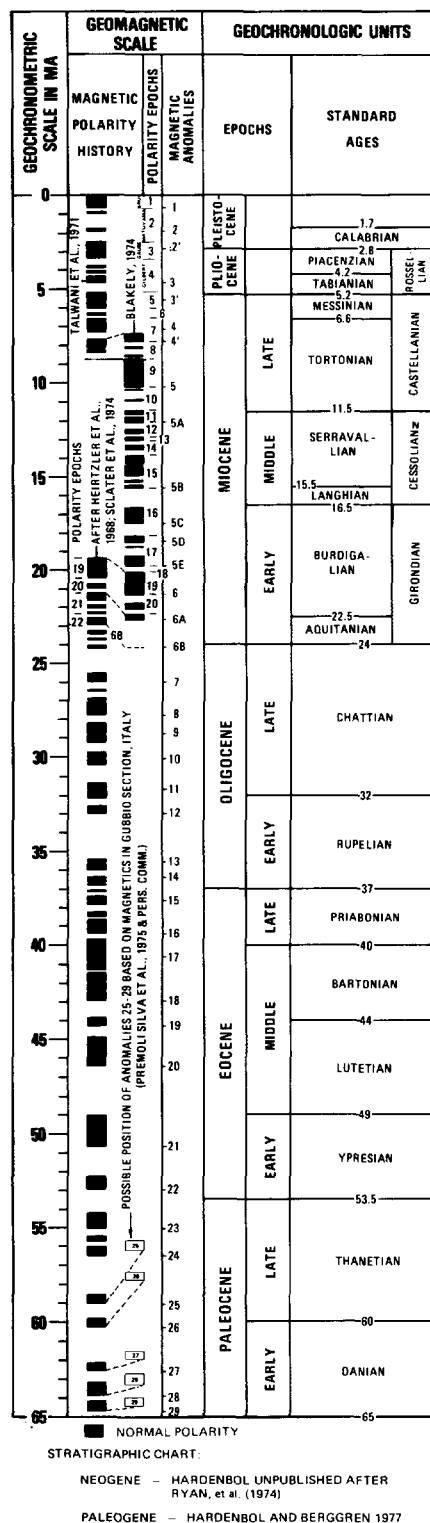
The global cycle charts (Figs. 1-3) show cycles of three orders of magnitude. The older of the two first-order cycles (Fig. 1) occurred from Precambrian to Early Triassic, with a duration of over 300 million years; the younger first-order cycle occurred from middle Triassic to the present within a duration of about 225 million years. The durations of the 14 second-order cycles (Fig. 1) range from 10 to 80 million years. Over 80 third-order cycles (Figs. 2, 3), not including late Paleozoic cyclothems, have durations that range from approximately 1 to 10 million years. In this paper we do not show the third-order cycles for the pre-Jurassic and Cretaceous periods. Pre-Jurassic cycles are not included because documentation comes mainly from North America with only limited data from other continents. Cretaceous cycles have not been released for publication.

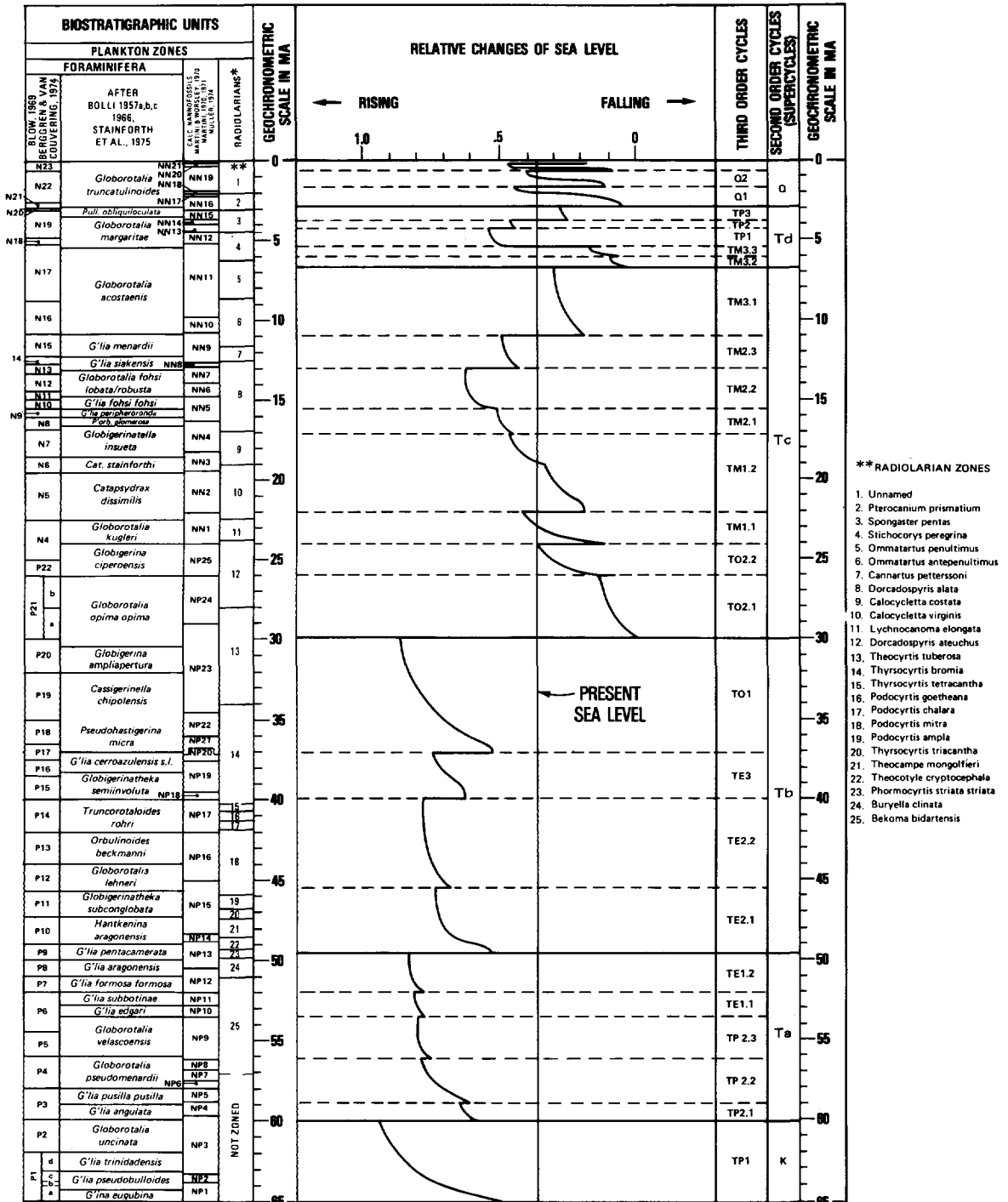
Trends of rise and fall of sea level reveal a marked asymmetry in the second- and third-order cycles. The relative rise generally is gradual and the relative fall generally is abrupt. In the first-order cycles, the cumulative falls tend to be more gradual and the curves are relatively symmetrical. Although the ages and durations of the first-, second-, and third-order cycles are fairly accurate, the amplitudes of the relative changes are only approximations.

Figure 1 shows first- and second-order cycles of the entire Phanerozoic. No distinct boundary occurs between the two first-order cycles, but the best dividing point appears to be between Early and Middle Triassic.

Figure 2 is a chart of relative changes of sea level on a global scale during Jurassic-Triassic time. The second- and third-order cycles are more clearly shown at this expanded time scale. The horizontal scale is the same as that of Figure 1 (see Part 7, Vail et al, this volume).

Figure 3 is a chart of the second- and third-order cycles during Tertiary and Quaternary time. A scale expanded from that of Figure 2 is needed to show the third-order cycles during these times; however, even at this scale all the cycles of glacial events in late Quaternary time are not clearly shown. The ages and durations of the Cenozoic third-order cycles have the best documentation, based mainly on zones of planktonic





* RIEDEL & SANFILIPPO 1970, 1971, MOORE 1971, FOREMAN 1973, THEYER & HAMMOND 1974

Late Neogene cycles prepared in cooperation with J. H. Beard.

Paleogene and Early Neogene cycles prepared in cooperation with J. Hardenbol & J. Lamb.

Notations: (e.g. TE^{1.1}) may be used to designate sequences and supersquences on seismic sections, etc.

FIG. 3—Global cycles of relative change of sea level during Cenozoic time. Basic references for the stratigraphic part of the chart are Hardenbol (unpublished after Ryan et al, 1974) and Hardenbol and Berggren (1977).

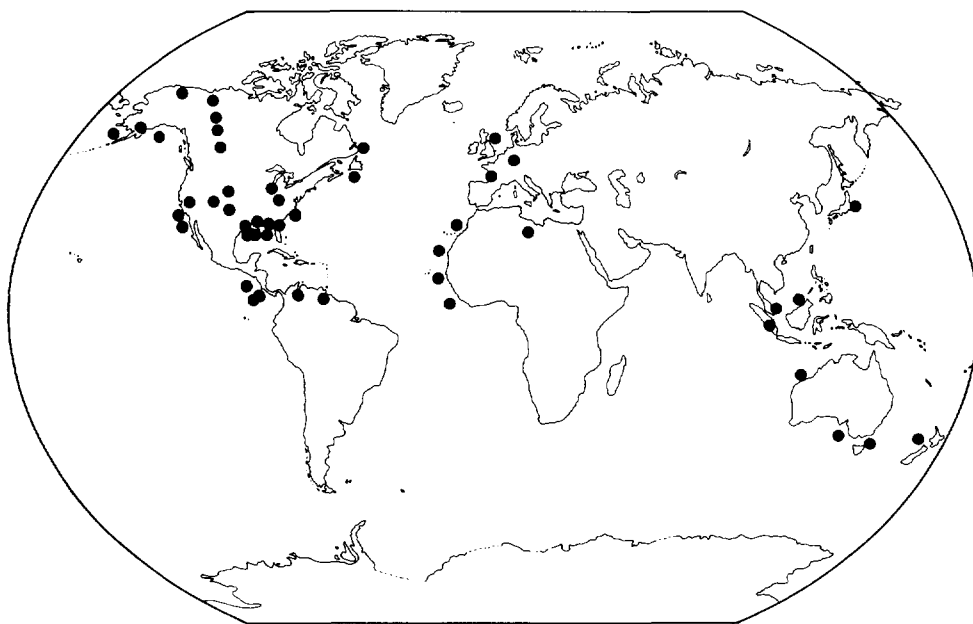


FIG. 4—Location of regional studies of seismic stratigraphy used in construction of global cycle chart for Phanerozoic time.

Foraminifera that have been tied to the geochronometric scale. Amplitudes of the relative changes are determined mainly from seismic stratigraphic analysis of grids of seismic sections tied to well data.

On the right side of the global cycle charts (Figs. 1-3), are columns containing notations that are useful for identifying stratigraphic units on seismic and stratigraphic sections. We identified depositional sequences according to their ages and their relations with cycles of relative changes of sea level. For example, the supersequence corresponding to the Jurassic supercycle is identified as J. It in turn is subdivided into J1, J2, or J3 corresponding to the Early, Middle, or Late Jurassic epoch in which the sequence occurs. Where more than one cycle of sea-level change occurs within a given epoch, such as the Middle Jurassic (J2), we used the notation J2.1 and J2.2, depending on the number of cycles. If we wanted to identify more than one sequence within a single cycle, we used the notation J2.1A, J2.1B, etc.

It also is important to identify sequence boundaries, especially those that are unconformities. This is because a given unconformity may truncate strata with a wide range of ages and also may be overlapped by strata of different ages. We identified an unconformity as pre- the oldest overlying sequence at the point where the surface

approaches conformity. For example, an unconformity that becomes conformable at the base of the Callovian would be identified as pre-Callovian (pre-J2.3).

CONSTRUCTION OF GLOBAL CYCLE CHART

Figure 4 is a world map that shows the general locations of the regional grids of seismic data used in the construction of the global cycle charts (Figs. 1-3). The seismic sections, supplemented by well control and other geologic data, provided the regional stratigraphic framework needed to measure and date the relative changes of sea level. These studies of seismic stratigraphy are drawn from all continents except Antarctica, and provide a representative worldwide sample for Jurassic and younger cycles. However, data are concentrated in areas of petroleum exploration where sedimentary sections are relatively thick and subsidence rates are high, with resultant higher rates of relative rise than would be recognized in thinner sections. Pre-Jurassic cycles are determined primarily on the evidence from North America, with supporting data from other continents.

The global cycle chart is simply a modal average of correlative regional cycles from many areas around the world. The construction of regional cycle charts is explained in Part 3 (Vail et al, this volume). A global cycle can be approximated

with a modal average of three or more correlative regional cycles from different continents. The more continents represented, the greater the accuracy of the resulting chart. Some obviously provincial effects such as orogenic deformation, excessive tectonic subsidence, or excessive sedimentary loading may distort the average amplitudes of sea level changes and should not be used without adjustment. Ages of the cycles in these regions generally correspond to the global pattern.

Figure 5 is an example of how four regional cycles are correlated and averaged to construct global cycles (column 5). In this example Cenozoic cycles of specific regions on four continents are used. Although many regional differences in the four curves are obvious, ages and durations of the cycles generally are correlative and amplitudes of the relative changes generally are similar. The global cycle curve is not based on these four regional curves alone, but from those of other areas shown in Figure 4.

The main bases of comparison are the ages of the major relative falls of sea level. For example, the pre-late Miocene fall (10.8 Ma) occurs on all three charts where data are present and is indicated by a major unconformity in all these regions. A pre-middle late Oligocene fall (30 Ma) can be recognized on all charts. The latest early Eocene fall (49 Ma) and the mid-Paleocene fall (60 Ma) are recognized in all three regions where Eocene and Paleocene deposits are found. After major falls are correlated and charted, ages of individual cycles are charted. These are quite similar in all four areas where data are available. Some differences in age relations may be explained by local differences in paleontologic techniques of age dating. Some cycles are not recognized with seismic data because the stratigraphic section is too thin, such as within the Tertiary of northwestern Africa.

Determination of average amplitudes of cycles is the least quantitative step in this procedure. With the exception of the Gippsland basin, shapes of the curves relating to the first- and second-order cycles generally show an overall fall with large fluctuations at supercycle boundaries. The Gippsland basin curve shows an anomalous overall rise probably related to the geotectonic history of Australia. Amplitudes of third-order cycles are charted, giving greatest weight to regions where most complete data are available. Although the first-order cycle of the Gippsland basin is anomalous, the third-order cycles fit the global pattern well.

Accuracy of the global cycle chart depends on the quality and quantity of the regional charts

that are used to construct it. On the charts in this report (Figs. 1-3), the ages, durations, and relative amplitude of the global cycles represent a relatively high level of accuracy, but measurement of the actual amplitudes is still a major problem. Direct measurement is made difficult by: (1) a sometimes wide difference range in thickness of coastal onlap for the same global cycle from various regions; (2) practical difficulties in making complete regional onlap analyses such as lack of control, erosion of critical portions of coastal onlap, or structural complications; (3) necessity of inferring coastal onlap from other facies relations where onlap for portions of the curve can not be measured directly; and (4) difficulties in measuring relative falls of sea level from seaward shifts in coastal onlap. For these reasons, the horizontal scale on the global charts showing amplitude of relative rises and falls is not calibrated in meters, but with a relative scale normalized on the maximum range of sea level positions of the curve. The highest position of sea level, occurring at the end of the Cretaceous (65 Ma), is set at 1.0 and the lowest position, at the mid-Oligocene (30 Ma), is set at 0.0. In the example cited (Fig. 5), each regional curve has been normalized according to this pattern. Where the regional curves do not include the Late Cretaceous high or the Oligocene low, they are normalized by making the best fit of the overlapping portions of the curves. If a given Upper Cretaceous or mid-Oligocene regional cycle has an anomalous magnitude, the regional curve is normalized by making a best fit to the other curves with a less distorted portion of the curve.

ESTIMATION OF EUSTATIC CHANGES OF SEA LEVEL

Global cycle curves (Figs. 1-3) summarize relative changes of sea level as described above. However, these curves include large-scale subsidence that must be discounted to determine the eustatic curve. An estimate of the true eustatic curve (Fig. 6c) has been made for Jurassic to Holocene time by calibrating the global cycle curve (Fig. 2) with the work of Pitman (in press), Sleep (1976), and J. H. Beard (personal commun.). These authors calculated quantitative values for the position of sea level during parts of Cretaceous, Tertiary, and late Neogene time. Their results conform to our preliminary estimates of eustatic change.

Pitman (in press) presented a curve of sea level change from Late Cretaceous to late Miocene time (Fig. 6a). His calculations, based only on rates of seafloor spreading and resultant volumes of midocean ridges, show a cumulative fall from

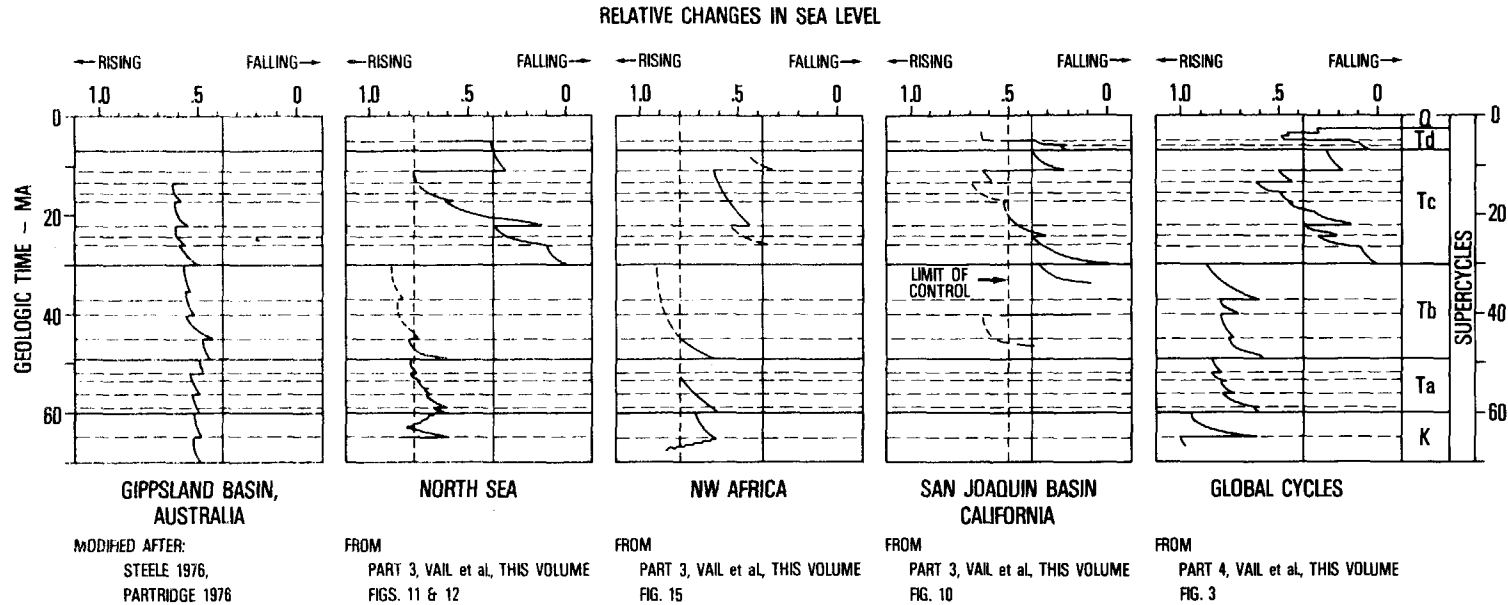


FIG. 5.—Correlation of regional cycles of relative change of sea level from four continents and averaging to construct global cycles.

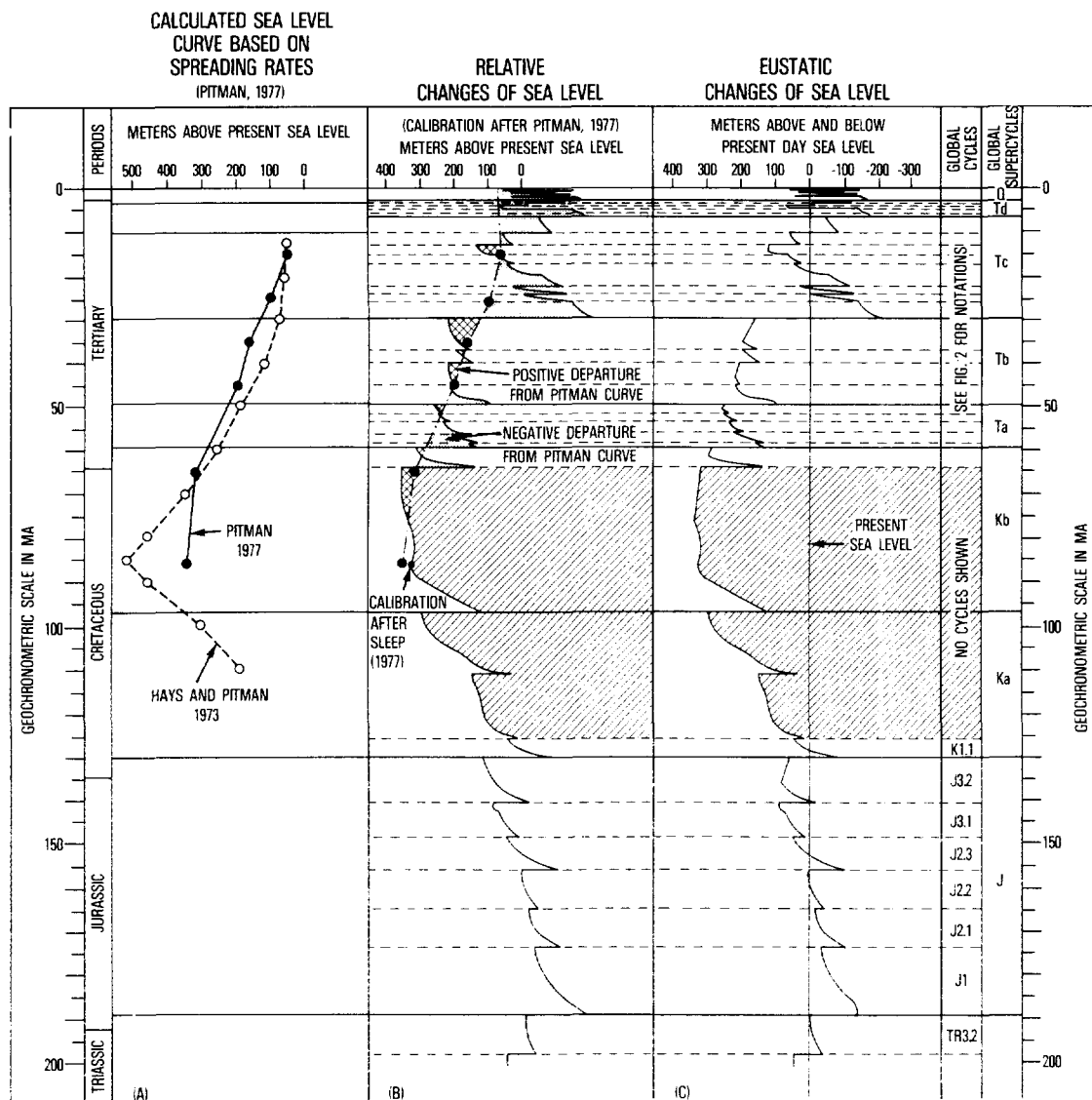


FIG. 6.—Estimation of eustatic changes in sea level from Jurassic to Holocene: **a.** Pitman's (in press) and Hays and Pitman's (1973) calculated sea-level curves based on rates of seafloor spreading and volumes of midocean ridges; **b.** Pitman's (in press) curve from (**a.**) overlain on global curve of relative changes of sea level; and **c.** best estimate of eustatic changes of sea level, calibrated from Pitman's (in press) curve.

350 to 60 m above the present position of sea level; he explained the remaining 60 m as water retained in present ice caps. His curve matches closely the Tertiary part of our Triassic-Holocene first-order cycle curve (Fig. 1). Sleep (1976) suggested sea level in the late Turonian to be 300 m above the present, based on work in the Precambrian shield area of Minnesota. J. H. Beard (personal commun.) estimated late Neogene eustatic changes by relating them to known Pleistocene eustatic changes using paleontology and seismic sequence analysis. This work provided a calibration for the youngest part of our chart.

Pitman's curve and our first-order cycle curve are very similar. However, our second- and third-order cycles show significant departures, both positive (higher) and negative (lower), from Pitman's curve (Fig. 6b). Where our curve is higher than Pitman's, his curve indicates that an overall gradual eustatic fall of sea level may be in progress, but our analysis of onlap indicates a relative rise. This discrepancy may be due to the fact that in our study areas with relatively thick sedimentary columns, subsidence occurs at a greater relative rate than sea level falls, producing a relative rise of sea level (see Part 3, Vail et al., this volume). During such a relative highstand, Pitman's curve (showing a gradual fall) is considered more representative of eustatic change than is ours.

The negative departures of our second- and third-order cycle curves from Pitman's curve are rapid falls of sea level probably caused by glacial withdrawals of water not evaluated by Pitman (see later section on causes of global cycles). Subsequent deglaciation produces a rise in sea level that diminishes in rate until the rises reach the position of the eustatic fall shown on Pitman's curve. As discussed later, glaciation is not documented in the geologic record prior to Oligocene within our last first-order cycle, so additional evidence of glaciation or of some other cause is needed to explain some of the rapid changes, especially the falls, of the second- and third-order cycles in the Early Tertiary and Mesozoic.

Although not covered by Pitman's curve, a general first-order rise from Early Jurassic to Late Cretaceous is indicated from our curve. If glaciation or some other factor produced the rapid second- and third-order falls, the subsequent rises should not cross the first-order curve. Therefore, no gradual eustatic falls are indicated except possibly during the Tithonian and Berriasian.

Our best estimate of true eustatic changes from Jurassic to Holocene is shown on Fig. 6c. Amplitudes of the changes are calibrated in meters with respect to present sea level, based on our curves,

those of Pitman (in press), and data from Sleep (1976) and J. G. Beard (personal commun.). A more accurate curve for the Triassic through Early Cretaceous segment can be made when the first-order rise of sea level for that part of the curve has been calculated from rates of seafloor spreading or from some other long-term cause.

GLOBAL HIGHSTANDS AND LOWSTANDS AND MAJOR INTERREGIONAL UNCONFORMITIES

Table 1 lists the major global highstands and lowstands (or comparative lowstands) of sea level during Phanerozoic time. They are separated by major global falls of sea level. These falls are associated with major interregional unconformities.

A *global highstand* is an interval of geologic time during which the position of sea level is above the shelf edge in most regions of the world. Conversely, a *global lowstand* is an interval during which sea level is below the shelf edge in most regions. A *comparative lowstand* occurs when sea level is at its lowest position on the shelf between periods of highstand.

Global highstands of sea level (Part 3, Vail et al., Fig. 9, this volume) are characterized by widespread shallow marine to nonmarine deposits on the shelves and "starved" basins. If the supply of terrigenous sediment is abundant, delta lobes may prograde over the shelf edge into deep water. Global lowstands are characterized by erosion and nondeposition on the shelves, and deposition of deep marine fans in the basins. After a major fall of sea level to a global lowstand, a major interregional unconformity commonly is developed by subaerial erosion and nondeposition on shelves and basin margins, and by periods of nondeposition or shifts in depositional patterns in the deep-water parts of the basin.

The two first-order global cycles of sea-level change (Fig. 1) may be generally described in terms of global lowstands and highstands. During the older first-order cycle, sea level rose from a lowstand in late Precambrian time to a highstand during a long interval from Late Cambrian to Mississippian, and gradually fell to a lowstand which was at a broad minimum through Permian and Early Triassic time. In the cycle from Triassic to the present, cumulative rises built to a highstand peak in Late Cretaceous followed by cumulative falls to lowstand with many fluctuations.

CAUSES OF GLOBAL CYCLES

According to Fairbridge (1961), a eustatic change of sea level on a global scale may be produced by a change in the volume of sea water, by a change in the shape of the ocean basins, or by a combination of both. A change in the volume of

seawater may be produced by glaciation and deglaciation, or by additions of juvenile water from magmatic sources (Rubey, 1951, p. 1137-1138), volcanos, or hot springs (Egyed, 1960). A change in the shape of the ocean basins may be produced by geotectonic mechanisms or sedimentary filling of the basins.

Among these factors, only geotectonic mechanisms appear to be of sufficient duration and magnitude to account for the first-order and most of the second-order cycles. Glaciation and deglaciation probably account for many third-order cycles and some of the second-order cycles, especially those in the late Neogene. Other unidentified causes may produce the rapid changes evident in second- and third-order cycles, or may work in combination with geotectonics and/or glaciation to accentuate or diminish the changes. Pitman (in press) discussed the effect of abrupt changes in rates of seafloor spreading on onlap patterns along continental shelves.

Changes in volume or elevation of midocean ridges, which are related to changes in the rate of

seafloor spreading, appear to produce significant changes in the shape of ocean basins (Hallam, 1963, 1969, 1971; Menard, 1964; Russell, 1968; Wise, 1972, 1974; Flemming and Roberts, 1973; Rona, 1973a, b; Hays and Pitman, 1973; and Rona and Wise, 1974; Pitman, in press). Volumetric changes along subduction zones are more difficult to quantify and evaluate and have not been treated quantitatively to our knowledge. Carey (1976) suggested that earth expansion may be the major cause for the rapid changes.

Pitman (in press) stated that, except for glacial effects, volumetric change in the midocean ridges related to change in rate of seafloor spreading is potentially the fastest and volumetrically the most significant way to change sea level. According to his calculations, sea level has fallen steadily but at varying rates from the Late Cretaceous, due to a contraction in size of oceanic ridges related to decreasing rates of seafloor spreading. At the same time, passive continental margins of the Atlantic and other ocean basins have subsided tectonically at decreasing rates, following a pre-

Table 1. Global Highstands and Lowstands of Sea Level and Associated Major Interregional Unconformities During Phanerozoic Time.

SEA LEVEL HIGHSTANDS	MAJOR GLOBAL SEA LEVEL FALLS	SEA LEVEL LOWSTANDS
EARLY & MIDDLE PLIOCENE	PRE-LATE PLIOCENE & PRE-PLEISTOCENE (3.8 & 2.8 MA)	LATE PLIOCENE - EARLY PLEISTOCENE
MIDDLE MIOCENE	PRE-LATE MIOCENE & PRE-MESSINIAN (10.8 & 6.6 MA)	LATE MIOCENE
LATE MIDDLE EOCENE & EARLY OLIGOCENE	PRE-MIDDLE LATE OLIGOCENE (30 MA)	MIDDLE LATE OLIGOCENE
LATE PALEOCENE - EARLY EOCENE	PRE-MIDDLE EOCENE (49 MA)	EARLY MIDDLE EOCENE
CAMPANIAN & TURONIAN	PRE-LATE PALEOCENE (60 MA)	MID-PALEOCENE
ALBIAN - EARLIEST CENOMANIAN	PRE-MIDDLE CENOMANIAN (98 MA)	MID-CENOMANIAN
EARLY KIMMERIDGIAN	PRE-VALANGINIAN (132 MA)	VALANGINIAN
NORIAN & MIDDLE GUADALUPIAN	PRE-SINEMURIAN (190 MA)	SINEMURIAN
WOLFCAMPIAN & EARLIEST LEONARDIAN	PRE-MIDDLE LEONARDIAN (270 MA)	MID-LEONARDIAN
OSAGIAN & EARLIEST MERAMECIAN	PRE-PENNSYLVANIAN (324 MA)	EARLY PENNSYLVANIAN
MIDDLE SILURIAN	PRE-DEVONIAN (406 MA)	EARLY DEVONIAN
LATE CAMBRIAN & EARLY ORDOVICIAN	PRE-MIDDLE ORDOVICIAN (490 MA)	EARLY MIDDLE ORDOVICIAN
		EARLY CAMBRIAN & LATEST PRECAMBRIAN

dictable thermal cooling curve (Sclater et al, 1971). The general model can be used to explain the cumulative first-order fall since the Late Cretaceous.

There may be a general correspondence of times of orogenic movement and volcanism with times of second-order sea-level highstands (Fig. 1). In general, high rates of seafloor spreading should be associated with relatively shallow ocean floors, highstand flooding of continental and basin margins, and greater subduction. Increased subduction should tend to produce increased volcanism and orogeny from continent-continent collisions. Such orogenic episodes should have fairly long terms of occurrence associated with durations of second-order highstands. However, pronounced angular unconformities associated with rapid falls of sea level can give impressions of short periods of orogeny. If short-term orogenies can be documented, they may be related to third-order cycles.

First-order cycles show a possible overall relationship to patterns of seafloor spreading rates and orogeny. For example, rifting and continental pull-apart dominate times of major sea-level rise in Cambrian and Jurassic–Early Cretaceous, and orogenies dominate intervals of falling sea level within each first-order cycle.

Many workers have noted unconformities which occur simultaneously in many regions of the globe (Stille, 1924; Arkell, 1956; Sloss, 1963, 1972; Gussow, 1963; Vail and Wilbur, 1966; Moore et al, 1974; and Dennison and Head, 1975). Most of these unconformities are coincident with major relative falls of sea level on our charts (Figs. 1-3). The unconformities that correspond to major sea-level falls at the end of the second-order cycles are shown on Table 1.

We concur with Sleep (1976) that unconformities caused by major eustatic changes of sea level modify the history of subsidence within cratonic basins and continental margins. Where thermal contraction of the lithosphere controls basin subsidence, basins should continue to subside even during times of eustatic lowstands. Sleep calculated that significant unconformities in the geologic record could be produced by eustatic falls of sea level, with amplitudes of those presented on Figure 6c, even in rapidly subsiding basins. Sleep's work supports our contention that interregional unconformities are not primarily due to uplift of the continental interior or continental margins, but are primarily caused by erosion or non-deposition during eustatic changes in sea level.

Glaciation and deglaciation are the only well understood causal mechanisms that occur at the relatively rapid rates of third-order cycles (Pit-

man, in press). Rates of geotectonic mechanisms related to seafloor spreading are too slow. Glaciation has been documented in the Pleistocene, late and early Miocene, and to some degree in the late Oligocene, but there is no evidence of glaciation at the times of many other lowstands. Other evidence for climatic changes, such as from oxygen isotopes (Savin, in press; Savin and Douglas, in press; Fischer and Arthur, in press) and other faunal studies (Haq and Lohmann, 1976) show that lowstands generally represent climatically cool conditions, and highstands represent climatically warm conditions.

Other evidences of cyclicity which correlate in general with global cycles include frequency of unconformities in deep sea cores and cycles of faunal diversity (Fischer and Arthur, in press), and changes of calcite compensation depth (van Andel, 1975, in press).

In summary, the cause for the first-order and some second-order cycles may be related to geotectonic mechanisms. Some of the second- and third-order cycles can be explained by glaciation. The empirically observed rapid falls of sea level at the ends of the third-order cycles remain unexplained where evidence for glaciation is not known.

APPLICATIONS

Major applications of global cycles fall into three categories: (1) improved stratigraphic and structural analyses incorporating the effects of sea-level changes, (2) estimation of geologic age ahead of the drill, and (3) development of a global system of geochronology.

In regional stratigraphic studies, after analysis of seismic sequences and regional sea-level changes is begun (Parts 2, 3, 7, Vail et al, this volume) comparison of regional and global sea level curves can aid prediction of age of sequences for which control is lacking and fill gaps in regional sea-level curves. Correlation of regional curves with times of unconformities, lowstands, and highstands on global curves aids prediction of depositional facies and distribution of sequences (Parts 3, 9, 10, Vail et al, this volume). Moreover, departures of the regional curve from the global curve indicate anomalous regional effects such as tectonic subsidence or uplift.

Estimation of geologic age of strata prior to drilling is a seismic-stratigraphic technique commonly applied in areas of sparse or no well control. Where wells are present and biostratigraphic zones are determined, they can be tied to seismic sequences for accurate age dating throughout the area of the seismic grid. If there is no well control within the grid, geologic age can be inferred by

GLOBAL CYCLE CHART JURASSIC-TERTIARY

REGIONAL CHART

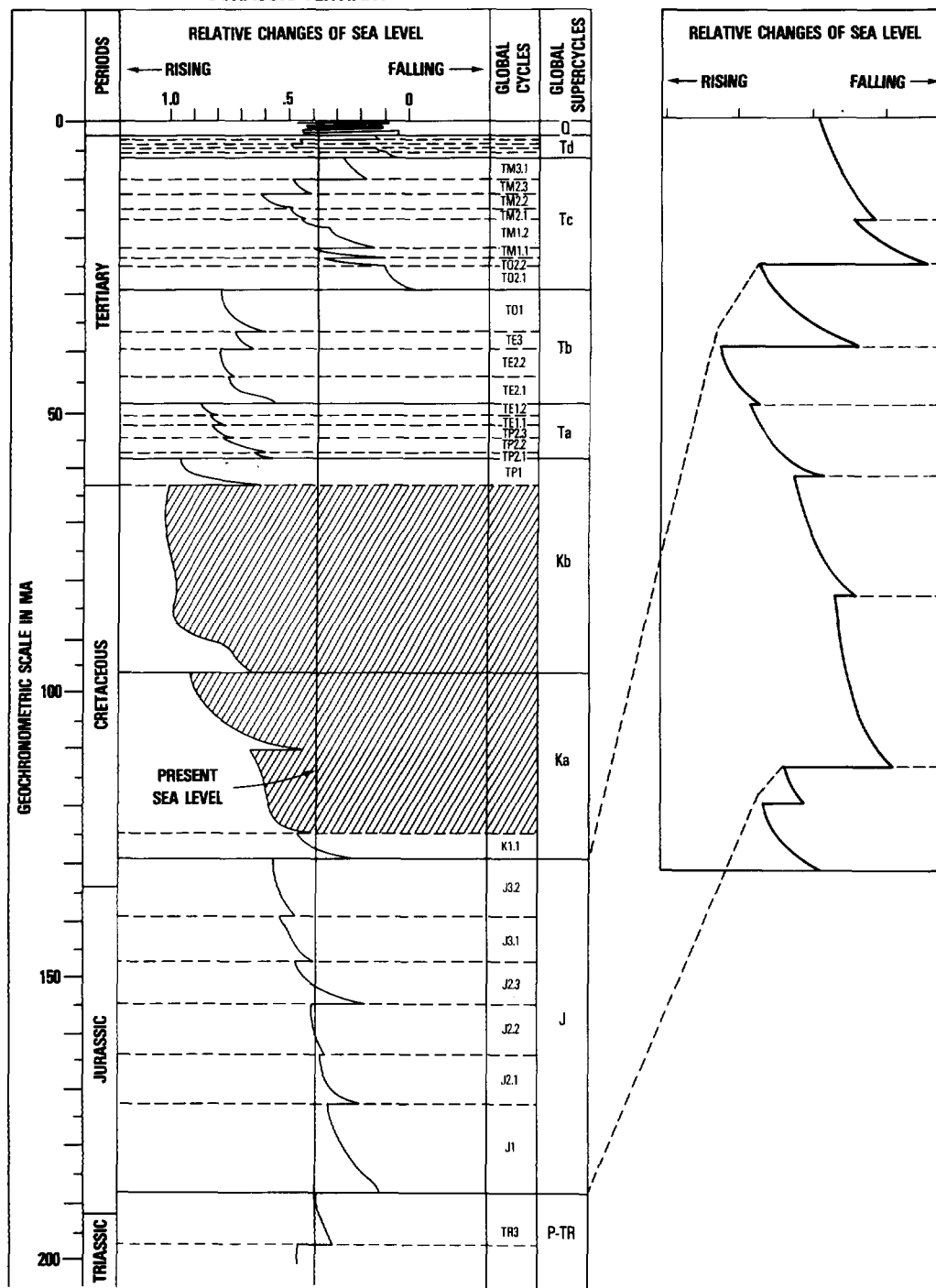


FIG. 7—Estimating geologic age prior to drilling.

building a regional chart of relative changes of sea level from seismic data and matching it with the global chart (Fig. 7). Accuracy can be improved with information from outcrops or distant wells that help to establish the general age of strata that are known to be present in the basin.

One of the greatest potential applications of the global cycle chart is its use as an instrument of geochronology. Global cycles are geochronologic units defined by a single criterion—the global change in the relative position of sea level through time. Determination of these cycles is dependent on a synthesis of data from many branches of geology. As seen on the Phanerozoic chart (Fig. 1), the boundaries of the global cycles in several cases do not match the standard epoch and period boundaries, but several of the standard boundaries have been placed arbitrarily and remain controversial. Using global cycles with their natural and significant boundaries, an international system of geochronology can be developed on a rational basis. If geologists combine their efforts to prepare more accurate charts of regional cycles, and use them to improve the global chart, it can become a more accurate and meaningful standard for Phanerozoic time.

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