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CAUSES OF CRETACEOUS OSCILLATIONS OF SEA LEVEL IN WESTERN AND ARCTIC CANADA AND SOME GENERAL GEOTECTONIC IMPLICATIONS

J.A. JELETZKY

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CAUSES OF CRETACEOUS OSCILLATIONS OF SEA LEVEL IN WESTERN AND ARCTIC CANADA AND SOME GENERAL GEOTECTONIC IMPLICATIONS

Abstract

Refined biochronological studies revealed an almost complete lack of interbasinal correlation of Cretaceous transgressions and regressions in Western and Arctic Canada. A comparison with the literature data available indicates that the same is true of the Cretaceous transgressions and regressions the world over and indeed of all Phanerozoic transgressions and regressions on the global scale. These data contradict the presently fashionable hypothesis claiming that the Phanerozoic transgressions and regressions were caused largely or entirely by geologically instantaneous, world-wide eustatic oscillations of sea level. The popularity of this hypothesis appears to be caused by:

1. *Currently widespread neglect of the biochronological method of age determination coupled with an unjustified reliance on incomparably less precise and commonly unreliable physical methods of age determination (e.g. radiometry or magnetostratigraphy); and*
2. *The common lack of realization that many (?most) Phanerozoic tectonic movements (orogenic as well as epeirogenic) were very rapid events which lasted only from one to a few zonal moments in terms of the biochronological standard. These pulses occured very frequently and had local to regional (apparently never global) extent.*

As eustatic oscillations of sea level undoubtedly occurred in the past, the almost total absence of their record in Phanerozoic rocks must be due to the subsequent destruction (overprinting) by the tectonic movements. This is indicated by:

1. *The short duration and frequent occurrence of orogenic and epeirogenic pulses; and*
2. *The minor amplitude of eustatic oscillations as compared with that of tectonic pulses. The amplitudes of eustatic oscillations apparently averaged only 40 to 110 m and did not exceed 300 m (i.e. from -150 to +150 m). The estimated vertical amplitudes of minor tectonic movements ranged from 200 to 2000 m. The amplitudes of eustatic oscillations are, therefore, almost an order of magnitude less than those of the minor (let alone medium to large which have amplitudes of several to many thousands of metres) tectonic movements.*

Because of the overprinting, the effects of ancient eustatic oscillations may only be preserved either during infrequent tectonically quiescent intervals in the Phanerozoic history of the globe (e.g. the global Maastrichtian regression) or within such most stable tectonic elements of the continental crust as Precambrian shields and stable shelves.

Résumé

Des études biochronologiques approfondies ont indiqué qu'il n'y a presque pas de correspondance, d'un bassin de sédimentation à l'autre, entre les diverses transgressions et régressions qu'ont subies au Crétacé l'Ouest et l'Arctique canadiens. La littérature à ce sujet indique qu'il en est de même des transgressions et régressions du Crétacé à l'échelle globale, et en fait, de toutes celles qui ont eu lieu pendant le Phanérozoïque. Ces données sont en contracdiction avec l'hypothèse actuellement admise, suivant laquelle les transgressions et régressions du Phanérozoïque ont été en grande partie ou entièrement provoquées par des oscillations eustatiques globales du niveau marin, instantanées à l'échelle géologique. La popularité de cette hypothèse a été provoquée par la prédominance des attitudes suivantes:

1. *on néglige généralement de faire appel à des méthodes biochronologiques de datation, et on s'appuie inconsidérément sur des méthodes physiques de datation, beaucoup moins précises et ordinairement peu fiables (par exemple, la radiométrie ou la magnétostratigraphie); et*
2. *on ne se rend généralement pas compte qu'un grand nombre (ou la plupart?) des mouvements tectoniques du Phanérozoïque (qu'il s'agisse de mouvements orogéniques ou épirogéniques) se sont déroulés très rapidement, et à l'échelle biochronologique, se limitent a la durée d'une ou de quelques zones. Ces oscillations se sont produites très fréquemment, et ont eu une extension locale à regionale (apparemment, jamais globale).*

L'absence presque totale dans les roches du Phanérozoïques d'indices de mouvements eustatiques anciens, qui ont pourtant certainement eu lieu, est probablement due à la destruction de ces indices par superposition par des processus tectoniques. C'est ce que révèlent:

1. *la brièveté et la fréquence des épisodes orogéniques et épirogéniques susmentionnés, et*
2. *la faible amplitude des mouvements eustatiques, par rapport aux mouvements tectoniques. L'amplitude des oscillations eustatiques a varié entre seulement 40 et 110 m en moyenne, et n'a jamais dépassé 300 m (les oscillations du niveau ont varié entre -150 et 150 m). L'amplitude verticale estimée des mouvements tectoniques de faible envergure a varié entre 200 et 2000 m. Par conséquent, l'amplitude des oscillations eustatiques est presque dix fois inférieur à celle des mouvements tectoniques faibles (dans le cas des mouvements modérés ou forts, l'amplitude peut être de quelques ou de plusieurs milliers de mètres).*

En raison des effets de superposition (ou surimpression), les indices des anciennes oscillations eustatiques n'ont pu subsister que pendant quelques intervalles peu fréquents de calme tectonique, au cours de l'histoire phanérozoïque du Globe (par exemple, pendant la régression globale du Maastrichtien), ou dans des elements tectoniques les plus stables de la croûte continentale, tels que les boucliers précambriens et les plates-formes stables.

CAUSES OF CRETACEOUS OSCILLATIONS OF SEA LEVEL IN WESTERN AND ARCTIC CANADA AND SOME GENERAL GEOTECTONIC IMPLICATIONS

INTRODUCTION

The writer feels strongly that the extraordinary advances made in marine geology and geophysics during the last twenty-five years or so have been accompanied, unfortunately, by a marked neglect of some of the most fundamental aspects of continental geology. Furthermore, among some of the most enthusiastic recent workers concerned with marine geology and geophysics, there is a marked tendency to consider only those data about the relevant aspects of continental geology which fit the currently fashionable, but by no means proven, ideas regarding the fundamentals of their sciences and to disregard all other, older and recent, information which contradicts these ideas. One of the most prominent examples of such neglect of continental geology and of consciously or subconsciously biased treatment of available information is provided by the recent treatment of the problem of the relative importance of the so-called eustatic movements of sea level (Suess, 1906) versus the vertical tectonic movements of the major continental regions (Lyell, 1832) as the causes of large-scale transgressions and regressions of the geological past.

The recent adherents to the preponderance of eustatic movements as the cause of such transgressions and regressions tend to treat the continental masses as relatively inactive tectonic elements of the Earth's crust which were influenced by the much more pronounced tectonic events affecting oceanic blocks of the lithosphere. According to these workers (e.g. Brookfield, 1970; Hancock, 1975; Hallam, 1963, 1969, 1975; Jacoby, 1972; Hays and Pitman, III, 1973; Kauffman, 1973a, b; Valentine and Moores, 1970; Naidin, 1971; Pessagno, 1972; Rona, 1973, 1974; Russell, 1968), it is the latter events that were the primary cause of the allegedly world-wide transgressions and regressions which episodically affected the continental blocks throughout the geological history of the globe. The recent Symposium on Global Sea Level and Plate Tectonics through time, held during the 1973 Annual Meeting of the Geological Society of America, was, for example, dominated by this attitude. So far as the writer can remember, only Sloss (1973) and himself (in the discussion) protested against the idea of eustatic movements of the sea level being the primary cause of ancient transgressions and regressions and declared this idea to be an inadmissible oversimplification of the actually existing, extremely complex tectonic interaction known to exist between the continental and the oceanic blocks of the lithosphere. These protests were ignored generally by the rest of participants in the Symposium. Furthermore, the participants of the Symposium and most of the above-mentioned, recent adherents of the eustatic control hypothesis failed to consider, and even to acknowledge, all published evidence unfavourable to their ideas. For example, their publications and talks mention but rarely, let alone analyze fairly, Arkell's (1956, p. 632-642, Tables 27, 28) convincing demonstration of all then known Jurassic transgressions and regressions being decisively influenced by areally to interregionally restricted (never global!) diastrophic episodes, and his inevitable conclusion (Arkell, 1956, p. 641) that "There was no pulse of the earth". Nor do they mention, as a rule, Matsumoto's (1952, 1967) penetrating analysis of pronounced regional variation in timing of transgressions and regressions in the Circum-Pacific belt; Yanshin's (1973) irrefutable marshalling of the wealth of data opposed to the eustatic control of transgressions and regressions on the global scale; the arguments of Sloss (1963, 1972, 1976), and Sloss and Speed (1974) regarding the active role of vertical movements of cratonic blocks in controlling transgressions and regressions; and Jeletzky's (1971a, p. 75, 76; 1974a, p. 810; 1975, p. 14, 15) analysis of evidently tectonically caused regional variation of Cretaceous transgressions and regressions in Western and Arctic Canada. The citation of Matsumoto's (1967) paper by Hancock (1975, p. 103, expl. of Fig. 5) is one of rare exceptions known to the writer.

This paper is an attempt to counteract these attitudes of recent adherents of the eustatic control hypothesis. It has the following objectives:

a) To develop and to summarize the writer's ideas on the subject, which were derived primarily, but not exclusively, from a study of Cretaceous history of some sufficiently well known orogenic and intracratonic depositional basins of Western and Arctic Canada. Some of these ideas have been presented orally and published as an abstract (Jeletzky, 1974a, p. 810) whereas others were discussed more or less casually in connection with other related topics (e.g. Jeletzky, 1971a, p. 75, 76; 1975, p. 14, 15, 43-47, Figs. 17-22). The bulk of the evidence, however, is presented herein for the first time.

b) To compare the results obtained through the study of the Cretaceous basins of Western and Arctic Canada with other data available in the literature, in order to arrive at a more general conclusion concerning the relative roles played by eustatic movements of sea level and the contemporary orogenic and epeirogenic movements in determining the course of ancient transgressions and regressions within orogenic and intracratonic basins; and

c) To analyze some of the general causes of the present-day popularity of the hypothesis of world-wide eustatic movements of the sea being the primary cause of ancient transgressions and regressions in all intracontinental basins.

HISTORY OF CRETACEOUS OSCILLATIONS OF SEA LEVEL IN WESTERN AND ARCTIC CANADA

General remarks about basins studied

To find out whether or not the course of Cretaceous transgressions and regressions in Western and Arctic Canada has been determined by eustatic oscillations of sea level, the writer analyzed Cretaceous geological records of the following five principal depositional basins shown in Figures 1 and 2:

1. Tyaughton Trough of the mainland of western British Columbia as originally defined by Jeletzky and Tipper (1968, p. 3-5). As presently known (Fig. 1), this trough is restricted to southwestern British Columbia. The northernmost known segment of the trough comprises parts of Mount Waddington, Taseko Lakes, Pemberton, and Ashcroft map-areas. To the south, the trough extends all the way to the International Boundary and for some distance into the State of Washington. In the southernmost part of British Columbia, the trough includes the area confined between the western shore of Harrison Lake in the west and the eastern side of Manning Park synclinorium in the east. The Canadian part of the trough, at least, was transformed into an elevated source area (a youthful tectonic land) early in Late Cretaceous (?Turonian) time and, apparently, did not accumulate any sediment thereafter until the end of the Cretaceous (Fig. 2).

2. Insular Trough of the Insular Belt of British Columbia as originally defined by Sutherland Brown (1966, p. 83). Throughout Early Cretaceous and in early Late Cretaceous, the trough comprised only western and northern parts of Vancouver Island and most or all of Queen Charlotte Islands (see Fig. 1). However, in the late Late Cretaceous (beginning with the late Santonian), the southern part of the

trough migrated eastward and became structurally and paleogeographically separated from the northern part. The resulting structurally independent residual basins of the Insular Trough are disignated as (1) the Queen Charlotte Trough, and (2) the Georgia Basin (Fig. 2). Contrary to the previously held ideas (Matthews, 1958; Jeletzky, 1971a, p. 63, Fig. 17), the Late Cretaceous Georgia Basin apparently did not include any part of the British Columbia mainland.

3. Sverdrup Basin of the Canadian Arctic Archipelago as defined by Tozer and Thorsteinsson (in Douglas et al., 1970, p. 550, Fig. X-1). Unlike Tyaughton and Insular troughs, the Sverdrup Basin persisted as a subsiding depositional basin until the end of the Cretaceous.

4. Richardson Mountains-Porcupine Plain Trough as defined by Jeletzky (1975, p. 2-3, Fig. 1). As now known, this Cretaceous trough comprises most of northern and west-central Yukon and adjacent parts of northwestern District of Mackenzie, N.W.T. North therefrom it is inferred to extend for some distance beneath the Yukon Coastal Plain and Beaufort Sea and then to abut against the Arctic Platform. To the south, the trough is inferred to join and to be structurally contiguous with the Eastern Cordilleran Orogenic Belt (=Columbian Orogen of Gabrielse and Wheeler, in Price et al, 1972, p. 2, 3, Fig. 1) in Berriasian to Aptian time. The Richardson Mountains-Porcupine Plain Trough was transformed into an intracratonic basin by Aptian and mid- to late Albian orogenic movements. The basin (see Fig. 2) persisted at least until the end of the Cretaceous on the Yukon north slope and adjacent parts of Porcupine Plain.

5. Alberta and Liard troughs of the Foothills Belt of Alberta, northeastern British Columbia, and adjacent parts of District of Mackenzie. For the sake of simplicity, but contrary to Stott's (in Douglas et al., 1970, p. 449, 456, 457, Figs. VIII-37, VIII-41, VIII-42) original definition, these two troughs are treated herein as a continuous northwest-trending trough which existed through the Cretaceous (Figs. 1, 2).

The Tyaughton and Insular troughs are successor troughs, in the sense of King (1966) and Eisbacher (1974, p. 274), of the Western Cordilleran Orogenic Belt of British Columbia, which was recently re-named the Pacific Orogen by Gabrielse and Wheeler (in Price et al., 1972, p. 2, 3, Fig. 1).

The Sverdrup Basin, including its Early and Late Cretaceous generations, is a successor basin on the early to mid-Paleozoic Innuitian Orogenic System as defined by Trettin et al. (1972, p. 84, 85, Figs. 1, 11, 12). However, as it wil be shown below, it behaved like a moderately mobile intracratonic trough through most of the Cretaceous.

The Berriasian to late Aptian generation of the Richardson Mountains-Porcupine Plain intracratonic trough shown in Figure 1 is interpreted as a Mesozoic aulacogene of the Eastern Cordilleran Orogenic Belt (=Columbia Orogen of Wheeler et al., in Price et al, 1972, p. 2, 3, Fig. 1) following Jeletzky (1975, p. 2, 3). This aulacogene was closed by the Aptian orogenic movements and transformed first into an Early Albian western intracratonic (foredeep) flysch trough coupled with an Early Albian shelf basin in the east and then into a gradually shrinking and northward retreating Late Cretaceous intracratonic basin (see Fig. 2).

The Alberta-Liard Trough, finally, is interpreted as the westernmost part of Western Canada Basin immediately flanking the Eastern Cordilleran Belt to the west. Stott's interpretation (in Douglas et al., 1970, p. 444, 448, 455, Fig. VIII-36, VIII-37) of Jurassic, late Early and Late Cretaceous generations of Alberta and Liard troughs as independent orogenic troughs confined between the Columbian Orogen and the Rocky Mountain Exogeosyncline is unacceptable to the writer because of general considerations fully discussed elsewhere (Jeletzky, 1963, p. 58-61).

Geological background data and methods used

The currently prevalent practice either to segregate the presentation of litho- and biofacies data from transgression-regression graphs inferred therefrom (e.g. Hancock, 1975, p. 104, Table I; Figs. 1-5), or to publish only the oscillation graphs proper without any supporting evidence (e.g. Russell, 1968, Fig. 2; Grasty, 1967, Fig. 3; Kauffman, 1973a, Figs. 6-10) is considered to be unfortunate. It deprives even the best informed reader of an immediate insight into the factual basis and hence the reliability of inferences made. It was decided, therefore, following the example of Matsumoto (1952, Figs. 2-5, Table I), to provide a summary of biochronologically dated and arranged Cretaceous history of each of the depositional basins mentioned above beside the sequences of oscillations of sea level inferred for these basins (see Figs. 3-7). This history, including formational nomenclature, had to be generalized considerably and the paleontological zones were omitted in each case. Nevertheless, the summaries provide the outlines of Cretaceous environmental history of the basins concerned and elucidate the factual data underlying the inferred sequences of transgressions and regressions within them.

A great deal of factual information incorporated in Figures 3 to 7 is self-explanatory. However, the caption for each figure includes references to the most important publications containing those basic data utilized in its compilation most of which are neither recapitulated nor summarized in the text of this paper. Many of such basic data dealing with the paleoenvironmental interpretation and biochronological dating of Cretaceous rock units of the basins studied were summarized in Jeletzky's (1971a) report on marine Cretaceous biotic provinces and paleogeography of Western and Arctic Canada, and that report should be used in conjunction with this paper. This report, however, does not include some important additions ot our knowledge of paleoenvironmental, biochronological, and depositional-structural interpretation of these Cretaceous rocks published after the end of 1969. This more recent information, which necessiated a number of significant changes in the interpretation of the rock records of the basins concerned, and hence in their transgression-regression patterns, can be found in other publications cited in the captions of Figures 3-7. The most important of these data are briefly summarized below for the benefit of average readers.

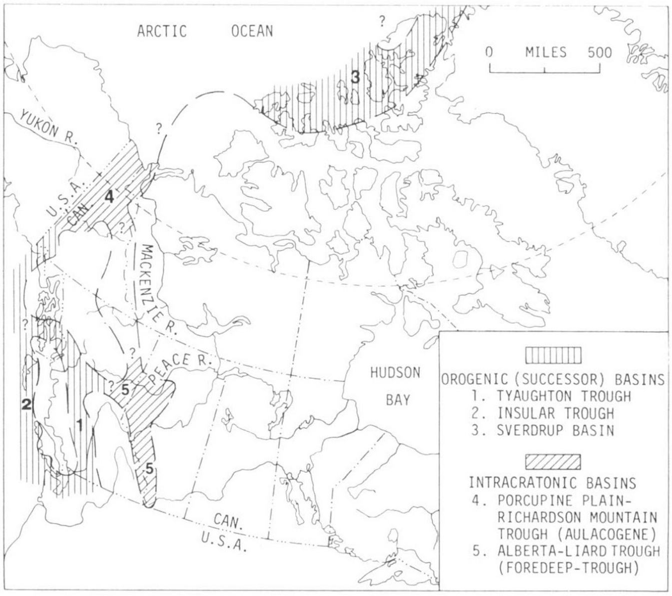

Figure 1. Principal Early Cretaceous marine basins of Western and Arctic Canada (using the example of mid-to late Valanginian time, modified from Jeletzky, 1971a, p. 38, Fig. 6).

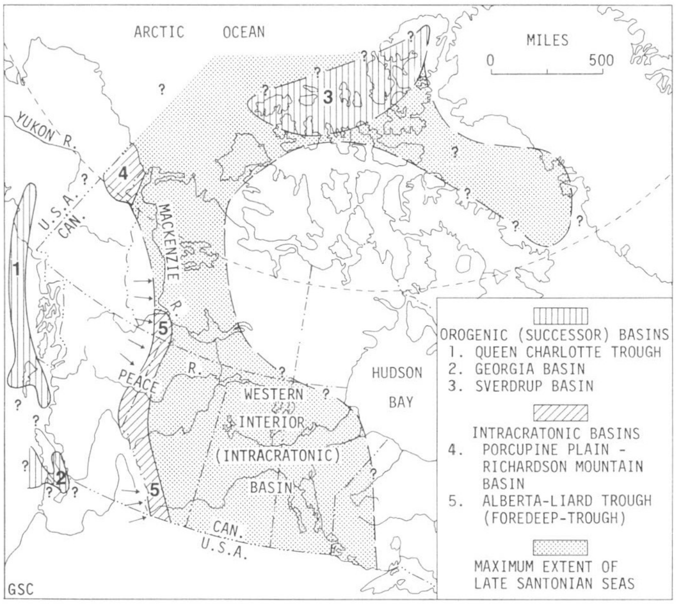

Figure 2. Principal Late Cretaceous marine basins of Western and Arctic Canada (using the example of late Santonian time: modified from Jeletzky, 1971a, p. 60, Fig. 15).

The compilation of averaged graphs of oscillations of sea level placed to the right of the summaries of geological histories of all Cretaceous basins discussed in the paper (see Figs. 3 to 7) proved to be unexpectedly difficult, and involved many interpretations based on scant or uncertain information and some partly or even largely arbitrary, personal decisions. These difficulties are discussed below. The lack of basin-wide uniformity of the Cretaceous history prevalent in all the basins studied presented the greatest obstacle to the objective interpretation of their oscillatory regimes.

Only a few geological events, as for example the Hauterivian-Barremian uplift of the Alberta-Liard Trough (see Fig. 7), which resulted in a complete retreat of the sea from all its now known extent, were truly regional in character. Other examples of comparable regional events are: 1) the geologically instantaneous late Hauterivian-Barremian transgression in the Richardson Mountains-Porcupine Plain Trough (see Fig. 5) which flooded the whole of the basin whithin the zonal moment of **Simbirskites** cf. **S. kleini**; 2) the mid- to late Albian regression in the same trough (see Fig. 5; Jeletzky, 1975, p. 41); and 3) the geologically instantaneous Christopher transgression in the Sverdrup Basin (see Fig. 6) which flooded the whole of that basin in early or mid-Aptian time and receded (apparently geologically instantaneously) in the late mid-Albian. A number of other similar, basin-wide events are indicated clearly in Figures 3 to 7 and need not be discussed here. This class of events presents no problems since it provides quite unambiguous oscillatory evidence.

The majority of the events of the geological history of these basins, including the sequences of marine transgressions and regressions, were found to be predominantly localized features. Consequently, the sequences of such events were found to differ widely in different parts of each basin studied. A great number of these tectonically caused intrabasinal to local geological histories have been discussed by Jeletzky (1971a). Others have been described in detail and analyzed as to their depositional-structural origin in another more recent paper (Jeletzky 1975, p. 42-47, Figs. 17-22). Still others have been described by other recent workers (i.e. Muller **in** Muller and Jeletzky, 1970; Stott, 1975, p. 454-463). The reader is referred to these publications for the bulk of this information. However, it is essential to discuss a few typical examples of these events to illustrate further their complex depositional-structural nature and classification, and to explain the difficulties involved in their oscillatory interpretation.

Generally, the difficulties stem from the fact that these events were not caused by simple uplift or subsidence of the areas concerned, but by much more complex tectonic events including differential subsidence, hinge-like movements, tiltings, planar rotation and uncoordinated vertical movements of the areas concerned reflecting, in turn, faulting or arching of the underlying major structural elements (see Jeletzky, 1971a, p. 75, 76). The simplest type is the differential subsidence[1] exemplified by the late Late Campanian Bearpaw transgression in the Alberta-Liard Trough (see Fig. 7), the Albian Haida transgression in the Insular Trough (see Fig. 4), or the early Early Cretaceous (Valanginian) transgression of Bluish-grey shale division time in Richardson Mountains-Porcupine Plain Trough (see Fig. 5). All these events apparently were restricted to certain parts of the basins concerned. However, a closer inquiry reveals that they have been expressed merely in a different way in other parts of the basins. For example, there may be clear paleoenvironmental indications that the interface of the whole basin did in fact subside, but some part of it subsided much more than the other. This is the case with the Bearpaw transgression (Jeletzky, 1971a, p. 71; this paper, Fig. 7) which onlapped westward and northward but failed to reach the northern part of the Alberta-Liard Trough which, relatively, was downwarped least. In the latter area, nevertheless, the subsidence is reflected clearly in the finer grained, paludal to alluvial facies of the correlative parts of the Edmonton Formation contrasting with the much coarser grained, partly conglomeratic lithology of the underlying Belly River Formation. The same may be true of the correlative part of the Brazeau (=Wapiti) Formation still farther north. These facies changes permit one to infer a basically regional but subregionally uneven subsidence of the Alberta-Liard Trough in Bearpaw time. The Dunvegan regression is a similar event, permitting an inference of regional but uneven uplift

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[1] It must be pointed out in this connection that, like every other worker constructing oscillation graphs of ancient depositional basins, the writer is concerned only with the movements of the interface between the sediment and the sea water (or the atmosphere when that interface is uplifted above sea level) in relation to the mean sea level. Neither the thickness of sediments accumulated during the corresponding intervals of geological time nor the resulting subsidence of the basins' "bottoms" (i.e. of the lower surfaces of the rock units previously deposited within the basin) are being taken into the consideration since there is no coordination between these processes and the relative movements of the interface between the sediment and the sea water (or the atmosphere). However, an attempt is made to exclude from consideration those areas of marine sedimentary basins which were abnormally affected by the lateral sedimentary accretion (i.e. represented the deltaic lobes proper) and to average the relative movements of the interface on a broadly regional or basin-wide basis. This procedure is intended to exclude, or at least to diminish, the influence of factors other than the tectonic movements and eustatic fluctuations of sea level on the oscillatory regime of the basins studied.

apparently caused by an upwarp of the Mackenzie Salient (Jeletzky, 1971a, p. 49; this paper, Fig. 7). These two events, and many others clearly indicated in Figures 3 to 7, permit an unambiguous interpretation of the oscillatory events that can be extended to a basin-wide scale after a close scrutiny. The same is not true, however, of many other intrabasinal to local events which were caused by combinations of directionally opposed vertical tectonic movements occurring simultaneously in adjacent parts of the same depositional basin.

Typical examples of one class of such events caused by hinge-like tectonic movements have been described recently by Jeletzky (1975, p. 43-46, Figs. 17-19; this paper, Fig. 5) in the Richardson Mountains-Porcupine Plain Trough. Similar events are just as common in all other Cretaceous basins studied. Another class of these events is dominated by uncoordinated tectonic movements occurring in adjacent fault blocks, and is exemplified by the pronounced intraregional late Early Albian deepening of the central zone of Tyaughton Trough which was progressing concurrently with major uplifts of both its flanks, including the adjacent source areas. This development is indicated clearly by the upward replacement of littoral to neritic rocks by predominantly argillaceous turbidites in central parts of the trough (e.g. the Grey shale-siltstone unit and the basal to upper lower Albian part of the upper Hauterivian to lower Albian siltstone division). This upward facies change was, however, paralleled by a contemporaneous upward replacement of predominantly shallow marine, argillaceous to arenaceous rocks by very thick nonmarine (i.e. French Bar Formation) to marine strata (i.e. Lower Albian conglomerate unit, Basal conglomerate unit) on the trough's flanks (see Fig. 3). This early Albian event (like many other similar events) apparently was caused not by previously mentioned hinge-like tectonic movements but by diametrically opposed, large-scale vertical movements of adjacent, longitudinally oriented fault blocks of Tyaughton Trough separated from each other by major longitudinal faults. Such faults abound on the flanks of Tyaughton Trough.

The events caused by hinge-like tectonic movements and those caused by uncoordinated vertical tectonic movements are fundamentally incapable of an unambiguous basin-wide oscillatory interpretation. For example, if one uses the

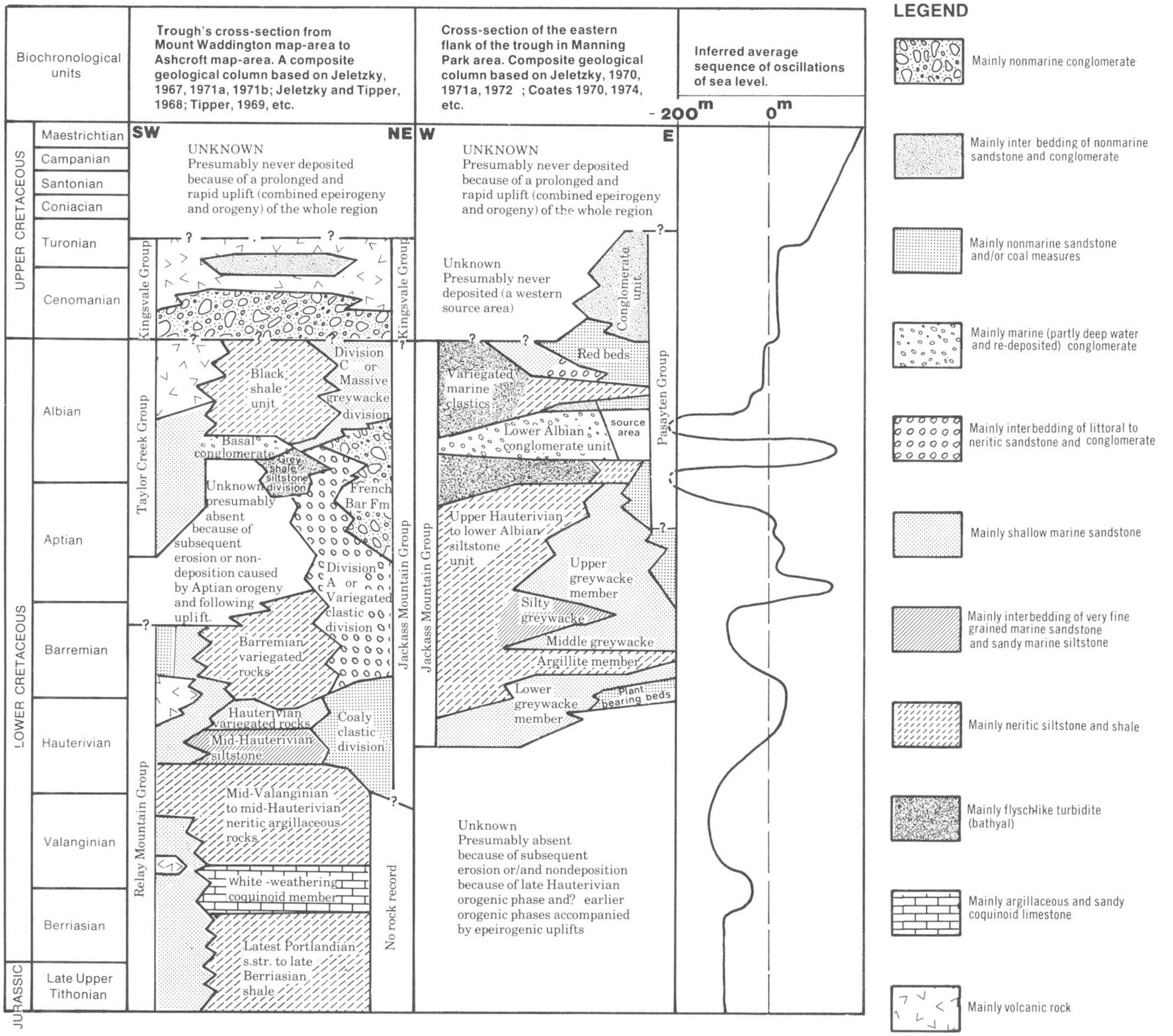

Figure 3. Summary of Cretaceous facies and inferred history of oscillations of sea level in the Tyaughton Trough (a successor trough of Western Cordilleran Orogen).

Husky transgression which dominated the eastern flank of the Richardson Mountains-Porcupine Plain Trough in late Oxfordian to early Berriasian time (see Fig. 5; Jeletzky, 1975, p. 43, 46, Fig. 18), the event is wholly transgressive. However, if one uses the roughly contemporaneous Late Jurassic regression which dominated the western flank of the same trough, the event is almost entirely regressive. The writer interpreted the event as wholly transgressive (see Fig. 5) because the Husky transgression was judged to involve a greater part of the trough than the roughly contemporaneous regression, and the subsidence which caused it was inferred to be relatively much greater than the uplift which caused the roughly simultaneous regression. Finally, the acme of Late Jurassic regression on the western flank of the Richardson Mountains-Porcupine Plain Trough had passed prior to late late Tithonian to Berriasian time when the acme of Husky transgression was reached (see Fig. 5; Jeletzky, 1975, p. 43, 46, Fig. 18).

In the case of the early Albian event in Tyaughton Trough (see Fig. 3; Jeletzky, 1970a; Jeletzky and Tipper, 1968), the marked contraction of the trough by large-scale uplifts of its flanks was judged to be much more widespread and hence much more significant than the simultaneous marked subsidence of its central zone. The event was classified accordingly, and somewhat arbitrarily, as a strong regional regression (see Fig. 3) in the averaged graph of oscillations of sea level, and the deep subsidence of the residual central zone was ignored. Another example is the roughly contemporary Albian uplift of the Insular Trough. This was expressed in the apparent transformation of most of Vancouver Island into a strongly elevated source-area, and in deposition of thick nonmarine conglomerates of the Blumberg Formation north therefrom in Quatsino Sound area (see Fig. 4; Jeletzky, 1976 for further details). It was classified likewise as a marked regional regression, ignoring the presence and the possible transgressive nature of a contemporary shallow-water Albian sea on Queen Charlotte Islands.

Generally, the writer treated every orogenic phase and epeirogenic uplift that resulted in the spreading of major coarse clastic wedges into the basin concerned, and caused an estimated reduction of the area of marine facies of that basin to less than 35 to 40 per cent of that characteristic of the

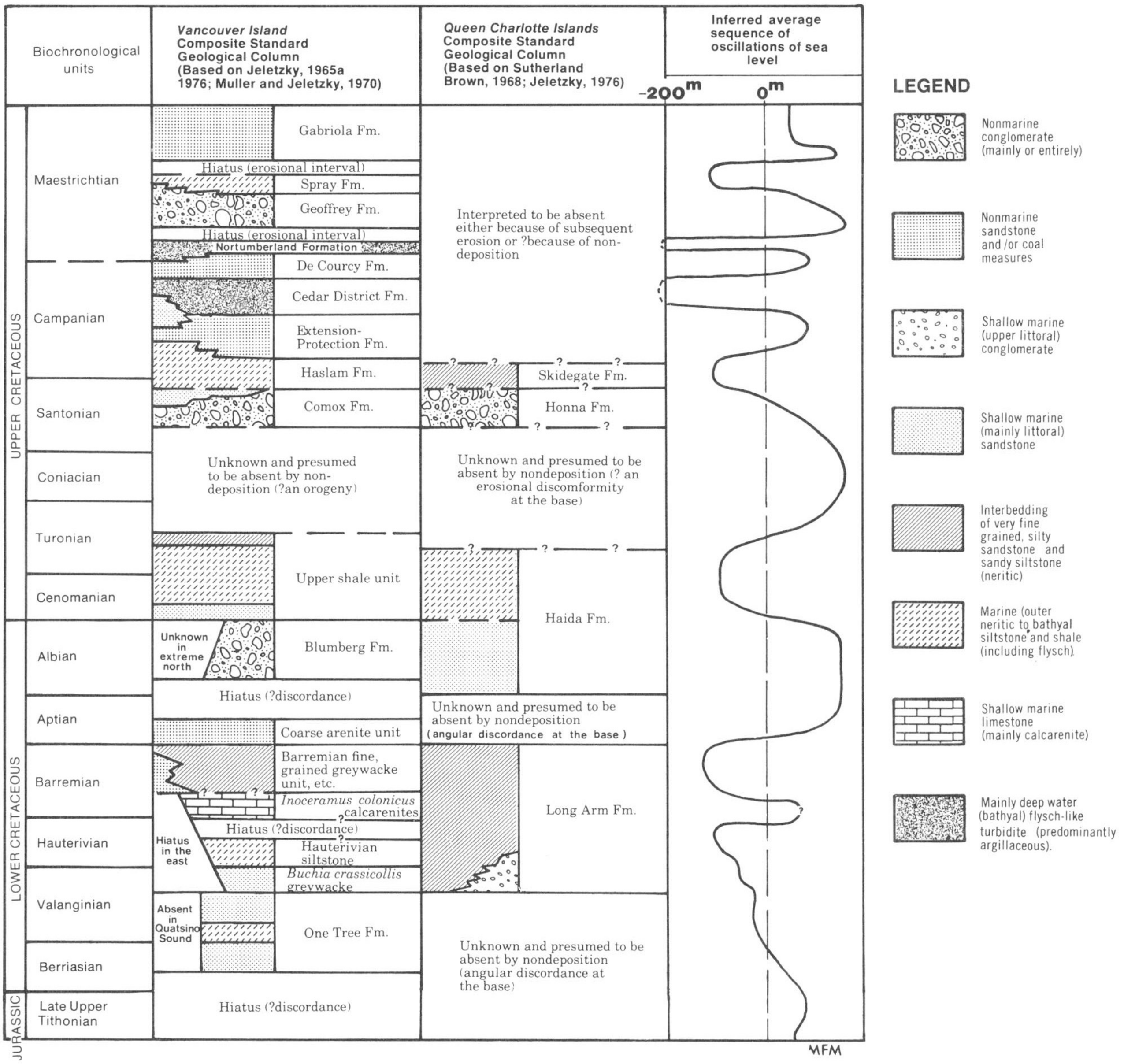

Figure 4. Summary of Cretaceous facies and inferred history of oscillations of sea level in the Insular Trough of Western Canadian Cordillera.

immediately preceding stage of its history, as a marked regional regression, regardless of whether or not the residual marine area was shallowing, remaining stationary, or deepening. The somewhat arbitrary nature of such a procedure is quite obvious, if one considers how rough and tentative the estmates of the ratios of those parts of the basins uplifted above sea level are bound to be. These estimates commonly approach educated guesses and could be challenged, particularly by those actively seeking evidence supporting the prevalence of eustatically controlled, geologically simultaneous, world-wide transgressions and regressions. However, no better approach to the oscillatory interpretation of these intrabasinal to local events appears to be available. For example, the plotting of the individual, known or assumed areas of continental blocks covered by seas during consecutive periods of time (i.e. ages of epochs), their planimetric measurement, and comparison (Yanshin, 1973) is believed to produce even more crude and less reliable results (see p. 22-23 Fig. 11). In many cases, the areas occupied by seas would not change when the tectonic movements discussed here occur, because a transgression in one part of the basin would be compensated for by a regression elsewhere.

Another serious obstacle to the unambiguous oscillatory interpretation of geological events within the basins studied is the unavoidable incompleteness of their Cretaceous record. Furthermore, the degree of this incompleteness varies widely from one area to another within each of the basins studied. This circumstance necessitated constant use of composite geological columns consisting of several partial sections (or groups of sections) situated in different, commonly remote parts of the basin concerned, for the restoration of its Cretaceous record. This approach is illustrated most clearly by the inclusion of two complementary geological columns, each showing pronounced lateral changes of facies, in the left-hand columns of Figures 3 and 4 summarizing Cretaceous histories of the Tyaughton and Insular troughs. However, it was used just as much in the compilation of the left-hand columns of Figures 5 and 7 which summarize Cretaceous histories of the Richardson Mountains-Porcupine Plain and Alberta-Liard troughs. These apparently unified histories are, in fact, just as composite as those of Tyaughton and Insular troughs since they include pronounced lateral facies changes extending anywhere from some 180 km across (in the case of Richardson Mountains-Porcupine Plain Trough) to some 700 km along (in the case of Alberta-Liard Trough) the

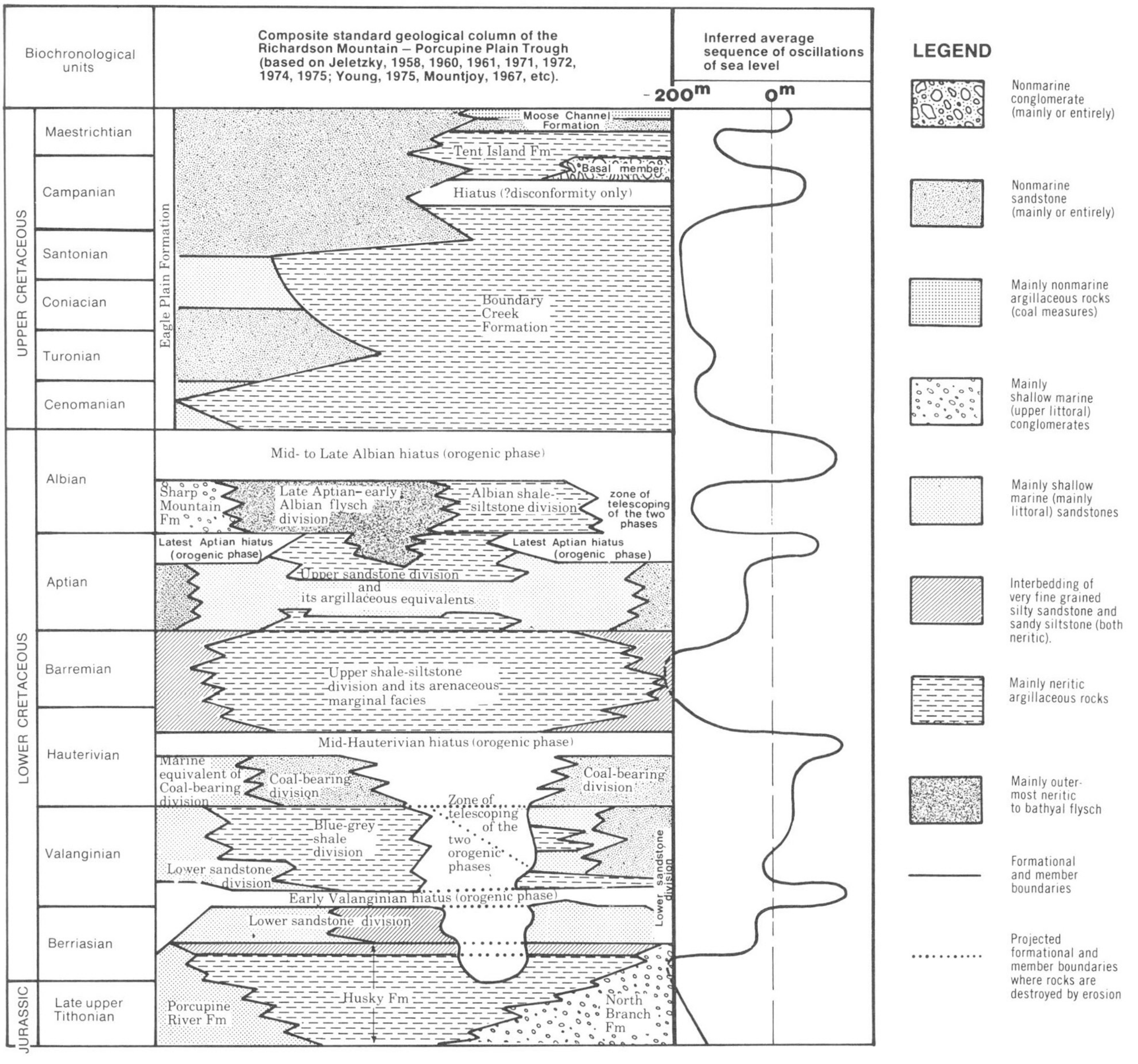

Figure 5. Summary of Cretaceous facies and inferred history of oscillations of sea level in the Richardson Mountains-Porcupine Plain Trough (an aulacogene).

depositional basins. Only the Cretaceous history of Sverdrup Basin, summarized in Figure 6, appears to be relatively unified, since its rocks exhibit only minor lateral facies changes within the basin. This appearance, however, may be deceptive because of the scarcity of data presently available.

The potential source of error contained in the use of composite geological columns had to be ignored in this study since no alternative method is available for obtaining reasonably complete Cretaceous records of the basins studied.

The graphs of inferred average sequences of oscillations of sea level forming parts of Figures 3 to 7 and comprising all of Figures 8 and 9 do not include any strictly quantitative data. The median, straight, dashed line of each graph marked 0^{m} at the top denotes the approximate position of the mean sea level. The heavy solid lines meandering across the line of mean sea level are plots of transgressions and regressions in the individual basins against the biochronological time scale. These plots were inferred from a paleoenvironmental analysis of litho- and biofacies summarized in the left-hand columns of Figures 3 to 7 and then markedly generalized in accordance with the principles outlined in preceding paragraphs.

Those parts of the graphs situated to the left of the line of mean sea level represent biochronologically defined segments of time when the basins concerned were predominantly to completely flooded. The -200 m signs in the upper left corners of all columns denote negative parts of the oscillation graphs which are meant to represent the prevalence of shelf seas with depths of 200 m or less, except where they are shown to abut the left boundaries of the columns and to continue as dotted lines into the adjacent parts of the column to the left. The latter relationship depicts an inferred prevalence of bathyal depths during the time intervals concerned (e.g. in Figs. 3, 4, 5 and 7).

No attempt was made to calibrate closely the inferred depths of shelf seas depicted by the oscillation graphs.

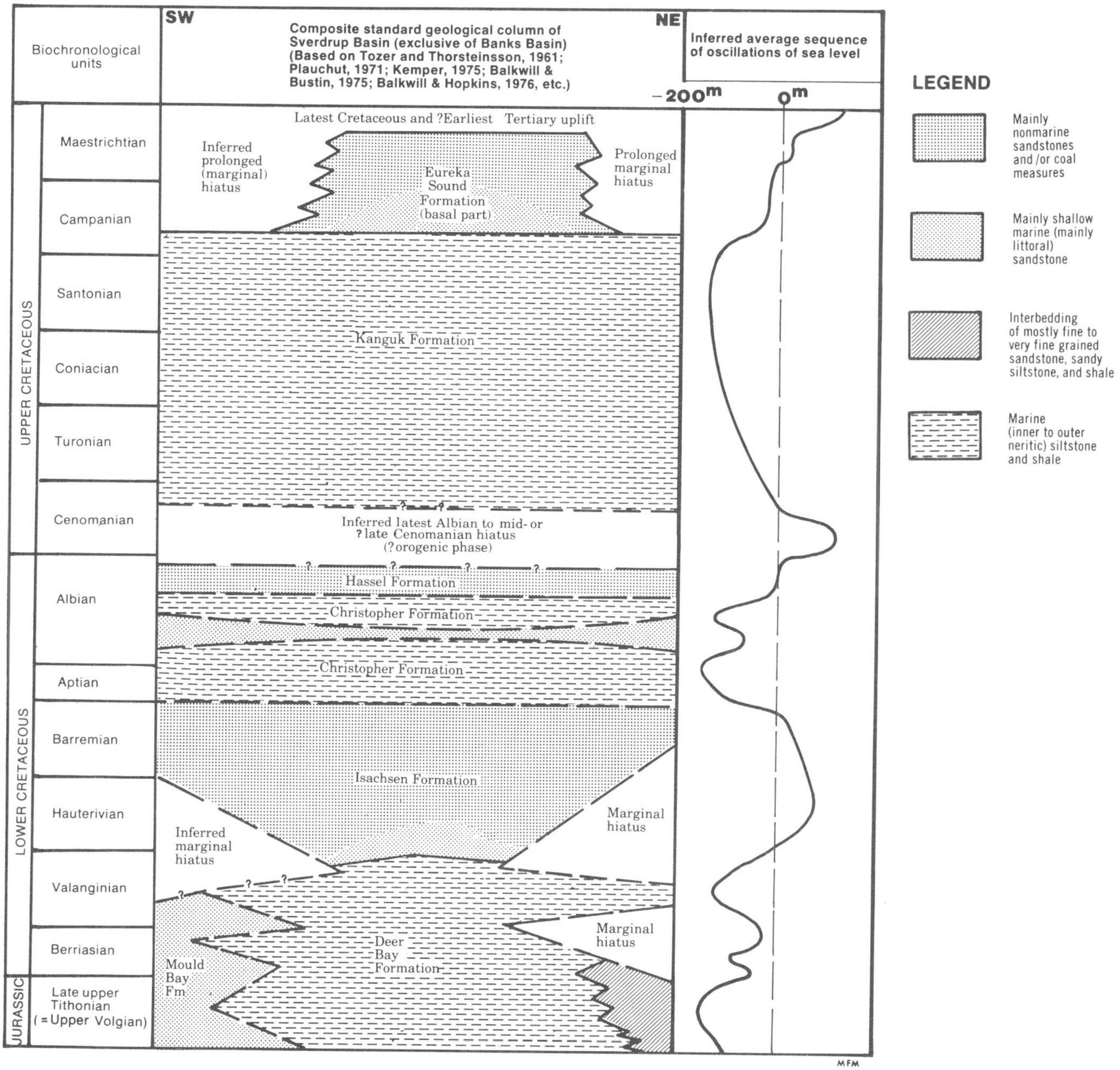

Figure 6. Summary of Cretaceous facies and inferred history of oscillations of sea level in the Sverdrup Basin, Northwest Territories.

However, the relative positions of their individual negative segments and peaks within the span between 0^{m} and -200 m points have been positioned in order to approximate the inferred depths of the sea at any moment of Cretaceous time. It cannot be overstressed that a negative position of any oscillation graph does not imply necessarily a total flooding of the known extent of the basin concerned but only its prevalent flooding as discussed in previous paragraphs. Similarly, the roughly estimated depths of the basin pertain only to the inferred depth of deposition of that particular marine facies which, in the writer's opinion, was prevalent at the time concerned.

Those parts of the oscillation graphs situated to the right of the line of mean sea level represent segments of biochronologically defined geological time when the basins concerned were either predominantly (i.e. no less than 60-65%, est.) or completely uplifted above sea level. The nonmarine character of deposition during these regressive intervals was inferred from the paleoenvironmental analysis of litho- and biofacies concerned, the results of which are summarized in the left hand columns of Figures 3 to 7. No attempt was made to express numerically the inferred elevations of deposition of nonmarine lithofacies included in these diagrams in order to stress the unreliability of such estimates in nonmarine environments. However, it is assumed that most or all of these nonmarine rocks (including lava flows and nonmarine pyroclastics) have been deposited on lowlands with elevations not exceeding 200 to ?400 m above sea level and more commonly approaching this level. The short- to long-lasting periods of nondeposition indicated in Figures 3 to 7 are assumed always to reflect times when the basins became considerably elevated source areas. Following Jeletzky (1974a, p. 810; 1975, p. 43), they are believed to be situated at least 610 to 1220 m (2000 – 4000 ft) above sea level. This idea is supported by the fact that these hiatuses commonly are replaced basinward by thick units of nonmarine to marine conglomeratic rocks, most of which are piedmont deposits. Good examples are provided by the predominantly lower Albian French Bar Formation, Basal conglomerate unit, and lower Albian conglomerate unit of Jackass Mountain Group (see Fig. 3) which indicate the mountainous character of adjacent source areas on the trough margins where early Albian time is represented only by hiatuses. The relative positions of individual positive segments and peaks of the oscillation graphs above mean sea level have been arranged so as to approximate the above-mentioned, inferred increased elevations.

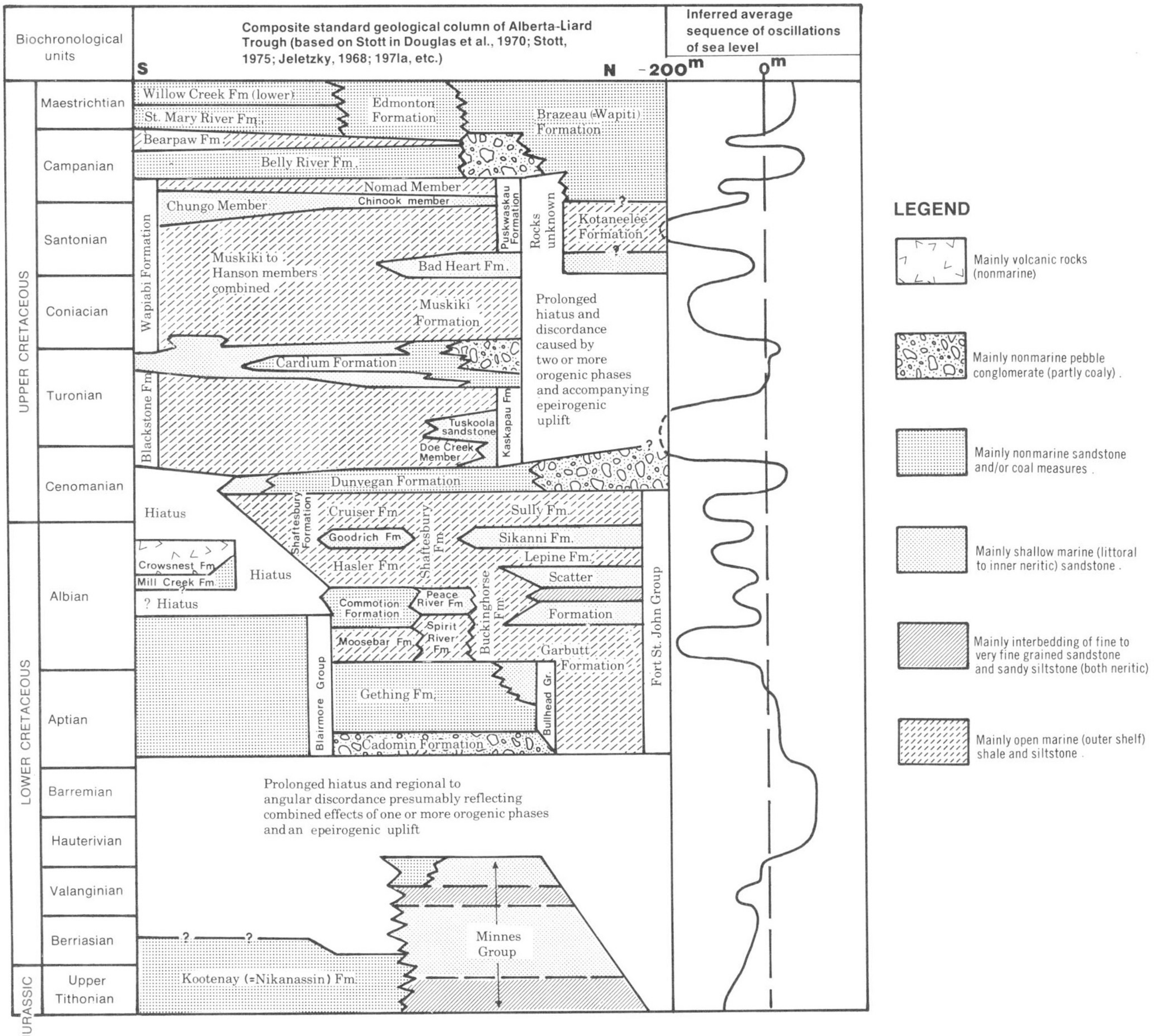

Figure 7. Summary of Cretaceous facies and inferred history of oscillations of sea level in the Alberta-Liard Trough comprising the westernmost part of Western Canada Basin (a foredeep of Columbian orogenic belt).

Comparative analysis of oscillation graphs

Early Cretaceous time

The Early Cretaceous parts of the oscillation graphs, illustrated in Figures 3 to 7, and inferred to be representative of five orogenic and intracratonic basins, are brought together in Figure 8 for a comparative analysis. The conventional symbols, the methods used in compilation of these graphs, and the inherent limitations of these methods have been discussed previously.

The first rather arbitrarily selected stage reproduced in Figure 8 comprises the late late Tithonian to late Valanginian segments of the graphs, all of which segments differ considerably from each other. This applies even to the adjacent, tectonically equivalent (successor basins of the Pacific Orogen) and broadly connected Tyaughton and Insular troughs. The corresponding segments of the oscillation graphs differ almost as markedly in the adjacent and connected Richardson Mountains-Porcupine Plain Trough and Sverdrup Basin. Also, these latter segments do not match the equivalent segments of graphs of the Tyaughton and Insular troughs graphs. Only the presence of a short-term regression at the Berriasian-Valanginian boundary allies these two graphs with one another and with the corresponding segment of the Tyaughton Trough graph. Finally, the late late Tithonian to late Valanginian segment of Alberta-Liard Trough graph differs fundamentally in featuring an almost steady, gradual regression of the sea, and culminating in the regional uplift of the basin well above sea level either in the latest Valanginian or in the earliest Hauterivian.

The Hauterivian-Barremian segments of the graphs are somewhat more co-ordinated, but only in so far as they fall into two well-defined, diametrically opposed groups. The first group, comprising the Tyaughton and Insular troughs and the Richardson Mountains-Porcupine Plain Trough, features longlasting and widespread transgressions which peaked in the late to latest Barremian. The second group, comprising the Sverdrup Basin and the Alberta-Liard Trough features, in contrast, equally long-lasting and widespread regressions.

The Hauterivian-Barremian transgressions in the first group of basins are far from uniform in detail. The Tyaughton and Insular troughs experienced a strong, but apparently somewhat localized, regression in the late Hauterivian (compare Figs. 3, 4) which resulted in emergence of much of their presently known extents, in spite of being barely noticeable in some areas. In these two orogenic troughs the regressive, apparently orogenic, late Hauterivian episode splits the Hauterivian-Barremian transgression into two well-defined transgressive phases. This regressive episode seems to be unknown in the Richardson Mountains-Porcupine Plain Trough, the whole known extent of which continued to subside through most of late Hauterivian and most of Barremian time. However, this long-lasting transgression was preceded by a prolonged Valanginian to mid-Hauterivian regressive episode which caused an emergence of most (over 90% of the known extent) of the Richardson Mountains-Porcupine Plain Trough. Therefore, this aulacogenic trough, which ought to be the most mobile type of intracratonic basin by definition, may have reacted belatedly to the strong, regional subsidence of the adjacent parts of the Pacific Orogen. Using this entirely plausible hypothesis, it is possible to interpret the mid-Hauterivian peak (an orogenic phase) of the Valanginian to mid-Hauterivian regressive period in the Richardson Mountains-Porcupine Plain Trough (compare Fig. 5) as an equivalent of the late Hauterivian regressive episode in the Tyaughton and Insular troughs. The preceding Valanginian to early Hauterivian "trough" of the same regressive segment of the graph would then be comparable to the Valanginian transgressive phase of the other two troughs, even though the subsidence of the sediment-atmosphere interface of the Richardson Mountains-Porcupine Plain Trough was too small to cause its regional flooding by the Valanginian seas. The profound and regional late Hauterivian to late Barremian subsidence of the interface of the Richardson Mountains-Porcupine Plain Trough would, finally, be comparable with the Barremian transgressive phase of the Hauterivian-Barremian transgression in the Tyaughton and Insular troughs. All discussed episodes of oscillatory history of the Richardson Mountains-Porcupine Plain Trough would be somewhat out of phase with their apparent equivalents in the Tyaughton and Insular troughs (see Fig. 8). However, their correspondence is judged to be close enough to classify the Hauterivian-Barremian oscillatory history of this aulacogene with that of both successor troughs of the Pacific Orogen.

The second group of basins consists of the Sverdrup Basin and the Alberta-Liard Trough, the Hauterivian-Barremian oscillatory histories of which are almost identical (see Fig. 5). These two basins experienced equally long lasting Hauterivian-Barremian regressions which resulted in a complete withdrawal of the sea from all their presently known extent. The regimes of these basins only differ in a much greater uplift of the Alberta-Liard Trough, all of which apparently was a mountainous source area through the Hauterivian and Barremian. It must be stressed in this connection that the writer (e.g. Jeletzky, 1970a, Fig. XI-8; this paper, Fig. 7) continues to believe in a complete absence of any rocks of Hauterivian to Barremian age in the Alberta-Liard Trough. Stott (1975, p. 453, 454) states, in contrast, that only Hauterivian rocks are absent in the trough.

Unlike the Alberta-Liard Trough, most of the Sverdrup Basin was transformed only into a lowland by the Hauterivian-Barremian regression. This is indicated by the ubiquitous presence of the mostly paludal to alluvial Isachsen Formation, and the restriction of hiatuses separating it from the underlying Deer Bay Formation to the marginal parts of the basin (see Fig. 6). The lesser Hauterivian-Barremian mobility of Sverdrup Basin in comparison with the Alberta-Liard Trough appears to conflict with the former being genetically an orogenic successor basin. However, Sverdrup Basin remained stable throughout the Cretaceous phase of its oscillatory history and was a typical intracratonic basin in this respect.

The Aptian segments of the oscillation graphs fall into the same two well-defined groups as their Hauterivian-Barremian segments. However, the direction of oscillatory movements is reversed. Namely the Tyaughton, Insular and Richardson Mountains-Porcupine Plain troughs experienced strong regional uplifts in the Aptian whereas the Sverdrup Basin and the Alberta-Liard Trough experienced comparably strong regional subsidences (Fig. 8). As in the earlier Cretaceous, the individual Aptian oscillatory histories commonly are out of phase from basin to basin and differ in many details in every basin belonging to one of these two groups.

In the Tyaughton Trough, forming part of the first group, the uplift following the strong early Aptian orogenic phase, which transformed its marginal parts into a tectonic highland and restricted considerably its marine central part, was followed by a marked subsidence in the late Aptian. This subsidence, which lasted into the earliest Albian, restored a marine regime in the larger part of the trough. So far as is known, there was no such late Aptian transgression anywhere in the Insular Trough forming part of the same group. This trough apparently was completely emergent throughout the Aptian, and only its northernmost part (ignored in Figs. 4, 8) was flooded again in the earliest Albian. In the Richardson Mountains-Porcupine Plain Trough, which is the third member of the group, the latest Barremian regional uplift was too small to end the marine regime even over most of its marginal zones. By far the greatest part of this trough continued as a littoral to neritic basin well into the late Aptian when a strong orogenic phase restricted the marine regime to its central part (see Fig. 5). Furthermore, the late Barremian uplift and the late Aptian orogenic phase apparently were restricted to the Richardson Mountains-Porcupine Plain Trough proper. That is, the Aptian sea was already transgressive in the adjacent, still poorly understood but entirely intracratonic basin, underlying the Anderson Plains east of Mackenzie Delta (Jeletzky, 1971a, p. 42).

In Sverdrup Basin and Alberta-Liard Trough, comprising the second group, Aptian time was dominated by a subsidence which apparently began in the earliest Aptian and lasted into the Early Albian. However, their oscillatory histories differed significantly. The Sverdrup Basin was flooded completely either in the early or in the mid-Aptian by the mostly neritic early Christopher sea (see Fig. 6). In contrast, only the northern part of Alberta-Liard Trough ceased to be an elevated source area; it became the site of paludal to deltaic deposition with some gradually increasing incursions of lagoonal and shallow marine facies (ignored in Figs. 7, 8), and remained such until the end of the Aptian. This difference probably reflects the much higher Hauterivian-Barremian elevation of the Alberta-Liard Trough rather than any marked difference in amplitudes of Aptian subsidences which affected this trough and the Sverdrup Basin.

As noted by Jeletzky (1971a, p. 75, 76; 1974a, p. 810), the mid-Early Cretaceous (i.e. early Hauterivian to late Aptian) phase of oscillatory history of the basins studied conforms closely to Haug's (1900, p. 683; 1907, p. 505) "law of epeirogenic compensation". Namely, orogenic belts were flooded when cratonic basins were drained and vice versa. However, this generalization is true ony if: (1) Sverdrup Basin is included among the intracratonic basins. This agrees well with the moderately dislocated to nearly undisturbed state of Cretaceous rocks and relatively stable (i.e. amplitudinally small) oscillatory behaviour of this basin, but contradicts its superposition on the Franklinian Orogen, which makes it a successor basin genetically; and (2) The Richardson Mountains-Porcupine Plain aulacogen is included with the Pacific Orogen, in spite of its genetically intracratonic character.

Unlike the previously discussed mid-Early Cretaceous segments of the oscillation graphs, their Albian segments do not fall into any well defined groups. They all differ considerably and resemble more closely the previously discussed late late Tithonian to late Valanginian graphs in this respect. The only exception is the occurrence of a pronounced subsidence either in the earliest Albian [i.e. in the zonal moment of **Leconteites lecontei** and the roughly equivalent moment of **Sonneratia** (sensu lato) n. sp. A; see Jeletzky **in** Douglas et al., 1970, p. 650, Table XI-8] or in the latest Aptian and earliest Albian compined. This subsidence is recognizable clearly in four out of five basins studied (see Fig. 8). Furthermore, the local presence of earliest Albian marine rocks with **L. lecontei** in Queen Charlotte Islands (Jeletzky, 1971a,p. 42) suggests that this subsidence did affect at least the northwesternmost end of the Insular Trough. This event is reflected in the left-hand column of Figure 4. However, it had to be excluded from the oscillation graph of the Insular Trough (see Figs. 4, 8) because of the pronouncedly positive behaviour of the greater, southern part of the trough throughout late Aptian and Albian times. This earliest Albian or latest Aptian to earliest Albian subsidence is the only known oscillatory event in the whole Early Cretaceous history of Arctic and Western Canada that is almost ubiquitous and at the same time almost geologically (i.e. biochronologically) instantaneous in the basins studied.

The remaining late early to late Albian parts of the oscillation graphs are completely uncoordinated (Fig. 8). Neither the very strong but brief late early Albian (only the early part of the time of **Brewericeras hulenense**; see Jeletzky **in** Douglas et al., 1970, p. 650, Fig. XI-1) uplift of Tyaughton Trough nor the immediately following very strong but brief subsidence and the later gradual, but apparently pulsating, retreat of mid-to-late Albian seas from that trough can be matched in the other four basins.

The greater, southern area of the adjacent Insular Trough represented a strongly elevated tectonic highland throughout the Albian. It was presumably rising and wasting steadily, judging by the local accumulation of more than 1000 m of nonmarine conglomerate (piedmont deposits) of the Blumberg Formation which, apparently, is overlain immediately by the conglomeratic lower Cenomanian beach deposits (Jeletzky, 1976, p. 109, 111). Furthermore, the upper lower to upper Albian shallow marine rocks of the northern part of the Insular Trough (i.e. the Sandstone member of the Haida Formation; see Sutherland Brown, 1968, p. 87-91) do not appear to comprise a transgressive deposit and so are compatible with the upward movement of its southern part.

The late early to late Albian oscillatory history of the Richardson Mountains-Porcupine Plain Trough is unlike those of both troughs discussed above but resembles more closely that of the Sverdrup Basin. Following the pronounced interregional subsidence which (unlike those in the other two troughs) lasted through the early Albian, the whole known extent of that trough was uplifted well above sea level. As far as is known, it remained so uplifted and formed a source area for the adjacent basin on Mackenzie Lowlands at least until the end of the Albian. This is suggested by an apparently total absence of either marine or nonmarine middle to upper Albian rocks within the trough's area (see Fig. 5).

The late early to late Albian oscillatory history of the Sverdrup Basin differs from that of the Richardson Mountains-Porcupine Plain Trough first in the much longer duration of the initial interregional subsidence

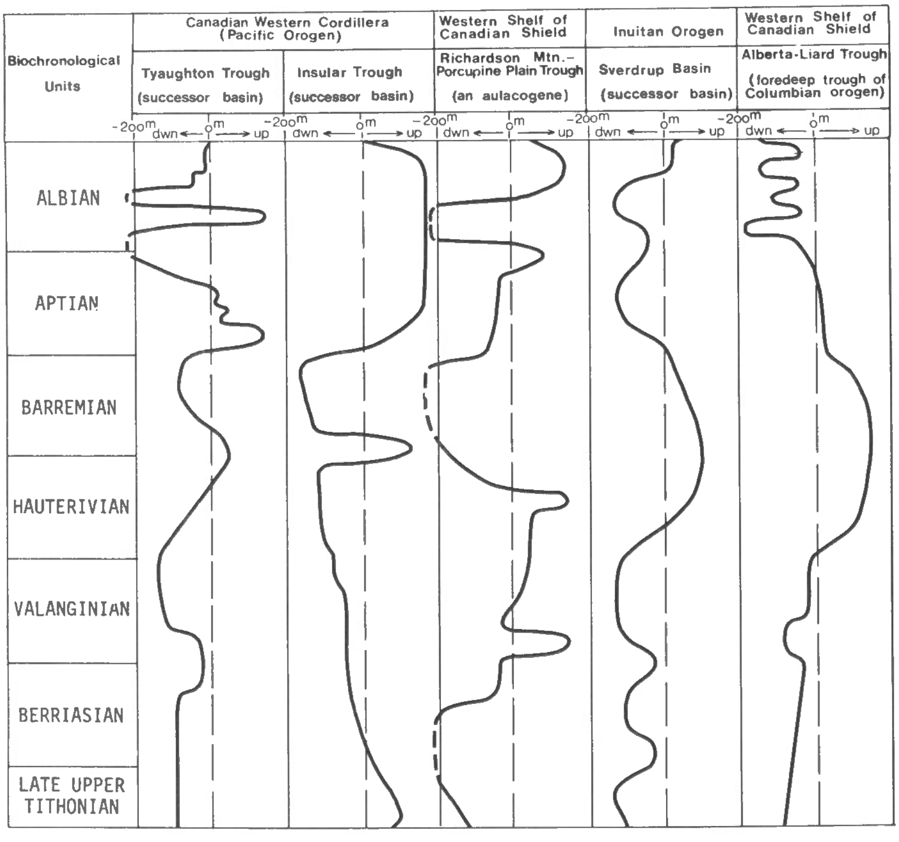

Figure 8. Summary of Early Cretaceous oscillations of sea level in the orogenic and intracratonic basins of Western and Arctic Canada.

which lasted from mid- or ?early Aptian to the end of middle Albian (i.e. **Gastroplites** sensu lato) time. Furthermore, this subsidence was interrupted by a shortlived regional shallowing of the Christopher sea sometime in the late early Albian. This uplift is registered by the presence of a widespread glauconitic sandstone member of the Christopher Formation (Fig. 6) confined between shale beds. These shales contain the late early Albian **Cleoniceras (Anadesmoceras?)** aff. **subbaylei** (more recently referred to the subgenus **Grycia**) and **Arcthoplites belli** (see Jeletzky, 1964, p. 74, pl. XXIII, Figs. 3, 4, 6) below the sandstone and a still undescribed early mid-Albian **"Gastroplites"** (a new genus?) ex aff. n. sp. A of Jeletzky 1964 and **Cleoniceras (Cleoniceras)** n. spp. aff. **C. (C.) tailleuri** and **C. (C.) cleon** fauna (i.e. GSC loc. C-22283) above the sandstone. Finally, the regional but relatively small scale late Albian uplift registered by the upward intergradation of the uppermost Chrisopher shale containing **Gastroplites** sensu lato into predominantly (i.e. except for the basal 90 m or so; H.R. Balkwill, written com., 1976) nonmarine deposits of the Hassel Formation was not followed by an early Cenomanian subsidence (see Figs. 6, 8). Instead, this uplift was followed by another, considerably larger (judging by the hiatus and a possible regional unconformity; see Fig. 6) Cenomanian uplift which apparently peaked in the mid-Cenomanian (see Figs. 8, 9). In spite of these differences, the late early to late Albian segments of oscillation graphs of the Sverdrup Basin and Richardson Mountains-Porcupine Plain Trough resemble each other more closely than they do the equivalent segments of any of the other three graphs.

Finally, the late early to late Albian oscillatory history of the Alberta-Liard Trough is unlike that of any other basin studied. Disregarding a number of local irregularities and events, some of which are shown in Figure 7, this part of the Albian history of the trough begins with a regional regression immediately following the earliest Albian (or Garbutt) interregional transgression. This regression is followed by three more regional transgression-regression cycles culminating in the Cenomanian Dunvegan regression. All of these transgression-regression cycles have been comprehensively described by Stott (1975, p. 454-460, Fig. 7). None of the three cycles following the earliest Albian interregional transgression has recognizable counterparts in any of the other four basins studied (see Fig. 8).

Late Cretaceous time

The Late Cretaceous parts of oscillation graphs of the five orogenic and intracratonic basins discussed in the preceding section (see Figs. 3-7) are brought together in Figure 9 for the purpose of a comparative analysis. The conventional symbols, the methods used in the compilation of these graphs, and the inherent limitations of these methods have been discussed in the preceding section. The geographical location of all basins discussed is indicated in Figure 2.

The Late Cretaceous oscillation graph of the Tyaughton Trough begins with a regional uplift at or near the Albian-Cenomanian boundary. This uplift resulted in a complete retreat of the sea and the deposition of Cenomanian to ?Turonian nonmarine volcanics and predominantly molassoid nonmarine sediments in most parts of the trough. Some other areas of the trough became elevated source areas at the same time (see Fig. 3). This phase of the oscillatory history of Tyaughton Trough is diametrically opposed to the Cenomanian-Turonian oscillatory history of the adjacent and genetically related Insular Trough and to that of the Richardson Mountains-Porcupine Plain Basin. These two basins began to subside at the end of the Albian, were largely flooded by neritic seas by the early Cenomanian, and remained deeply submerged either well into the Turonian (i.e. Insular Trough; see Fig. 4) or until the early Campanian (i.e. Richardson Mountains-Porcupine Plain Basin; see Fig. 5).

Surprisingly, the Cenomanian oscillatory history of the orogenic Tyaughton Trough is similar to, although far from identical with, the Cenomanian histories of the geographically remote and tectonically dissimilar Sverdrup Basin and Alberta-Liard Trough. Both of these basins experienced marked uplifts resulting in an apparently total (Sverdrup Basin; see Fig. 6), or prevalent (Alberta-Liard Trough; see Fig. 7) emergence. However, unlike Tyaughton Trough, these uplifts were short-lived. They were followed by major and longlasting, regional subsidences either in the late Cenomanian (Alberta-Liard Trough; see Figs. 7, 9) or in the earliest Turonian (Sverdrup Basin; see Figs. 6, 9). These transgressions resulted apparently in a complete flooding of these basins by outer neritic to bathyal Turonian seas.

It must be stressed that the generally accepted presence of Cenomanian marine fossils in the northeastern part of Sverdrup Basin is rather questionable. These fossils were dated originally (McLearn in Fortier et al., 1963, p. 411) only as: "Upper Cretaceous, about the stage of Cenomanian to Turonian," rather than definitively Cenomanian. After having restudied these fossils the writer concurs with this dating and withdraws the previously published unqualified Cenomanian dating (Jeletzky, 1971a, p. 49). Even should these poorly preserved fossils be later proven to belong to the diagnostic late Cenomanian form **Inoceramus pictus** J. de C. Sowerby (see Hattin, 1975, p. 68, 69) by the discovery of better preserved topotype material, this would leave all of early and middle Cenomanian time unaccounted for. Considering the regionally abrupt and possibly regionally

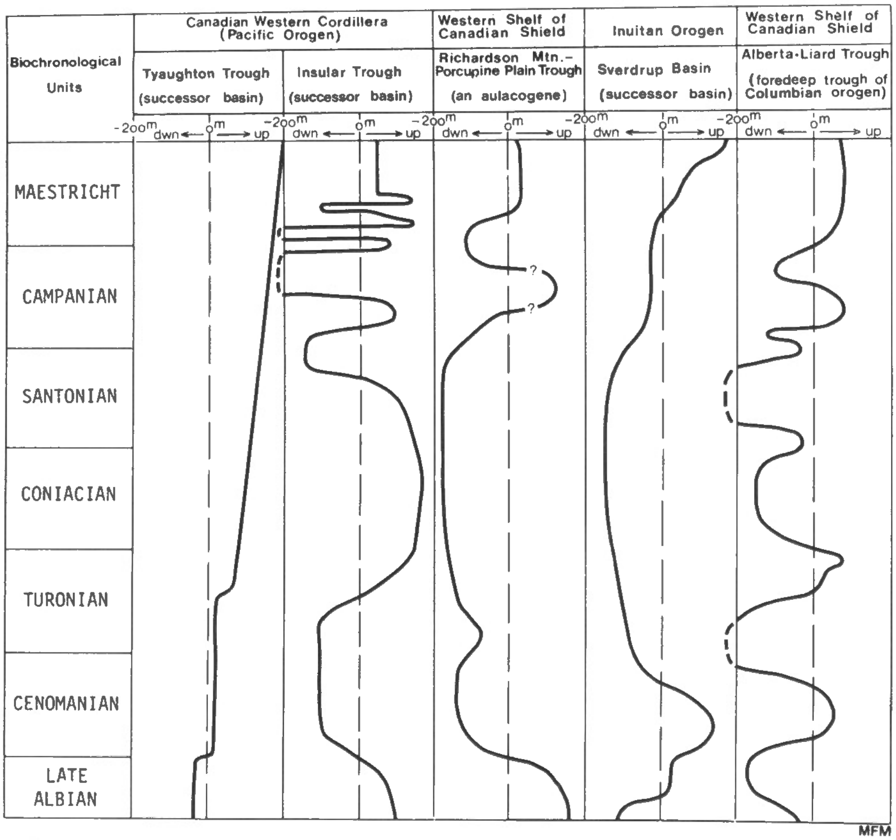

Figure 9. Summary of Late Cretaceous oscillations of sea level in the orogenic and intracratonic basins of Western and Arctic Canada.

unconformable character of the Hassel-Kanguk contact (e.g. Tozer in Fortier et al., 1963, p. 90; Greiner in Fortier et al., 1963, p. 412; Souther in Fortier et al., 1963, p. 441; Balkwill and Hopkins, 1976, p. 329; Balkwill and Bustin, 1975, p. 514, Fig. 1), the writer infers that at least early and mid-Cenomanian times are represented only by a hiatus in Sverdrup Basin (Fig. 6).

Following the Cenomanian-Turonian phase of nonmarine deposition, the Tyaughton Trough apparently experienced another pronounced, regional uplift. This uplift, which is assigned only tentatively a mid- to late Turonian age (see Figs. 4, 9), is indicated by an apparently total termination of deposition within the trough. So far as is known, no post-Turonian Upper Cretaceous sediments of any kind were deposited within the confines of the earlier Cretaceous Tyaughton Trough. It is concluded, accordingly, that the trough ceased to exist as a Late Cretaceous depositional basin after the ?mid- to late Turonian tectonic event. This possible orogeny and the following uplift apparently inverted the trough and transformed it into a rapidly rising and wasting tectonic highland which provided molassoid sediments to adjacent Late Cretaceous nonmarine basins of the Pacific Orogen (see Eisbacher, 1974, p. 283-285, Fig. 7 for further details). So interpreted, this Late Cretaceous phase of oscillatory history of Tyaughton Trough bears no similarity whatsoever to the corresponding phases of oscillatory history of the other four basins studied, except for the late Turonian to mid-Santonian phase of the adjacent Insular Trough and the interregional late early to latest Maastrichtian regression (see below). However, most areas of the Tyaughton Trough are known on a reconnaissance basis only and this interpretation of its post-Turonian oscillatory history conceivably may be discredited by future discoveries of middle to upper Upper Cretaceous nonmarine (or even marine) rocks within the region.

Following the Cenomanian to mid-Turonian submergence, the Insular Trough experienced what appears to be (the record is still incomplete and partly ambiguous) a very strong and prolonged, regional uplift. This uplift, which apparently lasted from the late Turonian to the mid-Santonian inclusive, is recorded, apparently, by a total absence of any rocks of these ages. Also, there are definite signs of shallowing in the youngest preserved marine sediments on northern Vancouver Island and Queen Charlotte Islands, and of discordant onlap of the upper Santonian basal beds of the Nanaimo Group and their presumed equivalents (i.e. Honna Formation) on Turonian or older rocks (see Fig. 4). These data suggest that the trough was completely inverted and was a tectonic highland, during most or all of late Turonian to mid-Santonian time. This highland was possibly contiguous with the adjacent highland of former Tyaughton Trough.

Except for the previously mentioned similarity of this phase of oscillatory history of Insular Trough to the corresponding phase of Tyaughton Trough, it bears no resemblance to the late Turonian to mid-Santonian oscillatory histories of any of the basins studied. The Richardson Mountains-Porcupine Plain Basin, in contrast, experienced a long-lasting and marked regional subsidence with hardly any reversals throughout late Turonian to mid- or ?late Santonian time with the mid- or ?late Santonian maximum of the subsidence corresponding closely to the acme of late Turonian to mid-Santonian uplift in the Insular Trough. The late Turonian to mid-Santonian oscillatory regime of the Insular Trough is also diametrically opposed to those of the Sverdrup Basin and the Richardson Mountains-Porcupine Plain Basin (see Figs. 4, 6 and 9). However, the latter two histories are all but identical. The apparent absence of any traces of that shortlived and weak early Turonian uplift which interrupted the prolonged Cenomanian- to mid-Santonian episode of subsidence in the Richardson Mountains-Porcupine Plain Basin in the equivalent episode of subsidence in the Sverdrup Basin (see Fig. 6) may be an illusory phenomenon caused by the reconnaissance character of the published geological studies.

The Turonian to mid-Santonian oscillatory history of the Alberta-Liard Trough is inverse to that of the Insular Trough. However, it is basically similar to the equivalent phases of oscillatory histories of the Richardson Mountains-Porcupine Plain and Sverdrup basins since it is dominated by a sequence of strong, regional subsidences which reached their acme in mid-Santonian time (see Fig. 7; Jeletzky, 1971a, p. 50, 56-58, Fig. 14). This prevalent negative trend is complicated by several shortlived and invariably localized but pronounced episodes of uplift which do not seem to be present either in the Sverdrup or in the Richardson Mountains-Porcupine Plain Basin. This much greater complexity of the Turonian to mid-Santonian oscillatory regime in the Alberta-Liard Trough could reflect, in part, the much better state of our knowledge of its Late Cretaceous geology in comparison with that of the Richardson Mountains-Porcupine Plain and Sverdrup basins. However, the differences are far too pronounced to be largely or entirely explained that way. Therefore, the much more active Turonian to mid-Santonian oscillatory regime of the Alberta-Liard Trough must have reflected the comparatively much stronger tectonic activity in the adjacent parts of the Columbian Orogen that flanked the Alberta-Liard Trough on the west (Jeletzky, 1971a, p. 76).

The late Turonian to mid-Santonian phase of the oscillatory history of the basins studied is the second segment which conforms reasonably closely to Haug's (1900, p. 683; 1907, p. 505) "law of epeirogenic compensation". However, the sense of movement is opposed to that of the previously discussed early Hauterivian to late Barremian history. It is the two orogenic successor basins (i.e. Tyaughton and Insular troughs of the Pacific Orogen) which were drained completely and uplifted strongly in late Turonian to mid-Santonian time in contrast to the intracratonic basins and the Sverdrup Basin which were subsiding strongly and flooded entirely by seas (Fig. 9). The late Turonian to mid-Santonian instance of "epeirogenic compensation" is considerably more straightforward than the early Hauterivian-late Aptian case. For example, the oscillatory regime of the by now typically intracratonic (i.e. no longer an aulacogene; see Fig. 2) Richardson Mountains-Porcupine Plain Basin conformed with those of the intracratonic Alberta-Liard Trough and the only nominally orogenic Sverdrup Basin.

The pronounced and regional but fairly shortlived late Santonian to earliest Campanian phase of subsidence in the Insular Trough does not have any close analogues in the other basins studied. As far as we know, the tectonic upland of the inverted Tyaughton Trough continued to rise and to be eroded throughout this time interval corresponding to the above-mentioned phase of marked subsidence in the adjacent successor basin.

The Richardson Mountains-Porcupine Plain and Sverdrup basins rose steadily following the approximately mid-Santonian acme of their prolonged periods of subsidence (see Fig. 9) when the Insular Trough began to subside rapidly. The same is true of the Alberta-Liard Trough which was experiencing a series of ever stronger late Santonian to early Campanian uplifts after attaining the maximum of Late Cretaceous subsidence and transgression in the mid-Santonian (see Fig. 7; Jeletzky, 1971a, p. 62).

In contrast to the immediately preceding late Santonian to earliest Campanian subsidence, the very strong, apparently regional but very short lived (no longer than two or ?three ammonite zonal moments) late early Campanian or Extension-Protection uplift of the Insular Trough is matched closely in three out of four other basins. In the Richardson Mountains-Porcupine Plain Basin, this uplift appears to correspond to the beginning of more prolonged but approximately dated late early or ?mid-Campanian uplift separating the Boundary Creek and Tent Island formations (see Figs. 5, 9). In the Sverdrup Basin, this uplift appears to correspond to the abrupt late early Campanian uplift which terminated the deposition of the neritic Siltstone member of Kanguk Formation and ushered in the period of deposition of the upper littoral to ?lagoonal sands of the basal Eureka Formation (see Fig. 6). In the Alberta-Liard Trough, this uplift appears to correspond, at least approximately, to the beginning of the prolonged regional Belly River uplift which followed immediately the deposition of Nomad (or Pakowki) shale. This uplift is registered by the start of regional deposition of nonmarine rocks of basal Belly River Formation and its equivalents (see Fig. 7; Jeletzky, 1971a, p. 68, 69). Finally it is possible, although unproven, that the same early, but not the earliest, Campanian uplift was felt also in the tectonic upland of the previously inverted Tyaughton Trough but is unrecognizable there because of the apparently complete absence of suitable rock record.

On the whole, the late early Campanian or Extension-Protection uplift appears to represent the first known Late Cretaceous oscillatory event in the history of Arctic and Western Canada that is almost (or even possibly completely?) ubiquitous and at the same time almost (i.e. within the precision of one or two ammonite zonal moments) geologically instantaneous in the basins studied (see Fig. 9).

The following late early Campanian to earliest Maastrichtian oscillatory history once again appears to lack almost completely any clearly discernible interbasinal correlation.

The tectonic highland of the previously inverted Tyaughton Trough probably continued to rise and to be eroded throughout this time. However, the adjacent Georgia Basin of the Insular Trough was at this time experiencing a series of extremely short lived (no longer than one or two ammonite zonal moments each) and closely spaced but very large scale uplifts and subsidences. The Cedar District and Northumberland generations of this basin were dominated by proximal to distal turbidites deposited mainly or entirely in the bathyal depths and the succeeding Spray River generation was at least predominantly outer neritic (see Figs. 4, 9; Muller **in** Muller and Jeletzky, 1970). The intervening uplifts caused the apparently complete emergence of the Georgia Basin. Some of these uplifts (see Fig. 4) are represented only by periods of nondeposition which suggests that the bottom of Georgia Basin was elevated from bathyal (i.e. -200 to -800 m) or outer neritic (i.e. -150 to -200 m) depths to levels at least 800 to 1200 m above sea level (see Jeletzky, 1974a, p. 810; 1975, p. 43). This suggests total vertical uplifts ranging between 950 and 2000 m. Other uplifts, for example those registered by the deposition of nonmarine conglomeratic sandstone of DeCourcy Formation and nonmarine conglomerate of Geoffrey Formation (see Fig. 4), had lesser but nevertheless large (anywhere between 200 and 1200 m) vertical amplitudes.

The late early Campanian to earliest Maastrichtian time here discussed apparently is represented only by a hiatus in the middle part of Vancouver Island (i.e. between Port Alberni and Campbell River areas in the south and Quatsino Sound-Port McNeil–areas in the north; see Muller and Jeletzky, 1970; Jeletzky, 1976, p. 115, 116, Fig. 14). This area accordingly is interpreted as a rapidly rising and wasting tectonic highland which acted as the northern source area for the late early Campanian, late Campanian, and earliest Maastrichtian generations of the Georgia Basin (see Sutherland Brown, 1966, Fig. 6-7; Jeletzky, 1971a, p. 66-68, Figs. 18, 19). North of this tectonic highland, the upper Campanian rocks of Suquash Basin and Quatsino Sound are all shallow-marine to nonmarine deposits (see Jeletzky **in** Muller and Jeletzky, 1970, p. 58-62; 1976, p. 115, 116, Fig. 14). This, and the absence of earliest Maastrichtian and pre-upper Campanian rocks in this northern basin, suggests that the closely spaced but large-scale uplifts and subsidences described above are localized features confined to the Georgia Basin and adjacent, structurally connected parts of the northern source area. They probably were caused by the contemporary but unco-ordinated vertical movements of individual fault blocks. Still farther north in Queen Charlotte Islands, the late early Campanian, late Campanian, and earliest Maastrichtian time is now (i.e. contrary to Jeletzky, 1971a, p. 62, 68, Figs. 16-20) believed to be represented only by a prolonged hiatus (Fig. 4). This southernmost part of the Queen Charlotte Trough (see Fig. 2), therefore, is interpreted as another tectonic highland which rose in the late early Campanian within the previously continuous trough and served as a source area for the Suquash-Quatsino Sound basin situated south of it. It is impossible to reproduce this complex geological history of the closing stages of the Insular Trough graphically even in the left-hand graphs of Figure 4, let alone in the oscillation graph of Figure 9.

The late early Campanian to earliest Maastrichtian oscillatory history of the Richardson Mountains-Porcupine Plain Basin lacks any signs of the complexities described above of the contemporary history of the Insular Trough. The larger northern part of the basin subsided deeply in late early or ?mid-Campanian time following the interregional late early Campanian uplift. It was flooded by the mostly outer neritic (and possibly deeper) Tent Island sea and remained submerged at least into earliest Maastrichtian time (Fig. 5; Young, 1975, p. 10, 11, Table 5)[2]. The poorly known southern part of the basin apparently subsided much less and was not covered by the Tent Island sea (see Fig. 5), but was the site of deposition of nonmarine rocks of the upper Eagle Plain Formation. No hiatuses or other indications of shortlived uplifts are known to occur either in the Tent Island (Young,

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[2] Since this was written, the following information about the age of the Ministicoog shale member was kindly communicated by F.G. Young (letter of June 2, 1977):

"I recall you made use of the idea that the Ministicoog shale member of the Moose Channel Formation is Maastrichtian in age, based on my Bulletin 249. I want to point out that recent research done by Art Sweet on megaspores (mainly **Azolla** species variations) and other palynomorphs has shown rather convincingly that the Moose Channel is entirely Paleocene in age, and that the Upper Cretaceous/Tertiary boundary lies somewhere in the Tent Island Fm. He has promised to place his findings to date on paper as soon as possible, but you may wish to alter your discussion if there is still time."

The writer is not at all surprised about this Paleocene dating of the Ministicoog Member. However, he finds it somewhat hard to accept the new positioning of the Upper Cretaceous/Tertiary boundary "somewhere in the Tent Island Formation", unless its upper part should be proven later to be of nonmarine origin. This opinion is not based on any kind of biochronology which opposes that advanced by A. Sweet. However, it does not fit the idea, well documented (in the writer's opinion), that the sea retreated from all continental plates during the Maastrichtian (see p. 15-16 for further details). That is why the writer accepts the global Maastrichtian regression as one of the very few credible instances of negative eustatic movements of the sea level preserved in the geological record. Therefore, and because of a considerable scepticism concerning the resolving power and biochronological reliability of palynology on the standard stage and zone level, the writer cannot accept the post-Maastrichtian age of the upper part of the Tent Island Formation at present. Considering the apparently marine origin of the uppermost part of the Tent Island Formation, (see Young, 1975, p. 19, 20) he is inclined to place the Cretaceous/Tertiary (i.e. the Maastrichtian/Danian) boundary either within the Basal sandstone member of the Moose Channel Formation or, at the very lowest, at the base of this member.

1975, p. 7-10) or in the upper part of the Eagle Plain Formation.

As it is known now, the late early Campanian to earliest Maastrichtian oscillatory history of Sverdrup Basin is just as simple as that of the Richardson Mountains-Porcupine Plain Basin but is not similar to the latter (see Fig. 9). It also differs radically from the complex contemporary history of the Insular Trough. Following the previously discussed interregional early, but not the earliest, Campanian uplift, the marine basin became much shallower but apparently persisted, except in the emergent marginal parts. This predominantly littoral phase of existence of the Sverdrup Basin is documented by the deposition of largely marine arenaceous beds of basal Eureka Sound Formation in the central part of the basin (see Fig. 6; Balkwill and Hopkins, Jr., 1976, p. 331) and by hiatuses at its margins (see Fig. 6; and in Balkwill et al., 1975, p. 205). This phase probably lasted from the late early Campanian into the early or ?mid-Maastrichtian (see Fig. 6; Balkwill and Hopkins, Jr., 1976, p. 331, 333, Fig. 58.2). However, this conclusion is based solely on palynological evidence which does not permit a close dating of the rocks concerned.

The late early Campanian to earliest Maastrichtian oscillatory histories of the Alberta-Liard Trough and the Richardson Mountains-Porcupine Plain Basin are exceptional in being closely matched (see Fig. 9). The late early to mid-Campanian Belly River uplift appears to correspond closely to the uplift that caused the hiatus and disconformity separating the Boundary Creek and Tent Island formations in the latter basin. The late Campanian Bearpaw subsidence, immediately following, appears to correspond closely to the Tent Island subsidence in the Richardson Mountains-Porcupine Plain Basin. Though regionally diachronous, the early Maastrichtian uplift in the Alberta-Liard Trough was approximately contemporaneous also with the Moose Channel uplift of the Richardson Mountains-Porcupine Plain Basin.

The final late early to latest Maastrichtian oscillatory phase of the basins studied is yet another exception to the largely to entirely unco-ordinated pattern of oscillations of the sea level characterizing their Cretaceous history. All five basins remained uplifted above sea level throughout this period of time. Few localized or regional phases of marine ingressions are known within any of them, except for that of the Ministicoog Member in the Richardson Mountains-Porcupine Plain Basin (see below).

The invariably emergent, late early to latest Maastrichtian regime is extremely variable in detail from one basin to another. The tectonic highland of the earlier inverted Tyaughton Trough apparently continued to experience a steady uplift and erosion until the end of the Maastrichtian and into the early Tertiary since neither Maastrichtian nor basal Tertiary rocks are known to occur anywhere in the region.

Most of the territory of the former Insular Trough apparently formed part of the same steadily rising and rapidly wasting tectonic highland throughout the Maastrichtian as did the territory of the former Tyaughton Trough (see Fig. 4). This is indicated by the complete absence of Maastrichtian and basal Tertiary rocks therein. However, the residual Georgia Basin had a different oscillatory history (see Fig. 4) which alone is shown in Figure 9. There, the late early Maastrichtian began with a complete emergence registered by a short-lived time of nondeposition and erosion separating the Spray and Gabriola formations. The vertical amplitude of this uplift probably was as large as that of the preceding uplift separating the Northumberland and Geoffrey formations (Fig. 4). This uplift was followed by a considerable subsidence which is reflected in the deposition of the nonmarine, partly conglomeratic sandstones of the Gabriola Formation in the central parts of Georgia Basin. This subsidence must have transformed the exclusively late early Maastrichtian tectonic highland into an alluvial lowland with a considerable gradient. These lowland conditions may have persisted at least to the end of Maastrichtian (possibly into the early Tertiary) time (Fig. 4). However, this conclusion is based only on long-ranging plant fossils found in the Gabriola Formation and other presumably comparable nonmarine formations (e.g. Chuckanut Formation) of Georgia Basin.

The Richardson Mountains-Porcupine Plain Basin and the Alberta-Liard Trough apparently had almost identical late early to latest Maastrichtian oscillatory histories, which differ markedly from those of all other basins studied. These two basins were uplifted and transformed into swampy alluvial lowlands sometime in the early Maastrichtian. This is indicated by the upward gradation of open-marine shales of the Bearpaw and Tent Island formations into the nonmarine, partly coal-bearing sandstones and siltstones of the later Maastrichtian St. Mary River and upper Edmonton formations and the basal sandstone member of the Moose Channel Formation (see Figs. 4, 5). In the Alberta-Liard Trough, this uplift began in the northwest and gradually spread southward and eastward (Jeletzky, 1971a, p. 71, 72). The persistence of the lithological types mentioned above into the upper, definitely or presumably earliest Tertiary parts of these formations, indicates that neither of the two basins experienced any further uplifts either in the younger Maastrichtian or in the earliest Tertiary (Stott in Douglas et al., 1970, p. 464; Young, 1975, p. 23-25). The northern part of the Richardson Mountains-Porcupine Plain Basin, at least, experienced a weak subsidence at or near the Maastrichtian-Tertiary boundary because the upper, or Ministicoog, Member of the Moose Channel Formation is a predominantly tidal-flat to marine shelf deposit (Young, 1975, p. 23-25, 40) and so reflects a limited and short-lived ingression of the ?latest Maastrichtian or ?earliest Tertiary shallow sea into the northeasternmost part of the Richardson Mountains-Porcupine Plain Basin.

The late early to latest Maastrichtian oscillatory history of Sverdrup Basin apparently differed markedly from the oscillatory histories of all other basins studied. In the eastern marginal zone (Balkwill et al., 1975, p. 205), and presumably in other marginal zones as well, the upper (lower Tertiary) beds of Eureka Sound Formation overlap paraconformably the pre-Maastrichtian Cretaceous and older rocks. Neither the marine nor the nonmarine Maastrichtian beds of the basal Eureka Sound Formation are known in this zone. They are presumed to be absent completely either because of nondeposition or, more likely, because of subsequent, early Tertiary erosion (Jeletzky, 1971a, p. 73).

According to Balkwill et al. (1975, p. 205) and to Balkwill and Hopkins (1976, p. 331, 333), at least the lower to mid-Maastrichtian marine to nonmarine rocks of the lower Eureka Sound Formation are preserved in the central part of Sverdrup Basin. In this part of the basin, the late early to latest Maastrichtian phase of oscillatory history begins with a small amplitude uplift. Deposition of previously discussed, presumably mid-Campanian to lowermost Maastrichtian littoral sands and silts of the basal Eureka Sound Formation was replaced by deposition of nonmarine, plant- and lignite-bearing sandstones. According to Balkwill and Hopkins (1976, p. 331), these sandstones, which comprise the topmost beds of the preserved lower part of Eureka Sound Formation in the area, are not younger than mid-Maastrichtian. The presumably absent upper Maastrichtian rocks may or may not have been destroyed by the same early Tertiary (i.e. ?mid-Eocene) orogenic phase which cuts out most or all of the Cretaceous beds in the eastern marginal part of Sverdrup Basin (Jeletzky, 1971a, p. 73; Balkwill et al., 1975, p. 205; Balkwill, pers. comm., 1976). Although incomplete and, in part, questionable (e.g. the attempted refined datings of Maastrichtian rocks on palynology alone), the data available indicate an epeirogenic uplift of the Sverdrup Basin in the Maastrichtian. According to H.R. Balkwill (written com., 1976), this epeirogenic uplift was a rather complex tectonic event; he states: "From late Maastrichtian into the Tertiary the Sverdrup Basin became fragmented, with uplifted blocks (or arches) that supplied clastics to adjacent subsiding basins (much like the southern U.S. Rockies). The entire basin was not uplifted." However, the writer cannot agree with Balkwill's last conclusion. In the writer's opinion, the fragmentation of the Sverdrup basin (and of the southern U.S. Rockies as well) represents but a complicating structural detail of the regional epeirogenic uplift indicated by a complete retreat of the Maastrichtian seas from the basin. Some fault blocks (or arches) have been uplifted considerably more than the others during this uplift. Consequently, the former became local source areas whereas the latter became local, nonmarine depositional basins. The subsidence of these newly formed, nonmarine, depositional basins under their sedimentary load appears to be a localized event which followed closely the regional epeirogenic uplift proper.

This interesting structural detail had to be ignored when compiling the Maastrichtian part of the oscillation graph of the Sverdrup Basin (Figs. 6, 9) which, consequently, reflects only the regional Maastrichtian uplift of the entire basin.

Conclusions

The preceding detailed discussion and comparative analysis of the compiled oscillatory graphs indicate that the histories of Cretaceous transgressions and regressions of the individual basins studied are characterized by an almost complete lack of interbasinal chronological co-ordination. Furthermore, many of the transgressions and regressions are distinctly to markedly diachronous within the individual basins. These two types of transgressions and regressions must have been controlled by differential subsidences (or uplifts) of the bottoms of the individual basins. In some basins a transgression was in progress in one part while a regression proceeded in another area. As pointed out by Jeletzky (1975, p. 43-46, Figs. 17-19) and in preceding sections of this paper, such transgression-regression patterns can be explained only by either the hinge-like movements of the basins concerned or by the unco-ordinated movements of individual fault blocks within them.

None of the transgression-regression patterns discussed, and which were prevalent in the orogenic and intracratonic basins of Western and Arctic Canada, could have been caused or perceptibly influenced by the eustatic fluctuations of sea level. The latter fluctuations are by definition global phenomena which result in a world-wide geological (for all practical purposes only biochronological; Jeletzky, 1956) isochroneity of transgressive and regressive maxima (Suess, 1906, p. 538-544). The above considerations amply justify the earlier conclusions of the writer (Jeletzky, 1971a, p. 75, 76; 1974a, p. 810; 1975, p. 43) that the bulk of the Cretaceous transgressions and regressions in Western and Arctic Canada were not influenced perceptibly, let alone controlled, by the eustatic movements of sea level.

As noted by Jeletzky (1971a, p. 75, 76; 1974a, p. 810) and pointed out earlier in this paper, some isolated instances of the oscillations of sea level in the Canadian basins investigated seem to conform closely to Haug's (1900, p. 683) "law of epeirogenic compensation". As originally conceived (Haug. 1900, p. 683), and subsequently applied (Haug, 1907, p. 505 etc.), this "law" was intended to formulate an allegedly existing world-wide correspondence of ancient transgressions on the "platforms" (i.e. cratons of the present day usage) to ancient regressions in geosynclines (i.e. orogenic belts) and vice versa. The validity of Haug's "law" in this sense was denied by Stille (1924) and a number of other prominent workers of the pre-Second World War period (e.g. Arkhangel'sky, 1923). Its validity was made even more unlikely by the denial of the very idea of a world-wide extent of orogenic phases by Gilluly (1949, 1950), Arkell (1956) and other prominent workers following the end of the Second World War. However, Haug's "law" was considered recently to be valid by some workers in Europe and North America (e.g. Goguel, 1962, p. 31; Jeletzky, 1971a, p. 75, 76; 1974a, p. 810).

Following Yanshin's (1973) convincing demonstration of a complete absence of world-wide co-ordination of transgression-regression patterns in all Phanerozoic periods (p. 22-23, Fig. 11), and the writer's confirmation of Yanshin's results based on the example of the Cretaceous basins of Canada (and some foreign Cretaceous basins) given in this paper (see below; Figs. 8-10), it is no longer feasible to invoke Haug's "law" to explain the previously discussed early Hauterivian to late Aptian and late Turonian to mid-Santonian episodes of "epeirogenic compensation" in Western and Arctic Canada. Nor is it feasible to invoke eustatic movements of sea level to explain these episodes when some of the basins were experiencing approximately synchronized prolonged periods of subsidence while others experienced approximately synchronized periods of uplift. Because the maxima and minima of these major oscillations of sea level were diametrically opposed in the groups of Canadian basins discussed previously (Figs. 8, 9), they must have been tectonically controlled. The instances of "epeirogenic compensation" previously discussed appear to be relatively rare, isolated episodes in the Cretaceous oscillatory history of Western and Arctic Canada. Therefore, they cannot be used to support a "law" that claims to reflect a fundamental world-wide regularity.

The Canadian interregional to subcontinental episodes of "epeirogenic compensation" are now interpreted as examples of unusually large scale, hinge-like tectonic movements involving either large segments of, or even the whole length and width of, the Canadian Cordilleran Orogenic Belt instead of the flanks of a single trough (e.g. Jeletzky, 1975, p. 43-46, Figs. 17-19). Pronounced Mesozoic and Tertiary downwarps of many continental margins discussed by Hallam (1963), Rona (1974) and other workers appear to be other examples of several possible types of such hinge-like (or lever-like) tectonic movements. The commonly inferred (i.e. Haarmann, 1930; Gilluly, 1955, 1965; van Bemmelen, 1976, p. 161, Fig. 9) formation of mantle bulges, aptly called "geotumors" by Haarmann (1930), underneath the marginal or interior part of continental blocks is one geological phenomenon which could have been responsible for these interregional to subcontinental episodes of "epeirogenic compensation". These episodes, however, could have been caused also by the gradual cooling and sinking of the oceanic crust adjacent to the continental margins. As will be pointed out, such gradual cooling and sinking is to be expected as the newly formed oceanic crust is being passively displaced away from the mid-oceanic ridges in the early stages of the opening of new oceans caused by the expansion of the earth (e.g. Carey, 1975).

The obviously intraregional to subcontinental and hence non-eustatic character of all oscillations of sea level cited above leaves us with but three instances of oscillations which occurred approximately at the same time in most or all of the five basins studied. These are the late early to latest Maastrichtian regression, the earliest Albian transgression, and the late early Campanian regression. All of these oscillations are entirely isolated episodes interspersed with long periods of either entirely unco-ordinated or "epeirogenically compensated" oscillations. Furthermore, their durations and acmes coincide only approximately in the different basins studied. This is true even of the truly world-wide, apparently geologically contemporaneous retreat of the seas from the continental blocks which began at rather different times in the different basins studied but peaked at about the same (i.e. late early to latest Maastrichtian) time.

Of the three oscillation episodes mentioned above, that of the late early to late (and especially late) Maastrichtian episode definitely had a global character. As demonstrated by decades of research on most of the continental blocks and repeatedly pointed out by modern workers (e.g. Jeletzky, 1951, p. 8, 9; Matsumoto, 1952, p. 112; Dunbar, 1960; Newell, 1962, p. 608, 609; 1967, p. 86-88, Fig. 10; Hallam, 1969, p. 406), the late early to latest Maastrichtian was the time of either a complete or prevalent retreat of the seas from all continental blocks of the lithosphere. The transitional contacts between the upper Maastrichtian and lowermost Tertiary (i.e. Danian) rocks are exceptionally rare and, to the best of the writer's knowledge (i.e. Jeletzky, 1960b, 1962), confined to the nonmarine facies. The above data, and especially the fact that following the global late Maastrichtian regression the Tertiary seas never returned to their Cretaceous extent on any of the continental blocks of the lithosphere, strongly suggests that this particular regression was caused by a large scale negative eustatic oscillation of sea level.

The appreciable variations in the strength and duration of the late early to latest Maastrichtian regression in all of the Canadian basins studied (Fig. 9) were caused apparently either by local to regional tectonic movements or by different initial positions of these basins in relation to the sea level. These movements perceptibly modified the courses of this regression in the individual basins but were unable either to eliminate or to reverse its principal eustatically caused sense of movement. This finding supports Russell's (1951, p. 47, 66, 67) conclusion that the tectonic movements which occurred in the Front Range of the American Cordillera at the end of the Cretaceous were, invariably, of a small magnitude and were one of the weak preliminary phases of the Early Tertiary Laramide Revolution. The same is undoubtedly true of the other basins discussed in this paper.

The scarcity of usable data makes it difficult to recognize the extent of the other two previously discussed interregional oscillatory events, outside of Western and Arctic Canada, and hence either to establish or to disprove their eustatic nature. However, the earliest Albian transgression apparently was a broadly regional and, hence, a non-eustatic event since it is not discernible in the Cretaceous oscillation graphs compiled by Hancock (1975, Fig. 5; see Fig. 10 of this paper) for the western interior basin of the United States of America and the basin of northern Europe. Furthermore, this transgression is not discernible in the Cretaceous oscillation graph of Kauffman (1973a, Fig. 7; see Fig. 10 of this paper) purporting to represent the closely synchronized transgressive-regressive histories of epeiric seas throughout the world. It is interpreted, accordingly, to be the result of either geo- or mega-undation of the mantle in the sense of van Bemmelen (1976, p. 156, Fig. 7).

The late early Campanian regression appears, in contrast, to be a world-wide event caused largely or entirely by a short-lived eustatic fluctuation of sea level. As indicated in Figure 10, this event is clearly discernible on the above-mentioned oscillatory graphs of Hancock (loc. cit.) and Kauffman (loc. cit.). Should this tentative conclusion be confirmed by further research, a second eustatically caused event would be added to the Cretaceous oscillatory history of Western and Arctic Canada. Even so, these eustatically caused oscillations would be extremely rare exceptions confirming the general lack of interbasinal co-ordination of Cretaceous transgressions and regessions in the Canadian basins studied and hence their non-eustatic nature.

COMPARISON OF CRETACEOUS OSCILLATORY HISTORIES OF CANADIAN BASINS STUDIED WITH THOSE OF SOME FOREIGN BASINS

Most of the recently published foreign graphs of the Cretaceous oscillations of sea level known to the writer (e.g. Russell, 1968, Fig. 2; Grasty, 1967, Fig. 3; Naidin, 1971, p. 12, unnumbered textfig.; Rona, 1973, Fig. 1) cannot be compared meaningfully with the detailed oscillation graphs compiled by the writer for the individual orogenic and intracratonic basins of Western and Arctic Canada. All of the graphs referred to, which invariably purport to summarize the globally synchronous, eustatically controlled transgressions and regressions, are too generalized. They utilize only epochs and periods as geochronological parameters and do not provide any written comments about the timing of transgressional and regressional peaks in terms of paleontological zones and stages. It is possible, however, to compare the Canadian oscillation graphs with some more detailed foreign graphs which use paleontological stages as the principal geochronological parameter. These include:

1. the Cretaceous graph compiled by Kauffman (1973a, p. 364, Fig. 7; 1973b, p. 687) for the allegedly synchronous oscillations of the level of epeiric seas of the globe;

2. the Albian to late Maastrichtian graphs compiled by Hancock (1975, p. 102-104, Fig. 5) for the fluctuations of sea level in northern Europe and the Western Interior region of the United States; and

3. a series of graphs compiled by Matsumoto (1952, Figs. 2-5; 1967, Fig. 2) summarizing the Cretaceous oscillations of sea level in the most important epeiric and orogenic basins of the circum-Pacific region.

The Cretaceous oscillation graphs constructed by Kauffman (1973a, b) and Hancock (1975) indicate, almost exclusively, transgressional peaks and regressional troughs dated in terms of the international standard stages. To facilitate the comparison of these graphs with those of the Canadian basins summarized in Figures 8 and 9, the latter had to be simplified accordingly. The result is presented in Figure 10 and will be analyzed in the following two sections.

Analysis of Kauffman's graph summarizing the global oscillatory history of epeiric seas

As indicated in Figure 10, the oscillatory graph compiled by Kauffman (1973a, p. 364, Fig. 7) begins with a major Berriasian-Valanginian transgression which peaks at or near the end of the Valanginian. This prolonged transgression is not matched in any of the Canadian basins studied. Except for the Tyaughton Trough, the Berriasian-Valanginian history of these basins is characterized either by a regressive or by a pulsating behaviour. However, even the transgression of the Tyaughton Trough differs from that depicted by Kauffman (1973a, p. 264, Fig. 7) in lasting until the late Hauterivian.

The Berriasian-Valanginian transgression is followed by a regression which peaks at or near the mid-Hauterivian (Fig. 10). This regression resembles the Hauterivian-Barremian regressions occurring in the Richardson Mountains-Porcupine Plain Trough, Alberta-Liard Trough, and Sverdrup Basin. However, only in the Richardson Mountains-Porcupine Plain Trough does the regression peak in the mid-Hauterivian, to be followed immediately by a regional transgression. In the other two Canadian basins, the mid-Hauterivian regression lasts either well into or until the very end of the Barremian (Fig. 10).

The Hauterivian history of the Canadian Western Cordillera does not match that indicated in Kauffman's (1973a) graph (see Fig. 10 of this paper). In the Insular Trough the mid-Hauterivian was the peak time of the above-mentioned regional Berriasian to Hauterivian transgression. In the Tyaughton Trough, the mid-Hauterivian corresponds only to the beginning of a prolonged regression which peaks considerably later than the mid-Hauterivian regression of Kauffman (1973a, p. 364, Fig. 7), at or near the Hauterivian-Barremian boundary.

None of the Canadian basins exhibit the individualized late Hauterivian transgression indicated on the graph of Kauffman (e.g. T_2; see Fig. 10).

The brief regression indicated just above the Hauterivian-Barremian boundary in the graph of Kauffman (e.g. R_2; see Fig. 10) is matched closely in the Tyaughton and Insular troughs. It corresponds, however, to the middle part of a prolonged, latest Hauterivian to late Barremian transgression in the Richardson Mountains-Porcupine Plain Trough and forms part of an even more prolonged Hauterivian-Barremian regression in the Sverdrup Basin and the Alberta-Liard Trough.

The brief mid-Barremian transgression of Kauffman (e.g. T_3; see Fig. 10) apparently did no occur either in the Sverdrup Basin or in the Alberta-Liard Trough which experienced the later phase of a prolonged early Hauterivian to late Barremian regression. However, this might reflect only the inherent imperfections of the nonmarine Hauterivian-Barremian record of these two basins. This mid-Barremian transgression is, in contrast, developed in the Richardson Mountains-Porcupine Plain aulacogene, Tyaughton Trough and Insular Trough (Fig. 10), even though the peaking times and the durations of these regional transgressions differ markedly.

Similarily, the late Barremian regression (i.e. R_4 of Fig. 10) indicated below the Barremian-Aptian boundary in Kauffman's (1973a, Fig. 7) graph is matched closely by either short-lived (i.e. in Tyaughton Trough) or long-lasting (e.g. in the Insular and Richardson Mountains-Porcupine Plain troughs) regressions in both succussor troughs and the aulacogene of the Richardson Mountains-Porcupine Plain. However, this regression did not occur either in the Sverdrup Basin or in the Alberta-Liard Trough which began to subside at about that time (Fig. 10).

The strong Aptian transgression peaking just below the Aptian-Albian boundary (i.e. T_4; see Fig. 10) has equivalents closely comparable in the Tyaughton Trough and the Sverdrup Basin. However, in the greater southern part of the Insular Trough this transgression corresponds to the acme of the prolonged Aptian-Albian regression whereas in its northern part it corresponds to the closing stage of the prolonged Aptian regression (see Fig. 4). In the Richardson Mountains-Porcupine Plain Trough, the peak of this transgression closely corresponds to the peak of a minor regression which failed to drain the basin. Finally, in the Alberta-Liard Trough its peak corresponds to the initial stage of a pronounced interregional latest Aptian to earliest Albian transgression.

The brief regression at or slightly above the Aptian-Albian boundary indicated in the graph of Kauffman (1973a, Fig. 7; $R_4$of Fig. 10) has hardly an approximate, let alone exact, equivalent in any of the Canadian basins studied. Four of these basins experienced a strong, regional, earliest Albian transgression at about that time (Fig. 10) and the same may have been true of at least the northern part of the fifth (i.e. of the Insular Trough; see Fig. 4). Only the larger southern part of the Insular Trough was experiencing a prolonged, major regression which included the time of Kauffman's (1973a, Fig. 7) regression.

The mid- to Late Albian transgression indicated in Kauffman's (1973a, Fig. 7; $T_5$of Fig. 10) graph and designated as a "Middle Albian" transgression elsewhere (Kauffman 1973b, p. 687) did not occur at all in the Tyaughton Trough, Richardson Mountains-Porcupine Plain Trough, and Sverdrup Basin (Fig. 10). These basins experienced instead either the early (i.e. Tyaughton Trough, Sverdrup Basin) or the late (i.e. Richardson Mountains-Porcupine Plain Trough) phases of prolonged and pronounced regional regressions which include the time of the brief regression at the Albian-Cenomanian boundary designated R_5in Kauffman's (1973a, Fig. 7) graph. The Insular Trough may have begun already to subside in the latest Albian (see Fig. 4) but even there the peak of the mid- to late (or only mid-) Albian transgression as indicated by Kauffman (1973a, Fig. 7; 1973b, p. 687) must have been equivalent to the late stages of the above-mentioned prolonged Albian regression.

The rapid and rather irregular mid- to latest Albian oscillations of sea level in the Alberta-Liard Trough (Fig. 10) cannot be matched at all with the continuous mid- to late Albian transgression indicated in Kauffman's (1973a, Fig. 7) graph.

It should be noted that the "Middle Albian transgression" marked T_5in Figure 10 also is claimed to be the earliest of four major Cretaceous transgressions consistently present in the cratonic interiors by Kauffman (1973b, p. 687).

The major Cenomanian transgression T_6 (see Fig. 10), also claimed to be the "maximum Cretaceous transgression" (Kauffman, 1973a, p. 365, expl. of Fig. 8), is shown as peaking in the latest Cenomanian or earliest Turonian (Kauffman, 1973a, Fig. 7). This transgression is stated, in another publication (Kauffman, 1973b, p. 687), to be the second of the four Cretaceous transgressions consistently present in the cratonic interiors. The Cenomanian transgression does occur in the Insular and Richardson Mountains-Porcupine Plain troughs (Fig. 10). Furthermore, there is an event roughly approximating this transgression in the Alberta-Liard Trough. However, in this trough the transgression begins in the late Albian (i.e. in the middle part of generalized **Neogastroplites** zone), peaks in the presumably earliest Cenomanian **Neogastroplites septimus** subzone (Figs. 7, 9), and is followed immediately by a strong mid- to late Cenomanian (i.e. Dunvegan) regression.

As far as is known, there was no Cenomanian transgression in the Sverdrup Basin. There, this major transgression of Kauffman (1973a, b) corresponds either exactly or almost exactly with a pronounced regional Cenomanian regression. The same is true of the Tyaughton Trough (Fig. 10).

The strong early to mid-Turonian regression indicated in Kauffman's (1973a, Fig. 7 or R_6 of Fig. 10) graph apparently is of basal to early Turonian age in terms of the biochronological scheme used by Jeletzky (1968a, p. 32) because Kauffman (1975, text-fig. 4) places his uppermost Turonian **Inoceramus schloenbachi** zone in the early Coniacian. This regression does occur in the Tyaughton and Insular troughs (Fig. 10). The latter trough was uplifted above sea level at about that time whereas the former was transformed into a mountainous source area (Figs. 3, 4, 10).

The mid- to late Turonian regression of Kauffman (1973a, Fig. 7) is approximated by a strong and regional late Turonian regression in the Alberta-Liard Trough. It is not represented at all, however, in the Richardson Mountains-Porcupine Plain Trough and Sverdrup Basin which experienced the early stages of a prolonged (i.e. late Cenomanian or early Turonian to mid-Santonian; see Fig. 9) regional subsidence at that time.

The latest Turonian (i.e. latest mid-Turonian in the sense of Jeletzky, 1968a, p. 32) to mid-Santonian transgression, with a peak in mid-Santonian, is shown in Kauffman's (1973a, Fig. 7 or T_7 of Fig. 10) graph. However, this transgression is designated as the late Coniacian to early Santonian transgression elsewhere (Kauffman, 1973b, p. 687) and is claimed to be the third major Cretaceous transgression consistently found in the cratonic interiors. If one uses the dating and peaking shown by Kauffman (1973a) in his Figure 7 and disregards some localized deviations (e.g. the Bad Heart regression in the Alberta-Liard Trough; see Figs. 7, 9) this transgression is well matched in the Alberta-Liard Trough, Richardson Mountains-Porcupine Plain Trough and the Sverdrup Basin (Fig. 10). However, this transgression began much earlier (i.e. in the late Cenomanian or early Turonian) in the Richardson Mountains-Porcupine Plain Trough and Sverdrup Basin which did not experience the mid- to late Turonian regression.

The Tyaughton and Insular troughs did not experience the late Turonian to mid-Santonian transgression at all. Instead these troughs experienced a pronounced regional regression which uplifted their former depositional areas well above sea level and transformed them into mountainous source areas (see Figs. 3, 4, 9).

As mentioned previously, the late Santonian to early Campanian regression of Kauffman (1973a, Fig. 7), which peaked at or near the middle of the early Campanian, corresponds closely to the late early Campanian regressive episode in Western and Arctic Canada. The latter episode was felt in at least four out of five Canadian basins studied (see p. 15-16, Figs. 9, 10). This suggests that this late Santonian to early Campanian regression was eustatically caused (compare p. 16). However, the approximate time span of the late Santonian to mid-Campanian regression of Kauffman (1973a, Fig. 7) is represented by a pronounced late Santonian to earliest Campanian transgression and an equally pronounced late early Campanian regression in the Insular Trough. Furthermore, an approximately equal time span is occupied by two regressional episodes intercalated with a pronounced transgressional episode in the Alberta-Liard Trough.

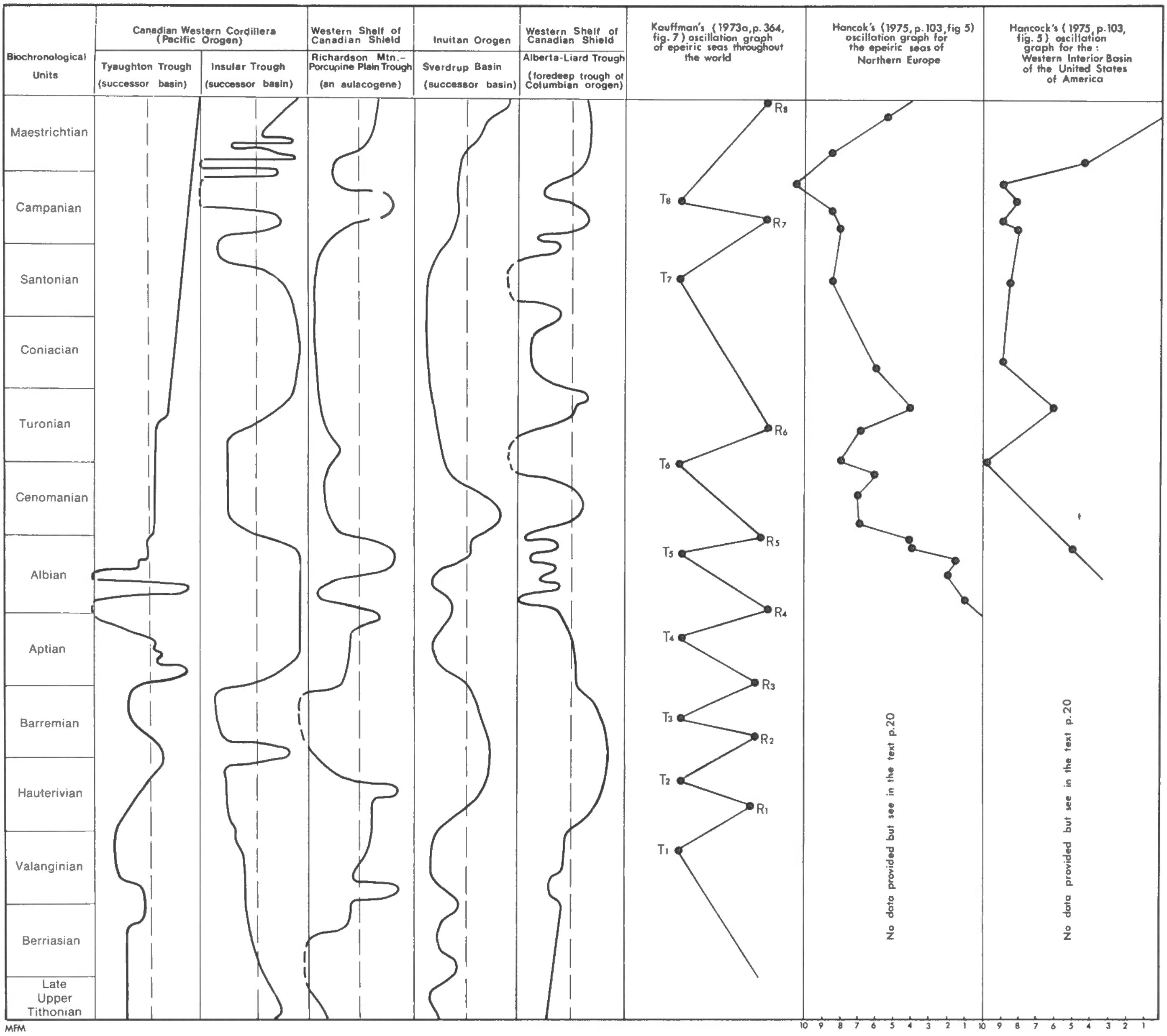


Figure 10. Comparison of the Cretaceous oscillation graphs of the Canadian basins summarized in Figs. 8, 9 with the oscillation graphs compiled by Kauffman (1973a, p. 364, Fig. 7) and Hancock (1975, p. 103, Fig. 5). Kauffman's (loc. cit.) graph is reversed to conform with the orientation of the peaks of transgressions and regressions adopted by Hancock (loc. cit.) and the writer (see Figs. 3-9). The inferred positions of the mean sea level and all other semiquantitative data indicated elsewhere (see Figs. 3-9) for the Canadian graphs are omitted. No attempt was made to reproduce the relative levels of the peaks of transgressions and regressions shown in the original graph of Kauffman (loc. cit.) as it was not possible to infer their relative positions to the mean sea level. All radioactive ages indicated in the original diagrams of Kauffman (loc. cit.) and Hancock (loc. cit.) are omitted. The writer considers all such attempts at the radioactive dating of the Cretaceous oscillatory events to be meaningless and hence misleading for reasons explained in the text.

The approximately dated mid-Campanian regression in the Richardson Mountains-Porcupine Plain Trough may or may not have been partly contemporaneous with the R_7 regression of Figure 10. Finally, there is no indication of this late Santonian to mid-Campanian regression in the region of the former Tyaughton Trough which apparently was rising and wasting setadily before, throughout and after this time.

The mid-Campanian transgression, peaking at or near the early late Campanian boundary (Kauffman, 1973a, Fig. 7 or $T_8$of Fig. 10) was claimed to be the latest of the four major Cretaceous transgressions consistently found in the cratonic interiors in another publication (Kauffman, 1973b, p. 687). This transgression has some close analogues in Canada (Fig. 10). The most closely comparable major transgressions, such as the Cedar District transgression in the Georgia Basin of the Insular Trough, the Bearpaw transgression in the Alberta-Liard Trough, and apparently (dating is poor) the Tent Island transgression in the Richardson Mountains-Porcupine Plain Basin, had their start in the early late Campanian (either in **Hoplitoplacenticeras vancouverense** time or later; see Jeletzky, 1971a, p. 66, 69; Young, 1975, p. 10, 11, Table 5) and lasted through most or all of the late Campanian and, in places, into the earliest Maastrichtian. In the Sverdrup Basin and, as far as is known, in the Tyaughton Trough, the time of this mid-Campanian transgression was occupied by regional uplifts (Figs. 3, 6, 9).

The terminal Cretaceous regression, definable as the late Campanian-Maastrichtian regression from Kauffman's (1973a, Fig. 7; 1973b, p. 687 and $R_8$of Fig. 10) chart and comments, starts appreciably later in most of the Canadian basins studied (Fig. 9). However, as pointed out in the preceding section, this discrepancy does not alter its global, presumably eustatically controlled nature.

The above analysis of the Cretaceous oscillation graph of Kauffman (1973a, p. 364, 365, Fig. 7; 1973b, p. 687), alleged to represent the closely co-ordinated oscillations of epeiric seas of the globe, demonstrates conclusively that it does not agree closely with the Cretaceous oscillatory history of any of the orogenic and intracratonic basins of Western and Arctic Canada studied by the writer. Some examples of reasonably close agreement in duration and timing of individual pulsational events and their peaks are restricted almost invariably to some (mostly one to tree only) of the Canadian basins. These examples of reasonably close agreement of oscillatory pulses are, furthermore, completely haphazardly distributed among the five Canadian basins studied. The similarity of the oscillatory histories of the Canadian intracratonic basins, including the history of the Alberta-Liard Trough, is no closer to the oscillatory history depicted in Kauffman's (1973a, Fig. 7) graph than is that of the Canadian orogenic successor troughs. This non-correspondence of Cretaceous oscillatory history of the Canadian intracratonic troughs to that depicted by Kauffman (1973a, Fig. 7; 1973b, p. 867) is especially significant since the latter is expressly stated to be valid only for most (over 50%) of the epeiric seas of the globe.

On the whole, these examples of reasonably close correspondence between the oscillatory pulses observed in the Cretaceous basins of Western and Arctic Canada and those depicted in Kauffman's (loc. cit.) oscillatory curve appear to be coincidental only, with the exception of the terminal regressive event in the Maastrichtian and the possible exception of the late Santonian to early Campanian regression.

Kauffman (1973a, p. 464, 465, Fig. 7; 1973b, p. 687) did not publish any factual data supporting his conclusions and generalizations. Consequently, his oscillation graph had to be analyzed as it is on the assumption that the background data are sound. However, there are some reasons to doubt this.

First, as previously pointed out by Hancock (1975, p. 104, expl. of Fig. 5): "The diagram by Kauffman (1973a, Fig. 7), said to be based on world evidence, agrees rather closely with the graph given here for Europe. In contrast, a similar diagram by Matsumoto (1967, Fig. 2) would seem to show significant differences from the European graph for eastern Brazil, South Africa-Madagascar, Southern India, and Japan". With the sole exception of Japan, the regions mentioned by Hancock (loc. cit.) are cratonic regions, the oscillatory history of which should agree closely with those compiled by Hancock (loc. cit.) and Kauffman (loc. cit.), if the latter is globally valid.

Second, the Cretaceous parts of oscillatory graphs of all better known major continental regions compiled by Yanshin (1973, Figs. 6, 7) and analyzed below (see p. 22, 23, Fig. 11) also exhibit numerous and strong differences from the graph compiled by Kauffman (loc. cit.). It is to be hoped that these discrepancies will be resolved soon by publication by Dr. E. Kauffman of a comprehensive paper including the background data concerned.

Analysis of oscillatory graphs of northern European and United States Western Interior basins

The oscillatory graphs compiled by Hancock (1975, p. 102-104, Fig. 5) to summarize the Albian to late Maastrichtian fluctuations of sea level in northern Europe and the Western Interior of North America and compared with those of the Canadian basins in Figure 10 require some general comments.

First, the graph said to cover the Western Interior of North America (Hancock, 1975, p. 102, 104, expl. of Fig. 5) actually excludes the Western Interior region of Canada. This is made obvious by comments made elsewhere in the text (e.g. Hancock, 1975, p. 85, 104).

Second, the graph implicitly covers the pre-Albian oscillatory history of the Western Interior region of the United States also, since the latter consists basically (at least as far as is known) of a continuous episode of uplift and erosion recorded only by accumulation of various nonmarine sediments in local depressions (Cobban and Reeside, 1952). The same is basically true of northern Europe.

This second general point is particularly important in revealing the profound dissimilarity of the Berriasian to Aptian oscillatory histories of northern Europe and the Western Interior of the United States to the much more complex, mainly marine contemporary oscillatory histories of all five Cretaceous basins of Western and Arctic Canada analyzed in this paper (Fig. 10).

Although undoubtedly similar, the Albian to Maastrichtian oscillatory histories of northern Europe and the Western Interior region of the United States are not as similar as it is believed by Hancock (1975, p. 102-104, Fig. 5). This is illustrated by the comments made below in conection with the comparison of these histories with the Cretaceous oscillatory histories of the Canadian basins studied. It was necessary to handle the discussions of oscillatory histories of northern Europe and the Western Interior of the United States separately in several instances and to separate the graphs themselves (Fig. 10).

The Albian oscillatory history of both northern Europe and the Western Interior of the United States is one of an almost steadily progressing transgression. It is so unlike the Albian oscillatory histories of all five Canadian basins studied (Fig. 10) that there is no need for further comment.

The Cenomanian history of the Western Interior region of the United States is a continuation of the above mentioned Albian transgression. Considered alone, this Cenomanian transgression corresponds to the Cenomanian transgression in the Insular and the Richardson Mountains-Porcupine Plain troughs of Canada (Fig. 10). However, the immediately preceding and the immediately following stages of oscillatory histories of these two troughs differ markedly from the corresponding stages of the history of the American basin.

The Cenomanian histories of the Tyaughton Trough, Sverdrup Basin, and Alberta-Liard Trough (Fig. 10) are almost the reverse of the Cenomanian history of the Western Interior region of the United States in being dominated by regional regressions which brought most or all of these troughs above sea level. The regression was short lived in the Sverdrup Basin and the Alberta-Liard Trough where it lasted only through the early and mid-, or through mid- to late Cenomanian. However, in the Tyaughton Trough it ushered in a permanent inversion.

The occurrence of a mid- to early late Cenomanian (i.e. Dunvegan) regression in the Alberta-Liard Trough is especially interesting since the trough forms part of the Western Interior basin of Canada (Fig. 2) which represents a direct northward continuation of the Western Interior basin of the United States. The situation was caused apparently by a strong but short-lived mid-Cenomanian uplift of the Mackenzie Salient (Jeletzky, 1971a, p. 49, Fig. 11) combined with strong but equally short-lived mid-Cenomanian subsidence in the southernmost Canadian Foothills and farther south.

The more complex Cenomanian oscillatory history of northern Europe (Hancock, 1975, Fig. 5) differs from that of the Western Interior of the United States in the presence, in the former region, of a marked mid- to early late Cenomanian regression which appears to correspond closely to the Dunvegan regression in the Alberta-Liard Trough and the unnamed Cenomanian regression in the Sverdrup Basin (Fig. 10). This regression also parallels the initial Late Cretaceous uplift in the Tyaughton Trough (Figs. 3, 9). However, the Cenomanian oscillatory history of northern Europe is almost the reverse of the Cenomanian histories of the Insular and Richardson Mountains-Porcupine Plain troughs which experienced regional subsidences during that same time (Fig. 10).

The latest Cenomanian to early Turonian transgression immediately followed by the late Turonian regression in northern Europe and the Western Interior region of the United States (the two graphs are identical at that time; Hancock, 1975, Fig. 5) are closely matched only in the Alberta-Liard and the Insular Troughs (Fig. 10). In Sverdrup Basin and Richardson Mountains-Porcupine Plain Trough, there is no trace of the late Turonian regression. In contrast, the Tyaughton Trough does not exhibit any traces of early Turonian transgression but registers the mid- or late (dating is very poor) Turonian uplift (Fig. 9).

As noted by Hancock (1975, p. 104), the Coniacian to mid-Campanian sections of the northern European and United States Western Interior oscillation graphs are markedly different. Like the Cenomanian parts of the graphs, they must be analyzed separately.

The graph of the Western Interior region of the United States begins with an earliest Coniacian (latest Turonian according to Jeletzky, 1968a, p. 32) transgression peaking in the early Coniacian and followed by a prolonged but small-amplitude regression peaking in the earliest Campanian. The latter regression is followed by a small-amplitude early Campanian transgression which, in turn, is followed by a small-amplitude mid-Campanian regression. This oscillatory graph resembles the Coniacian to mid-Campanian part of the graph of the Alberta-Liard Trough, although the latter exhibits an additional earliest Santonian (i.e. Bad Heart) regression which is unknown in the American region (another instance of hinge-like tectonic movements). The United States Western Interior graph, however, does not resemble any of the other Canadian oscillatory graphs (Fig. 10), except for the presence of the nearly ubiquitous late Santonian to earliest Campanian regressive episode.

The northern European graph (Hancock, 1975, p. 104, Fig. 5), characterized basically by a prolonged, gradual levelling off of the earliest Coniacian to mid-Campanian transgression, with a barely suggested earliest Campanian regressive notch, does not resemble closely the corresponding part of the oscillation graph of the Alberta-Liard Trough (Fig. 9), except for the regressive notch. Nor does it resemble that of the now inverted Tyaughton Trough. However, this basically transgressive graph is comparable with the earliest Coniacian to mid-Campanian parts of the graphs of the Insular and Richardson Mountains-Porcupine Plain troughs and the Sverdrup Basin (Fig. 10).

The late Campanian to Maastrichtian parts of northern European and Western Interior of the United States graphs are nearly identical (Hancock, 1975, p. 104, Fig. 5). They are comparable to the corresponding parts of oscillation graphs of the Alberta-Liard and the Richardson Mountains-Porcupine Plain troughs (Fig. 10) where the late Campanian transgressions are followed immediately by the latest Campanian to late Maastrichtian regressions.

The late Campanian to Maastrichtian part of the graph of the Insular Trough differs markedly because of the presence there of several previously discussed, closely spaced late Campanian to earliest Maastrichtian transgressions and regressions. However, it ends in the late early to ?latest Maastrichtian regression just as the other graphs do (Fig. 10).

The late Campanian to Maastrichtian part of the graph of the Tyaughton Trough region appears to reflect a simple continuous uplift.

Finally, the late Campanian to Maastrichtian part of the graph of the Sverdrup Basin (Fig. 10) differs in the apparently complete absence of the late Campanian transgression.

Like the late early to latest Maastrichtian emergence of the Canadian basins studied, that of the northern European and the Western Interior of the United States regions corresponds to the global terminal Cretaceous regreat of the seas from all continental blocks of the lithosphere.

The bulk of pre-Maastrichtian events of the Cretaceous oscillatory histories of northern Europe and the Western Interior of the United States do not agree closely with the Cretaceous oscillatory history of the orogenic and intracratonic basins of Western and Arctic Canada studied by the writer. Except for the late Santonian to early Campanian regressions, the few examples of reasonably close agreement of duration and timing of individual pulsational events and their peaks are restricted to some (mostly one to three only) of the Canadian basins. These examples of reasonably close agreement of oscillatory pulses, furthermore, are haphazardly distributed among the five Canadian basins studied. The oscillatory histories of the Canadian intracratonic basins, including that of the Alberta-Liard Trough, do not resemble the oscillatory histories of the northern European and the United States Western Interior regions any more than they do those of the Canadian orogenic successor troughs. This overall non-correspondence of pre-Maastrichtian oscillatory episodes in the Canadian basins with those in northern Europe and, especially, with those in the adjacent Western Interior region of the United States, is most significant. It indicates that the isolated instances of close agreement of oscillatory pulses are either entirely coincidental or, using Arkell's (1956, p. 641) words, were caused by "spasms in the mobile belts (which) were great enough to affect very large areas". This result of the analysis of the oscillatory graphs compiled by Hancock (1975, p. 102-104, Fig. 5) duplicates the results of the analysis of the graph compiled by Kauffman (1973a, p. 264, Fig. 7; 1973b, p. 867) presented in the preceding section of this paper.

Hancock (1975, p. 113) stated: "The major transgressions and regressions are simultaneous on the two continents. Because the European graph has been deliberately built from evidence around tectonically quiet massifs, it probably gives a closer picture of world-wide changes of sea level. The differences in the Western Interior during the Coniacian to Middle Campanian result from the 'noise' of Sevier orogenic movements, but, in general, transgressions and regressions in the Western Interior are independent of local tectonics and, therefore, must have been controlled by world-wide eustatic movements". The present writer consideres this sweeping conclusion completely unfounded for the following reasons:

1. Hancock's (loc. cit.) research was limited to only two relatively small regions of the continental lithosphere which must have been situated in proximity to each other in the Cretaceous, regardless of whether one favors the hypothesis of the expanding earth (e.g. Carey, 1975) combined with the undation hypothesis of van Bemmelen (e.g. 1976) (as the writer does) or that of the global plate tectonics (as Dr. J. Hancock does). Contrary to the previously cited statement of Hancock (1975, p. 113), his conclusions are not based on the study of oscillatory histories of "the two continents" concerned but only on regions of northern Europe and the Western Interior of the United States of America.

2. The actually close, but far from complete, correlation of oscillatory movements characteristic of northern Europe and the Western Interior of the United States, breaks down completely in such adjacent regions of North America as Western and Arctic Canada. This was amply demonstrated in the preceding paragraphs of this section.

3. Matsumoto's (1967, Fig. 2) research of Cretaceous oscillation patterns in the circum-Pacific region does not favor their control by the eustatic, world-wide changes of sea level as it was pointed out by Hancock (1975, p. 103, expl. of Fig. 5) himself; and

4. The review and analysis of the Cretaceous oscillation graphs produced by Kauffman (1973a, b), Matsumoto (1952, 1967), and Yanshin (1973) undertaken in this paper flatly contradicts the world-wide eustatic control of the ancient transgressions and regressions in the Cretaceous.

In these circumstances, most of which were known to Hancock (loc. cit.), it is more reasonable to ascribe the far-reaching, but far from complete, similarities of the Cretaceous oscillatory histories of northern Europe and the Western Interior region of the United States to the action of particularly strong tectonic pulses which were powerful enough to affect at least the adjacent parts of neighbouring blocks of the continental lithosphere (e.g. Arkell, 1956, p. 641). For example, the well-documented cases of pronounced Mesozoic downwarps of continental margins (e.g. Hallam, 1963; Rona, 1974) indicate that such downwarps may have been approximately simultaneous on the margins of continents facing each other across spreading oceans of the Atlantic type. It is, in fact, theoretically logical to expect such behaviour of the Atlantic type continental margins. The commonly inferred gradual cooling and sinking of the newly formed oceanic crust as it moves in both directions away from the mid-oceanic ridges can be expected to exert a downward pressure on the adjacent parts of continental blocks on both sides of any expanding ocean of the Atlantic type. This downward pressure, more than any of the factors considered by Hallam (1963) and Rona (1974), may be responsible for the observed downwarps of the continental margins. At the same time, it provides an admittedly hypothetical but plausible mechansim for the simultaneous or nearly simultaneous transgressions on both sides of the widening Atlantic type oceans, especially if one assumes that the spreading of the oceanic crust resulting from the increase of the globe's radius occurred in individualized surges or pulses. The above hypothesis appears to offer a much more plausible overall explanation for the recurring, but by no means persistent, similarities existing between the oscillatory histories of the Cretaceous basins of northern Europe and the Western Interior of the United States than their eustatic control as invoked by Hancock (1975, p. 113). The writer does not deny the possibiity of eustatic control of these movements in principle, since he actually favors such a control in the case of the Maastrichtian regression in northern Europe and the Western Interior of the United States. However, he is unable to see any justification for the assumption made by Hancock (1975, p. 113) of such control of the bulk of earlier Cretaceous transgressions and regressions in these two regions.

Analysis of Matsumoto's graphs summarizing the oscillatory history of principal basins of circum-Pacific region

Matsumoto's (1952, Figs. 2-5; 1967, Fig. 2) graphs summarizing the Cretaceous oscillatory history of the principal basins of the circum-Pacific region have been compiled using the same methods and principles as those employed by the writer in compiling the Canadian graphs (Figs. 8, 9) described and analyzed in the preceding sections of this paper. Furthermore, Matsumoto's (loc. cit.) graphs and, particularly, the earlier set of much less generalized, regionally restricted graphs (Matsumoto, 1952, Figs. 2-5), include sufficient factual background data to understand why they were drawn the way they are. Therefore, it is unnecessary to analyze Matsumoto's (1952, 1967) oscillation graphs in the same way that the writer analyzed the graphs published by Kauffman (1973a, b) and Hancock (1975). It suffices to state that the writer agrees with the bulk of Matsumoto's (1952, 1967) conclusions and to make a few brief comments on some of his results which bear on particularly interesting aspects of the Cretaceous oscillatory history of the investigated basins of Western and Arctic Canada.

Like the Canadian oscillatory graphs (Figs. 8, 9) compiled by the writer, Matsumoto's (1952, Fig. 2) graphs indicate that the Cretaceous oscillatory histories of several Japanese basins studied were, for the most part, only poorly coordinated with one another. Another prominent feature of these histories is the generally short duration of transgressions and regressions in terms of the biochronological time scale. However, most (but not all!) of the Japanese basins studied feature pronounced Hauterivian-Barremian and Aptian-Albian transgressions separated by a regression accompanied by orogenic movements. Another prominent feature of these histories is the common (but again not invariable!) presence of a regression at or near the Albian-Cenomanian boundary. The Cenomanian-Turonian transgression is well developed only in some basins, such as the Mid-Kyushu Parageosyncline and Kuma-Kii "Labile Shelf". Some other basins (e.g. Kitakami-Abakuma "Shelf") experienced marked regressions and were uplifted above sea level at exactly the same time when the former basins experienced the Cenomanian-Turonian transgression whereas yet others (e.g. the Hokkaido-Saghaline Geosyncline) apparently were neither transgressive nor regressive. A strong Coniacian to mid-Campanian transgression is a ubiquitous feature of all marine basins of Japan. It was followed by what Matsumoto (1952, Fig. 2) originally believed to be an equally ubiquitous Maastrichtian-Danian regression. However, this regression was later recognized (Matsumoto, 1960, Fig. 2) as an entirely Maastrichtian event except, possibly (Matsumoto, 1960, p. 52), in the Hokkaido-Saghaline Geosyncline. The summation of the above oscillatory histories in a unified oscillatory graph said to be representative of all Japan (Matsumoto, 1967, p. 50, Fig. 2) is an overgeneralization in the writer's opinion.

The above comments are sufficient to show that the Cretaceous oscillatory history of Japanese marine basins, which is poorly coordinated in itself, is not coordinated at all with that of any of the investigated basins of Western and Arctic Canada. This appears to be true even of the Tyaughton and Insular Troughs of western British Columbia which are situated geographically closest to Japan. In fact, the oscillatory history of the Insular Trough with its prolonged Aptian-Albian and late Turonian to late Santonian periods of regression (Figs. 8, 9) is, perhaps, the least similar to that of any of the Japanese marine basins analyzed by Matsumoto (1952, Fig. 2).

THE SIGNIFICANCE OF CRETACEOUS SEGMENTS OF PHANEROZOIC OSCILLATION GRAPHS OF YANSHIN

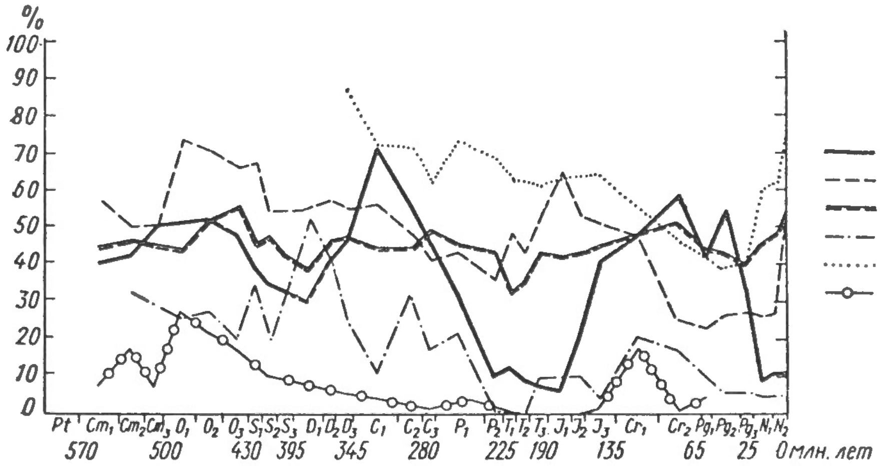
It has been pointed out that it is impossible to compare the detailed oscillatory graphs of the Canadian Cretaceous basins studied with the Cretaceous segments of the Phanerozoic oscillation graphs compiled by Yanshin (1973, Fig. 6, 7) for all the better known, major continental regions of the globe. These graphs were compiled using a method which is utterly different from that employed by the writer. The method used (Yanshin, 1973, p. 20) consisted of a rough planimetric estimation of the areas which were shown to be occupied by ancient seas on all available series of regional to continental paleogeographical maps compiled by various workers for successive ages or epochs of the Phanerozoic time. These estimates were used then to determine the ratios of these major regions of the continental lithosphere occupied by ancient seas in successive ages and epochs of the Phanerozoic. The results were arranged into a series of graphs which then were plotted against the geological time axis (Yanshin, 1973, Figs. 6, 7) and analyzed.

It must be stressed in this connection that the superficially similar method of analysis used by Hallam (1969, p. 54-61, Figs. 3-8; 1975, p. 165-173, Figs. 8.2-8.7) to reconstruct the Jurassic oscillatory history of the globe is actually completely unlike Yanshin's (1973) method. Instead of compiling these data separately for each of the major Jurassic regions of the continental lithosphere and then comparing the resulting graphs with one another, Hallam (loc. cit.) plotted the areas occupied by seas on the continents in different Jurassic ages or epochs on a series of very crude global maps. The obtained percentage data were then compiled into a single oscillatory graph representing the transgression-regression regime of the whole globe. Unlike Yanshin's (1973) broadly regional to continental oscillatory graphs, this global graph is meaningless for the decision as to whether or not the Jurassic oscillations of the sea level were global and hence eustatically controlled.

Although similar in principle to the graphs of the oscillations of sea level compiled by Matsumoto (1952, 1967), Hancock (1975), and the writer (Figs. 3-9), Yanshin's (1973) graphs are much less refined than these, being compiled mechanically (statistically), for much longer spans of geological time. Because of the method of compilation employed, none of the qualitative, refined data incorporated in graphs of the writer and his predecessors were considered by Yanshin (1973, p. 20). And yet Yanshin's (1973) graphs in general, and their Cretaceous segments in particular, are most important for our purposes. Unlike the graphs of Matsumoto (1952, 1967), Hancock and the writer (Fig. 8, 9), Yanshin's (1973, Figs. 6, 7) graphs cover all the better known, major geological regions of the globe. Therefore, they are much better suited to provide the ultimate answer to the question of whether or not the Cretaceous transgressions and regressions were global in scope and hence eustatically controlled. Furthermore, Yanshin (1973, p. 22-27) supplements his crude but workable graphs with valuable, fairly detailed written comments which permit an insight into why the details of these graphs have been arranged as they are. The following text is a brief summary of Yanshin's comments arranged around the reproduction of his Figure 6 (i.e. Fig. 11 of this paper) and supplemented by some critical comments.

The Cretaceous oscillatory regime of the western half of USSR, including the West Siberian Depression (Yanshin, 1973, p. 22, Fig. 6.1), was characterized by a prolonged transgression which began in the earliest Cretaceous and reached its acme in the Turonian. It was followed by a prolonged regression which reached its acme at or near the Cretaceous-Tertiary boundary. The Cretaceous regime of the eastern half of USSR, beginning roughly east of Yenissei River (Yanshin, 1973, p. 23, Fig. 6.2) was dominated, in contrast, by an equally pronounced regression which continued from the beginning to the very end of the Cretaceous. During its end phase the sea persisted only in some areas of the Sakhalin Island, Kamchatka Peninsula, Koriak Plateau and Novosybirski Islands.

The Early Cretaceous regime of North America compiled from Schuchert's (1955) paleogeographical maps and evidently pertaining only to the eastern and central parts of the subcontinent (Yanshin, 1973, p. 24, Fig. 6.3) is dominated by a prolonged transgression. Its course was entirely similar to that of the western half of USSR according to Yanshin (1973). However, this is an obvious oversimplification because the pre-Albian seas are all but absent in the greatest part of eastern and central North America and its overall Berriasian to Aptian oscillatory history should be more properly designated as a regression followed by an Albian transgression. This is a good example of the disadvantages of the planimentrical method used by Yanshin (1973). The Early Cretaceous transgression of North America reached its acme in the Turonian. According to Yanshin (1973, p. 24), this Turonian acme coincides with that of the transgression in the western part of USSR. The North American transgression was followed by a regression which lasted till the end of the



1. *Western half of U.S.S.R.;*
2. *Eastern half of U.S.S.R.;*
3. *North America;*
4. *South America*
5. *Japan and regions adjacent to it;*
6. *Australia.*

Figure 11. Graphs of development of transgressions and regressions in different major regions of the continental lithosphere (from Yanshin, 1973, p. 22, Fig. 6).

Cretaceous. It should be noted that the acme of this regression coincides with the acme of the Late Cretaceous regression in the western part of USSR.

The Early Cretaceous regime of South America (Yanshin, 1973, p. 26, Fig. 6.4) features a long lasting transgression which was limited to the western half of the subcontinent. This transgression began in the early Tithonian (= mid- to late Kimmeridgian) and reached its acme in the Aptian when it spread to some parts of the Atlantic seaboard of South America. Thereafter, a prolonged regression began which lasted through the Albian and the Late Cretaceous and into the Tertiary. In the Maastrichtian, as in all other places, the sea all but left the continental surface of South America. As stressed by Yanshin (1973, p. 25), this oscillatory regime is unlike any of the previously discussed Cretaceous regimes. However, once again, Yanshin (loc. cit.) obviously misses the global extent of the Maastrichtian regression.

Yanshin (1973, p. 26, Fig. 6.5) claims a complete absence of the Cretaceous transgression in the region of the Japanese Islands and in unspecified adjacent areas. This claim, however, conflicts with the results of a more detailed analysis carried out by Matsumoto (1952, p. 111, Fig. 2; 1967, p. 55, Fig. 2) and discussed elsewhere in this paper. This discrepancy illustrates again the extreme crudeness of the method used by Yanshin (ibid.) as compared with that used by Matsumoto (ibid.) and the writer. However, it does not alter Yanshin's (ibid.) basic conclusion that the Cretaceous oscillatory regime of the Japanese region differed fundamentally from those of all regions previously discussed.

Finally, the Cretaceous oscillatory history of Australia (Yanshin, 1973, p. 27, Fig. 6.6) features a prolonged latest Jurassic to late Barremian regression which apparently resulted in a total emergence of this continent. This continental regression, which is widespread in the southern hemisphere (e.g. in New Zealand) but is uncharacteristic of the Northern Hemisphere, was followed by a widespread epicontinental Aptian-Albian transgression. This transgression was followed by another prolonged regression which lasted till the end of the Cretaceous. Here again, Yanshin's (ibid.) conclusions about the absence of Late Cretaceous transgression in Austrailia is an over-simplification (compare Matsumoto, 1967, Fig. 2, graph for Western Australia). However, the presence of a weak late Coniacian to Campanian transgression in Western Australia does not invalidate Yanshin's (ibid.) principal conclusion that the oscillatory history of the Australian continent was different from that of all other regions analyzed.

However imperfect they may be, the results of Yanshin (1973), summarized in Figure 11, do substantiate the absence of world-wide contemporaneity of Cretaceous oscillations of sea level and of an intercontinental coordination of their peaks. Together with the preceding critical analysis of the contrary conclusions of Kauffman (1973a, b) and Hancock (1975), the information available amply demonstrates that the claims of all previously cited modern workers that the Cretaceous transgressions and regressions were world-wide and hence eustatically controlled are erroneous.

Yanshin (1973, p. 36, 37, Fig. 7) also analyzes the patterns of Cretaceous transgressions and regressions within the principal ancient (i.e. Precambrian) platforms of the globe using the same planimetric method. The results of this analysis duplicate the results of the analysis of the Cretaceous transgressions and regressions of the principal continental blocks of the globe. Therefore, there does not seem to be any need to review these results in any detail in this paper. It should be pointed out, however, that Yanshin's (1973, p. 36, 37, Fig. 7) results contradict the claims of essential contemporaneity of transgressions and regressions of the Cretaceous epeiric seas on the global scale made by Kauffman (1973a, b).

THE VALIDITY OF ARKELL'S SYNTHESIS OF JURASSIC OSCILLATORY HISTORY

As mentioned previously, the writer relies on the results of Arkell's (1956) masterly analysis of the Jurassic of the globe which indicates the absence of any world-wide orogenic and epeirogenic movements and the absence of any proof of the existence of world-wide transgressions and regressions in the Jurassic. These conclusions are summarized as follows (Arkell, 1956, p. 641):

> So far as our knowledge goes at present, it does not point to any master plan of universal, periodic, or synchronized orogenic and epeirogenic movements. The events were episodic, sporadic, not periodic. There was no "pulse of the earth".
>
> Different regions of the earth had different histories, but some spasms in the mobile belts were great enough to affect very large areas. Perhaps a strong spasm in one part of a mobile belt would touch off others at points of weakness or mounting unbalance in distant parts of the globe. Movements under the huge water reservoir of the Pacific could have repeatedly caused world-wide changes of sea level but the effects of these would vary according to the relief in different parts of the world and might often be modified by local land movements.

These conclusions of Arkell (loc. cit.) were challenged recently by Hallam (1969, 1975) who suggested that the Jurassic transgressions were, in fact, eustatically controlled. Hallam (1969, p. 45, 46) stated:

> Although Arkell's masterly synthesis (1956) still provides the basis for present knowledge of the Jurassic, the vast amount of work done since its publication necessarily demands reappraisal of many of his conclusions. In earlier studies, summarized in Duff et al. (1967), I have inferred world-wide changes in sea level to account for certain major marine transgressions and regressions which previously had been related to local subsidence, uplift and erosion. An attempt is here made to assess the general role of eustasy in the Jurassic and to explore possible relationships with regional diastrophism.

As stated by Hallam (1969, p. 63), this reappraisal of Arkell's (1956) conclusions was undertaken for the following reasons:

> With regard to the dominant Jurassic motive of transgression it appears more plausible to invoke a eustatic rise of sea level than a more or less uniform subsidence of the continents. Admittedly regional subsidence and relief must have played a role in controlling the variable extent of transgression from one stage to the next in different parts of the world, but this appears to be only a subsidiary factor. To support the eustatic hypothesis, a structure or structures on the ocean floor must be sought whose uplift was of the required amount and rate to account for the deduced rise in sea level from the Hettangian to the Oxfordian.
>
> Such a structure is the Darwin Rise in the Pacific, which according to Menard (1964) was established as a huge oceanic welt by about the middle of the Cretaceous (sic; writer's note). Subsequent to this time progressive subsidence began which had continued to the present. Menard has estimated that this subsidence was sufficient to lower sea level by about 100 m. Taking a figure of 100

million years for the approximate time of subsidence, this gives an approximate mean rate of eustatic fall of 1 mm/10^3years. Because of lack of evidence, Menard (1964, p. 241) is obliged to dismiss the earlier history of the rise with the statement (sic; writer's note): "Sometime during the Mesozoic the Darwin Rise was elevated as a vast bulge of the mantle in the western and central Pacific.

Unfortunately for Hallam's (loc. cit.) thesis, all of the above-cited arguments in favour of the eustatic control of the Jurassic transgressions are invalid. As already mentioned in connection with the discussion of Yanshin's (1973) oscillatory graphs (p. 22), Hallam (1969, p. 54-61, Figs. 3-8; 1975, p. 165-173, Figs. 8.2-8.7) does not compile the planimetrically estimated spaces occupied by the successive Jurassic seas on the continents separately for each of the major Jurassic regions of the continental lithosphere in order to compare the resulting oscillatory graphs with one another. Instead, Hallam (loc. cit.) plots these planimetrically estimated spaces on a series of very crude global maps. The obtained percentage data are then compiled into a single oscillatory graph representing the Jurassic transgression-regression plot of the whole globe. When drawing the above cited conclusions from this global graph Hallam (loc. cit.) fails to see that the latter is meaningless for the decision as to whether or not the individual Jurassic oscillations of the sea level have been coordinated from one major Jurassic region to another. However, only the presence of such coordination would demonstrate their being global in scope and hence presumably eustatically controlled. Furthermore, Hallam's (loc. cit.) appeal to the possible influence of Darwin's Rise upon the Jurassic fluctuations of sea level is not supported by any geological evidence which would as much as suggest its existence in the Jurassic. This is quite evident from the text of the above citation. Furthermore, a fleeting remark in a later publication (Hallam, 1975, p. 175) reiterating his above cited thesis in principle informs us that: "this interpretation must be abandoned."

As the reader can see, the above cited, important conclusions of Arkell (1956, p. 641) are just as valid today as they were when his "Jurassic Geology of the World" was published.

The erroneous conclusions of Hallam (1969, p. 45, 63; 1975, p. 173-176),cited and analyzed above, deserve attention not just because of the above-mentioned necessity to demonstrate the validity of Arkell's (1956) conclusions bearing on the subject of this paper. Hallam (loc. cit.) happens to be, perhaps, the most prominent representative of a large group of paleontologists and stratigraphers insistently and, in the writer's opinion, rather unfairly (see p. 25) promoting the world-wide scope and the eustatic control of ancient transgressions and regressions. Hallam's (loc. cit.) style of argumentation and his general approach to the problem is representative of that of the whole group which is deplored by the writer (see p. 25).

SOME GENERAL CAUSES OF EXAGGERATION OF THE ROLE OF EUSTATIC MOVEMENTS OF SEA LEVEL

In the writer's opinion there are several important reasons for the underestimation of the relative tectonic activity of the continental blocks of the lithosphere. These must be discussed briefly before one can generalize effectively about the causes and general implications of Cretaceous oscillations of sea level in Western and Arctic Canada and elsewhere.

Comparative neglect of biochronology and overestimation of other geochronological methods

Only biochronological (or if one prefers biostratigraphic) data have been used in the preceding sections of this paper to decipher the geological, and particularly the oscillatory, history of Cretaceous basins of Western and Arctic Canada. The same is true of all attempted correlations of their individual oscillatory histories with one another and with those of Cretaceous basins elsewhere. Furthermore, the writer strived consistently to attain the greatest degree of resolution possible by the biochronological method in regional and intercontinental correlation of geological events. This procedure contrasts with that utilized by a great many recent workers attempting to unravel the geological history of the oceanic and continental blocks of the lithosphere, including the allegedly existing synchrony of their oscillatory regimes on the global scale. These workers (e.g. Gilluly, 1965; Russell, 1968; Grasty, 1967; Rona, 1973, 1974; Hays and Pitman, III, 1973; Sloss, 1963, 1972, 1976; Sloss and Speed, 1974; Whitten, 1976; Cloud, 1976) tend to effect the regional and global correlations of geological events using either various radiochronometrical methods or other physical methods of age determination. They tend either to ignore or at least to neglect the biochronological method of dating and correlation. Furthermore, only the higher rank (i.e. the least precise) units of the biochronological scale (e.g. epochs and periods) are regularly used by these geologists and geophysicists. No explanation of this preference for physical methods of age determination and a "broad brush" approach to the biochronological dating and correlation is given by the majority of these workers. Some of them, however, frankly express their distrust of the generally accepted precision (e.g. Gilluly, 1949, p. 582-587, Figs. 14-16; Schmidt-Thomé, 1972, p. 262) and even the general reliability (e.g. Sloss, 1963, p. 94) of the biochronological method. Some other workers (e.g. Armstrong, 1975, p. 151; Sloss, 1976, p. 273; Cloud, 1976, p. 3, 4) are frankly confident that the precision of presently available radiochronometrical methods is sufficient for their purposes in spite of the awareness of their glaring imperfections (e.g. Sloss, 1976, p. 276).

The following quotation from Cloud (1976, p. 3, 4) is selected to elucidate the general philosophy of this school of thought:

> "Systems of geologic time other than radiometric, if I may use the word system in that sense, are either restricted in time and space (varves) or depend on integration with radiometric time for numerical values (biostratigraphy, paleomagnetism, cyclical phenomena). It would be more objective, perhaps, to speak in terms of events (e.g. fission or paleomagnetic events, stage of biologic evolution) rather than years, but the convention is to deal in radiometric years, and convert other systems to these (sic! underlined by the writer). No great harm is done by this as long as we realize that the radiometric year as now defined has not always corresponded with the solar of sidereal year. In any case, I will not be preoccupied with seeking great precision in giving radiometric ages for events later to be discussed – primarily because, in a broad canvas of the sort here painted, it makes for stilted writing and no great improvement in accuracy to be overly fastidious in this otherwise important matter.

This strong bias toward the use of radiochronometrical and other physical methods of age determination and correlation of geological events, and the tendency to neglect the biochronology, is characteristic also of a number of modern paleontologists and stratigraphers concerned with the deciphering of the geological history of the oceanic lithosphere or ancient transgressions and regressions (e.g. Hallam, 1963, 1969, 1975; Pessagno, 1972; Naidin, 1971, p. 12, unnumbered text-fig.; Kauffman 1970, 1973a, b; Brookfield, 1970). These workers, like the previously cited modern geologists and geophysicists, adhere to the hypothesis of the world-wide extent and eustatic control of ancient transgressions and regressions; they characteristically stress generalities and abstract, purely hypothetical examples of what may have happened. When giving concrete geological examples they tend to support them with geophysical, radiochronometrical and palaeomagnetic data, in some cases supplemented by very generalized biochronological information. With some exceptions, no analysis of detailed biochronological data pertinent to the problem discussed is undertaken by these workers.

The writer deplores this inductive, simplistic approach as, generally speaking, nonproductive. He feels that any workable geological model or hypothesis can only be obtained by a deductive approach, i.e. by assembling and digesting as much specific factual data as possible and then attempting to see whether or not they fall into a certain pattern(s).

In view of the widespread use of the radiochronometrical and other physical (e.g. magnetostratigraphical) methods of age determination and correlation of geological events, in preference to the here favored biochronological method, and the writer's decided opposition to this attitude, it is imperative to analyze critically the relative precision, reliability, and limits of applicability of the principal geochronological methods now available. The need for such a critical appraisal is strengthened further by the writer's conclusion (see below) that most of the ancient transgressions and regressions and many (?most) of the orogenic phases proper were episodic events of a short to very short duration in terms of geological time. Consequently, only the most precise, reliable, and widely applicable geochronological method can be used for dating and correlation of such geological events.

Magnetostratigraphical method

The much publicized (e.g. Berggren, 1972; Berggren and van Couvering, 1974; Berggren et al., 1975; van Hinte, 1976a, p. 489) recent discovery of the allegedly world-wide sequence of reversals of the geomagnetic field imprinted in the rocks does not represent a major geochronological break-through, in the writer's opinion. This magnetostratigraphy is, indeed, based solely on episodically (not periodically) repeating geological events, none of which is characterized by unique distinguishing features of its own. Therefore, these reversals have no practical geochronological value in themselves. Like several previously known kinds of rocks with time-parallel boundaries, such as bentonitic beds, lava flows, and rhythmic sediments (Jeletzky, 1956; p. 682), the individual normally or reversely polarized rock sequences, or their particular groupings, depend on diagnostic fossils for the determination of their geological age relationships. In other words, one must first establish the biochronological age of at least one of the normally or reversely magnetized rock units occurring in every studied, demonstrably or allegedly continuous rock sequence before it becomes possible to utilize magnetostratigraphic units geochronologically. Furthermore, one must re-establish biochronological ages of the magnetostratigraphic units as soon as any fault or discordance is crossed (or is suspected of being crossed). This undeniable fact is commonly glossed over by magnetostratigraphers. Finally, it is becoming more and more obvious that the individual magnetostratigraphic horizons commonly fail to register global, or even interregional, persistent fluctuations of the magnetic field of the earth. The imperfect recording or subsequent overprinting of the original remanent magnetism is particularly common in ancient sediments that can be dated best by contained fossils (e.g. Verosub, 1975; Watkins, 1976, p. 19). On the whole, the writer is unable to see that magnetostratigraphy is anything more than yet another valuable but subordinate geochronological tool which is capable only to supplement (but not to supplant!) biochronology under some special circumstances (compare Morley and Larochelle, 1964, p. 51).

Radiochronometrical methods

Jeletzky's (1971a, p. 7, 10) more recent conclusion that all presently known radiochronometric methods remain just as crude, cumbersome and, in part at least, unreliable as at the time of his earlier attempt (Jeletzky, 1956) to evaluate them critically, was corroborated by, perhaps, the best radiochronometrical authority in existence. As pointed out by Harland (**in** Harland et al., 1971, p. 4) in the supplement to "The Phanerozoic Time Scale":

> A major difficulty is the misplaced faith so many geoscientists have in published scales. This leads to frequent use but little improvement of them. The impression that we are now on a path that is fast approaching perfection, even if asymptotically, generates the feeling of diminishing returns for an expended effort. In some quarters the Phanerozoic time-scale had an effect opposite to that intended. It sealed within the authority of hard covers a work intended to pinpoint and publicize the deficiences of the current time-scale.

In accordance with the spirit of this frank evaluation of the then current status of practical usefulness of radiochronometry, Lambert (**in** Harland et al., 1971, p. 13, 29) proposed to round the bulk of pre-Tertiary major boundary ages to at least ± 5 m.y. This proposal was accepted and used in the most recent Cretaceous time scale published by van Hinte (1976b, p. 499). However, even such rounding of the radiochronometric ages of series and systemic boundaries in the Mesozoic is believed to be overly optimistic, even when the geochemist deals with minerals derived from semiconsolidated to only slightly consolidated sedimentary rocks of the cratonic regions or with those occurring in the volcanic ash-derived bentonitic interbeds contained in these rocks. The following critical comments pertain to such optimal, rather exceptional (i.e. Obradovich and Cobban, 1975, p. 33) conditions alone.

Limits of precision and reliability of radiochronometric methods in unmetamorphosed rocks of cratonic regions

The great limitations with respect to precision and reliability of all presently known radiochronometric methods when employed in dating sedimentary rocks of the cratonic regions, are made evident by the laudably frank discussions of gross uncertainties involved in the computation of most or all major points of the Cretaceous radiochronometric scale (e.g. Baldwin et al. 1974; van Hinte, 1976b, p. 498-501, Fig. 1). The long-known (see Polevaya et al., 1961; Obradovich, 1964; Hurley, 1960, 1961) and confirmed (i.e. Lambert, **in** Harland et al., 1971) unreliability of even the best glauconite ages, furthermore, is amply illustrated by the recent attempt of van Hinte et al (1975) to date the Early-Late Cretaceous boundary at Orphan Knoll by K/Ar method. This attempt resulted in the apparent age of paleontologically dated, apparently unaltered Cenomanian rocks ranging from 100.91 to 105 m.y. whereas the immediately underlying, paleontologically dated upper Albian rocks produced an apparent age of 96 m.y.

As pointed out by Baldwin et al (1974, p. 268, 269), the allegedly more reliable K-Ar ages (i.e. those based on igneous minerals derived from volcanic ash beds) obtained from paleontologically dated Albian-Cenomanian rocks exhibit similar, irreconcilable discrepancies, including reversals of known biochronological ages. An even more dramatic example of the unreliability of the K-Ar ages based on such igneous minerals is provided by Macdougall's (1971) study of a sample derived from the basaltic "basement" in one of boreholes drilled in the Western Atlantic Ocean basin. This alleged basement yielded an apparent K-Ar age of only 16 m.y. in spite of being overlain by the fossiliferous Late

Cretaceous sedimentary beds. Space forbids giving more examples of such quite unreliable apparent radioactive ages scattered in the world literature. These spurious ages are, however, only rarely compiled by radiochronometrists.

Like Baldwin et al. (loc. cit.), the writer believes that the reversals of K-Ar ages referred to above invalidate the current (i.e. Casey in Harland et al., 1964; van Hinte et. al. 1975; van Hinte, 1976b, p. 501, Fig. 1) assignment of the about 100 m.y. age to the Early-Upper Cretaceous boundary. He feels that this dating is an enlightened guess only and considers the other recently proposed dates of 93 m.y. or 110 m.y. (e.g. Baldwin et al., 1974, p. 268, Table 1; Obradovich and Cobban, 1975, p. 43, 44, Table 1; van Hinte, 1976b, p. 499, Fig. 1) as equally plausible and at the same time equally unproven. Consequently, the age of the Early-Late Cretaceous boundary is only known within the limit of 20 m.y. or so. Furthermore, the same appears to be true of the Jurassic-Cretaceous boundary and of most or all of the Cretaceous stage and superstage boundaries. This is indicated by the results of the analysis of the late Hauterivian dating by Baldwin, et al. (1974, p. 268, Item 75), by that of the duration of the Cenomanian stage of Jeletzky (1971a, p. 7, 10), and by that of the proposed datings of the Jurassic-Cretaceous boundary by Lambert (in Harland et al., 1971, p. 16).

The general conclusion of Harland (in Harland et al., 1971, p. 4), cited previously, and the more specific results of van Hinte et al. (1975), Baldwin et al. (1974), and van Hinte (1976b) discredit all recently made attempts to estimate the duration of Cretaceous ammonite and other molluscan zones (e.g. Kauffman, 1970; Owens and Sohl, 1973; Gill and Cobban, 1973; Obradovich and Cobban, 1975; Williams and Baadsgaard, 1975). As stressed by Baldwin et al (1974), they also discredit the even more ambitious widespread attempts to estimate the rates of sea floor spreading, or to recognize periods of surges and slow-downs of this spreading, etc. (see the list of references given by these workers for further details).

For example, Kauffman (1970, p. 639) declares unreservedly that:

> Geochronology must be an integral part of biostratigraphy if biotic zones are to be used in dating and correlation with a high degree of confidence.

However, he contradicts himself when he states almost immediately thereafter (Kauffman, 1970, p. 640) that his radiochronometric parameter, which is supposed to impart "a high degree of confidence" to biotic zones, consists of a mere:

> 21 radiometric dates available for the Albian through Maastrichtian sequence of the Western Interior which are tied to biostratigraphic zones. Nearly half of these are unpublished. Only two known to me have been regionally cross-checked with double, samples. The error factor on each date ranges from 1.5 to 4 (or rarely more) million years; the error factor thus covers the time ranges of two to eight overlap assemblage zones as defined in this revision. Further, there is only one radiometric date available per 4.5 biostratigraphic zones at present.

And yet this scant, avowedly crude, and almost never cross-checked radiochronometric parameter then is almost unreservedly used (Kauffman, 1970, p. 630, 635, 656-664, Figs. 8-10) for an estimation of the duration of Cretaceous ammonite and other molluscan zones in the United States Western Interior Region, an estimation of age and duration of transgressive-regressive episodes there, and an estimation of evolutionary rates of animal taxa. Kauffman (1970, p. 630, 635) claims that the Cenomanian-Turonian zones of the region lasted between 0.12 and 0.25 million years and that the average duration of Cretaceous ammonite zones there was about 0.45 million years. These conclusions, however, are based solely on the extrapolation of the above mentioned scarce, avowedly crude, and hardly ever cross-checked K-Ar isochrons, using the method of equal stages and zones. Furthermore, the inherent unreliability of all K-Ar isochrons stressed by Casey (in Harland et al., 1964, p. 193) and dramatically confirmed by the reversals of apparent K-Ar ages cited previously at the Albian-Cenomanian, and Hauterivian boundaries is not even mentioned by Kauffman (1970). Finally, the equal stage and zone method is made unreliable by the extremely variable rates of evolution of various fossil organisms serving as zonal indices (Jeletzky, 1971a, p. 7). Consequently, all the above-mentioned claims of Kauffman (1970) must be suspect and considered to represent one of the numerous examples of that "misplaced faith" in published radiochronological scales deplored by Harland (in Harland et al., 1971, p. 4). The durations of the individual paleontological zones concerned may, in the writer's opinion, be from a few to several (conceivably up to 10 or even 15) times longer or shorter than it is believed by Kauffman (1970), because he started his equal stage and zone computations with apparent K-Ar ages which may be uncertain within 20 million years or so. The above criticisms are applicable also to the more recent attempt of Gill and Cobban (1973) to estimate the radiometric ages and durations of various paleontological and geological events of the Cretaceous history of the Western Interior basin of the United States of America.

The fundamental inadmissibility of attempts described previously to estimate ages and durations of Cretaceous (or for that matter older Mesozoic or Paleozoic) zones and stages using the equal stage and zone method is revealed just as clearly by the discrepancies contained in the most recent attempts of Obradovich and Cobban (1975) and Williams and Baadsgaard (1975) to date the Turonian to lower Campanian molluscan zones in the American and Canadian parts of the Western Interior region. As pointed out by Williams and Baadsgaard (1975, p. 424):

> The **Prionocyclus woollgari-Inoceramus labiatus** zones (upper part of microfaunal assemblage zone V), at the top of the Favel Formation, are dated at 89 to 90 million years. The **Inoceramus deformis** zone (microfaunal assemblage zone VI) is considered to be between 88 and 89 million years old and the **Clioscaphites vermiformis** zone (upper part of microfaunal assemblage zone VII) to be 80 to 86 million years old. Microfaunal assemblage zone VIII (**Scaphites hippocrepis** to **Baculites mclearni** zones) is about 80 to 81 million years old. These ages appear to be two to three million years older than ages proposed for the same zones by Obradovich and Cobban (this volume), except for the **P. woollgari-I. labiatus** zones, the ages of which are in good agreement.

These marked discrepancies in determinations of radiometric ages and durations of the same paleontological zones made by different workers in adjacent parts of the same basin confirm the previously stressed crudity of even the best K-Ar age determinations made on igneous minerals derived from apparently unaltered Cretaceous bentonites.

It is concluded therefrom, that the physical (or astronomical) ages and durations of Obradovich and Cobban's (1975) and Williams and Baadsgaard's (1975) molluscan zones cannot be determined with a precision greater than ± 5 million years and that the degree of imprecision is mostly considerably greater because of the general unreliability of apparent K-Ar ages as discussed above. Consequently, these extremely crude and possibly unreliable estimates of radiochronometric durations and ages of Cretaceous paleontological zones should not be used to estimate radiochronometric durations of paleontologically dated hiatuses or average rates of sedimentation as Williams and Baadsgaard (1975, p. 422-424, Fig. 3) attempt to do. As pointed out by Jeletzky (1971a, p. 7), Harland (in Harland et al., 1971, p. 4) and Baldwin et al (1974, p. 269), such "attractively packaged", allegedly quantitative but actually only semi-quantitative data are apt to mislead the average members of the geological and geophysical profession.

Owens and Sohl's (1973) estimates of radiochronometric ages and durations of Cretaceous stages based on glauconites from the New Jersey-Maryland coastal plain, exhibit discrepancies similar to those noted by Williams and Baadsgaard (1975, p. 424) and discussed above (e.g. Owens and Sohl, 1973, p. 2830, 2831, 2835, Fig. 11). The refusal of Dr. J. Obradovich to accept the interpretations of the authors concerning the reliability of K-Ar ages based on the glauconite (Owens and Sohl, 1973, p. 2835), is particularly revealing. In the writer's opinion, Owens and Sohl's (1973) glauconite ages and their interpretations are suspect even more than those of Kauffman (1970), Obradovich and Cobban (1975) and Williams and Baadsgaard (1975) based on primary minerals from bentonites.

Jeletzky has stressed repeatedly (1956, 1971a, p. 7, 10), that all of the estimates of radiochronometrical durations and ages of paleontological stages and zones attempted so far are not really estimates but a kind of educated guesswork providing extremely rough, theoretically valuable ideas about their possible physical (or astronomical) ages. The durations of the Cretaceous paleontological zones discussed above might, for example, be anywhere between 0.05 (50 000 years) and 2 million years, in the writer's opinion, which is, of course, an enlightened guess only.

Radiochronometric methods in tectonized or metamorphosed rocks

An even more severe limitation of the usefulness of all presently known methods of radiometric age determination consists in their almost complete lack of applicability to severely tectonized or metamorphosed rocks. The limits of precision and reliability of the radiometric results obtained for the Cretaceous part of the geological column and discussed previously, for example, are valid only for unaltered to slightly consolidated sediments of cratons and their shelves (in the sense of von Bubnoff; see Jeletzky, 1963, p. 58-60 for further details).

The period of almost unquestioning faith (e.g. Gilluly, 1965, p. 23) in the validity of most or all radioactive ages obtained in the tectonized, heated up, and strongly indurated or metamorphosed rocks of ancient mobile belts, including dislocated intracratonic troughs and basins, appears to be ending. It becomes more and more obvious that even the crude but valid radiochronometric ages commonly obtainable in unaltered to slightly consolidated cratonic and shelf rocks, as a rule, are unobtainable in the ancient mobile belts (e.g. Engels, 1975; Evernden and Smith-Evernden, 1970; Harper, 1967; Hutchinson, 1970; Fox and Rinehart, 1973; Krummenacher et al., 1975; Miller and Engels, 1975; Wanless and Reesor, 1975; White et al., 1967; Okulitch and Cameron, 1976). This is revealed by the frank analysis of the insuperable difficulties faced by the radiochronometrist and geologist attempting to decipher the apparent radioactive ages of pre-Tertiary (and in part of the Tertiary; see Evernden and Smith-Evernden, 1970) rocks of these belts presented in the above-cited and many other papers. It appears fair to say, as stressed by Harper (1967, p. 129, 131), that in these mobile belts one should not trust any apparent radioactive ages obtained on igneous, volcanic, and sedimentary rocks that have been affected by one or more strong and regional orogenic episode. This dictum is true even of the radioactive lead method as indicated by the geochemical complications discussed by Boyle (1959) and the most recent doubts about the significance of apparent Pb-U ages of orthogneiss of the Shuswap metamorphic complex (Wanless and Reesor, 1975) raised by the biochronological research of Okulitch and Cameron (1976). Also, it is true, almost invariably, of the apparent pre-Tertiary ages obtained by K-Ar methods, regardless of whether or not these ages are discordant or concordant (e.g. Engels, 1975; Hutchinson, 1970; Fox and Rinehart, 1973; Krumenacher et al., 1975; Miller and Engels, 1975).

This fundamental unreliability of radioactive ages may also explain the remarkable lack of coordination of volcanism, tectonism, and plutonism which characterizes the Phanerozoic history of Western United States according to Gilluly (1965, 1973). In the writer's opinion this conclusion is completely unfounded, as Gilluly (1965, 1973) relies almost exclusively on radiochronometric data and hardly ever mentions biochronological data in his papers. This attitude is exemplified by Gilluly's (1965, p. 23) insistence that: "It seems out of question that all but two pre-Jurassic plutons (of the Western United States; writer's remark) would be completely "rejuvenated" radiometrically by a later episode of metamorphism". In this connection Gilluly (1965, p. 9) goes so far as to disregard a lead-alpha date of 335 ± 35 m.y. published for the Climax stock in Nevada only: "because the average of six K-Ar determinations from this mass is only 93 m.y. (F.N. Houser, oral communication, January 1964)". Contrary to Gilluly (loc. cit.), the writer considers a total or near total rejuvenation of Paleozoic plutons in the orogenic belt of Western United States to be most likely. He would also accept an isolated Palaeozoic lead-alpha date in preference to any number of contrary apparent K-Ar dates.

An excellent, and extremely pertinent example of an unjustified reliance on radiometric time scales in the Cretaceous mobile belts, is provided by a controversy about the true geological age of the so-called Coast Intrusions of western British Columbia. The Coast Intrusions of this region of Canada and adjacent regions of the western United States of America are, perhaps, the largest concentration of the post-Paleozoic granitoid plutons of the globe.

Biochronologists, including the writer (e.g. Jeletzky, 1954a, b, 1976, p. 63, 64) are, and have been, convinced of a Jurassic age for the bulk of the Mesozoic Coast Intrusions of western British Columbia since the pioneering work of Crickmay (1930) in the Harrison Lake area. According to them, the Jurassic (mainly mid-Jurassic) phase of igneous activity was followed by a long period of intrusive (but not extrusive) quiescence which lasted through all of the Early Cretaceous and most or ?all of the Late Cretaceous. This period of quiescence was followed by another major phase(s) of intrusive activity which began in the ?late Late Cretaceous (late Campanian or Maastrichtian), continued in the earliest Tertiary (?Paleocene) and either lasted into or was resumed in the middle to late Eocene. Geochemists – and geologists following them – favour, in contrast, a quasicontinuous mode of intrusive activity in western British Columbia from the beginning of the Mesozoic and culminating with a pronounced peak in the Early Cretaceous. The controversy was started by the appearance of Beveridge and Folinsbee's (1956) paper. These workers have emphatically rejected the biochronologically founded mid-Jurassic dating of the Mesozoic Coast Intrusions on Vancouver Island proposed by Jeletzky (1954a, p. 14; 1954b, p. 1269-1270) and the Late Jurassic dating of the Coast Intrusions in Harrison Lake area proposed by Crickmay (1930, p. 484, legend of geol. map). Beveridge and Folinsbee (1956, p. 24) dated the bulk of these Coast Intrusions as Early Cretaceous solely on the basis of their alleged contemporaneity with radiochronologically dated granitic intrusions (e.g. Nelson Batholith) situated elsewhere in British Columbia. However, their dating of the Nelson Batholith subsequently was discredited by Gabrielse and Reesor (1964, p. 120-121, Table I, Appendix, Fig. 6) whereas Jeletzky's (loc. cit.) mid-Jurassic dating of the Coast Intrusions on Vancouver Island has been found to be in essential agreement with the subsequently obtained radiometric data (e.g. Sutherland Brown, 1966, p. 85; Northcote and Muller, 1972, p. 52).[3] Nevertheless, the general idea of Beveridge and Folinsbee (1956) found favour with Gabrielse and Reesor (1964) and Roddick (1966) because of the observed clustering of apparent (sic) radiometric ages in the mid-Cretaceous part of the radiometric time scale then accepted.

Roddick (1966, p. 79) and Gabrielse and Reesor (1964, p. 106, Table 11) were apparently the first of the Survey geologists to switch to the idea of a quasicontinuous mode of plutonic activity in the Mesozoic and Tertiary of British Columbia and of its peaking in Early to mid-Cretaceous time. In 1965, Roddick (1965, p. 178) pointed out that the Mesozoic Coast Intrusions of the Vancouver North, Coquitlam, and Pitt Lake map-areas were exposed commonly by Late Jurassic time whereas some other

> "plutonic rocks moved upward either by faulting or intrusion while in an active (recrystallizing) state after the Upper Cretaceous Helm Formation was deposited".

This conclusion agrees remarkably well with the previously discussed conclusions of Crickmay (1930) based on his field work in the adjacent Harrison Lake area. However, Roddick (1966, p. 79) changed this opinion soon after in pointing out that:

> "It should be noted that within the Coast Crystalline Belt only one date falls in the Upper Jurassic (the 143 m.y. date of the Eagle Granodiorite) in apparent contradiction to the traditional assumption (sic; writer's underlining) of major plutonic activity in the Upper Jurassic of this area".

Gabrielse and Reesor (1964, p. 106) concluded that:

> "In general, however, the available determinations (of radioactive age; writer's remark) support the conclusion obtained from stratigraphic data that plutonic activity embraced essentially all of the Mesozoic and extended into the Tertiary".

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[3] It must be stressed that even these roughly speaking correct (because of their general agreement with the biochronological evidence available; Jeletzky, 1954a, p. 14; 1976, p. 68, etc.) radiometric ages of the Coast Island Intrusions are crude to the point of being misleading. This crudity, expressed in the extremely wide scatter of apparent radiometric ages, had actually mislead some geologists studying the "Island Intrusions" and the Bonanza volcanics. This is illustrated by the following quotation from Northcote and Muller (1972, p. 52): "Carson (1972) reports age determinations ranging between 148 and 181 million years for Island Intrusions. White and Harakal (pers. comm.) at the University of British Columbia potassium-argon laboratory have obtained dates ranging between 145 and 169 million years from biotite from Island Intrusions and whole-rock determinations ranging between 135 and 161 million years for Bonanza volcanics. The older ages for Bonanza volcanics are probably the most meaningful.

"It is necessary to comment briefly on the relationships of radiometric and stratigraphic ages of the Jurassic volcanic and plutonic rocks. According to the Geological Society of London time-scale (1964), Island Intrusion ages of 181 to 145 million years would range from Pliensbachian (Early Jurassic) to Kimmeridgian (Late Jurassic). Bonanza volcanics at 161 to 135 million years would range up to the Jurassic-Cretaceous boundary. Paleontologically dated Sinemurian beds are the youngest ones known definitely to be interbedded with volcanic rocks. It is conceivable that the youngest possibly non-marine Bonanza volcanics are Toarcian (latest Early Jurassic) or even middle Jurassic. It is rather improbable that they are as young as Callovian (early Late Jurassic), as entirely non-volcanic sediments of that age are the only ones known on Vancouver Island. The apparent discrepancy between radiometric whole-rock dates and paleontological dates may be at least partially resolved by two considerations.

"(1) The whole-rock radiometric dates for Bonanza volcanics, although analytically accurate to within narrow limits, must be considered to be minimum ages for these rocks. The younger ages were obtained from rocks of rhyodacitic composition containing various amounts of potassium feldspar. These rocks would be expected to lose radiogenic argon and give radiometric ages younger than their absolute ages.

"(2) It is conceivable that the 162-m.y. date quoted for the base of the Callovian in the Geology of London time scale could be shifted upward. This 162-m.y. date appears to have been interpolated by the authors at between 163 m.y. for Bathonian and 139 m.y. for Callovian. This suggests that there may be room for shifting the base of the Upper Jurassic to about 145 m.y.

"Additional methods of whole-rock radiometric dating are necessary to help resolve this problem. At present it is justifiable and sufficient (sic; writer's remark) to say that the available age determinations and the similarity of magmatic evolutionary trends support the Bonanza volcanic-Jurassic intrusive comagmatic concept."

As evidenced by the above quotation, Northcote and Muller (1972) are fully aware of the strong constraints imposed by the biochronological data on the respective geological ages of the Bonanza volcanics and "Island Intrusions" (see Jeletzky, 1954a, p. 14; 1954b, p. 1269-1270; 1970c, p. 20, 21) and of the extreme crudeness of the apparent radiometric ages available for these same rocks. The biochronology indicates that all significant units of the true Bonanza volcanics known on Vancouver Island predate the entirely to ?almost entirely sedimentary Pliensbachian-?Toarcian greywacke unit (now known to be entirely Pliensbachian because of the recent ammonite identifications provided by Dr. H. Frebold in an internal fossil report). The "Island Intrusions" of the same area are, in contrast, known to postdate the Pliensbachian-?Toarcian greywacke unit and to predate the Callovian sedimentary rocks containing their pebbles. The two plutonic events are, therefore, not coeval but clearly successive. However, Northcote and Muller (loc. cit.) fail to admit that the contrary evidence of radiochronometry is far too crude to be used at all and end up relying on it. This is yet another instance of a harmful influence of the previously discussed "misplaced faith" in the radiochronometry.

A number of geologists within the Geological Survey of Canada (e.g. Muller and Carson, 1969; Northcote and Muller, 1972) and outside that organization (e.g. White, 1966; Eastwood, 1965) accepted these conclusions as valid. It seems fair to say that the idea of quasicontinuous plutonic activity in the Mesozoic and Tertiary of western British Columbia and that of predominantly Early to mid-Cretaceous age of the Mesozoic Coast Intrusions is now accepted overwhelmingly by both field geologists and geochemists. As mentioned previously, these conclusions are based entirely on the assumption of a general validity of the apparent K-Ar ages of these rocks. This faith in K-Ar ages appears to be responsible, in particular, for the exclusion of the definitely mid-Jurassic (biochronological and radiochronometrical data agree closely in this case) granitic intrusions of Vancouver Island from the Coast Intrusions. These mid-Jurassic plutons recently were renamed Island Intrusions (Eastwood, 1965; Muller and Carson, 1969; Northcote and Muller, 1972; Carson, 1973) to stress their alleged temporal and structural independence of the radiometrically younger Coast Intrusions of the British Columbia mainland. However, Dawson (1887, p. 11B) had pointed out an intimate connection existing between the Coast Intrusions of Vancouver Island and those of the adjacent parts of the Coast Mountains on the mainland of British Columbia. The dykes, sills and larger intrusive bodies of northwestern Vancouver Island were interpreted accordingly by Dawson (1887) and following him by Jeletzky (1976, p. 63, 64) to be very shallow to hypabyssal apophyses and cupolas of larger intrusive bodies still hidden at depth and either intimately connected with, or representing a direct continuation of, the principal plutons of Jurassic Coast Intrusions of adjacent parts of the Coast Mountains. Other than these mid-Jurassic plutons, only the post-Nanaimo Early Tertiary or ?late Late Cretaceous plutons have been found on Vancouver Island (Jeletzky, 1976, p. 121, 122). These plutons (?Sooke Intrusions) appear to be equivalent to, and intimately connected with, the biochronologically dated late Late Cretaceous and/or Early Tertiary phase of the Coast Intrusions on the mainland of British Columbia.

This intimate connection between the definitely mid-Jurassic "Island Intrusions" and the allegedly Early to mid-Cretaceous Mesozoic phase of the Coast Intrusions proper is, in itself, sufficient to raise grave doubts regarding the validity of the apparent isotope ages of the latter. Even more important is the fact that, so far as the writer knows, there is no stratigraphic or biochronological evidence supporting these apparent isotopic ages. Instead, more and more additional stratigraphical and biochronological evidence is emerging (e.g. Jeletzky and Tipper, 1968, p. 16; Tipper, 1969, p. 24-25, 68-70; Baer, 1968) which suggests the presence of only two generations of the Coast Range plutons long recognized by Crickmay (1930). Finally, the apparent Early to mid-Cretaceous isotopic ages of the Mesozoic Coast Intrusions do not seem to have any equivalents within the adjacent Alaskan segment of the Coast Range plutonic belt. According to the latest data of Reid and Lamphere (1968, 1973), the south Alaskan and Aleutian equivalents of the Canadian Coast Intrusions yield only Early to Middle Jurassic (180 to 155 m.y.), Late Cretaceous (84 to 72 m.y.) to Early Tertiary (65 to 50 m.y.), and Middle Tertiary (40 to 34 m.y.) isotopic ages. No Early to mid-Cretaceous ages have been obtained in these regions where the radiochronometric data appear to agree closely with the stratigraphic (i.e. biochronological) data.

The above considerations, combined with the large amount of recent data revealing the nearly complete unreliability of apparent Mesozoic K-Ar ages obtained in the Cascade Mountains (e.g. Fox and Rinehart, 1973), the Shuswap metamorphic complex (e.g. Wanless and Reesor, 1975), and the southwestern United States of America (e.g. Evernden and Smith-Evernden, 1970; Fox and Rinehart, 1973; Krummenacher et al., 1975; Miller and Engels, 1975), give good reason to consider the above-mentioned early Early to mid-Early Cretaceous isotopic ages for the Canadian Coast Intrusions as spurious minimum ages caused by an updating of the original Jurassic (mainly mid-Jurassic) isotopic ages by subsequent orogenic and/or plutonic events. The retention of true isotopic ages (i.e. those confirmed by biochronology) by the mid-Jurassic phase of Coast Intrusions on Vancouver Island and the prevalence of reset Early to mid-Cretaceous isotopic ages in the closely related Mesozoic phase of Coast Intrusions of the Coast Mountains proper, likely is caused by the predominantly shallow-seated nature of the former and the largely intermediate to deep-seated nature of the latter (Jeletzky, 1976, p. 63, 64).

Hutchinson's (1970, p. 394-396) recent discovery of an approximate correspondence between the regional metamorphic pattern and that of K-Ar ages in the Prince Rupert-Skeena area and Central Coast Mountains cannot be applied directly to the situation in the Southern Coast Mountains and Vancouver Island. However, it is important in suggesting yet another probable source of error for the radiochronometric ages of intrusive rocks of western British Columbia. The writer strongly favours the idea of Hutchinson (1970, p. 396), according to which the regional belts of isotopic ages of Prince Rupert-Skeena area and Central Coast Mountains do no reflect the relative times of emplacement of plutonic bodies but "reflect relative times of uplift and/or subsequent unroofing of these belts" instead.

Because of the above considerations, it is recommended that the heavy reliance on unsupported radioactive ages for the purpose of dating and correlation of post-Precambrian plutonic, volcanic and metamorphic rocks in Western British Columbia be terminated. Instead, our personnel should concentrate on attempts to control these apparent ages biochronologically in order to establish whether or not they are valid and, if so, their degree of reliability in the individual areas of this region. A good example of such critical treatment of radiochronometric data is provided by Trümpy's (1973, p. 234, 237, 241) study of the timing of orogenic events in the Central Alps.

Conclusions

The above data are deemed to be ample to demonstrate that the previous conclusion (e.g. Jeletzky, 1971a, p. 7, 10) about biochronology remaining the only basis of practical geochronology on the paleontological zone and stage level still holds true. Even the most recent radiochronometric ages and durations assigned to the Cretaceous stages or zones of such exceptionally favourable geological regions as the Atlantic Coastal Plain and the Western Interior of North America (e.g. Kauffman, 1970; Owens and Sohl, 1973; Gill and Cobban, 1973; Obradovich and Cobban, 1975; Williams and Baadsgaard, 1975; van Hinte, 1976b) are extremely crude or unreliable. Most or all of other published radiochronometric dates are either still more approximate or are meaningless. On the whole, none of the radiochronometric methods available is capable of dating geological events with a precision greater than 5 to 10 million years, except possibly in the late Tertiary (e.g. Berggren and van Couvering, 1974). Consequently, the presently available Cretaceous radiochronometric ages of paleontological zones and stages still must be viewed as almost entirely hypothetical elements of a scale that in the blunt but true words of Casey (in Harland et al., 1964, p. 199) was "set up purely as a basis of discussion in the absence of a more positive scale of calibration."

The above, unavoidably harsh criticisms of the precision, reliability and hence practical usefulness of all presently available radiochronometric methods are not directed against these methods as such. There is no doubt in the writer's mind that most (possibly all) of the recently to most recently developed numerous radiochronometrical methods have at least some geochronological potential which must be thoroughly investigated and appraised. The writer's criticisms are directed solely against the unfortunately widespread "misplaced faith" in the radiochronometrical methods and, even more, in the calibrated time scales made possible by their introduction into various geosciences. The existence of this "misplaced faith" and of the strong tendency to favour radiochronometric methods (and other physical methods of age determination as well) over the biochronological method, appear to be promoted by the fact that we are living in the time of an ever increasing multiplication and complexity of geological methods in general, and geochronological methods in particular. Another contributing factor appears to be that in our age of ever increasing specialization a number of geologists and geophysicists (particularly those concerned with the Phanerozoic intrusive and volcanic rocks and, even more so, those concerned with their petrology and mineralogy) have lost sight of the relative merits and demerits of various available methods of dating and correlation of the Phanerozoic rocks. Therefore, and because of the ever increasing quantitative and computerized environment of contemporary geology, many of these workers have come to rely almost entirely, or entirely, on the most recent, quantified and/or calibrated geochronological methods which happened to be favoured in their geological schools.

The above criticisms of the radiochronometrical methods are especially pertinent because of the, on the whole (there are notable exceptions), rather disappointing performance of the radiochronometric methods in the Phanerozoic rocks during the last 18 years or so and by the common refusal of their geological (including paleontological-stratigraphical) users to recognize this fact. As mentioned in the preceding sections, this disappointing performance was stressed by many radiochronometrists. These warnings were ignored, however, by some overenthusiastic radiochronometrists and by most of the geophysical and geological users of radiochronometric data. Examples of this misuse and abuse of radiochronometrical methods have been given in the preceding sections of this paper. However, this "wall of overconfidence and misplaced faith" begins to show most welcome "cracks". This is exemplified by the paper of Baldwin et al. (1974).

It follows from the above analysis that the presently widespread attempts to utilize any of the presently available radiochronometric methods for: the dating and estimation of duration of ancient transgressions and regressions; dating and estimation of duration of brief to very brief orogenic phases; correlation of oscillatory movements of sea level and orogenic phases on an interregional or global scale; and estimation of rates and recognition of periods of surges and slowdowns of the spreading of the oceanic bottom; are completely unwarranted. It is impossible to overstress this point since most of the recent conclusions on these subjects, made by marine and continental geologists and geophysicists alike, are based largely, or even entirely, on radiochronometrical data. A critical review of all these conclusions based on direct or indirect use of the biochronological method is urgently needed.

RELATIVE ROLES OF EUSTASY AND TECTONIC MOVEMENTS OF CONTINENTAL BLOCKS IN CONTROLLING ANCIENT TRANSGRESSIONS AND REGRESSIONS

At the beginning of this section it must be stressed that, like most other recent opponents to the idea of a controlling influence by eustasy upon ancient transgressions and regressions of the continental blocks (e.g. Sloss, 1973, 1976, p. 273; Sloss and Speed, 1974; Nikolaev, 1972; Yanshin, 1973, p. 32, 33; von Bubnoff, 1963, p. 32, 33), the writer does not deny the real existence of several kinds of eustatic fluctuations of sea level recently ennumerated and comprehensively discussed by Nikolaev (1972). Of these, the following are the most important in the writer's opinion:

1. Glacial eustatic fluctuations effected by ancient climatic changes (e.g. the development and disappearance of continental glaciations in the Quaternary); and

2. Tectonoeustatic fluctuations caused by positive and negative movements of major tectonic structures of the oceanic blocks of the lithosphere. These movements include inflation of mid-oceanic ridges and the thermal contraction of aging oceanic lithosphere capable of effecting major changes in the volume of oceanic basins. Other less important kinds of eustatic fluctuations of sea level include those caused by the accumulation of sediments on the sea bottom, discussed by Nikolaev (1972).

The purpose of this paper is accordingly not a denial of the existence of eustatic movements of sea level, but an evaluation of their relative role, in comparison with that of the vertical tectonic movements of the continental blocks of the lithosphere, in influencing the oscillatory behaviour of the latter.

The following sections of this paper summarize the evidence presently available, and present the writer's conclusions on the subject.

Duration and amplitudes of Quaternary tectonic movements

The following few examples selected from the wealth of data available should suffice to elucidate the limits of duration and vertical amplitudes characteristic of the recent and older Quaternary tectonic movements in the stable and tectonically active regions of the continental lithosphere:

1. The postglacial Champlain Sea occupied the St. Lawrence Lowlands in eastern Canada from about 12 000 until about 9000 years before present (Prest in Douglas et al., 1970, p. 726, 727, Figs. XII-16h to XII-16s). However, the strandlines of this postglacial inland sea occur at levels up to 230 m (750 ft) above sea level north of Trois Rivieres and Montreal. This entirely tectonically (i.e. broadly epeirogenically) caused, geologically instantaneous regression of the Champlain Sea was attained in spite of the fairly rapid postglacial eustatic rise of sea level characteristic of the same time span (e.g. Nikolaev, 1972, p. 11, 12, Figs. 2, 3).

2. The present day tectonic uplifts in California and Europe and a calculation of their projected rates within the time of a single biochronological zone (Gilluly, 1949, p. 563-567, Figs. 1-4) indicate even greater vertical amplitudes. Even the yearly uplifts of from one-fifth of an inch to one inch actually measured in California, and manifestly caused by local tectonic movements (Gilluly, 1949, p. 565), are capable of producing mountains, 305 to 762 m (1000 – 2500 ft.) high within periods of geological time ranging from 25 000 to 200 000 years. These randomly selected, local uplifts cannot be considered as large, let along great, uplifts as illustrated by other examples cited below.

3. The relatively stable areas of northwestern Europe have been affected by similarly fast, large amplitude, vertical tectonic movements in the Pleistocene. According to Woldstead (1952), the surface of the oldest interglacial marine terrace is situated about 60 m above sea level in the London area. Whereas, in the Netherlands the same terrace was reached in boreholes at a level of 255 m below sea level. Nikolaev (1972) provides a number of other examples of rapid (i.e. geologically instantaneous), large-scale, vertical tectonic movements in relatively stable regions of Europe (e.g. Scandinavian Peninsula) and North America (e.g. Hudson Bay area) in the Pleistocene and concludes that the Quaternary oscillatory history of these regions was controlled by tectonic rather than glacial-eustatic or other eustatic phenomena.

4. The orogenically active regions of Asia experienced much larger, tectonically caused, vertical movements during the Quaternary Period. These geologically, almost instantaneous (within the last 500 000 to 1 000 000 years), vertical movements are measured commonly in several hundreds to thousands of metres. For example, according to Devdariani (1964), the early Quaternary Chauda Terrace occurs 100 to 110 m above-sea level along the coasts of Abkhasia,

Caucasus. However, in the adjacent Colchidan Depression, near the city of Poty, this terrace was reached in boreholes at a depth of 286 m below sea level. In Indonesia, according to Strakhov (1948, Vol. I, p. 245), the Quaternary coral reefs occur locally at heights up to 1050 m above sea level. Elsewhere in the region they were discovered by dredging in depths up to 3924 m. Here again, other examples of similarly large-scale Quaternary (including postglacial) tectonic movements in tectonically active regions are available in Nikolaev's (1972) paper.

5. The orogenically active central American region experienced, tectonically caused, vertical movements during the Quaternary Period, the amplitude and speed of which match closely those of the Asian regions discussed under 4. Recent investigations by Horsfield (1975) have demonstrated conclusively that the Quaternary marine terraces of the Greater Antilles have been strongly tilted in many areas. Some of these terraces have been raised to as much as 640 m above sea level whereas others have been submerged for several tens of metres at least. As pointed out by Horsfield (1975), these variable elevations of the Pleistocene marine terraces in the region indicate the prevalence of tectonic over the eustatic control.

Duration and vertical amplitudes of pre-Quaternary tectonic movements

It must be pointed out that the problem of estimating the duration and vertical amplitude of the pre-Quaternary tectonic movements is different from that of estimating the duration and vertical amplitude of the Quaternary tectonic movements (see the preceding section). In the geologically very brief Quaternary there is no need to separate the discussion of the two topics concerned because the recent and even early Pleistocene tectonic movements could only be very brief to instantaneous in terms of the biochronological standard. Therefore, the discussion was concerned almost exclusively with the vertical amplitudes of the Quaternary tectonic movements. Nor is it too important to differentiate between the Quaternary orogenic and epeirogenic movements for the purposes of this paper.

The situation is quite different in the enormously long pre-Quaternary segment of Phanerozoic time. There, the concept of a short to very short duration and episodic occurrence of ancient tectonic movements is still in dispute. The idea has been rejected by a number of authoritative recent workers (e.g. Gilluly, 1949, 1950, 1965; Shatsky, 1951; King, 1966, 1969; Gabrielse and Wheeler in Douglas et al., 1970) who argue for a quasicontinuous and consequently long-lasting character of all ancient tectonic processes and tend to amalgamate orogenic and epeirogenic movements (e.g. Cebull, 1973, p. 102). Hence, the problem of the short to very short duration of the ancient tectonic movements favoured by the writer is a complex subject which must be argued separately from the equally complex subject of the determination of vertical amplitudes of ancient tectonic movements, and from that of the determination of their frequency in terms of the biochronological standard. The estimation of the duration of the pre-Quaternary tectonic movements is complicated further by the necessity to consider the independent but closely related effects of orogenic and epeirogenic movements. Consequently, all of the above mentioned important problems will be dealt with separately in the following sections of this paper.

Duration of tectonic movements and related problems

The independent existence of orogenic and epeirogenic movements

As was pointed out correctly by Stille (1950a, p. 100, 101; 1950b, p. 109, 110), many followers of Stille (loc. cit.), Schmidt-Thomé (1972, p. 261-263), Cebull (1973, p. 102), and also by Gilluly (1949, p. 567, 571; 1950, p. 103, 104), it may be very difficult to differentiate between orogenic and epeirogenic movements in practice. These two kinds of tectonic movements are characteristically related closely in time and in space in all ancient tectonically active belts of the globe. However, the writer (e.g. Jeletzky, 1976, p. 8, etc.) accepts as valid Stille's (1950a, p. 92, 93), von Bubnoff's (1963, p. 31-39, Figs. 4, 5) and Trümpy's (1973, p. 247, Fig. 3), conclusion that orogenic movements proper, as recorded by a gentle or tight folding and subsequent erosional truncation of rocks underlying either discordances or regional unconformities (e.g. Stille, 1950a, p. 97; Gilluly, 1950, p. 104), are in many cases (especially in the Mesozoic where the biochronological control is particularly refined) not contemporary with, but precede, the "mountain-building" or epeirogenesis proper. The epeirogenesis consists exclusively or almost exclusively of either regional or interregional uplift of tectonic structure(s) produced by the orogeny proper. The fact that orogeny and epeirogeny, as above defined, may merge imperceptibly into one another and that any folding unavoidably includes some subordinate elements of uplift (and vice versa) certainly complicates their differentiation. However this situation is common in natural sciences. Natural phenomena and processes are seldom sharply (i.e. naturally) delimited from one another and it is only the inadequacy of the human mind that forces us to organize and artificially pigeon-hole them (e.g. Hedberg, 1948, p. 448, 449). While we may be forced to admit our inability to distinguish between the orogenic and epeirogenic movements in many specific instances, this situation does not justify the amalgamation of the orogenic and epeirogenic movements suggested by some modern workers (e.g. Gilluly, 1949, p. 567; 1950, p. 104; Cebull, 1973, p. 102).

The episodic character and the frequent occurrence of pre-Quaternary tectonic movements

In the writer's opinion, the thesis that at least a great number of pre-Quaternary tectonic movements had a well-defined episodic character and were closely spaced in terms of paleontological zones is well documented. A glance at the close spacing of well-defined local, intrabasinal and regional, obviously tectonically caused, diastems in the Cretaceous geological history of the orogenic and intracratonic basins of Western and Arctic Canada summarized in Figures 3 to 7, should suffice to demonstrate its validity. Furthermore, the validity of the thesis is amply confirmed by the similar diastrophic history of the Jurassic of England and the globe, masterly synthesized by Arkell (1933, p. 51, 96, Figs. 8-15, Table VI; 1956, p. 632-642, Tables 27, 28). Finally, the same story is told by the Late Tertiary tectonic record of California summarized by Gilluly (1949, p. 567-569, Fig. 5) and by that of the Central Alps summarized by Trümpy (1973). The above data clearly indicate that the contrary claims of the adherents of a quasicontinuous and long-lasting character of all ancient tectonic processes are, at least in part, erroneous. The error is undoubtedly attributable to their all too frequent failure to employ the biochronological instead of radiochronometrical method when dating geological events. The episodic, closely spaced tectonic events, discussed previously, fully deserve the name "tectonic phases", unless they can be ascribed to either orogenic or epeirogenic processes. If the latter, they should be termed respectively as "orogenic" or "epeirogenic" phases. This terminology will be employed in the following sections of this paper. However, it must be stressed that the evidence presently available is insufficient to deny the existence of long-lasting tectonic events beside the above discussed episodic, short term tectonic phases (see p. 33,34).

Some problems of practical recognition and dating of orogenic movements (phases)

Perhaps the most formidable obstacle confronting a geologist attempting to date an individual orogenic phase and to estimate its approximate duration in terms of paleontological zones consists in the immediate effects of an orogeny being largely masked by the rapid uplift of the orogenic region. Except in relatively rare localities or areas situated either in the most negative structural zones of the region or in the axial parts of its synclines (compare, Gilluly, 1950, p. 104; Sloss, 1976, p. 276), such post-orogenic, epeirogenic movements tend to cause a profound erosion of the underlying rocks. It is this erosion, and not the relatively minor erosion immediately accompanying the orogenic movements proper, that causes great erosional disconformities, the duration of which may comprise several stages or series of the standard geological column but generally varies greatly within short distances across and along the strike depending on the local attitudes of the underlying deformed rocks (see Figs. 3-7). The geological duration of the resulting erosional unconformities does not bear any recognizable relation to the actual duration of the preceding or accompanying orogenic phases, except that it is always longer than the latter. Furthermore, the erosion of underlying strata commonly is so deep (especially at the margins of structural basins) that the erosional unconformity concerned cuts down to or even beyond the plane(s) of the next older unconformity(ies), thus creating an illusion of an extremely prolonged orogenic phase(s) over large geological regions. Good examples of such "telescoping" of at least two well-defined orogenic phases in the Cretaceous rocks of Western and Arctic Canada are provided in Figures 3 to 7 of this paper. Other examples are discussed by Jeletzky (1963, p. 70, Fig. 4; 1975, p. 8, 9, 10, Figs. 4, 5, 6, 7). Any stratigrapher who has worked extensively in tectonically active regions should be able to recall other examples from his own experience.

The previous discussion indicates that it is the minimum observable duration of a hiatus accompanying an unconformity that approaches most closely the true duration of the orogenic phase that produced the two. In so far as such minimum durations of the hiatuses are, generally speaking, confined to the most negative central parts of ancient depositional basins where the effects of the accompanying or subsequent uplift(s) were minimal the geologists must strive to find representative sections situated in these parts of the basins in order to be able to separate the tectonic effects of the orogenic phases proper from those of the accompanying or closely following epeirogenic uplifts and, consequently, to date these orogenic phases closely using the biochronological method. Furthermore, this approach permits the differentiation between the major regional to interregional orogenic phases and localized, minor tectonic movements. Namely, those unconformities and hiatuses that are either traceable deep into the mid-basin or extend right across its deep water central zone were quite obviously caused by major orogenic phases. Conversely, those unconformities and hiatuses that are either restricted to the marginal parts of the basin or are limited to certain parts of the basin must have been caused by similarly localized, minor tectonic movements.

The conclusion that it is the central rather than the marginal parts of ancient depositional basins that are critical for the correct deciphering of their structural histories conflicts irreconcilably with Gilluly's (1949, p. 569) conclusion that:

> In the middle of the basins only the movements that finally stopped deposition could be recorded, and of course such movements would be most widely recorded. Movements while the basins were still drowned would leave structural records only at the borders – the places most vulnerable to erosion and loss of record. For example, it is most unlikely that there is an unconformity among the Quaternary sediments of the Santa Barbara Channel to record the mid-Pleistocene "Pasadenan orogeny" of Stille which has so pronounced a record on the Channel shore at Ventura just to the north. If we confine our attention to the middle of the basins, the only unconformity we can detect is the record of ultimate emergence. The movement this records might be smaller than many movements whose records are only locally preserved and thus less conspicuous, though quite as great in magnitude.

The writer's conclusion, however, is based on the analysis of the Cretaceous history of five Canadian depositional basins discussed in the previous sections of this paper and summarized graphically in Figures 3 to 7. Four out of five Canadian basins studied did, in fact, undergo one or more relatively short-lived, total but not final, emergences which were followed by submergences. It is sufficient to name the late Turonian to mid-Santonian emergence of the Insular Trough(p. 12, Fig. 4), the early Valanginian, mid-Hauterivian, and mid- to late Albian emergences of the Richardson Mountains-Porcupine Plain Trough (p. 9, 10, Fig. 5), the Hauterivian to Barremian emergence of the Sverdrup Basin (p. 19 and Fig. 6), and the Hauterivian-Barremian emergence of the Alberta-Liard Trough (p. 3, 10, and Fig. 7). It is these relatively rare but exceptionally strong, regional to interregional events accompanied by interruptions of marine sedimentation caused by subsequent uplifts that represent the milestones in the structural history of the basins concerned (p. 3). The more numerous tectonic events which affected either only the marginal parts or only some localized parts of these basins (p. 3-6) were quite obviously caused by relatively minor tectonic movements. The above cited conclusion of Gilluly (1949, p. 569) obviously is not applicable at all to the Cretaceous history of these basins of Western and Arctic Canada. The similar conclusions reached previously by Arkell (1956, p. 632-642, Tables 27, 28) on the basis of a painstaking study of the Jurassic System of the world, and the previously discussed general considerations suggest strongly that the tectonic behaviour of the Canadian Cretaceous basins studied is characteristic of all Phanerozoic depositional basins, and that the contrary conclusion of Gilluly (1949, p. 569) is invalid. In the writer's opinion, the Late Tertiary tectonic record of California used by Gilluly (1949, p. 567-569, Fig. 5) to support this conclusion is misleading. This record is far too short, too localized and, last but not least, too recent to permit a reliable differentiation of the localized, minor and hence insignificant depositional-tectonic events from first rank orogenic phases. The Jurassic System of the world analyzed by Arkell (1956, p. 632-642) and the Cretaceous basins of Western and Arctic Canada discussed in this paper are more straight forward and more easily decipherable examples. These examples permit differentiation of depositional-tectonic events because they cover much greater segments of geological time, deal with much larger geological regions, and are situated much farther away from the present. The latter circumstance is particularly important since it resulted in the destruction of a great deal of the less significant depositional-structural detail which obscures the principal features of the Californian record.

It follows inevitably from the above analysis that considerable detailed field and office research, supported by a wealth of biochronologic data, must precede any valid conclusions about even an approximate duration of orogenic phases. An inspired, mostly still valid, discussion of some of the difficulties involved in this task is provided by Gilluly (1949, p. 561-581; 1950, p. 103-107). This writer, however, does not agree with some of his conclusions because of his marked underestimation of the precision of the paleontological clock (Gilluly, 1949, p. 582-589, Figs. 14-16), overestimation of the significance of temporal migration of orogenic phases across and along orogenic belts, and his expressed doubts about the existence of "a real objective distinction between orogenic and epeirogenic movements" (Gilluly, 1949, p. 567; 1950, p. 104). In these three respects, but definitely not where the controversy about the world-wide extent of orogenic phases is concerned, Stille's (1950a, b) conclusions are believed to be more nearly correct than those of Gilluly (1949, 1950). It must be added, however, that Gilluly (1973, p. 500, 501) reversed some of his ideas subsequently and now insist on the existence of an objective distinction between orogenesis and epeirogenesis.

The correct interpretation of the so-called "synorogenic" (or molassoid) deposits also may be critical for the estimation of the duration of orogenic phases proper as some workers (e.g. Gilluly, 1949, p. 567; 1950, p. 105) consider them to be products of such phases only. This interpretation is erroneous under the definition of orogenic phases (or orogeny) adopted in this paper, because the "synorogenic" (or molassoid) deposits are most apt to reflect an uplift rather than folding of an orogenic region. However, following Stille (1950b, p. 109, 110), the writer feels that the coarse textured rocks may be either "synorogenic" or "synepeirogenic" deposits and that commonly it is difficult to differentiate between the two kinds of molasses.

Duration of orogenic phases and some related problems

As recognized by Stille (1924, 1936, 1942, 1950a, b), von Bubnoff (1931, 1954, 1963), Arkell (1933, 1956) and numerous followers of Stille's ideas, many pre-Quaternary orogenic phases proper (see Jeletzky, 1976, p. 3 and the preceding sections for a definition) had a very short duration in terms of biochronologically measured geological time. This conclusion commonly is disputed by recent workers (e.g. Shatsky, 1951; Gilluly, 1949, 1963, 1965, 1973; King, 1966, 1969; White, 1966; Gabrielse and Wheeler in Douglas et al., 1970). However, its validity for the Cretaceous and Jurassic history of North America was amply confirmed by the work of Crickmay (1930, p. 487; 1931, p. 45, 46), Arkell (1956, p. 633-642, Tables 27, 28), Jeletzky (1961a, p. 536-543, Fig. 1; 1963, p. 79, 80, Fig. 6; 1974b, p. 11; 1975, p. 35, 37, 42, 43, Figs. 17-22; 1976, p. 3-7, 34-38, 69, 70, 95, Fig. 5; as well as by the data presented in Figs. 3-7 of this paper and the accompanying explanatory comments). The duration of all reliably differentiated and dated, individual orogenic phases known to the writer ranges anywhere from a fraction of a paleontological zone to three or ?four paleontological zones (see in the above cited papers for further details). It is very difficult to express these non-calibrated durations in terms of everyday physical (or astronomical) time because of the gross imprecision and partial unreliability of all now available radioactive methods of measurement of geological time (Jeletzky, 1956, 1971a, p. 7, 10 and this paper). However, it is possible to suggest that brief orogenic phases lasted anywhere between 0.05 and 2.0 million years of everyday physical (or astronomical) time. Similar time spans of orogenic phases have been suggested by Stille (1924, 1936), Gilluly (1949) and other workers on still flimsier circumstantial evidence.

The personally studied examples of brief pre-Quaternary orogenic phases (see Figs. 3-7 and accompanying explanatory notes) and examples of those available in the literature (see in previously cited references) are insufficient to deny the existence of other longer-lasting orogenic phases. Furthermore, because of the already mentioned, unavoidable difficulties involved in the task of determining approximate but true durations of orogenic phases, it may never be possible to assemble sufficient data to rule out their existence. However, most of the apparently longer-lasting orogenic phases critically studied by the writer in great detail proved to be either a local to regional combination of two or more individual phases affected by an accompanying or subsequent epeirogenically caused erosion (see Figs. 3-7) or the result of a prolonged epeirogenic uplift that immediately followed the orogenic phase proper. These data suggest that brief orogenic phases were the rule rather than the exception in the geological past. Furthermore, the same is suggested by the recorded presence of no less than 42 local to regional unconformities separated from each other by appreciable segments of biochronologically measurable time in the geologically brief Cenozoic column of California (e.g. Gilluly, 1949, p. 567-569, Fig. 5). Even assuming that some of these unconformities are either too localized to rank as **bona fide** orogenic phases or attributable to such non-orogenic geological phenomena as soft sediment slumping, disharmonical folding etc., there are too many real orogenic phases left to suggest a geologically great duration for any of them.

On the basis of the data presented above the writer is convinced that most or ?all of such allegedly long-lasting Mesozoic orogenies proposed recently for the Cordilleran belt of Canada (see White, 1966; Gabrielse and Wheeler in Douglas et al., 1970, p. 431, 432, 440, 442, 443, 448, 450) as the Coast Range, Rocky Mountain, Tahltanian, Inklinian, Nassian, and Columbian orogenies either did not last as long as claimed by their authors or are composite events actually consisting of several individualized, brief orogenic phases (especially the so-called Coast Range or Columbian Orogeny). Furthermore, this is indicated clearly, by: the older data of Crickmay (1930, 1931), whose well-defined, geologically brief, and widespread (see Jeletzky and Tipper, 1968, p. 15, 16; Jeletzky, 1968b, p. 103) Agassidan Orogeny was disregarded by Gabrielse and Wheeler (loc. cit.); the recognition of very short duration (presumably latest Norian and/or early Rhaetian only) of Inklinian Orogeny on Vancouver Island by Jeletzky (1970c, p. 5-9, Fig. 1; 1976, p. 34, 35, Fig. 5); and the recognition of several, well-individualized regional or interregional orogenies in the Early Cretaceous of the Western Cordillera (e.g. Crickmay, 1930, p. 484; Jeletzky and Tipper, 1968, p. 64-74, Tables 3, 4, p. 88, 89) all falling within the time interval of the so-called Columbian Orogeny.

In the writer's opinion, the assumption of long duration of the Mesozoic orogenies in the Canadian Western Cordillera by White (1966), Gabrielse and Wheeler (in Douglas et al., 1970) and other workers is directly attributable to neglect of long available biochronological evidence (especially of that provided by Crickmay, 1930, 1931 and Arkell, 1956) combined with the unjustified reliance on the apparent radiometric ages of plutonic rocks associated with these orogenies (e.g. Armstrong, 1975, p. 151). As pointed out by Jeletzky (1976, p. 64, 67-69 and in the section of this paper dealing with the limits of precision and reliability of radioactive methods of age determination), one should not trust any biochronologically unsupported, apparent radiometric ages obtained on igneous, volcanic, and sedimentary rocks which were affected by one or more orogenies within ancient orogenic belts.

Therefore, the presently popular but largely or ?entirely erroneous idea of quasicontinuous and consequently long-lasting character of orogenic processes apparently was caused by the characteristic failure of its adherents to differentiate strictly between effects of the orogenic and epeirogenic movements and also to their frequent failure to date the orogenic movements by biochronological instead of radiochronometrical means.

The above documentation of the short duration of at least many of the pre-Quaternary orogenic phases proper and of the validity of their independent existence from epeirogenic movements is critical for the purpose of demonstrating that the individual orogenic phases can be recognized and dated only by means of the biochronological method and not by any other geochronological method now available.

Duration of epeirogenic movements

The Cretaceous basins of Western and Arctic Canada discussed in the earlier sections of this paper, generally speaking, are not suitable for the determination of the duration of pre-Quaternary epeirogenic movements. Most of these basins are either orogenic successor basins (e.g. Tyaughton and Insular troughs) or strongly tectonically active intracratonic troughs (e.g. Richardson Mountains-Porcupine

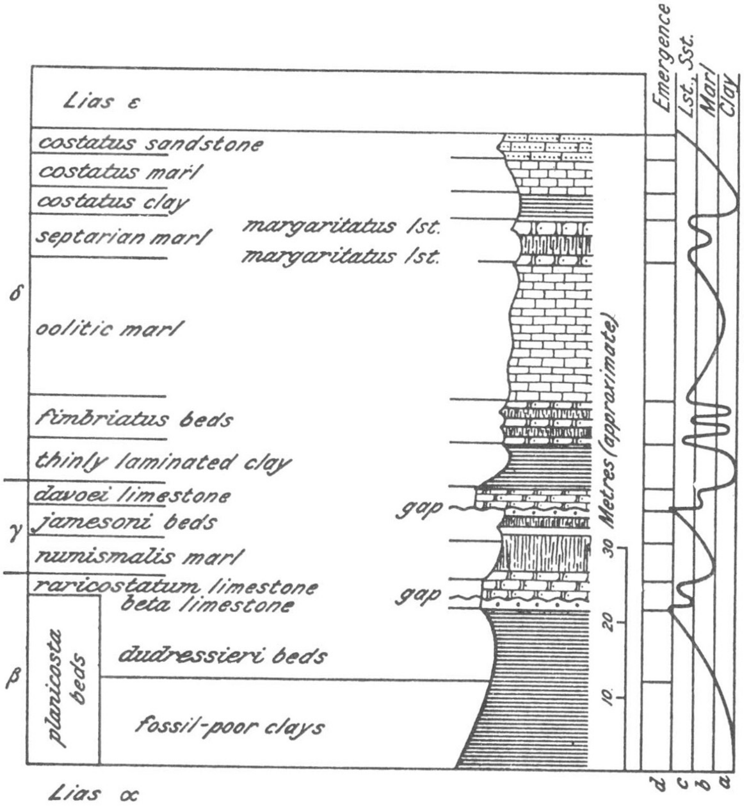

Figure 12. Geological profile through the Mid-Lias of West Germany exhibiting a characteristic alteration of deep neritic clays (horizontal ruling) and marls (blocks) with shallow neritic to littoral limestones (vertical ruling), arenaceous rocks (dotted), and emergences (gaps). This cyclical deposition reflects epeirogenically controlled oscillations of sea bottom as indicated by the oscillogram on the right. From von Bubnoff (1963, p. 138, Fig. 31). Arranged after Frebold (1927, p. 228, Fig. 2).

Plain aulacogene and Alberta-Liard foredeep trough). The Cretaceous histories of these basins were, accordingly, dominated by orogenic movements interspersed with pronounced epeirogenic uplifts. These uplifts resulted in an extremely deep erosion of the underlying rocks masking their actual duration. Only the Cretaceous generation of Sverdrup Basin, in spite of its being genetically an orogenic successor basin, was characterized by prevalence of epeirogenic movements of a moderate amplitude potentially more suitable for the estimation of their duration (Fig. 6). Unfortunately, the Cretaceous history of the Sverdrup Basin is known only on a reconnaissance basis. This makes it impossible to differentiate clearly the slight orogenic movements accompanied by regional unconformities (e.g. by overlaps of the gently tilted underlying rocks which can be observed in a series of sections but cannot be measured because of the small angles involved) from true epeirogenic movements expressed in cyclical sedimentation accompanied by erosional disconformities only. It is, for example, still obscure whether or not the inferred, apparently geologically instantaneous, latest Albian-early Cenomanian hiatus (Fig. 6) reflects an orogenic phase or a brief epeirogenic hiatus only. It is equally uncertain whether or not the apparently brief ?late Berriasian and ?earliest Valanginian hiatus recently discovered by Kemper (1975, p. 247-248, Fig. 2) in the marginal facies of the Deer Bay Formation reflects an epeirogenic uplift which extends entirely across the basin or a feeble orogenic phase restricted to some flexing and/or tilting of the marginal parts of the basin (Fig. 6). Therefore, we have to depend on previously published data derived from other more stable regions of the continental crust for the demonstration of the frequent occurrence of biochronologically brief to very brief pre-Quaternary epeirogenic movements. The best proof of this thesis is provided by the widespread occurrence of rhythmic or cyclic sedimentation involving rock successions dominated by frequent (i.e. several to some twenty cycles per paleontological zone or stage) repetition of shallow marine and nonmarine facies in all Phanerozoic systems.

The existence of a fairly recent comprehensive review of the whole subject of cyclic sedimentation by Duff et al. (1967) facilitates the presentation of the subject. It is limited here to the discussion of a few especially pertinent examples of biochronologically brief, obviously epeirogenically caused cyclic sedimentation in epicontinental marine and nonmarine successions.

As pointed out by many workers beginning with Klüpfel (1916) and including Frebold (1924, 1925, 1927), Arkell (1933, p. 56-59, Fig. 9) and Duff et al. (1967, p. 237, 238), the Lias beds of Germany include numerous rhythms consisting of alternating beds of clay, marl, limestone with a hard ground top, and some sandstone or conglomerate (e.g. coquina or belemnite "battle fields" with pebbles). The last type of bed usually is followed by a break in sedimentation after which the above succession is repeated monotonously. As recognized by Frebold (1924, 1925, 1927) and Arkell (1933, p. 56, 57), these rhythms and the paleontologically recognizable diastems separating them from each other obviously have been caused by frequent pulsatory epeirogenic movements of a regional character. Regardless of whether or not the hiatuses separating the individual cycles always reflected a true emergence of the region or only an uplift of the sea bottom into the littoral zone where a submarine "hard ground" and/or conglomeratic interbeds formed during an almost complete or complete interruption of normal sedimentation, the rhythms or cycles concerned undoubtedly reflect (Arkell, 1933, p. 57):

> "a gradual shallowing of water (raising of sea-bed) followed, after a pause, by relatively sudden deepening (subsidence of the sea-bed), after which shallowing began again. The same movements were repeated dozens of times and they occurred through the length and breadth of the sedimentary troughs of Europe. Frebold has traced the same individual cycles, their sharp boundaries marking the same faunizones, in the Middle and the Upper part of the Lower Lias of North-West Germany, Swabia, Lorraine and Aveyron in France.[1] They were therefore widespread and of epeirogenic origin.

The above-cited explanation of the causes of the cyclic sedimentation in the Mid-Lias shelf sea of northwestern Europe is accepted as valid by the writer (Fig. 12). These cycles were restricted to the shallow-marine troughs of that region and were connected intimately with tectonic movements of the large Jurassic geanticline that occupied all of northwestern Europe (Arkell, 1933, p. 58, 59). Duff's et al. (1967, p. 240) suggestion that some, at least, of these sedimentation cycles may have been connected with worldwide, eustatically controlled changes of the sea level is regarded as completely unfounded in view of the previously discussed invalidity of methods employed by Hallam (1969, 1975) to document the global synchrony of the Jurassic transgressions and regressions.

For the purposes of this paper it is important that these broadly regional, epeirogenic movements occurred frequently in terms of the ammonite paleontological zones. As stressed by all of the above-mentioned workers and illustrated by Figure 12, the duration of these oscillatory cycles ranged from a fraction of one ammonite zonal moment to one or two

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[1] H. Frebold (1927, p. 229)

ammonite zonal moments. Only rarely did their duration approach the regional time ranges of such more slowly evolving invertebrates as pelecypods, belemnites, etc. (e.g. Duff et al., 1967, p. 238, 239, Fig. 91).

As stressed by Arkell (1933, p. 57), similar cyclical sedimentation with frequent, brief hiatuses characterizes the Oxford Clay of Peterborough. The durations of these epeirogenically caused oscillations of the sea bottom do not exceed biochrons of the zonal ammonite species. Yet other examples of similarly brief and frequent, quite evidently epeirogenetically caused oscillations of the sea bottom in the epeiric seas of Europe are cited by Duff et al. (1967, p. 157-181, Figs. 60-71).

The second, equally convincing major example of biochronologically brief and frequent, broadly epeirogenically controlled cyclical sedimentation is that of the late Paleozoic cyclothems in the Western Interior region of the United States of America. There is no need to go into most of the details of this example since the subject has been summarized comprehensively and adequately a number of times in the North American, British and the European literature (e.g. by Duff et al., 1967). However, it is important to stress that the writer agrees completely with Weller (1956, p. 17; 1957, p. 329, etc), Moore (1950, 1959) and especially Elias (1937, 1964) that the deposition of these upper Paleozoic cyclothems, consisting of regularly alternating outer neritic to nonmarine deposits and punctuated by recurring erosional intervals, was caused by geologically frequent, broadly regional epeirogenic pulsations with vertical amplitudes of at least 100 to 150 m. The duration of these epeirogenic pulses must have been closely comparable to that of the above discussed mid-Lias pulses since several of them occur within the time of a single fusulinid or goniotite zone. Furthermore, several of these pulses have been observed to occur within the time of a single stage (Moore, 1954, p. 272-274, Figs. 1, 8).

The great lateral lithological and, hence, environmental variation of most of the above-mentioned cyclothems and the common presence of erosional intervals at their bases noted by most American workers and excellently reviewed by Duff et al. (1967, p. 81-97, Figs. 37-46, Table XV) amply demonstrate their being caused either directly by tectonic movements occurring within the depositional basins concerned or indirectly by those occurring in adjacent or distant source areas. In the writer's opinion, there is no reason to suggest eustatic control as "a plausible explanation" (e.g. Duff et al., 1967, p. 247) for even a minority of these late Paleozoic cyclothems.

A great number of examples of similar cyclic deposition in epicontinental nonmarine to marine Paleozoic (mostly Carboniferous) rocks of Great Britain and Europe have been reviewed by Duff et al. (1967, p. 117-156, Figs. 50-59, Tables XX-XXVII). The comparable duration and frequency of the epeirogenic pulses which have caused these depositional cycles is well documented by their Figures 50 and 53 which indicate that anywhere from a few to some twenty cycles occurred during the time of standard European or British goniatite stages or coral-brachiopod zones.

Yet other examples of similar, epeirogenically caused cyclical deposition in the Paleozoic rocks of USSR are cited by Yanshin (1973, p. 33, 34).

The above examples are deemed to be ample to document that biochronologically brief and frequent, broadly regional epeirogenic movements have been common and probably prevalent in the stable blocks of the lithosphere in all pre-Quaternary systems of the Phanerozoic. However, there is little doubt that they coexisted with much longer lasting, epeirogenically caused tectonic movements. For example, the Portlandian-Purbeckian (= Volgian or mid- to upper Tithonian) nonmarine to shallow marine sequence of northwestern Europe (mainly of the Anglo-Paris Basin) apparently reflects such a prolonged epeirogenic uplift of this rather extensive region. As far as is known, the Purbeck sequence appears to represent a period of more or less continuous, nonmarine to lagoonal sedimentation during a prolonged epeirogenic uplift confined between the Kimmeridgian and late Berriasian (= Riasanian) episodes of a regional subsidence (Casey, 1973, p. 215, 216). This episode of uplift and essentially continuous deposition apparently was punctuated only by local discordances and lacunae at the basin's margins (e.g. Bennison and Wright, 1972, p. 312, 313, 315-320, Figs. 14.1, 14.2; Casey, 1973, p. 215, 216; Hallam, 1975, p. 84-86, Fig. 4.12). Here again, other examples of what appears to be similarly prolonged episodes of regional epeirogenic uplifts in the pre-Quaternary Phanerozoic rocks of stable regions were comprehensively reviewed by Duff et al. (1967, p. 156, 157, Fig. 60, etc.) and the reader is referred to these examples for further details.

It should be stressed in this connection that it is unwarranted to explain either the Portlandian-Purbeckian uplift or other similarly prolonged periods of nonmarine deposition over geographically extensive regions by worldwide eustatic fluctuations of sea level. In the case of the Portlandian-Purbeckian uplift, the uplift was restricted to the northwestern part (mainly Anglo-Paris basin) and to a lesser extent the northern part of central Europe. Furthermore, contrary to Hallam (1975, p. 172, Fig. 8.6), the latest Jurassic acme of this Portlandian-Purbeckian regression corresponds to an interregional late Tithonian (= late Volgian) to early Berriasian (or from late Volgian to late Valanginian) transgression in northern Siberia (Saks, Shulgina, and Sazonova **in** Saks et al., 1972, p. 273, Fig. 17; Yanshin, 1973, p. 37, footnote) and Arctic Canada (Jeletzky, 1971a, 1973, p. 46, 47, Fig. 1; this paper Figs. 5, 6). The late Tithonian to early Berriasian (or late Tithonian to late Valanginian) seas were, furthermore, either stationary or at least somewhat transgressive in parts or ?all of the Tyaughton Trough of the Canadian Western Cordillera (Jeletzky and Tipper, 1968, p. 22, 81; this paper, Fig. 3).

Contrary to the opinion of Casey and Rawson (1973, p. 424, footnote), it is unwarranted also to explain the widespread late Berriasian (i.e. the time of **Riasanites rjasanensis**) transgression as a result of eustatically controlled changes of the sea level. The intercontinental analysis of the Berriasian paleogeography and transgressive-regressive episodes provided by Saks, Shulgina and Sazonova (in Saks et al., 1972, p. 274-281) demonstrates that the presence of this transgression from the Russian platform to southern England is but a broadly regional (all-European) episode evidently caused by broadly regional negative epeirogenetic subsidence of the Mesoeuropean continental block.

It follows inevitably from the above discussion that the episodic, biochronologically brief and closely spaced, local to broadly regional epeirogenic movements were common (probably prevalent) in all pre-Quaternary systems of the Phanerozoic. However, like Arkell (1956), Yanshin (1973, p. 33, 34) and many other "continental" geologists, the writer is convinced that, as a rule, there is no valid reason to assume the existence of either broadly intercontinental or global rhythms of sedimentation and tectonic pulsations causing global transgressions and regressions, such as were postulated, for example, by Grabau (1940) and recently by Pessagno (1972, p. 67, 68), Gussow (1976, p. 16, 17) and many other workers. The repeatedly cited, masterly analysis of the Jurassic of the globe by Arkell (1956) refutes the existence of any such global or intercontinental rhythms in Jurassic time. Yanshin's (1973) irrefutably documented global analysis does the same for all other Phanerozoic systems. Finally, the much more detailed analysis of the oscillatory history of some better known Canadian and foreign Cretaceous basins carried out earlier in this paper fully confirms Arkell's (1956) and Yanshin's (1973) conclusions for the Cretaceous System of the globe. Demonstrable or probable exceptions to this rule are extremely rare (e.g. p. 15, 16).

As rightly pointed out by Yanshin (1973, p. 33; writer's translation from Russian):

> It would have been senseless to deny its (i.e. cyclicity or rhythmicity; writer's remark) existence. This phenomenon was described many times, well studied and may be indubitably utilized even for the stratigraphical correlations of basin-wide magnitudes. However, the unfounded tendency of some geologists to infer a global character of the cycles or rhythms of sedimentation, that is to consider their number as equal and the times of their beginning and those of their end as contemporary in the Baltic region, on Siberian Platform and in Soviet Far East, in Eurasia and in America, or in northern and southern hemispheres, is an error in the light of the data provided earlier.
>
> It must be noted in this connection that such errors have never been made by the founders of the lithostratigraphical method. M.S. Shvetsov, who wrote classical papers about the Carboniferous geological history of the Moscow syneclyse, did not claim either in the first (110) or in the last (111; published in 1954) of these papers that the cycles of sedimentation recognized in this region could be recognized also in the Urals or in the Donetz Basin. However, he did note in a paper written in coauthorship with L.M. Birina (112) the existence of a certain parallelism of the epochs of uplift and subsidence in the Moscow and Anglo-Belgian basins.

Conclusions

Like the previously presented documentation of the short duration of at least many of the pre-Quaternary orogenic phases proper, the demonstration of brief duration and close spacing of many (perhaps most) ancient epeirogenic pulses in terms of paleontological stages and zones is critical for the purposes of this paper. It demonstrates that, like the brief orogenic phases, the individual pre-Quaternary epeirogenic pulses of this type can be recognized and dated only by means of the biochronological method. All other geochronological methods now available are useless for this purpose. For example, Sloss's (1963, 1972, 1973, 1976, p. 273) reliance on the radiochronometric methods for the purpose of intercontinental correlation and dating of epeirogenically caused Phanerozoic oscillations of North American and European cratonic blocks is quite unjustified. In the writer's opinion, the previously-discussed imprecision and partial unreliability of the radiochronometric data used by Sloss (loc. cit.) results in a completely haphazard comparison of oscillatory events on both sides of the Atlantic. This arbitrary selection of allegedly equivalent events simulates the parallelism of the Phanerozoic oscillations of these cratonic blocks. The validity of this criticism is confirmed by the crude but workable, ultimately biochronologically supported, results of the comparison of Phanerozoic oscillatory histories of the principal blocks of continental lithosphere carried out by Yanshin (1973, p. 20-31, 36-38, Figs. 6, 7) and discussed previously in this paper. Sloss's (1976, p. 273) assumption that his allegedly synchronous: "major trends in rates of deposition of preserved volumes would not be seriously affected by errors of a factor of two", is correct only in the sense that the doubling of the precision of radiochronometric data would produce equally haphazard results. As demonstrated previously in this paper, the resolving power of the radiometric methods used by Sloss would have to be increased at least tenfold (i.e. to some 0.5 m.y.) and their repeatability would have to be increased proportionally before it would be possible to obtain any meaningful correlations of radiometrically based oscillation graphs of North American and European cratonic blocks reflecting truly correlative transgressive-regressive events. Even such a (still unobtainable) degree of precision would register only the longer of the above discussed epeirogenic pulses (e.g. the Portlandian-Purbeckian pulse of the northwestern to central Europe) but not the apparently much more frequent, brief to very brief epeirogenic pulses which lasted for two or less paleontological zonal moments (see p. 34-35, Fig. 12). The invalidity of radiochronometric matrix of Sloss (loc. cit.) naturally discredits all far-reaching conclusions of Sloss and Speed (1974) concerning the coordination of cratonic and continental-margin tectonic episodes in the Phanerozoic.

The above documented, probable prevalence of brief to very brief orogenic and epeirogenic pulses in the Phanerozoic history of the globe and the almost complete absence of global sedimentological rhythms or cycles caused either by eustacy or by global epeirogenic pulses in the sense of Still (1924) and his followers (e.g. Pessagno, 1972; Gussow, 1976) is important also in discrediting the presently widespread idea that the durations of ancient transgressive and regressive episodes in terms of geologic time are proportional to their strength and interregional or global extent. This frivolous idea, in the writer's opinion, is illustrated by the following statement of Pessagno (1972, p. 68):

> A major transgression or pulsation is defined as one in which large areas of all the continental cratons were invaded by the sea during a period or epoch (sic. writer's remark) of earth history. A major regression or interpulsation is defined as one in which the cratons of all continents were emergent during a period of epoch (sic. writer's remark) of earth history. These definitions are meant to exclude local orogenic or epeirogenic events that affect a portion of a given continental craton (for example, the formation of the Mississippi Embayment during Mesozoic and Cenozoic times) and to include global tectonic events that influenced all continents similarly during a given interval of geologic time.

Like the conclusions of Hays and Pitman III (1973), Sloss (1963, 1972, 1973, 1976), Sloss and Speed (1974) discussed previously, this idea appears to be based on an erroneous assumption that the presently available radiochronometric methods are sufficiently precise to correlate the allegedly existing, long- to very long lasting transgressive-regressive pulses on an intercontinental to global scale. However, barring very rare exceptions (e.g. the global Maastrichtian regression), such an approach results in an entirely subjective, haphazard correlation of actually heterochronous (and hence unrelated), biochronologically brief, local to regional (or possibly rarely intercontinental; see p. 15, 16) transgressive-regressive pulses discussed earlier in this section.

Amplitudes of pre-Quaternary tectonic (orogenic and epeirogenic) movements

The following discussion is concerned only with the biochronologically brief and closely spaced orogenic phases and epeirogenic pulses of pre-Quaternary time. In the writer's opinion, only these two kinds of ancient tectonic movements were capable of destroying (i.e. overprinting) consistently the traces left by the eustatic fluctuations of sea level in the geological record (see following sections).

The analysis of the brief orogenic phases and epeirogenic pulses attempted in this section is concerned only with the vertical amplitudes and the senses of these two kinds of tectonic movements. Furthermore, this analysis does not discriminate between the orogenic and cratonic blocks of the continental lithosphere. Therefore, the phases and pulses concerned will be amalgamated herein under the name of "tectonic movements" for the sake of simplicity.

As pointed out by Jeletzky (1975, p. 43), it is obvious that:

> The minimum amplitudes of short term vertical tectonic movements (i.e. those occurring within the time of a single paleontological zone or stage) occurring in the ancient folded or faulted intracratonic troughs or orogenic belts (= geosynclines) fluctuated between 2000 and 4000 feet. This is indeed the range of amplitudes required to transform shelf to bathyal (i.e. 50 to 2000 ft deep) depositional areas into elevated tectonic highlands capable of providing large quantities of fine- to coarse-grained clastics (i.e. areas standing at least 1500 to 2000 ft above sea level).

The common occurrence of brief, localized to regional tectonic movements with such vertical amplitudes in the Richardson Mountains-Porcupine Plain Trough has been demonstrated amply in the above mentioned paper. Numerous other examples are illustrated in Figures 3 to 7 and discussed in the explanatory comments of this section and in the preceding section. The common existence of localized to regional tectonic movements with yet greater but indeterminate vertical amplitudes is attested by the occurrence of brief periods of nondeposition in these same basins. These examples indicate that even the briefest tectonic events recorded in the Cretaceous basins of Western and Arctic Canada commonly had vertical amplitudes ranging anywhere from 200 to 2000 m which is somewhat in excess of the previously given estimate.

Using Lyell's (1832) principle of uniformitarianism of geological events, the writer feels justified in inferring that the occurrence of brief vertical tectonic movements with the above-mentioned minimum amplitudes was a common phenomenon in all tectonically active pre-Quaternary basins of the globe.

Amplitudes of the eustatic fluctuations of sea level

As far as the writer knows, the earliest estimated value of the amplitudes of the eustatic movements of sea level derived from roughly estimated average ratios of the continental surfaces flooded by ancient transgressions was made by Kuenen (1939, p. 195) who assumes:

> "that the mechansims we are investigating must be able to account as a minimum for eustatic movements of more than 40 metres".

Kuenen's estimates were accepted as valid by the majority of more recent workers (e.g. Hallam, 1963; 1969, p. 63; 1975, p. 175; Naidin, 1971, p. 13, 16, 17; Fairbridge, 1961; Nikolaev, 1972, p. 9-14, Figs. 2-5; Yanshin, 1973, p. 32). Furthermore, the validity of principles on which Kuenen's (1939) estimates were based was confirmed recently by Wise (1972, p. 91-93).

Larger amplitudes of eustatic movements of sea level comprising 500 m or more have been suggested by some workers (e.g. Hay and Pitman, III, 1973, p. 20, 21, Fig. 3). However, as demonstrated by Baldwin, et al. (1974) and earlier in this paper (see p. 30), the computations on which these conclusions rest lack any reliable geochronological basis. Furthermore, these conclusions are based on an unrealistic assumption (Wise, 1972; Hallam, 1975, p. 175) of more than 40 per cent of the continental area having been covered by seas during the peak of the Cretaceous transgression. Accordingly, they are rejected by the writer.

In the writer's opinion, based on the principles developed by Kuenen (1939, p. 195) and confirmed by Wise (1972, p. 91-93) and other recent workers (see in Nikolaev, 1972 and Hallam, 1975, p. 175 for summaries of these results), even the amplitudes of eustatic fluctuations ranging from about -200 to +200 m (e.g. Berger and Winterer, 1974, p. 17) are an over-estimation. The data provided by Nikolaev (1972) and other recent workers indicate maximum amplitudes ranging from -100 or -150 to +100 or +150 m to be much more realistic figures, and these are accepted tentatively as valid in this paper. These amplitudes are 8 to 10 times (i.e. almost one order of magnitude) smaller than the minimum vertical amplitudes of the brief to very brief and frequent pre-Quaternary tectonic movements (both of orogenic and epeirogenic pulses) discussed in the preceding sections of this paper. This disparity in amplitude combined with the great frequency in the occurrence of pre-Quaternary tectonic movements is believed to be responsible for an almost complete obliteration of the record of ancient eustatic fluctuations of sea level.

GENERAL CONCLUSIONS

The evidence presented in the previous sections of this paper indicates an almost complete absence of geologically (i.e. biochronologically) simultaneous, demonstrably worldwide transgressions and regressions in the Cretaceous part of the geological column. The Maastrichtian regression, and possibly the late Santonian to early Campanian regression, are the only exceptions known to the writer. Furthermore, Yanshin's (1973, Figs. 6, 7; this paper p. 22, 23; Fig. 10) crude but workable analysis of the major Phanerozoic transgressions and regressions on the global scale indicates that this lack of contemporaneity holds true in all other Phanerozoic systems. This conclusion seems to contradict the very existence of geologically simultaneous, world-wide transgressions and regressions caused by the eustatic oscillations of sea level in the sense of Suess (1906, p. 538-544). However, as it was pointed out previously, such eustatic movements of the sea level undoubtedly occurred in the geological past. The almost total absence of their traces in the geological record of Phanerozoic time, therefore, must be caused by their destruction (i.e. overprinting) by some concurrent geological process. The overprinting of the geological record of the eustatic movements of sea level by the tectonic movements of the continental blocks of the lithosphere is indicated clearly by the following attributes of these tectonic movements documented earlier in this paper:

1. The local, regional or interregional (but apparently never global!) tectonic movements of the past were either commonly or prevailingly of a short to very short duration in terms of paleontological zones and stages. Furthermore, they occurred frequently throughout Phanerozic time;

2. The estimated minimum vertical amplitudes of those brief, ancient tectonic movements fluctuated between 200 and 2000 m. The similarly brief, average to large, ancient orogenic and epeirogenic movements had vertical amplitudes greatly exceeding (i.e. several to many thousand metres) the above mentioned minimum values. In contrast, the eustatic oscillations of sea level apparently averaged only 40 to 110 m and almost certainly did not have the amplitudes exceeding the range from -150 to +150 m.

The commonly brief duration, and episodic but frequent occurrence of ancient tectonic movements in combination with their minimum vertical amplitudes, which are 8 to 10 times (i.e. almost one order of magnitude) greater than the maximum inferred amplitudes of the concurrent eustatic movements, are judged to be ample to obliterate the geological record of the latter. The record of the eustatic movements of the sea level apparently was preserved only rarely, during the infrequent quiescent periods in the Phanerozic history of the globe. The time of the previously mentioned late early to latest Maastrichtian global regression appears to be a good example of such a tectonically quiescent period.

In his previous publications (Jeletzky, 1974a, p. 810; 1975, p. 43), the writer suggested that the nearly continuous overprinting of the effects of the eustatic fluctuations of the sea level by the effects of the contemporary tectonic movements may have been largely or entirely restricted to the ancient tectonically active belts of the globe. At that time the writer (Jeletzky, 1975, p. 43) envisaged the common preservation of the geological record of these movements within the most stable tectonic elements of the continental crust, such as the cratons or stable shelves (or stable platforms). However, the data presented earlier in this paper indicate that the vertical amplitudes and the frequency of the Quaternary and pre-Quaternary tectonic movements characteristic of such stable regions are ample for the overprinting there of the records of eustatic movements of the sea level. This conclusion is confirmed by the fact that the Cretaceous intracratonic basins of Western and Arctic Canada studied in this paper are characterized by exactly the same lack (excepting the already mentioned late early to latest Maastrichtian and late Santonian to early Campanian events) of interbasinal and interregional coordination of the oscillatory histories as the Canadian orogenic basins studied. This lack of coordination of the oscillatory histories of these Cretaceous basins also applies intercontinentally and globally. This is indicated by the results of the comparison of their oscillatory graphs with those compiled for foreign intracratonic basins by Kauffman (1973a, b), Hancock (1975) and Matsumoto (1952, 1967) carried out earlier in this paper. Furthermore, this conclusion regarding the almost complete lack of any global coordination of transgression-regression histories of the intracratonic basins appears to hold true in all Phanerozoic systems. This is indicated by:

1. An almost complete lack of coordination of the graphs of major Cambrian to Late Tertiary transgressions and regressions compiled by Yanshin (1973, p. 36, 17, Fig. 7) for the East-European, Siberian, North American, Australian, and South American platforms, and

2. By the demonstration of the correctness of Arkell's (1956, p. 641) conclusion that: "There was no pulse of the earth" in the Jurassic either on the cratons or in the tectonically active belts.

Even though the evidence available is somewhat scanty, it is believed to be sufficient to suggest that one should not expect a frequent and fairly complete preservation of the records of the eustatic fluctuations of sea level in Phanerozic rocks of the cratonic regions.

Concluding, there does not seem to be much doubt that, although they undoubtedly existed, the geologically instantaneous, world-wide eustatic movements of sea level did not control the ancient transgressions and regressions of the continental blocks of the lithosphere either in the Cretaceous Period or in the other Phanerozoic periods. Their record is, in fact, but very rarely preserved. The controlling role belongs instead to the ever-occurring local, regional or interregional (but apparently never global!) tectonic movements of either entire continental blocks of the lithosphere or their greater or lesser parts (down to the individual tectonic structures). Thus, the writer considers the attempts of the recent adherents of the hypothesis of the eustatic control of ancient transgressions and regressions either to ignore these tectonic movements or to dismiss them as an unimportant tectonic "noise" (e.g. Hancock, 1975, p. 113) to be completely wrong.

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