ON THE INTERPRETATION OF CORDILLERAN OROGENIC BELTS

R. W. R. RUTLAND
Department of Geology and Mineralogy,
The University of Adelaide, Adelaide, South Australia 5001

ABSTRACT. The concept of the geotectonic cycle is examined in relation to current plate tectonic models. The importance of the distinction between stratotectonic and morphotectonic aspects (Rast, 1969) is emphasized. The main morphotectonic zone derived from the arc-trench complex is described as the eutectonic zone while that developed between the arc-trench complex and the craton is described as mietectonic.

Comparative study of the Cordilleran system of North and South America suggests that major vertical movements and changes in plutonism and volcanism allow a geotectonic cycle consisting of four main stages to be recognized in Mesozoic-Cenozoic eutectonic zones:

1. generative and geosynclinal;
2. orogenic with plutonism;
3. planation with volcanism;
4. morphogenic with volcanism.

Although Mesozoic analogues of the present arc-trench complexes clearly existed, the Mesozoic plutonic belts (stage 2) cannot be regarded simply as eroded equivalents of Quaternary volcanic belts (stage 4), which occur in a different tectonic setting. Thus the present circum-Pacific tectonic pattern is not a close model for the past.

The Mesozoic-Tertiary orogenic cycle was preceded by previous orogenic activity in the same eutectonic belt. The extensive younger cover therefore severely limits the evidence available for Paleozoic stratotectonic interpretations in the east Pacific margins, although much fuller evidence is available in Australia. Current views that the boundary between the main mietectonic and eutectonic zones corresponds to the western limit of Precambrian continental crust appear not to be securely based. Forearc accretion during the Mesozoic-Tertiary cycle was both local and limited, and the superposition of the Mesozoic arc-trench complex in the Paleozoic orogenic complexes shows that any large-scale lateral continental accretion must have been pre-Mesozoic. The occasional association of Precambrian basement complexes with the Paleozoic complexes close to the coast is not plausibly explained by lateral accretion of exotic microcontinents and also suggests that fore-arc accretion has not been important during the Paleozoic.

Moreover the present contrast between east and west Pacific suggests that development of marginal basins, floored by oceanic crust, is unlikely to have occurred in the east Pacific Cordilleran belts. An ensialic model of Cordilleran development is therefore preferred.

The differences between east and west Pacific margins are probably related to different motions of these margins relative to the east Pacific spreading rise. Thus the east Pacific margins can be regarded as advancing margins and the west Pacific as retreating margins.

The indications are that volcanism and plutonism in the Paleozoic was not on the same scale as the later activity, and the Mesozoic-Cenozoic cycle is interpreted as a distinctive part of a longer term geotectonic cycle (about 1000 m.y.) which implies changes in ocean floor spreading with time. The late Precambrian miogeoclinal developments can be interpreted as an early stage in this long-term cycle. Thus the Pacific may be an ancient Ocean whose margins were inactive in the late Precambrian and only weakly active during the Paleozoic. The Permo-Triassic tectonic transition may mark the beginning of active spreading and contraction of the Pacific, whereas the Cretaceous-Tertiary tectonic transition may mark the complete uncoupling of the Pacific margins associated with continent dispersal.

It seems likely that long-term cycles in the Precambrian can be explained by similar relationships to ocean-floor spreading. The higher heat flow and thinner lithosphere in the Precambrian, however, have probably caused different expressions of the thermal cycle in the continental crust.
1. Introduction

Gilluly (1971) has pointed out that it cannot be assumed that “plate motion is the only kind nor even the generating engine of all tectonics” (see also Shaw, Kistler, and Evernden, 1971). Nevertheless, the general acceptance of the hypothesis of ocean-floor spreading (Hess, 1962; Isacks, Oliver, and Sykes, 1968) has led to the idea that plate interactions along subduction zones provide the driving energy for orogenic processes not only in the later Phanerozoic but throughout the geological record: different kinds of plate interaction have been recognized and correlated with types of “geosynclinal” development and orogenesis (for example, Dietz, 1963; Mitchell and Reading, 1969; Crook, 1969; Dewey and Bird, 1970; Dickinson, 1971).

In analyzing orogenic belts it is important to separate stratotectonic from morphotectonic aspects (Rast, 1969). Broadly, the belts may be interpreted in terms of stratotectonic patterns of sedimentation and volcanism on which various processes (for example, deformation, differential uplift, magmatism, metamorphism, et cetera) have operated to produce the observed morphotectonic zones (compare Gnibidenko and Shashkin, 1970). Current stratotectonic models distinguish two basic types of continental margin:

Passive margins of Atlantic type are developed in plate-interior settings, and miogeoclinal sequences are deposited across the margins. In the Cordilleran belts of the Americas the previously recognized miogeosynclinal belts may now be reinterpreted as miogeoclinal (Dickinson, 1971; fig. 1, this paper).

Active margins of island-arc type are developed on plate margins adjacent to subduction zones. These are the convergent plate junctures of Dickinson (1971) who recognizes a fundamental arc-trench couple: a “eugeosynclinal” trench setting characterized by the ophiolite assemblage and a volcano-plutonic arc characterized by the calc-alkaline suite. In addition he distinguishes fore-arc and back-arc settings for sedimentation. All these divisions of the arc-trench couple belong in the belts previously described as eugeosynclinal (fig. 1)). There may also be a fundamental stratotectonic distinction between east and west Pacific margins (Mitchell and Reading, 1969). In a steady-state spreading system, it is apparently implied that the arc-trench couple would be a constant feature of the stratotectonic setting, although the tectonic zones might migrate in space in response to changes of spreading and subduction patterns.

It should be noted that accumulation of sedimentary and volcanic material on both active and passive margins is commonly supposed to be largely ensimatic. This necessarily leads to the view that continents have grown by accretion at their margins as a result of orogeny, since accumulations on both types of margin may eventually become involved in orogenic belts and incorporated in the cratons.

Two morphotectonic models of orogenic belts are also generally distinguished (Dewey and Bird, 1970):
Cordilleran type, which are supposed to evolve from Active margins. Again distinction may be made between east and west Pacific types (Matsumoto, 1967; Dewey and Horsfield, 1970). It is evident, in view of the rates of subduction, that the oceanic plate must be essentially uncoupled from the continental margin, and it is not clear how the tectonism, plutonism, and metamorphism are related to the spreading and subduction process, but it is supposed by Dewey and Bird (1970) that the orogeny is thermally driven.

Collision type, which are developed at convergent plate junctures when subduction brings together either two continents (Himalayan type) or a continent and island arc (New Guinean type). Before collision one of the opposed margins must therefore be an active margin, and both may be. This type of orogeny with its basement shortening is regarded as mechanically driven.

It is then claimed on actualistic premises that these models apply for much or all of geological time; that is, older orogenic belts are similarly related to subduction zones and ocean-floor spreading (for example, Dewey and Horsfield, 1970).

Dickinson (1971) generalizes that for western North America “... we are forced to contemplate the possibility of several episodes of rifting and continental separation to form raw continental edges; several collisions of the main North American craton with other continents, microcontinents or island-arcs; as well as the complex unfolding of each major event with a special local flavor.” As a corollary of these views the con-

![Diagram of tectonic terminology of Cordilleran orogenic belts.](image-url)

Fig. 1. Tectonic terminology of Cordilleran orogenic belts. Supracrustal accumulations are indicated diagrammatically (s) and are normally earlier (Paleozoic) in the miogeotectonic zone than in the eutectonic zone (Mesozoic). Note that the continental crust beneath the eutectonic zone may be formed by lateral continental accretion (see text). Exogeosynclinal deposits are normally developed across the margin between the miogeotectonic zone and the craton, and mainly on the craton.
cept of intracontinental orogenic belts is rejected (Bird and Dewey, 1970, p. 1052).

In general, the analyses of orogenic belts in terms of plate tectonics (Bird and Dewey, 1970; Hamilton, 1969b, 1970) have been most illuminating in relation to stratotectonic aspects. The evolutionary development of active margins is implied by the interpretation of Cordilleran orogenic belts in terms of the island-arc stratotectonic model (Wilson, 1959; Hamilton, 1969b; Dickinson, 1971), but the evolutionary sequence (involving tectonism, magmatism, and metamorphism) is not explained adequately. It is different presumably from belt to belt since "Unlike the older geosynclinal theory the new synthesis does not require a regular sequence of geotectonic cycle of orogenic events to be recognized in the same order in all mountain belts" (Dickinson, 1971). It might be expected, therefore, that different belts would show different histories and different spatial relationships of morphotectonic zones according to the particular sets of orogenic events that had affected them.

In contrast the classical view of orogenic belts has suggested:

1. that orogenic phases are contemporaneous over wide areas;
2. that orogenic phases are spasmodic and short-lived on a time scale of hundreds of millions of years;
3. that orogenic belts display evolutionary sequences of events or geotectonic cycles.

Rodgers (1971) has recently discussed the first two alleged attributes in relation to the Taconic orogeny and has shown that both are illusory. He suggests that "orogeny (and by implication sea-floor spreading, or perhaps more likely its first time derivative) is neither sharply spasmodic, the spasms being separated by longer periods of calm, nor smoothly continuous, but is a sort of random walk produced by forces deeper in the Earth". On the other hand, Rodgers (p. 1170) most convincingly shows that the Taconic orogeny is characterized by a clear evolutionary sequence: "(1) disconformity on the carbonate bank (perhaps angular unconformity at its eastern or 'internal' margin), (2) severe early deformation in a more easterly or 'internal' volcanic zone, (3) gravity slides from near the latter into the former area, following an 'inversion of relief'; and finally (4) widespread deformation (generally with some metamorphism) especially strong with more westerly or 'external zones' . . . ."

This sequence has been interpreted by Bird and Dewey (1970) in terms of the early stages of closure of a proto-Atlantic ocean, collision occurring in the Late Devonian. The collision presumably brings subduction to a halt, and an evolutionary sequence of events is to be expected. It is possible to envisage different circumstances for collision so

1 It should be noted, however, that although paleomagnetic evidence apparently requires the Lower Paleozoic proto-Atlantic Ocean to remain open until the Devonian (Hailwood and Tarling, 1972), some geological interpretations deny the existence of a pre-orogenic ocean basin floored by oceanic crust (Church, 1972; Chidester and Cady, 1972).
that it cannot be anticipated that other collision orogenies will show
similar sequences.

It has been suggested that Cordilleran orogenies are also the result
of collisions with eastward-facing island-arc systems (Moore, 1970) in
order to account for their periodic characteristics. But if, as is generally
accepted, these belts are not of collision type, the problem of relating
the evolutionary characteristics of Cordilleran-type orogenies to con-
tinuous ocean-floor spreading is more severe (Dott, 1969; Coney, 1970).

The plate-tectonic models outlined above do imply two major
stratotectonic stages in the evolution of a Cordilleran belt. Since Cor-
dilleran belts cut across earlier tectonic trends, it would seem to follow
that the continental margins on which they were initiated began as
passive continental margins in an earlier episode of ocean-floor spread-
ing. Thus the miogeosynclinal belts, which are mainly of Late Precam-
brian and early Paleozoic age, can be reinterpreted as miogeoclinal belts
(compare Dickinson, 1971; Stewart, 1972). At a later stage these passive
margins have been converted to active by the superposition of arc-trench
complexes to form the eugeosynclinal belts of earlier terminology. The
resulting morphotectonic zones of the orogenic belts have been described
as the internal and external zones ("internides and externides"), but these
terms (see, for example, King, 1969, p. 46), which were developed for
apparently intracontinental orogenic belts, are unsatisfactory in Cor-
dilleran belts where the terms "inner" and "outer" are also used with
respect to paired metamorphic belts and island arcs. In this account,
therefore, the morphotectonic zone developed from the arc-trench or
eugeosynclinal belt is described as the eutectonic zone, whereas the mor-
photectonic zone developed from the miogeoclinal or miogeosynclinal
belt is described as the miotectonic zone (figs. 1 and 2).

An alternative explanation of the "miogeoclinal" stratotectonic
zones should perhaps be considered. There may have been long periods
in the Earth's history when ocean-floor spreading was either very slow or
inoperative,2 and if so it would be desirable to recognize a category of
inactive margins as well as active and passive. Sedimentary accumulations
interpreted as miogeoclinal may develop across inactive margins as well
as across passive margins produced during continental rifting and drift-
ing. Thus the late Precambrian and early Paleozoic miogeoclinal develop-
ment in the Cordilleran belts around the Pacific may not indicate that
the margins were produced by rifting of a continental plate on the
present site of the Pacific but rather that spreading was not active in the
ancestral Pacific ocean at that time. This would also imply that the
miogeoclinal developments are not accidentally associated with the
present active margins as a result of random plate movements but are
systematically related to them within a global thermal cycle.

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2 Spreading can be regarded as a superficial expression of the Earth's major
thermal cycles (Gastil, 1960), and it presumably reaches maximum activity at times
of highest heat flow and highest geothermal gradient.
The strongest evidence for a major geotectonic cycle comes from the evidence of systematic vertical movements both in the orogenic belts and in the stable continental areas. Khain and Muratov (1970) for example distinguish “general oscillations” or pulsations (undulations of Stille, 1924) on various time scales. The longest cycles are of about 200 m.y. duration and include the Caledonian, Variscan, and Alpine cycles. According to Khain and Muratov these cycles can be found “almost simultaneously both in geosynclines and on platforms (there is some time lag for platforms). . . . During the first half of the cycle both platforms and geosynclines are subject to sea transgressions. . . . At the close of a long cycle, vast but flat lowland areas develop on platforms, whereas geosynclines become the site of mountain ranges dissected by deep depressions” (p. 527).

Fig. 2. Major stratotectonic subdivisions of the Cordilleran orogenic belt. Base map and plate boundaries after Lipman, Prostka, and Christiansen (1972). The Mesozoic arc-trench complex is roughly equivalent to the traditional “eugeosynclinal” zone and to the morphotectonic “internal” zone whereas the Paleozoic miogeoclinal complex is equivalent to the “miogeosynclinal” zone and to the “external” zone (see fig. 1).
On the interpretation of Cordilleran orogenic belts  817

Whereas in the plate-tectonic models, volcanicity and seismicity similar to those of the present day must be regarded as more or less constant features of the tectonic system, they are regarded by Khain and Muratov (1970, p. 535-537) as late features of the geotectonic cycle. Calc-alkaline volcanism is described as "subsequent volcanism" associated with molasse formations, and a "final magmatism of central volcanoes is distinguished". The regions of high seismicity are correlated with the regions of most marked Neogene activation.

In contrast, Coney (1970) has specifically suggested that the geotectonic cycle be abandoned as a deterministic model of mountain evolution on the grounds that successive events in an individual belt may have only "accidental or indirect relation" to each other. He considers that "geologic histories of tectonic complexes are more readily comprehensible if they are simply considered as the result of successive and interpenetrative responses of various sorts rather than due to any orderly tectonic cycle".

It is clear that no common cycle is to be expected for both collision and Cordilleran orogenies. But it should not be concluded that the well established concept of a geotectonic cycle (see, for example, King, 1969) is incompatible with plate tectonics. At least four possible ways of generating a common cycle in different parts of the Cordilleran system might be envisaged.

1. A systematic shift of the subduction zones and therefore of the related tectonic zones either toward or away from the continental margin would lead to an apparent cycle of events in any one place, although the timing would evidently vary from place to place (Coney, 1970). A progressive change in dip of a subduction zone might have a similar effect (Souther, 1972).

If, as a consequence of the subduction process, new subduction zones were initiated oceanward of older ones, then oceanic crust, with its deep-water assemblage, would become overlain by arc-trench complexes, and a two-stage development of eugeosynclines comparable to that often described (Zonenshayn, 1971, p. 341-342) would be expected. Further shift in the subduction zone could result in the island-arc complex being overlain by a molasse-type exogeosynclinal development corresponding to a third, or final, structural stage.

2. Ocean-floor spreading may show periodic or secular variations that control a geotectonic cycle. Although there is some direct evidence of local changes in spreading rates, independent of magnetic anomaly patterns (for example Aumento, 1972), spreading is usually regarded as being continuous and fairly constant in rate over tens of millions of years (Heirtzler and others, 1968). Suggestions of major interruptions in spreading (Ewing and Ewing, 1967; Schneider and Vogt, 1968; Rona, 1971) have not been supported by Joides drilling (Maxwell and others, 1970). Nevertheless, changes in spreading pattern and direction have undoubtedly occurred, and some of these are associated with changes of rate
(Vogt and others, 1971; Vine, 1972). Moreover, there have been periodic increases in the lengths of active spreading ridges so that there have been corresponding increases in the rate of generation of unit area or volume of ocean floor. Since there have not been corresponding increases in the length of consuming margins, rates of subduction must have increased. Changes in the volume of the mid-ocean ridges due to changes of spreading rate or changes of length must also have made major contributions to eustatic changes of sealevel on the continents (Hallam, 1963; Schneider and Vogt, 1968; Armstrong, 1969; Sclater, Anderson, and Bell, 1971). Some of these factors have already been claimed to be applicable (Brookfield, 1971; Coney, 1971; Dott, 1969; Souther, 1970; Frericks and Shive, 1971) to the interpretation of events in Cordilleran orogenic belts.

3. The process of subduction with its attendant magmatism and volcanism must inevitably set up secondary responses causing progressive changes in the continental margin, and these may display a cyclic development even though the controlling ocean-floor spreading is of constant rate. This idea was developed by Elsasser (1970) and was also implicit in the synthesis of Dewey and Bird (1970).

4. If ocean-floor spreading is regarded as a superficial effect of major thermal cycles of the Earth, there may be effects of the thermal cycles within the continents and continental margins that are not directly controlled by ocean-floor spreading (Kistler, Evernden, and Shaw, 1971; Shaw, Kistler, and Evernden, 1971; Roberts, 1972). The effects of mantle plumes (Vogt and others, 1971) can also be included here, together with aspects of various other tectonic theories, emphasizing vertical tectonics (for example, Belousov, 1966).

The Mesozoic and Tertiary evolution of Cordilleran orogenies is therefore considered briefly below with particular attention to the concept of a geotectonic cycle. It is suggested here that local variations in the Cordilleran belts are superposed on a broad geotectonic cycle controlled by a major thermal cycle in the Earth's history (Gastil, 1960; Sutton, 1963) of about 1000 m.y. duration. The main variation in the expression of the cycle is between the east and west Pacific. The analysis suggests that it is unnecessary to postulate repeated opening and closing of the Pacific Ocean, and it also suggests that the continents have not grown significantly by lateral accretion.

2. TECTONIC EVOLUTION OF CORDILLERAN OROGENIC BELTS

The mobile belts around the Pacific have a long and complex history which goes back into the Precambrian (for example, Stille, 1955; Pushcharovsky, 1967; Matsumoto, 1967; King, 1969; Gneidenko, 1970). In general, however, the belts can be divided objectively into morphotectonic zones developed in three main periods of differing lengths. These are:

1. Late Precambrian to end-Paleozoic,
2. Mesozoic to early Tertiary,
3. Late Tertiary.
In the east Pacific the Mesozoic eutectonic zones lie adjacent to the continental margins and are separated from the craton by the Paleozoic miotectonic zones (fig. 2). The Late Tertiary morphotectonic elements are superposed with varying effects on both the Mesozoic and Paleozoic zones (figs. 3 and 4).

In the west Pacific, Paleozoic zones are less regularly developed between the Mesozoic zones and the craton except in Australia. In East Asia the Mesozoic belts cut across earlier tectonic trends (for example, Krasny, 1967). Parts of the Mesozoic belts, as in Japan and New Zealand, are now separated from the continent by marginal seas. Tertiary morphotectonic elements are in part superposed on the earlier zones, but in contrast to the east Pacific, new and separate Tertiary morphotectonic zones are developed in the island arcs.

It appears that major reorganizations of the tectonic pattern took place in Permo-Triassic times and again in mid-Tertiary times. Thus Matsumoto (1967) was led to suggest a sequence of three types of orogeny (ensialic, marginal, and ensimatic) which he thought might imply “major evolutionary changes in crustal and sub-crustal processes”. This interpretation cannot be discounted, although, if the possibilities of lateral migration of tectonic zones and lateral accretion of continental crust are taken into account, it is possible to interpret all three stages in terms of the simple plate-tectonic model outlined above.

2A. East Pacific Belts

The western United States is the best known segment of the Cordilleran system, but it is not a good reference area because it is a region of particular complexity incorporating the Basin Range provinces and the Colorado plateau. The southern Canadian Rockies and the central Andean belt (in Peru, Bolivia, Argentina, and Chile) present simpler belts for comparison.

A most important general feature of the Cordilleran system in the Americas is its division into two distinct belts of both morphotectonic and stratotectonic significance—an eastern (External or miotectonic) Paleozoic belt in which Precambrian to Devonian rocks are dominant and a western (Internal or eutectonic) Mesozoic belt in which Triassic to Cretaceous rocks are dominant. Upper Paleozoic rocks are of subsidiary importance in both belts and do not themselves form a well-defined belt. Mesozoic and Tertiary exo-geosynclines have also developed locally on the eastern side of the Paleozoic belt. This simple pattern is complicated by Tertiary basin development and by the distribution of Tertiary volcanism. The preservation of these continuous Paleozoic and Mesozoic linear belts clearly indicates that there has been a general similarity in the amounts and directions of vertical movements affecting them over great distances, in spite of local differences in depositional and deformational history (King, 1969).
Fig. 3. Morphotectonic zones of the Canadian Cordillera. The division between the Intermontane belt and the Omineca crystalline belt corresponds to the stratotectonic division between arc-trench complex and miogeoclinal complex. Note that the Tertiary volcanicity (here undifferentiated) is largely in the cutoenic zone. Miocene and Pliocene alkali-olivine basalts were erupted in approximately the same areas as Early Tertiary acid volcanics (see Souther, 1972). Pleistocene–Recent central vents are not shown.
The boundary between these two major belts is often accentuated by major faulting or crustal flexuring, and it is also closely related to eastward thrusting at various times. It separates two major morpho-tectonic regimes which differ in style and timing of deformation and in associated volcanism, plutonism, and metamorphism (King, 1969, fig. 13, p. 71). It approximates stratotectonically to the western edge of the Lower Paleozoic miogeosyncline, and folded and metamorphosed eugeosynclinal Lower Paleozoic rocks often occur further west. Over a long period of time, therefore, the crust has tended to show a marked contrast in mobility across this line. It can be argued in some areas that the line marks the western limit of older Precambrian crystalline basement (Monger, 1972; Burchfiel and Davis, 1972) and that Paleozoic evolution west of the line was ensimatic, but this view cannot be sustained everywhere (see below, sec 4). Such lines in Russian tectonic literature are usually interpreted in terms of deep faults.

2A(1) The Mesozoic belt.—The western belt itself has three major subdivisions: two belts of Mesozoic volcanic and sedimentary rocks are separated by an older basement and batholithic belt. The outer volcanic and sedimentary belt is best developed in California, where it is represented by the Franciscan and Great Valley sequences. It is not represented in the Insular belt of Canada and is also generally absent on-
shore in Peru and Chile although intermediate to high-pressure metamorphic rocks have been recognized locally close to the coast (Gonzalez-Bonarino and Aguirre, 1970). This outer belt is interpreted in terms of fore-arc and trench settings in the island-arc model (Hamilton, 1969b, Dickinson, 1971).

The central belt is represented by the Coast Mountains belt of Canada, the Sierra Nevada belt in California, and the coast range belt in Peru and Chile. Pre-Triassic basement rocks include Upper Paleozoic sediments and volcanics as well as older schist and granitic complexes (for example, Ruiz, 1965; Douglas and others, 1970). The older schist complexes are probably generally Lower Paleozoic, but Precambrian basement is present in some areas such as Oaxaca, Mexico and southern Peru (Cobbings and Pitcher, 1972b).

The relative importance of pre-Triassic basement rocks and Mesozoic plutons varies considerably. The batholithic development tends to be on the east flank of the basement high, and sometimes the two become separated by Mesozoic sediments and volcanics. In Chile, between 35° and 42°S the Tertiary fill of the longitudinal valley lies between the main Mesozoic batholith and the coastal basement complex. The belt was a positive element at least in Late Mesozoic time and is interpreted as the volcano-plutonic complex of the island-arc itself in the island-arc model and as the edge of the pre-Mesozoic continental crust. Others suggest, however, that the batholithic belt developed within an earlier geosyncline (Bateman and Wahrhaftig, 1966; Cobbing and Pitcher, 1972a). The two views may not be completely incompatible, if it is assumed that the batholith in the latter case has developed within a basin east of the main basement high.

The inner volcanic and sedimentary belt is present but poorly developed east of the Sierra Nevada (see Hamilton, 1969b, p. 2418-2419) but is clearly developed as the intermontane belt in Canada and the Central or Longitudinal valley belt in Chile. It has been described as a successor basin in Canada (implying a late stage of a longer geotectonic cycle) while it is the main Andean geosyncline of Chilean authors (Ruiz, 1965). In terms of the island-arc model, it may be regarded as a basin developed behind the arc (a back-arc setting of Dickinson, 1971).

The early Mesozoic development of the troughs of the Canadian Intermontane belt and of the West Andean “geosyncline” appears to have been very similar with volcanic facies in the west and clastic facies in the east. In Chile, however, the Mesozoic trough was apparently essentially limited to the present Mesozoic belt of the Andes, whereas in Canada the miogeosynclinal facies was developed east of a geanticline on the west margin of the present Omineca crystalline belt. Both belts were affected by late Jurassic to early Cretaceous orogeny which raised the areas above sealevel. Large thicknesses of continental cannibalistic volcano-clastic sediments were then deposited in the Andean belt. Similar rocks were deposited in Canada, but only small areas are
now preserved, and their original extent was probably much more limited. Instead, large Late Cretaceous exoegosynclines were developed both in Canada and the United States. This difference may be partly related to different climatic conditions operating in the uplifted mountains in the two areas.

The broad similarity between the two regions is emphasized by the history and spatial distribution of plutonism. Late Paleozoic and Triassic plutonism and volcanism is described from the eastern margin of the West Andean belt (Ruiz, 1965) and appears to correspond in timing and position with the plutonism associated with the Tahltanian (mid-Triassic) and Inklenean orogenies in Canada (Douglas and others, 1970, p. 438-439). The main stratotectonic elements of the Mesozoic belts were established at this time. Subsequent plutonism within the Mesozoic belts in both areas began in the west of the main volcano-plutonic complex during Jurassic time (Nassian) and migrated easterly with major late Cretaceous (Late Columbian) and early Tertiary (Laramide) episodes (fig. 1). As table 1 shows, therefore, the correlation is not only one of timing but also of petrographic character and tectonic position of the plutons (Rodrick and others, 1967; Hutchison, 1970). Table 1 shows also the essential similarity of the corresponding belts in the Sierra Nevada and Great Basin region of the USA and in Japan (see below). It appears that the early plutonism in all regions, during the generative

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<th>Table 1</th>
<th>Plutonism of West Cordilleran Eutectonic Belts*</th>
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<td>Canada m.y.</td>
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<td>Generative phase preserved on east margins</td>
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<td>Early orogenic phase on east and west margins</td>
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* Sources of date: Chile: Farrar and others, 1970; Quirt and others, 1971
  Canada: Douglas and others, 1970; Hutchison, 1970
  USA: Evernden and Kistler, 1970; Livingstone, Mauger, and Damon, 1968; Armstrong and others, 1969; McKee, Noble, and Silberman, 1970
  Japan: Kawano and Ueda, 1967.

** Plutonism giving dates in the range 143 to 110 m.y. occurs in the Omineca crystalline belt to the east of the Mesozoic belt.

*** Suspect single determination on altered granite.

**** Early Tertiary activity with porphyry copper development also occurs west of the main volcano-plutonic complex in Vancouver Island (Carson, 1969).
and geosynclinal stages, was relatively widespread and is now preserved on both margins of the belts. The plutonism became restricted to narrow linear belts and migrated away from the ocean during the orogenic stage from late Jurassic to late Cretaceous. The change from geosynclinal to orogenic stage may be marked in the USA by the unique high-grade blueschist metamorphic event in the Franciscan terrain dated at 150 m.y. by Coleman and Lanphere (1971). Suppe and Armstrong (1972) have shown that the range of K-Ar dates for the Franciscan as a whole (150-70 m.y.) is identical to the period of extensive magmatism in the batholith belt. The early Tertiary post-orogenic plutonism and volcanism shows further eastward migration in Canada, the USA, and Chile. There is no evidence that the trench and subduction zone suffered a similar eastward migration in all these areas, although it may have done so in Chile (Rutland, 1971). The evolutionary change represented by the eastward migration may, however, be due to a progressive reduction in dip of the subduction zone in all areas, or it may be related to the history of vertical movements in the orogenic belt. It is notable that in Australia, the mid-Paleozoic plutonism shows a similar migration away from the ocean between Silurian-Devonian and Devonian-Carboniferous, although the three main plutonic belts show much larger migrations in the opposite direction (see below).

2A(2) The Paleozoic Belt.—The Paleozoic belt is much more variable in detail than the Mesozoic, although in general it is a miogeosynclinal or miogeoclinal belt dating from Late Precambrian. It is suggested here, however, that the fold belt of the Purcell anticlinorium and Main Ranges of the Rocky Mountains in Canada correspond stratotectonically to the East Andean belt of Bolivia. They are belts of similar lithology and age and with similar tectonic position on the continental scale. Morphotectonically, however, they are different. Folding has been of different character and timing in the two belts, the Main Ranges showing overturned folds and listric thrusts, whereas the East Andean belt is characterized by upright folds and steep faults. There is no direct counterpart of the Omineca crystalline belt with its extensive Mesozoic plutonism in Bolivia, but this belt has very variable expression in Canada so that the northern Rocky and Cassiar mountains provide a closer analogy to Bolivia. The Frontal Cordillera of Argentina does appear to provide an analogue of the Omineca belt, and this may extend northward beneath the Puna of Bolivia. Both the Omineca and Frontal Cordillera belts represent plutonically active geanticlinal belts between the Paleozoic “miogeosynclinal” areas to the east and the Mesozoic “eugosynclinal” areas to the west. Nevertheless, overall there has clearly been greater plutonism and mobility in Canada than in Bolivia. The Columbian orogeny in Canada affected the whole of the present Mesozoic belt (the Insular, Coast Mountain, and Intermontane belts) and also intensely affected the Ominecan crystalline belt. In Chile where the Mesozoic trough had been limited to the present Mesozoic belt, the orogenic
activity was also more limited. There was important tectonism at the end of the Jurassic, but it was concentrated in the Coast Range belt and had only small effects on the east margin of the Mesozoic belt and in Bolivia. Orogenic activity affected the remainder of the eutectonic Mesozoic belt during the Cretaceous, but important folding did not occur in the miotectonic Paleozoic belt until early Tertiary.

The eastern edge of the folded Paleozoic belt in Canada corresponds both stratotectonically to the eastern limit of the late Precambrian Paleozoic miogeocline and morphotectonically to the margin between Laramide mobile belt and platform. Uplift along this line was also important during and after the formation of the Upper Cretaceous exogeosyncline (King, 1969), although the western margin of the latter was apparently roughly parallel and further west (Gilluly, 1963). The Front Range and Foothills belt of Canada corresponds closely to the Sub-Andean belt of Bolivia both stratotectonically and morphotectonically, and in this case the style of deformation is also similar. Deformation was probably intermittent in both belts, but in Canada the main deformation at the eastern margin is regarded as Late Laramide (Eocene), whereas in Bolivia it was apparently in the late Miocene and Pliocene. Again the different timing of fold deformation obscures a more fundamental similarity in tectonic setting, age, and lithology of rock successions and tectonic style. The difference of timing of folding may, in any case, not be as definite as at first sight appears. Minor folding certainly occurred at various times in the Sub-Andean belt to produce local unconformities, and the main folding in the Paleozoic Eastern Andean belt was early Tertiary as in Canada.

Thus it appears that the Canadian and South American Cordillera have very similar stratotectonic and morphotectonic development in spite of variations in timing and intensity of fold phases. In a general way, the Mesozoic belt in both the Andes and Canada shows the greater effects of the late Jurassic-early Cretaceous (Columbian) orogeny, whereas the Paleozoic belt shows the greater effects of early Tertiary (Laramide) orogeny. The migration of intense orogenic activity from west to east took place earlier in Canada, and this correlates with the wider eastward spread of the Mesozoic geosyncline across the Paleozoic stratotectonic zones.

2B. Tertiary Evolution

The division between western Mesozoic and eastern Paleozoic belts is less pronounced in the Tertiary. Tertiary volcanic activity occurs in belts close to the boundary between the two provinces, but it may spread locally well into the Paleozoic belt and beyond, as in the United States, or it may be confined to the Mesozoic belt as in Canada or southern Chile. The volcanism may possibly, as suggested by Hamilton (1969), be an indication of underlying batholithic development.
A significant feature throughout the Cordillera is the relation of the volcanic piles to planation surfaces. Great erosion and the development of extensive planation surfaces preceded and accompanied major volcanism both in the early and middle Tertiary. This planation was accompanied by Tertiary basin development in, and east of, the eastern Paleozoic belt. Large quantities of clastic debris were not accumulated in the western Mesozoic belt, however, until the main epeirogenic (or cymatogenic) uplift phase from Late Miocene to the Present which produced the present morphology.

In Chile and Bolivia the early Tertiary planation surface appears to have extended with low relief right across the Andean system and was modified during uplift by several later phases (Hollingworth and Rutland, 1968; Sillitoe, Mortimer, and Clark. 1968). Early Tertiary volcanics were largely buried by the late Tertiary and Quaternary accumulations.

In Canada the early Tertiary calc-alkaline volcanics (45-50 m.y.) are “preserved in isolated structural basins and fault troughs, or occur as upland remnants lying with angular unconformity on older rocks” (Douglas and others, 1970, p. 477), and the flat-lying Plateau basalts dated at 10 to 13 m.y. were erupted onto “a gently undulating erosion surface that had a relief of 1,500 to 2,000 ft”. In the west in the Coast Mountains they now lie at elevations as high as 2,400 m “in response to differential uplift in the Pliocene” (p. 479). Souther (1970) suggests that the differences between early and late Tertiary volcanism and “the profound changes in tectonic style that occurred during late Mesozoic and early Tertiary times” are due to changes in the interaction of Pacific crust with the continental margin. Similar relations between planation surfaces and volcanism have long been recognized in the western United States (for example, Thornbury, 1965; Livingston, Mauger, and Damon, 1968; Carl, 1970).

The temporal and spatial relationships of volcanism and plutonism in the western United States have been clearly analyzed by Lipman, Prostka, and Christiansen (1971) who recognize major breaks at 80 to 70 m.y. and at about 40 m.y. McKee, Noble, and Silberman (1970) also draw attention to a mid-Miocene hiatus in volcanic activity in the Great Basin area. Lipman, Prostka, and Christiansen (1971) suggest that the early and middle Tertiary volcanism is related to shallow imbricate subduction zones in contrast to the inferred steeply dipping subduction zones of Cretaceous time and in contrast to the steep and spatially limited subduction zone revealed by the volcanism in the Cascade region in late Tertiary time. They note that their analysis “leaves unresolved problems such as the cause of the abrupt shift in subduction geometry at about the end of Cretaceous time, the persistence of the potentially unstable imbricate geometry over much of the Tertiary and the periodicity of subduction-related igneous activity with well-defined Laramide and middle Tertiary peaks” (p. 825).
The evolution of the Cordilleran belts in Chile, Canada, and the USA therefore appears to have been quite similar until mid-Tertiary times. There is a dramatic change throughout the eutectonic West Cordilleran belt from orogenic deformation and plutonism in the late Mesozoic to epeiric uplift, planation, and volcanism in the Tertiary; within the Tertiary the main morphogenetic phase has been late Miocene to the present. This seems to argue against explanations invoking local changes of plate interactions as suggested by Souther (1970), except to account for the striking variations in late Tertiary volcanism (Scholz, Barazangi, and Sbar, 1971).

Late Tertiary morphogenesis is well-known as a global phenomenon (for example, De Sitter, 1952; King, 1967; Dott, 1969), and the argument against local tectonic controls is further extended by the correlation between Cordilleran events and transgressions or regressions on the craton. Damon and Mauger (1966) and Evernden and Kistler (1970) postulate an overall transgression during the period of Mesozoic plutonism with minor regressions perhaps corresponding to individual plutonic or "orogenic" pulses and a major regression after the completion of plutonic activity about 80 m.y. ago. Damon and Mauger suggest that two Cenozoic deformational and plutonic episodes are coincident with two regressions. Frericks (1970) and Frericks and Shive (1971) also postulate two major elevations of the continental plates in the Tertiary on the basis of bathymetric data.

Global studies support the generalization of Mesozoic (especially Cretaceous) transgression and Tertiary regression and suggest that these are superimposed on an overall regression throughout the Phanerozoic (for example, Hallam, 1971a). The change in the Cordilleran belts at about the end of the Cretaceous is therefore one expression of a global event.

It may be noted here that this example illustrates that simple correlations between orogeny, which may mean various things, and sealevel changes in the cratons are inadequate. Thus Grasty (1967) supports older views of a correlation between orogeny and continental regression by appealing to reductions of continental area and therefore increases of oceanic area in collision orogeny. Johnson (1971, 1972) however argues for a "Haug Effect" in which orogeny correlates with transgression as a result of plate movement. The different correlations are partly the consequence of differences of time scale and definition of orogeny. On a time scale of $10^7$ to $10^8$ m.y. the Cretaceous is the main plutonic and orogenic period in Cordilleran eutectonic zones and is related to cratonic transgression; the Tertiary is the main orogenic period in Cordilleran miotectonic zones and is related to continental regression. On a shorter time scale it may be argued that individual orogenic or plutonic episodes relate to minor regressions superimposed on the broad Mesozoic transgression (Damon and Mauger, 1966; Evernden and Kistler, 1970). The interpretation of the correlations is discussed further below.
3. THE MESOZOIC-TERtiARY GEOTECTONIC CYCLE

It is evident from the foregoing summary that the eutectonic Cordilleran belts display an evolutionary development through the Mesozoic and Tertiary. Four main phases can be recognized:

4. Late Miocene to Present  Morphogenic phase  ) Epeirogeny,  
                                 ) cymatogeny, and  
                                 ) volcanicity  
3. Early to Middle Tertiary  Planation phase  
2. Late Jurassic to  Orogenic phase  
                    Late Cretaceous  with plutonism  ) Progressive  
1. Triassic to Middle Jurassic  Generative and  
                                 geosynclinal phase  
                                 transgression  

This cyclic development was broadly synchronous in places as far apart as Canada and the central Andes although local differences exist in the timing, intensity, and extent of deformation episodes as has been indicated above. The broad similarities exist in spite of differences in plate-tectonic setting which have been especially marked in the Tertiary. Thus the morphogenetic evolution of the Cordillera is broadly similar irrespective of whether the present continental margin is marked by an active Benioff zone as in Northern Chile, an inactive zone as in southern Chile, or a transform fault system as in much of North America (compare, Dott, 1969). The cyclic development in the west Pacific is sufficiently similar to command attention. There was undoubtedly a major reorganization of the tectonic pattern in Permo-Triassic time, just as in the east Pacific. Thus the main part of the Tasmanides of Australia was stabilized, and tectonic activity was concentrated in New Guinea and New Zealand. Sedimentation in the New Zealand geosyncline (fore-arc setting) was largely complete by the end of the Jurassic, and orogenic activity was concentrated in the Cretaceous (radiometric dates mainly 95-120 m.y.). Penepalination was widespread by upper Cretaceous times (Landis and Coombs, 1967). Again the main morphogenetic phase is late Miocene to the present, and again central volcanoes characterize the Quaternary. Even more striking is the similarity of the spatial and temporal distribution of plutonism in Japan (Kawara and Ueda, 1967) to that in the Cordilleran system. In both cases early Mesozoic plutonism is preserved on the continental side of the volcano-plutonic complex. Later Mesozoic plutonism switches to the oceanic side of the complex and then migrates away from the ocean. Matsuda, Nakamura, and Sugimura (1967) have described the late Miocene to present emergence and vertical movements. It is clear that the Neogene vertical movements are not simply a consequence of the shift of the island arc system. In Hokkaido in particular the Neogene uplift and fold axes both had nearly meridional trends, roughly at right angles to the trend of the Quaternary volcanoes and the Kurile arc, but parallel to the older arc trends. In Honshu too the broad pattern of uplift can be regarded as controlled by the older trends, albeit modified in detail by the younger arc system. It is therefore in-
ferred that the morphogenesis is an evolutionary stage, largely independent of the shift of the volcanic arcs.

An important consequence of this conclusion is that the present tectonic pattern cannot be regarded as a close model for tectonic conditions during the Mesozoic. The active central volcanoes of the circum-Pacific region are the expression of volcanicity in the particular tectonic context of epeirogenic or cymatogenic uplift after planation in the early Tertiary. Thus although analogues of the present arc-trench couples clearly existed, they may have had substantially different characteristics. It therefore seems inappropriate to regard the present epeirogenic volcanism of the Chilean Andes as a model for the orogenic Mesozoic plutonism of the Sierra Nevada as postulated by Hamilton (1969a). The two regions had very similar development in Mesozoic and early Tertiary times, the acid volcanism and minor plutonism east of the main plutonic belt being a notable feature in both cases. They differ mainly in their Neogene tectonic development as a result of the development of a transform continental margin in California.

The similarity of the timing and spatial relationships of plutonism in North America, South America, and Japan surely demands a common explanation. Thus the North American plutonism can hardly be explained in terms of the North American margin moving northwestward “onto and across a Mesozoic feature that had characteristics like present-day oceanic rises” (Kistler, Evernden, and Shaw, 1971, p. 853), since similar plate relationships did not occur in the other areas. There must have been a common cause for the generation of the magmatic zones in the continental margins independent of local plate relationships.

The general tendency for orogenic activity to migrate from eutectonic to miotectonic zones during the progress of the cycle should also be emphasized (Aubouin, 1965). The change of location is accompanied by a qualitative change in orogenic activity. The main Mesozoic orogenies (Columbian and Nevadan) are internal or eutectonic orogenies involving break-up of the basement structure and extensive plutonism; the Tertiary orogenies (Laramide and younger folding in sub-Andean belt) on the other hand are external or miotectonic episodes characterized by thin-skinned tectonics and listric thrusts; the basement is affected only in relatively narrow zones.

It appears therefore that a similar sequence of events has occurred on both sides of the Pacific in spite of the fact that the shifts of the active margins were quite different. In the west Pacific, marginal seas and island arcs were developed (Karig, 1971a and b) while, in the east Pacific, transform margins were developed in some places (Atwater, 1970), and the Benioff zone apparently encroached on the continents in others (Rutland, 1971).

The cycle was initiated by the tectonic reorganization of Perm-Triassic times which heralded the major continental transgression of the Mesozoic. Major plutonism came to an end on both sides of the Pacific
about 80 m.y. ago, and this coincided with the beginning of a major continental regression. The main morphogenic phase has been from the Miocene to the present (see also Dott, 1969). A broad correlation with events in the oceans is evident. The Permo-Triassic period marks the beginning of the break-up of Gondwanaland, and most of the spreading system was developed by 80 m.y. ago. Thus the major continental transgression and associated plutonic activity correlate with the development of the spreading system. It can readily be argued that the progressive increase in the volume of spreading ridges is directly responsible for the continental transgression (Armstrong, 1969; Valentine and Moores, 1970; Johnson, 1971). However, there seems little reason to suppose that ridge volume has decreased substantially or progressively to account for the regression of the last 80 m.y. Indeed, this is precisely the period for which approximately constant rate spreading is indicated by the magnetic anomaly patterns, and major changes of spreading pattern and activity occurred about 80 m.y. ago. Valentine and Moores (1970) suggest that post-Cretaceous sealevel changes may have involved such events as movements on the “Darwin Rise”, suturing and continental underthrusting in the Alpine-Himalayan belt, and the well-known effect of ice and snow storage. But these factors do not account for a simultaneous change in the nature of Cordilleran orogeny.

It may be, as has been suggested (Coney, 1971), that the change in spreading pattern is responsible for the dramatic change in the Cordilleran system at about 80 m.y. But it appears to this writer that changes in spreading pattern and rate are more likely to induce synchronous quantitative rather than qualitative responses. The cessation of major plutonism and the shift of tectonic activity from the eutectonic to the miotectonic zones appears to be too fundamental a change to be accounted for by a change in the direction of motion of North America from northwesterly to southwesterly (Coney, 1972), especially when a corresponding change is observed in Japan and New Zealand. A change of geometry from steep to shallow and imbricate subduction zones may also appear to meet the case locally (Lipman, Prostka, and Christiansen, 1971, 1972), but the postulated change in geometry then requires explanation.

This change in tectonic character could be related perhaps to a world-wide change in the rate of ocean-floor spreading combined with a change in the nature of plate interaction along the Pacific margins. It might be postulated for example that Pacific spreading was much more rapid in the Mesozoic, but it is difficult to accept that rates of subduction were much more rapid than in the Tertiary, when the Atlantic spreading system reached its maximum development. Alternatively it is possible that before 80 m.y. the Cordilleran continental margins and Pacific ocean plates may have been much more closely coupled to each other and the underlying mantle (compare Shackleton, 1969, p. 6). The plutonism in the continental margins may then have facilitated the uncoupling of
the oceanic and continental plates to allow the rapid continental drift that ensued. The metamorphic belts now exposed along the continental margins (Franciscan of California, Sanbagawa and Shimoto belts of Japan) would then be regarded as having been formed prior to the complete uncoupling.

Another possibility is that the major continental transgression and plutonism prior to 80 m.y. and the major regression subsequently are controlled partly by direct continental expressions of a global thermal cycle. If the apparently eustatic changes of sealevel on the continents are the consequence of cyclic epeirogenic movements of the ocean rises, it is unlikely that the continents would be free of similar epeirogenic movements or other thermal effects. The change in spreading pattern and rate in the oceans at about 80 m.y. might therefore be regarded as a separate response to the global cycle, not itself the cause of the changes in the continental margins. Similarly, the morphogenic phase of the last 20 to 25 m.y. might be a separate response to the Earth's thermal cycle rather than a consequence of a change in spreading rate or pattern. It is notable that this latter feature is one of several similarities between the supposed collision orogenies and Cordilleran orogenies (for example, Trümpy, 1960, esp. p. 897-898) which are not predicted by the simple plate-tectonic models.

Frericks and Shive (1971) attempt to show a correlation between world-wide epeirogenic movements and magnetic discontinuities on the ocean floor between anomalies 3 and 5 and anomalies 21 and 23 (dated at about 10 m.y. and 55 m.y. on the Heirtzler and others, 1968, timescale). They, therefore, suggest that “the same basic driving force, episodic in nature, is responsible for these effects”. They suggest that the magnetic discontinuities represent lapses in spreading, and therefore that epeirogenic uplift corresponds with renewed spreading, which may or may not be in the same direction, but they do not comment further on the mechanism by which lapses in horizontal plate movements are related to vertical movements. It should be noted, however, that renewed spreading after a lapse would lead to renewed growth of the mid-ocean ridges, and this by itself should lead to continental transgression. Frericks and Shive point out that in fact the reverse happened: uplift of the mid-ocean ridges (Hsu and Andrews, 1970) occurred in the late Miocene at the same time as a period of continental uplift (Frericks, 1970) and regression. This is the same time also as the morphogenesis of the Cordilleran and Alpine-Himalayan systems. It would appear to follow that growth of the ridges must have been accompanied by an increase in the area or depth of the ocean basins in order to avoid continental transgression.

Kistler, Evernden, and Shaw (1971) and Shaw, Kistler, and Evernden (1971) have developed a model in which 30 m.y. and 200 m.y. thermal cycles are the consequence of the dissipation of the energy of Earth tides. They suggest (Shaw, Kistler, and Evernden, p. 870) that “Epeiro-
geny represents a cyclical variation of heat production in the mantle coupled with cyclical decay of consequent thermal disturbances, the cycles having a period of about 200 m.y.". The operation of such a thermal cycle on the mid-ocean ridges might account for the observed change in sediment thickness (Ewing and Ewing, 1967) without recourse to a lapse in spreading as postulated by Frericks and Shive (1971). A possible cyclic development of mantle plumes has also been recognized (Vogt and others, 1971).

The evidence from epeirogenic movements of spreading ridges, continents, and Cordilleran belts in the late Tertiary therefore seems to favor control by a global thermal cycle other than by changes in spreading rates, and this control may well be extended to other aspects of the Cordilleran geotectonic cycle. Only careful comparative studies will show how far global effects of the thermal cycle can be separated from local effects of variations of plate interactions.

4. PRE-MESOZOIC EVOLUTION

Paleozoic rocks are exposed mainly in the miotectonic zones. In the eutectonic zones they are largely covered by Mesozoic and Tertiary rocks, so that interpretation of the nature of the continental margin during the Paleozoic is based on very limited evidence. The role allocated to lateral continental accretion during the Paleozoic is of critical importance to the interpretation. The fact that Mesozoic arc-trench complexes in the East Pacific lie on top of rather than oceanward of their possible Paleozoic precursors clearly implies that lateral accretion during the Mesozoic and Tertiary has been small.

At least four kinds of lateral accretion are envisaged:

1. **Fore-arc accretion.**—Hamilton (1969b, fig. 5, p. 2425) suggests that the continental crust is built oceanward by the tectonic addition of oceanic materials, thus displacing the Benioff zone westward.

2. **Back-arc accretion.**—Marginal seas behind island arcs may become filled with sediments and subsequently become welded to the continent (Dewey and Horsfield, 1970).

3. **Micro-continent accretion.**—Hamilton (1969b, p. 2412) also envisages that island arcs or micro-continents may be swept in on the downgoing plate and welded to the continental margin.

4. **Magmatic accretion.**—Addition of magmatic materials generated from the subduction zone or the overlying mantle (for example, Taylor, 1967) might convert areas of oceanic crust, trapped behind trenches, into continental crust.

Brief comments on the proposed mechanisms follow.

In the case of fore-arc accretion, continuous growth of the continental crust is indicated, the resulting crust becoming progressively younger oceanward. The Franciscan of California provides the type example. Hamilton claims (1969b, p. 2414) that no continental basement rock was ever present below the western Cretaceous rocks of the Great Valley.
sequence or below the Franciscan Formation. The geophysical evidence on this point is inconclusive (Thompson and Talwani, 1964). Bailey, Irwin, and Jones (1964) and Ernst (1970) place the limit of continental crust at the west margin of the Great Valley sequence. In Japan, the Sanbagawa and Shimanto terrains are generally believed to have been formed on a thin continental crust. Lateral continental accretion is therefore undoubtedly plausible but is not perhaps an essential feature of the models.

It is likely, as current models accept, that initially the plate margin and the continental margin coincide, and that during subduction some oceanic sediments and igneous rock may be tectonically transferred from the lower to the upper plate. If the Benioff zone is not displaced oceanward, however, these oceanic materials may well be thrust on top of the marginal continental crust where they may become involved in thrust faults (“unsuccessful” subduction zones) parallel to the active subduction zone. The appearance of these rocks at the surface in response to uplift would not then demonstrate continental accretion. Even if the accretionary view of the Franciscan is accepted, however, it must be recognized that this tectonic element is generally absent on the east Pacific margin. Its exposure in California is apparently a consequence of the interaction between the continental margin and the East Pacific rise on the San Andreas transform fault system (Atwater, 1970). Elsewhere, as in northern Chile, the evidence may favor subduction of marginal continental crust rather than accretion (Rutland, 1971).

The evidence for lateral accretion in the Paleozoic is even less clear, because most of the critical evidence is buried by the Mesozoic arc-trench complexes and because the Paleozoic stratotectonic zones may not be parallel to the Mesozoic. Thus in the southwest USA, the boundaries of the Paleozoic miogeosyncline with both the eugeosyncline and the craton run southwestward into California so that the Paleozoic stratotectonic zones appear to be truncated by the Mesozoic Sierra Nevada system (Hamilton and Myers, 1966; Hamilton, 1969b). Precambrian basement rocks extend along the Texas transverse zone as far west as the Death Valley area (for example, King, 1969, fig. 10). Burchfiel and Davis (1971) suggest, therefore, that “part of the Late Paleozoic North American continent was truncated by faulting and removed by drift before the onset of Early Mesozoic underthrusting along the modified continental margin”.

Burchfiel and Davis (1972) consider that the boundary between eugeosynclinal and miogeosynclinal facies in Nevada corresponds approximately to the edge of the Late Precambrian-Early Paleozoic continent. They therefore are led to postulate large lateral continental accre-

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3 These same authors (1972) recognize that rifting or transform faulting could be responsible and prefer the former. The presence of an orogeny similar to the Antler in Central America suggests, however, that the Paleozoic tectonic zones more probably suffer a sharp change in trend toward the southeast (Roberts, 1972) or are displaced in the same direction by transform faulting.
tion at the end of the Paleozoic (Sonoma orogeny) but none for the mid-Paleozoic Antler orogeny.

In a similar way the Omineca crystalline belt in Canada is regarded by Monger and others (1972) as forming the western limit of Precambrian continental crust in Canada. The latter authors suggest that the Intermontane belt is floored by oceanic crust, but they recognize that this fore-arc accretion is an inadequate mechanism by itself. The Mesozoic volcano-plutonic complex of the Coast Mountains includes Lower Paleozoic schist and plutonic basement rocks and Monger and others (1972) argue therefore that the Coast Mountains belt is "allochthonous"—presumably an island arc or micro-continent which has been swept in against the continent by the subduction process. The occurrence of ultramafic intrusions, ophiolitic association, and blue schists inland of the Coast Mountains belt is held to support this interpretation.

It should be noted perhaps that the supposed actualistic basis for the hypothesis of microcontinent accretion is now discounted. The hypothesis was originally based on the idea that the marginal seas in the West Pacific might be closing (Hamilton, 1969b; Dewey and Bird, 1970), but Karig (1970, 1971a and b) has developed a model to account for such behind-arc basins by extensional processes. Admittedly, however, subsequent closure of such basins can also be envisaged (Karig, 1972).

In contrast to the Canadian interpretation, older Precambrian rocks occur west of the main Andean batholith in Southern Peru and are held by Cobb and Pitcher (1972a and b) to provide evidence that the Mesozoic Andean geosyncline was ensialic. No blue-schist belt or occurrences of ultramafic intrusions have been recognized here.

As has been pointed out above, the Intermontane belt of Canada is analogous to the West Andean geosyncline, and the older basement rocks commonly occur in association with the main batholithic belt on the east side of the Pacific. It seems unlikely that these older basement rocks are generally allochthonous with respect to the adjacent continents. Alternatively, therefore, the Intermontane belt and its analogues can be regarded simply as back-arc basins. It is possible that during extensional episodes the arcs became separated from their parent continents by marginal seas floored by oceanic crust, but there are reasons for believing that such marginal basins did not develop in the East Pacific margins (see below). In this case the lines regarded by Burchfiel and Davis (1972) and Souther (1972) as the western limits of Precambrian crust can be interpreted instead as the eastern limit of the tectonic effects of the arc-trench complex superposed on thin continental crust. Similarly the Antler and Golconda thrust belts can be regarded as thrusting between the arc-trench complex and the miotectonic zone, both being on continental crust. It then follows that such Paleozoic arc-trench complexes as existed were virtually coincident with the Mesozoic, and the burial of the former by the latter is readily understood. Conversely, if large continental accretion has occurred, as postulated by Burchfiel and
Davis (1972), it is difficult to understand why extensive tracts of the Paleozoic arc-trench complexes are not preserved between the Mesozoic arc-trench complexes and the miotectonic zones.

Thus the hypothesis of extensive lateral continental accretion on the American Cordillera during the Paleozoic appears to be weak. In Peru, moreover, it has been suggested (Cobbing and Pitcher, 1972b) that andesite volcanism did not begin until the Triassic, so that subduction may not have been active before then.

Even where older paired metamorphic belts do occur on the continental side of younger paired metamorphic belts the evidence for lateral continental accretion is equivocal. The Hida and Sangun belts, where metamorphism ceased in Triassic time, lie on the continental side of the Ryoke, Sanbagawa, and Shimanto belts (Miyashiro, 1967; Matsuda and Uyeda, 1971). However, Paleozoic sediments occur right across southwest Japan, and Miyashiro (1967) postulates a southerly source. Matsuda and Uyeda (1971) have studied the migration of the magmatic front between the paired belts, as an indication of the migration of the Benioff zone, and it appears that the front has migrated both toward and away from the continent at different times. There is little evidence of an overall lateral accretionary process, though thickening of the crust is inferred by Sugisaki and Tanaka (1971).

The fullest evidence for evaluation of the accretion hypothesis is likely to come from the Tasmanides of Australia where the Paleozoic belts are not obscured by the Mesozoic arc-trench complex as they are in the east Pacific. The accretionary hypothesis has been supported, in the context of plate tectonics, by Oversby (1971) and Solomon and Griffiths (1972).

The presence of fragments of exposed Precambrian crust in Tasmania and New Zealand precludes a simple fore-arc accretion hypothesis (Oversby, 1971) and, if the simplest plate-tectonic models are to be applied, apparently demands that micro-continents of older continental crust be alternately separated, rejoined, and separated again from Australia (Griffiths, 1971, Griffiths and Varne, 1972; Solomon and Griffiths, 1972). There can be little doubt that New Zealand was separated from Australia by the marginal basin of the Tasman Sea, but the date of development of this basin and the nature of the reassembly of the fragments are by no means clear. The reassembly of continental fragments is highly controversial even for passive continental margins (for example, for Madagascar), and the problems are much more severe on active margins. The postulated pre-Mesozoic separations and collisions of micro-continents are even more conjectural and, at present, unconvincing.

There are some reasons for believing that more elaborate models, which do not involve repeated separations and reassembly of micro-continents, may be required.

The Tasmanides of eastern Australia differ strongly from the east Pacific Cordilleran belts in the presence of well developed Paleozoic plu-
tonic belts (fig. 5). These decrease in age from west to east from the Kanmantoo belt (Cambro-Ordovician) to the main Lachlan belt (Siluro-Devonian) and the New England belt (Permian). The Mesozoic and Tertiary orogenic belts are now separated from the mainland in New Guinea and New Zealand. If the plutonic belts are considered to be closely related to subduction zones, then they also indicate lateral continental accretion. Both Oversby (1971) and Solomon and Griffiths (1972) suggest the presence of an extinct Cambrian trench near the eastern edge

Fig. 5. Morphotectonic zones of the Tasmanides of southeastern Australia. The boundary between the arc-trench complex and the miogeoclinal zone lies close to the eastern margin of the Lachlan belt. Note that the older Tertiary volcanicity is generally within the Paleozoic eutectonic zone. The Neogene Newer Basalts of Victoria, however, lie well to the west and are presumably related to fractures developed during the separation of Australia and Antarctica. Data from Tectonic Map of Australia and New Guinea, 1972.
of the Lachlan "geosyncline". Such a trench would need to lie west of the Heathcote line in Victoria (fig. 5), if the spilitic lavas and cherty sediments there are interpreted as representing Cambrian ocean floor of the oceanic plate (compare Dewey, 1971). However, it is difficult to interpret these Cambrian sediments as providing evidence that the Lachlan geosyncline was developed on oceanic crust, when it now appears to be underlain by normal continental crust. The alternative proposition that the chert-spilitite association was developed on thin continental crust which has been thickened by subsequent deformation (compare Trümpy, 1971) is here preferred. The evidence from Tasmania includes the presence of the Mt. Read calc-alkaline volcanics, interpreted as an island-arc, and of graywackes, shales, cherts, basalts, and relatively undeformed ultramafic volcanic complexes in the Dundas trough, interpreted as evidence for tensional development of new oceanic crust in a marginal sea. According to Solomon and Griffiths, the Tyennan Precambrian crustal block (fig. 5) which now lies east of the Mt. Read volcanics is supposed to have been carried into its present position on an oceanic plate that was consumed in a Benioff zone dipping westward beneath the Mt. Read arc. The whole zone of the Dundas trough and Mt. Read volcanics is only 30 or 40 km wide, and it seems unlikely to the writer that the phenomena imply subduction on the scale of that seen in the Mesozoic and Tertiary. Possibly all the features can be interpreted in a back-arc context, and a detailed discussion supporting this view has recently been supplied by Corbett, Banks, and Jago (1972).

In the Lower Paleozoic of mainland Australia, three main sedimentary volcanic facies can be recognized (Packham, 1969):

A. Most of the Lachlan geosyncline contains quartz-rich graywackes and graptolitic slates without lithic or feldspathic members. It can be compared with the miotectonic zones of the American Cordilleran system and was probably deposited on a relatively thin Precambrian crust. In the Ordovician a thin representative of this facies probably extended across the New England geosyncline (Nambucca Phyllites, Voisey, 1969, p. 230).

B. On the eastern side of the Lachlan belt, there is sporadic andesitic volcanism associated with pillowed basalts and with both limestones and graptolitic sediments in the Ordovician. The quartz-rich graywacke-slate association also occurs within and to the east of the volcanic belt. In the same general area Silurian and Devonian volcanics are generally of acid character and associated with shallow marine and terrestrial sediments (Packham, 1969).

C. In the New England geosyncline the Woolomin Reds (at least partly Silurian) display abundant basic lavas with cherts, jaspers, phyllites, and volcanogenic graywackes (Voisey, 1969). They have been interpreted as ocean-floor sediments (Oversby, 1971), but the coarser sediments do contain lithic fragments of phyllite, slate,
and siltstone indicating derivation from an older Paleozoic basement.

In the Upper Paleozoic, volcanogenic sediments of the Tamworth trough indicate the presence of a volcanic arc system in the region now occupied by the Sydney basin. Intermediate and acid volcanism spread into the Tamworth trough itself during the late Visean and Namurian (Campbell and others, 1969).

It does not appear that the New England Arch, where the New England batholith was intruded into Upper, and possibly Lower, Paleozoic rocks, was itself the site of a major volcanic arc.

It appears to the writer therefore that the evidence from the Tasmanides does not require large easterly movements of the Benioff zone during the Paleozoic. It can be suggested that a frontal arc began to develop as early as the Ordovician but was not well established until the Devonian and Carboniferous, when large quantities of volcanogenic debris were discharged into the Tamworth trough. The frontal arc was situated in the region of the Sydney Basin, and the New England Arch can be interpreted as a mid-slope basement high (Karig, 1970) which perhaps became the main frontal arc during the Permian.

Under this interpretation the various belts of granitic rocks were emplaced in different tectonic environments. The granites of the Kanmantoo belt were emplaced on the margin of the orogenic belt against the craton. The Siluro-Devonian intrusions of the east Lachlan belt were emplaced within and west of the main frontal arc, and the Permian batholith of New England was emplaced in the mid-slope basement high. The shift of tectonic activity to the New Zealand region prevented the New England belt from being covered by a Mesozoic arc-trench complex.

This interpretation also suggests that the various serpentine belts do not represent fossil subduction zones. It is possible that they mark the sites of incipient or actual marginal seas which opened and then closed again, but this seems unnecessary. The serpentine belts tend to run north-northwest oblique to the broader north-south stratotectonic trends, and they may be regarded alternatively only as marking major faults in the marginal continental crust (see for example, Ashley, and others, 1971). This more conservative interpretation is preferred here, and possibly ultramafic occurrences of the Intermontane belt of Canada, where there is a similar lack of true ophiolite sequences (Monger, 1972), can be similarly interpreted.

In summary, therefore, it has been argued that the presence of older basement complexes as a common feature of the eutectonic zones precludes fore-arc accretion as an important process in the growth of the continents and makes the process of accretion of exotic micro-continents implausible. Large-scale accretion could still be accomplished by back-arc accretion of marginal basins. Ultramafic belts may represent the sites of marginal basins that have been completely closed, in which case no lateral accretion ultimately occurs. If the marginal basins are not com-
pletely closed, lateral accretion would result. However, in this case some evidence should be preserved of their oceanic crustal character. This has not been demonstrated, and it is therefore concluded that lateral accretion has probably not been responsible for significant increases in continental area in Cordilleran orogenic belts.

A more general implication of this interpretation is that the Paleozoic belts are not close analogues of the Mesozoic but represent an earlier stage of the main chelogenic cycle (Sutton, 1963). Broadly the Pacific margin appears to have been inactive in the Lower Paleozoic. Arc-trench complexes became established in the Upper Paleozoic, but the calc-alkaline volcanic activity does not compare with that of the Mesozoic. The tectonic reorganization that took place around the Pacific in Permo-Triassic times is clearly of the greatest importance. A major change in the ocean-floor spreading system must have taken place at that time (compare Roberts, 1972; Cobbing and Pitcher, 1972b).

The nature of that change is not clear at present. It may be noted, however, that the Paleozoic was a time when oceanic areas were closing in the Appalachian-Caledonian and Ural mountain systems, so that the Pacific ocean was probably growing larger, and subduction at its margins was perhaps limited. The Permo-Triassic however marks the beginning of the process of opening of the Atlantic-Arctic oceans, and since that time the Pacific has been growing smaller. It must have occupied about half the area of the Earth's surface at the end of the Cretaceous, and subsequently its circumference has been decreasing.

The correlations between events in the Cordilleran orogenic belts with transgressions and regressions on the cratons can be extended to Paleozoic orogenies (Johnson, 1971), but differences are to be expected. The single cycle of distinctive stages in the Ridge and Valley Province of the Southern Appalachians (King, 1969, p. 11), for example, reflects the fact that the Taconic, Acadian, and Appalachian orogenies have differing characters. Paleozoic transgressions are probably not analogous to the Mesozoic transgressions which reflect continental fragmentation and dispersal (Sloss, 1963; Ham and Wilson, 1967; Durham and Murray, 1967; Veevers, 1971; Hallam, 1971b; Kent, 1972). Further analysis of the history of transgressions and regressions in relation to orogeny may well provide the clearest evidence of the nature of the long-term global cycle.

The tendency for the tectonic elements to migrate oceanward in the west Pacific and continentward in the east Pacific can perhaps be related to the asymmetry of the Pacific spreading system. Jurassic oceanic crust is still present adjacent to the Marianas arc whereas the East Pacific belts are in contact with oceanic crust of Paleogene age or younger. In North America the rise apparently came into contact with the active continental margin some 30 m.y. ago (Atwater, 1970).

This appears to imply that oceanic lithosphere consumption has in the past been much more rapid in the Cordilleran subduction zones than
in the island-arc zones. In terms of the Pacific Ocean, therefore, the North and South American plates have been advancing plates,\(^4\) consuming oceanic lithosphere faster than it was produced at the spreading rise, while the Asian plate has been retreating and consuming crust less rapidly. The reduction in area of the Pacific has certainly been made largely at the expense of plates east of the East Pacific rise, while the main Pacific plate west of the rise has probably increased in size. The ultimate control of the difference in motion of east and west Pacific margins relative to the spreading rise is presumably to be found in the Earth’s rotation. It appears that the lithosphere is tending to lag behind the underlying asthenosphere (compare Shaw, Kistler, and Evernden, 1971, p. 882).

It is proposed therefore that the distinctive characters of west Pacific and east Pacific active margins are related to the retreating character of the former and advancing character of the latter (compare Hyndman, 1972). Lateral continental accretion is possible but not proved in the west Pacific type, although oceanward migration of orogenic belts (Miyashiro, 1967), of plutonic activity (Evernden and Richards, 1962), and of island arcs (Karig, 1970) is indeed well established. Lateral continental accretion is unlikely in the east Pacific (Cordilleran) type, and subduction of continental crust may have occurred on a relatively small scale (Rutland, 1971). The migration of deformation and plutonism is in some places and at some times toward the continents (for example, fig. 3; and Farrar and others, 1970), and various phases of tectonic activity have been superposed on the same areas (for example Gilluly, 1968). The development of the Rocky Mountains well to the east of the earlier cratonic margin is a striking manifestation of this continentward migration.

This distinction of advancing and retreating active continental margins in terms of their motion relative to the plate-accreting margins therefore provides a further factor to be taken into account in the evaluation of ancient orogenic belts.

5. IMPLICATIONS FOR THE INTERPRETATION OF PRE-PHANEROZOIC OROGENIC BELTS

The proposition that pre-Phanerozoic orogenic belts can be interpreted in terms of Phanerozoic Cordilleran and collision models involves two major assumptions:

1. that ocean-floor spreading and subduction is the only driving force of Phanerozoic orogenies;

2. that the nature of the lithosphere and upper mantle has been sufficiently similar through geological time for similar tectonic processes to operate.

If the first assumption is valid, the conclusion that older orogenic belts are also related to ocean-floor spreading and subduction almost

\(^4\) Differences in the relative motion of North and South America are presumably a major factor in the tectonic development of the Central American region.
certainly follows. However, the possibility that some orogenic processes are controlled by a global thermal cycle, independently of spreading, as discussed above, reopens the possibility that some orogeny in the Precambrian was independent of ocean-floor spreading (Shackleton, 1969). Even so, it is difficult to escape the conclusion that ocean-floor spreading has played a similar role in earlier chelogenic cycles to that in the last cycle. Major plutonic episodes are likely to mark maxima of development of spreading systems just as the Cretaceous episode does. The close analogy between the Adelaidean-Phanerozoic and Nullaginian-Carpentarian cycles in Australia (Rutland, 1973) tends to confirm this view.

Differences between Precambrian and Phanerozoic tectonics have been widely recognized (for example, Sutton, 1967; Anhauser and others, 1969). Failure of the second assumption therefore seems likely, but this does not necessarily imply that ocean-floor spreading has not occurred. A more reasonable interpretation would be that ocean-floor spreading has had different expression in the different continental lithosphere of the Precambrian.

The interpretation of Precambrian belts by strict analogy with the Phanerozoic models also probably requires acceptance of continental accretion as an essential part of the model. If, as argued above, Cordilleran orogeny does not involve significant accretion, then plate tectonics provides no important mechanism for increasing continental area, while lateral compression and severe collision orogenies may reduce the area. Without continental accretion the zonation of progressively younger orogenic belts around Archaean nuclei cannot be interpreted in terms of successive Cordilleran-type orogenic belts unless the later belts were progressively narrower, and models of periodic cratonization of pre-existing granitic crust are more plausible (Sutton, 1967; Muehlberger, Denison, and Lidiak, 1967).

The plate-tectonic model also requires that Precambrian orogenic belts which have older rocks on both sides should be interpreted as collision orogenies which themselves incorporate at least one active margin of Cordilleran or island-arc type. Failure of either of the above assumptions would again allow alternative models to be reasserted (Shackleton, 1969), and there are good grounds for believing that intracratonic orogenies, as distinct from intercontinental collision orogenies, commonly occur in the Precambrian. One type of intracratonic belt characterized by granulite-facies metamorphism has been described as vesti-geosynclinal by Clifford (1969). The present writer has discussed the interpretation of apparently intracratonic orogenies in relation to plate tectonics elsewhere (Rutland, 1973).

CONCLUDING DISCUSSION

An attempt has been made to reassert the importance of the geotectonic cycle both for 200 and 1000 m.y. periods, and a preliminary attempt has been made to assess the significance of the cycles in terms of plate tectonics.
Analysis of the Cordilleran system in the context of plate tectonics suggests that the timing of fold episodes should be relegated in importance as a factor in classifying orogenic belts. More important are the major vertical movements of linear belts and the timing of plutonism and volcanism. Eutectonic (internal) and Miotectonic (external) orogenies differ in kind as well as in timing. The main phases of the orogenic cycle in the eutectonic Mesozoic belts are (1) geosynclinal, (2) orogenic with plutonism, (3) planation with volcanism, (4) morphogenic with volcanism. The timing of these phases is broadly similar in North and South America, and there also appear to be similarities with the west Pacific mobile belts.

Reorganizations of the stratotectonic pattern indicate reorganizations of the spreading and subduction pattern at about the end of the Paleozoic, the end of Cretaceous, and the middle of Tertiary times. These reorganizations, however, appear not to be the cause of the progressive changes in Cordilleran orogenic belts. Rather, they are themselves among the effects of the global thermal cycle.

The long-term cycle apparently began less than 850 m.y. ago in North America (Stewart, 1972), but it began earlier, perhaps as much as 1400 m.y. ago (Thomson, 1966), in Australia. The continental margins across which the miogeoclinal deposits were laid may have been Passive margins produced by rifting and drifting, in which case the Pacific Ocean was born at the beginning of the current chelogenic cycle. Such a hypothesis also implies, however, that other continental margins were active at this time and that collision orogenic belts were formed within the new continents Gondwanaland and Laurasia. This has not yet been demonstrated, although some belts in Central Asia (Zonenshain, 1971, fig. 3, p. 345) may allow this interpretation. Alternatively, it is possible that the Pacific is a much older ocean and that the Late Precambrian miogeoclinal deposits were laid down on inactive margins during a period when spreading was weak or inoperative.

The relative paucity of calc-alkaline volcanics suggests that spreading may have been weak throughout the Paleozoic, but the evidence is poor since the Paleozoic active margins are largely obscured by the Mesozoic. The Permo-Triassic tectonic transition is presumed to mark the beginning of active spreading and of contraction of the Pacific. Lateral continental accretion is considered not to be of major importance at any stage.

The interpretation of spreading activity depends greatly on the interpretation of Mesozoic calc-alkaline plutonism and volcanism. It is apparently widely assumed that this plutonic and volcanic activity is evidence of active subduction leading to the development of a mobile core (Dewey and Bird, 1970). Hamilton (1969a) has argued that the Quaternary volcanism of Chile provides a model for Mesozoic activity in the Sierra Nevada. It has been argued above, however, that the Tertiary activity in both North and South America is qualitatively different.
from the Mesozoic. The Mesozoic plutonism occurred in the eutectonic zones and was associated with world-wide transgression. The Tertiary volcanism tends to occur landward of the eutectonic zones in the east Pacific and oceanward in the west Pacific, but it is associated with the uplift of planation surfaces and with world-wide regression. These differences may be merely second-order effects of continuous spreading as implied by Dewey and Bird (1970), but if so it is remarkable that the tectonic transition occurs at about the same time on both sides of the Pacific and is therefore apparently independent of local spreading and subduction rates.

It is also remarkable that the plutonism in the eutectonic zones ceased at about the time the spreading system reached its maximum development, that is, before the main development of the new oceans. It has therefore been suggested above that the Mesozoic plutonism and metamorphic belts may mark a period of Pacific spreading when the uncoupling of the Pacific margins was incomplete. On this view the 80 m.y. tectonic transition marks the complete uncoupling of the Pacific margins associated with continental dispersal. During this dispersal the East Pacific margins became advancing margins and the West Pacific margins retrograding margins relative to the East Pacific rise. Consequently, the Tertiary volcanic zones tend to migrate eastward relative to the Mesozoic plutonic belts on both sides of the Pacific.

In terms of spreading, therefore, it is suggested that the long-term tectonic cycle is divided into three episodes: (1) pre-spreading, (2) active spreading without rapid drift, (3) active spreading with rapid drift. These episodes are regarded as a consequence of a global thermal cycle that has had effects in the continents independent of spreading. The most notable of these effects in the Cordilleran belts is the Neogene morphogenesis which appears to be independent of the migration of Tertiary strato-tectonic zones. It is one aspect of the world-wide regression and continental emergence in the Tertiary, a feature that apparently cannot be explained by a decrease of spreading rates and therefore of volumes of spreading ridges.

It seems likely that long-term cycles in the Precambrian can be explained by similar relationships to ocean-floor spreading. The higher heat flow and thinner lithosphere in the Precambrian, however, has probably caused different expressions of the thermal cycle in the continental crust. Concepts of progressive cratonization and of intracontinental orogeny are probably therefore plausible components of Precambrian plate tectonics.

The above conclusions are evidently tenuous. They are offered in the hope of stimulating further analysis of the differences of tectonic activity with time. It seems clear that the simple applications of the Neogene tectonic pattern to the past, on actualistic grounds, is unlikely to be rewarding in detail.
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