[From The American Journal of Science, Vol. XXXVIII, July, 1914.]

A REVISED GEOLOGIC TIME-TABLE for NORTH AMERICA.

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(Contributions from the Geological Department, Yale University, New Haven, Conn., U. S. A.)

THE

AMERICAN JOURNAL OF SCIENCE

[FOURTH SERIES.]

Art. I.—*A Revised Geologic Time-table for North America*; by Charles Schuchert and Joseph Barrell.

Preface.

The writers, having to teach historical geology to elementary classes in the two undergraduate schools of Yale University, have felt the need of a table of geologic chronology which shall assemble in brief space and in proper order and proportion the more significant facts of earth history. Some kind of a time-table is indeed very necessary for the elementary student in order that he may coördinate the mass of data which accumulates day by day, but not all textbooks contain such tables, and those which are given are either brief or may not express the latest views. The ideas of geologists as to what such a table should indicate grow with succeeding years. This perhaps has been especially true of the past decade.

A table of geologic ages and events is needed also as a wall chart for teaching other branches of the earth sciences, such as physical geology and organic evolution, where references must be made to the periods and eras, and it was for the purpose of such a wall chart that the table accompanying this paper was first drawn up. It is thought, however, that the results may be of use beyond this University.

The senior author is chiefly responsible for the general discussion of principles and for the portion of the chart embracing post-Proterozoic time. The junior author is responsible for the pre-Cambrian discussion and classification.

Part I. Post-Proterozoic Time (C. S.).

The well-known and beloved Californian geologist, LeConte, in reviewing the progress of geology during the Nineteenth Century, said: Through this century a gradual movement of what might be called the center of gravity of geological research took place westwardly, until now, at its end, the most productive activity is here in America. This is not due to any greater ability on the part of American geologists, but to the superiority of their opportunities. Dana has well said that *America is the type continent of the world.* All geological problems are expressed here with a clearness and a simplicity not found elsewhere (1900).

North America is the type continent, because of its simplicity of geologic structure, not only throughout its vast extent but as well throughout the geologic ages. The other continent of the northern hemisphere, on the contrary, is more complex in structure, since only in the course of time, through the welding together of several land masses by orogenic (mountain-making) forces, has Eurasia been formed. A typical continent, Dana states, is "a body of land so large as to have the typical basin-like form,—that is, independent mountain chains on either side of a low interior" (1895).

A great part of the northern half of North America has the form of a depressed shield, and has been well named by Suess the *Canadian Shield* (see fig. 1). Here in the rocks is revealed nearly all of its pre-Cambrian history, events which took an eternity to accomplish, and the details of which will always remain far less clear than those of the southern half of the continent. Though the geological history recorded in the surface rocks of most of the United States and Mexico is far shorter and later in time, the sediments are better preserved and contain an abundance of fossils accessible to geologists. To the north, and more especially to the south and west of the shield, lie vast depression fields, or neutral and subpositive areas, which have tended through the geologic ages to lie slightly below sea-level. Because of this low level, the sea has often spread over these fields and recorded there the post-Proterozoic events.

To the east of the southern depression field occur the basal remnants of a mountain system, exposing a complex of metamorphic and igneous rocks and showing that again and again through geologic time majestic mountain ranges, studded at times with volcanoes, have been raised above the present basal structures. These mountains lay on the western side of Appalachia, the eastern shore of which has in the course of time sunk deeply into the abysses of the Atlantic ocean.

The western depression field is a very wide one, bordered on the west by another old land, Cascadia, which faced the Pacific, but of this land little is as yet known. These latter two regions were the scene of tremendous geologic activity, the struggle for dominance between the continent and the

FIG. 1.

FIG. 1. The North American continent in Paleozoic time, showing in white the lands or positive elements, in darkest shading the geosynclines or sub-positive elements, and in lighter shading the extensive neutral medial area.

father of oceans, in which the land was victorious, but only after building and rebuilding marginal bulwarks of chain upon chain of mountains, marked by volcanoes from Alaska to Mexico City. This western region now embraces the grand Cordilleras of the continent and also all of Mexico.

Hence we see that North America has the form of an elongate basin, widely open at the north and nearly closed at the southeast; though in the latter place there stood for a long time a transverse mountain range, the Ouachitas, of which only the bases now remain, and these in part concealed by later mantles of sediments. The geology of the Arctic shelf sea is not yet well known, but the sediments in the folded United States mountains are of considerable thickness and extent. Between these elevated margins lies the great basin, much of which has always lain near sea-level, and over it, entering through the gaps between the marginal uplands, the oceanic waters have again and again flowed widely, to form interior shallow seas. These floods have come from the four quarters, most widely from the Pacific and Arctic, least from the Atlantic, and most persistently from the Mexican mediterranean. The partial deciphering of these multitudinous events in their orderly sequence, in addition to the similar unravellings in Eurasia by the geologists of that continent, has given the very imperfect geologic time-table here presented.

The basis of chronology.—The fundamental principle underlying all geologic endeavor is evolution, the oscillating but progressive changes wrought in the long ages, changes whose interpretation leads to the history of the earth—the science of Historical Geology.

The earth develops as a whole, but the record is far from being everywhere alike; even if it were so, it would not be wholly accessible for study, because sheet upon sheet of rock hides others below, and the atmospheric agencies have destroyed much through erosion. Likewise, the more complete stratigraphic record buried under the oceans is hopelessly lost. Therefore the completed geologic record will eventually be put together from the evidence of all places which are at present land, mainly, however, from the northern hemisphere, because this is preëminently the land hemisphere. Such history is largely brought about through the periodic adjustments of continental and oceanic areas settling down upon a shrinking nucleus, and in so doing crushing the crust into great folds which tend to rise, especially upon the margins of the continents. Broad movements of a vertical nature also take place at times, whereby the continents, being underlain by lighter rock matter, tend to warp up and restore the elevations destroyed by erosion, while the sea floors, loaded with sediment, tend to sink.

During the past twenty years much has been done in deciphering the historical geology of North America, and as this chronology needs to be adapted as far as possible to the older European sequence, it is well to put the scattered information into better order. The scheme here offered for North America does not as a rule go into detail beyond the "systems" of rocks or the "periods" of time, and it is also our desire to stand by the old and well-known terminology as far as possible.

We may well begin by repeating the questions asked by Suess in 1885: What constitutes a period and what determines its beginning and its end? How does it happen that these stratigraphical subdivisions extend over the whole earth? His answer then was: "If we could assemble in one brilliant tribunal the most famous masters of our science and could lay this question before them, I doubt whether the reply would be unanimous, I do not even know if it would be definite." While in this Twentieth Century we are coming much nearer to a definite answer, and see more clearly the several principles which serve as a basis for determining the earth's history, still a fixed geological chronology is not yet established.

The evidence of fossils.—Fossils furnish the first step in the process of stratigraphic correlation. Their testimony is checked by the geographic distribution of the sediments that contain them and the relation of the latter to the formations beneath and above them (superposition). These principles are easy to state but very difficult to apply accurately to so great a land mass as North America, and even though approximately a century of work has been devoted to it, the ground is only about half covered by detailed studies.

In general, sedimentation is a slow process, and by the time one foot of average rock accumulates, probably a thousand generations of marine invertebrates have appeared, passed their life on to their descendants, and vanished. Under relatively constant surroundings, it is held that but little if any recognizable change in the species is developed, but as the environment of the organisms is continually changing, even though only to a minor extent, these physical alterations cause the faunas (animal associations) at the very least to alter their combinations and to shift from place to place. They die out in one area, but gain a foothold elsewhere, and although this to-and-fro migration is slow when measured in years, yet in stratigraphy the faunal assemblages appear as if suddenly introduced. This fact has always excited the interest of the paleontologist, and he has explained the phenomena according to the view of his generation. Once he thought them due to special creations of new types or recoinages of old, but since the time of Darwin they have been looked upon as slow evolutions of which glimpses only are obtained in the fragments of the geologic record; or they may be due to shiftings of faunas, or to geologically sudden migrations into the continental or interior seas from the permanent or outer oceanic reservoirs, the continuous realms of marine organic evolution. The fossil faunas from the oceans spread as fast as the sea transgressed the land, and, for practical purposes in stratigraphy, may be accepted as having appeared simultaneously in widely separated places.

In all faunas there are more or less large percentages of persistent species. These static and irregularly evolving forms cannot therefore be used as fossils determinative of limited geologic time. Although on the one hand the localized species are of the greatest value in the stratigraphy of small areas, the new forms which attain wide dispersal are, on the other hand, of most significance in correlating the time stages in separated regions, for they are the progressives, the time heralders, as distinguished from their variously conservative associates. Therefore in the chronologic correlation of the stratified rocks most dependence is put upon a few species, known as "guide fossils," together with the collateral evidence of associated forms. These guide fossils may be of any class of organisms and may be represented by many or few individuals. The more abundant they are in individuals, the greater is their geographic distribution apt to be, and the more easily do they mark a geologic formation. On the other hand, the wider the geologic distribution of a guide fossil, the less can it be depended upon for detailed chronology.

Locally successive, but distinct geologic faunas derived from the same oceanic realm usually have a more or less ancestral or direct genetic relationship with one another. In some cases they are the returning, slightly altered descendants of an older fauna, in other words, "recurrent faunas." Therefore the possibility of a "break" in sedimentation between such superposed faunas is easily overlooked and the time value of the recurrent faunas underestimated. Or, two locally superposed faunas may be totally dissimilar, not only in the species but even in the majority of the genera, and yet the time break between them be a comparatively short one, the reason for this unlikeness being that the two faunas are transgressions from different oceanic realms and have therefore had independent ancestral developments.

A geologic "period" begins as a time of quiet, following a disturbance and uplift of the land. The time of quiet is marked by the erosion of the land and the spread of shallow seas. Waterways broaden and unite across a continent, only to be drained and destroyed by the crustal unrest with continental uplift which marks the close of periods. During the middle age of the periods, when the oceanic transgressions are greatest, the faunas throughout a continent are most alike in composition and have the greatest number of species in common; they have therefore been called by Chamberlin "cosmopolitan faunas." Again, faunas of the same age are most dissimilar in the early times of the periods, when the oceanic realms are most localized and the transgressions upon the continents are smallest. Similar restriction also takes place during the closing age of the periods, though at these times there are many more hold-over species from the earlier, widely dispersed faunas; in other words, there is no marked introduction of new organic types during the recession of the continental seas. However, when the oceans again spread over the continents, a long time has elapsed, many of the old familiar forms have disappeared under the stress of restricted habitat, and new forms have been developed, the prophets of a new period and indicative of the next trend in evolution.

The appearance of identical fossil genera of land animals, and more especially of mammals, in two continents that are now widely separated, is often taken as proof of the former connection of the two areas by land bridges that have since vanished beneath the sea, or of migration by routes in high latitudes which are no longer available because of the present frigid climates. This method of correlation is undoubtedly correct in the main, but as genera apparently alike have been developed under similar stimuli from unrelated stocks ("parallel development" and "homœomorphy"), single appearances on two continents cannot be accepted as migrant individuals from a common center of evolution and dispersal until the ancestral relationship (phylogeny) has been established in each case. In the same way, single marine invertebrate genera appearing in two or more oceanic realms at the same time may be parallel developments or independent evolutions from different species of the same genus.

When the lands are least overlapped by the oceans, the fresh waters more often record themselves, and especially is this true in the areas where mountains have just been born. Unfortunately, however, these, the "continental deposits," are frequently devoid of fossils, because here the great bulk of organisms live, not in the sediments, under the protective covering of water, but on the dry land, where after death, instead of receiving natural burial, they are exposed to the atmosphere and thus either eaten by other animals or attacked by bacteria and so reduced through further oxidation into the elements from which they came. In the same way, plants fail to fossilize. As for animals living in the fresh waters, they often leave traces of themselves in the form of teeth, scales, or scattered bones, but their remains are apt to be very fragmentary, due to the streaming action of the rivers; besides, they are so unchanging in specific form through successive periods as to be of little value in chronology. The animals of the dry land, however, are the best of history markers, because they evolve far more quickly under the most changeable and trying of environments. Their remains unfortunately are rarely entombed in the sediments, and as a rule those preserved are the unfortunates that have fallen victims to accidents through drowning, or miring in soft places, especially in times of drought, or have been suffocated through protracted outpourings of volcanic ashes.

The evidence of periodic oceanic spread.—The primary principle of period value underlying geologic chronology is the recognition of the times when the surface of the earth and the oceanic level are in decided motion. This movement may be of small and narrow extent, as the result of horizontal compression (local or orogenic); or its vertical effects may be felt over areas of great magnitude (epeirogenic). Not only do the lands move up and down, the sum of this motion being in the main upward (positive movements), but it is also now clear that the ocean bottoms are periodically more or less in motion, with the sum of their movements downward (negative movements). For these reasons, the oceanic level in relation to the continents is inconstant, and therefore the marine spreadings over the lands, with their concomitant sedimentation, are not only variable in time, but as well in geographic extent. On the other hand, when the lands protrude more than usual above the strand-line, the oceans naturally overlap the continents least widely and make at such times limited marine stratigraphic records, which are restricted to the margins and their embayments and to the persistent axes of depression, the geosynclines of the continent. As the oceans and seas are all connected one with another, and are as well the receivers of most of the land wash or detritus, it follows that a displacement of the strand-line anywhere, through any cause, must be transmitted to all marine waters. Then under these waters there is continuous sedimentation, and they abound in more or less of evolving life that is most advantageously situated for burial and preservation; hence the marine stratigraphic sequence is the least broken of the several kinds of historic records accessible to geologists.

It is now known that the oceans have spread periodically and more or less widely over the North American continent, the areal extent of which is about 8,300,000 square miles. These floods occurred hardly at all during the Cenozoic, 1 per cent to 6 per cent of the continent being then covered; four times widely during the Mesozoic, the submergences reaching 3 per cent to 33 per cent; and, with the maximum spread, apparently eleven times during the Paleozoic, when 1 per cent to 47 per cent of the continent was flooded. More broadly it may be stated that the floods begin and end with shelf seas marginal to the continents and varying in extent between 1 per cent and 5 per cent of the total areas of the continental platform, the conditions being thus not unlike the present conditions of overlap; while the greatest inundations during the middle of the periods attain from 12 per cent to 47 per cent of the continent.

It is therefore apparent why the major portion of the earth's chronology depends for its determination upon the marine sediments. These formations, except in so far as they are later eroded, record the extent of the transgressions, and, in their physical characters, something of the topographic form of the adjacent lands, with a hint as well of their climates; and through their fossils they establish the chronology from place to place. However, this is by no means all, for the newer geology also teaches, as we have seen, that the strand-line is constantly and geographically irregular in motion, either very slowly transgressing more or less of this or that land, or receding as the lands emerge. Therefore in no land is there a total record, but everywhere the story is more or less incomplete, and our chronology is but a patchwork of all the local histories pieced together into one still very imperfect geologic time-table.

In the marine formations we are then everywhere dealing with oceanic overlaps whose records for the time being were more or less complete, but each series of beds is nearly everywhere separated from the adjacent ones by erosion intervals. The latter are due to the periodically recurring emergent times in the history of the continents, which may be either local or of wide extent, the marine records in the latter case being swept away by the atmospheric forces. These erosion intervals are the "breaks" and they are not only significant of absence of sedimentation, but in addition are actually records of another type, that is, erosion histories resulting in topographic forms whose carving has required the lapse of a time more or less long.

Just as the marine waters are constantly registering their existence, so also do the fresh waters, but the areas of the latter are usually of comparatively small extent. The "continental deposits" tend to be an evanescent record made at one time only to be subsequently more or less completely swept away into the sea. When we observe that this record is made in the areas of erosion and subtraction, it is all the more astonishing to learn of the great thicknesses of some of these accumulations. Such, however, were made in regions which were undergoing pronounced subsidence. In Connecticut the coarse red Triassic formations attain to a maximum thickness of 13,000 feet, and in New Jersey to upward of 20,000 feet, while in Scotland the Old Red Sandstone of Devonian time also has a thickness of 20,000 feet. These deposits are the remains of beheaded mountains, the tops of which are deposited in their former valleys, that is, they are "intermontane continental formations." Again, other thick continental formations are intimately connected with marine deposits. Here we pass almost insensibly from the ocean or sea across the brackish water delta into the area of fresh-water deposition upon the land. A good example is the great Appalachian delta of Devonian times, the deposits of which in Pennsylvania reach a maximum thickness of upward of 10,000 feet. Because of these natural interfingering conditions, we are often able to fit the marine record into that made on the land, and so use both toward a more complete physical and organic chronology.

The evidence of erosion.—Geologic chronology has been so far almost wholly, though necessarily, interpreted on the basis of stratified rock accumulations, that is, the marine and continental strata. There is, however, still another record that has so far been almost refused recognition in our time-tables. This is the time evaluation of topographic form at any given stage of development (the physiography of the present, the paleophysiography of the past). To be sure, it is mainly a condition of removal by erosion of previously made histories, but nevertheless the topographic form of the land still remains and has a time value. We all appreciate to a certain extent the significance of unconformities as records of emergence and erosion between periods of inundation, but can any one tell what time value is to be accorded to the complete removal to sea-level of mountain ranges like the present Alps of southern Europe? Many times have similar mountain chains been washed away and then rejuvenated to some extent, only to be worn away again after each reëlevation.

The "breaks" and "lost intervals" are known to be many, but they are far greater in number, and their time durations, although admittedly very variable, are far longer than is usually believed to be the case. The geologic column will probably never be completed on the basis of the recoverable physical and organic evidence, but it will grow into greater perfection for a long time to come, and this growth will take place through the discovery of formation after formation along the lines of these breaks, and more particularly in the areas nearest to the continental margins. The perfection of the column will also bring about a greater harmony in the very variable estimates as to the age of the earth, as given on the one hand by the geologists and on the other by the physicists.

The major breaks in the geologic record are indicated in the time-table by "intervals," the marked erosion periods representative in the main of wide and high continents and of dominant erosion, not recorded by sediments within reach of observation; therefore in geologic chronology these are "lost times" of long duration. It was not thought desirable to give a new and independent name to each one of these intervals, but rather to use in modified form an old and familiar one. Therefore we have adopted the Greek word *epi* (= upon or after) as a prefix to the era terms, to indicate the subsequent time, that is, the intervals, thus naming these intervals *Epi-Mesozoic*, *Epi-Paleozoic*, *Epi-Proterozoic*, *Epi-Neolaurentian*, and *Epi-Paleolaurentian*. This method of naming was first proposed by Lawson for the interval following the Archean (1902, 1913). The same combination can be used, when it becomes necessary, for the intervals between the periods, as *Epi-Silurian*, etc.

Diastrophism.—As shifting of the strand-line is the most important criterion in ascertaining diastrophic action (a term to include all movements of the outer parts of the earth), it is well to state here briefly how these alternations are most readily determined. Organically they are recorded: (1) by abrupt changes in the superposed faunas, and (2) by the sudden appearance of newly evolved stocks; physically (3) by more or less obvious breaks in the sedimentation, due to sea withdrawal, (4) by changes in the character of the deposits, especially when this involves abrupt transition from organically formed strata (marl, chalk, limestone, dolomite) to mudstone and sandstone, or a change from continental to marine deposition, and (5) by marine overlaps upon rocks of earlier age, producing typical unconformities.

Correlation of formations in separated regions is made in part on a physical basis. This is done by finding similarities in disconformities (time breaks in conformably superposed or parallel strata; also called accordant unconformities), unconformities (time breaks indicated by two sets of strata inclined at varying angles to one another and easily seen by the eye=structural unconformities), and changing petrologic characters. A physical correlation is in general, however, far less reliable, and must ever remain second in importance to correlation by biotas (combined faunas and floras) for the discernment of diastrophic action. Of course, the most easily determined crustal movements are those which are compressive in character and lead to mountain-folding. Upon erosion and subsequent sea invasion, these angular or structural unconformities are the most easily found and those about which there can be the least doubt. The broad and gentle flexures known as crustal warpings, on the contrary, as a rule bring about the disconformities. The number and importance of these, on account of their difficulty of detection, are only now beginning to be appreciated.

The crustal oscillations of the earth are not due to heterogeneous and unrelated movements, but are connected, in that areas of elevation and depression remain positive or negative

FIG. 2.

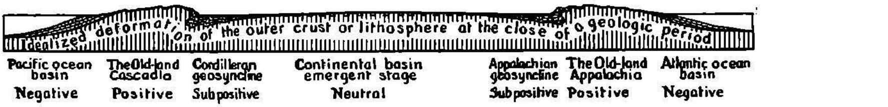

FIG. 2. Diagrammatic cross section through North America in Paleozoic time at about lat. 38°, to show effects of diastrophism. Vertical scale greatly exaggerated.

throughout the eras, or during more or less long stretches of geologic time. According to Chamberlin (1910), "Deformations are inheritances, one of which follows another in due dynamical kinship. The succession is therefore homogeneous and the results co-ordinate. . . . Under this view, ocean basins and continental elevations tended toward self-perpetuation."

The major crustal deformations are periodic in appearance, and their visible areas of movement are now in this continent, now in another; and it is this periodicity which conditions geographic history and organic evolution. All of these active and decisive movements are of long duration, and their major work is confined to the marginal areas of the continents. Farther inland, new axes or depressed folds may rise or old ones be accentuated, and so divide the continental basins into a series of smaller water-ways. Not only are the margins of the continents elevated, but apparently at the same time the oceanic basins are made either deeper or larger, or both. This simultaneous movement of the oceanic bottoms and the continental margins is proven by the fact that the major crustal deformations occur during the emergent times of the geologic periods, and this is true not only for the continent undergoing deformation, but as well for other land masses which have not moved at all, but whose strand-lines have been lowered in consequence of the oceanic enlargement.

The long-enduring middle portion of the periods is marked by relative crustal stability, as shown by more or less reduction of the continents to sea-level (peneplanation). The sediment from the eroded lands adds that much volume to the sea and causes its level to rise as a result of the partial filling. This effect, accompanying the general leveling of the land surface, produces, in the middle of the periods, maximum sea invasion. On the other hand, the earlier times of each cycle exhibit less crustal constancy and more marked erosion. The lands then warp more or less along predetermined lines, due to internal adjustments following the major movement and the reëstablishment of the balance between the sinking and rising areas (isostatic balance or isostasy), which has been altered by these deformations, by the sea invasion, and by the unloading of emergent land areas into the seas of the continents. During the closing stages of the periods, there is a renewal of crustal unrest, seen in the vanishing of the continental seas, which finally ends in another major crustal movement and in more or less complete withdrawal of the seas from the lands.

There is a certain amount of rhythm in these periodic movements and this meter permits us to group the formations into systems or periods. The more active introductory orogenic movements are of comparatively short duration. In contrast, the quieter but broader deformations within the period, of epeirogenic nature, as shown by world-wide movements of the strand-lines (eustatic movements), are of long continuance. Each submergence with the following emergence is seemingly the natural basis for the delimiting of a period. Among these periodic movements some are far more intense and of greater geographic extent than others, at times when mountain ranges in more than one continent are simultaneously or successively in motion. These are the diastrophic grand cycles, or, according to Dana and LeConte, the "critical periods" or "revolutions" in the history of the earth, and they bind, as it were, the chapters into the book of geologic time.

Chamberlin (1898) has well said that "the ulterior basis of classification and nomenclature must be dependent on the existence or absence of natural divisions resulting from simultaneous phases of action of world-wide extent. . . Great earth movements affect all quarters of the globe" because "in a globe, all of whose parts owe their positions to the stress and tension of other parts, every rearrangement that rises in magnitude above the limits of local support extends its influence to the whole." The movements are not heterogeneous, but are periodic, for "the oceanic basins became progressively deeper and more capacious, while the continents became higher (degradation aside). In this assumption . . . there lies, if it be true, a basis for the natural division of geologic events, these movements being in themselves and in their immediate consequences the basis of such division.

"The major movements of the earth's surface have consisted of the sinking of the ocean bottoms and the withdrawal of additional waters into the basins whose capacities were thereby increased." Then, too, the master factor in the great crustal readjustment has been the progressively greater "radial shrinkage of the ocean bottoms" surpassing the "radial shrinkage of the continental platforms to the average amount of some 10,000 or 12,000 feet." Besides these periodic crustal readjustments resulting from internal causes, there are external readjustments of long duration, the quiescent periods, working "to precisely opposite ends, the degradation of the land and the filling of the basins."

Terminology and definition.—The local warpings as a rule bring about the development of formations and disconformities. These are grouped together into the periods by the "minor diastrophic movements," or the "epicycles" of Willis (1913), when local mountain ranges are developed. As there are many of these movements and as they are not of the first order of magnitude, we propose to call them ***disturbances***, to distinguish them from the rarer but far greater events, the "major diastrophic movements," or ***revolutions*** of Dana, which group the periods together into eras.

It seems probable that the periods were all separated by disturbances, events occurring now in this and now in that continent, but in each case enlarging some oceanic basin and so reacting on the strand-line the world over. On the other hand, during the revolutions, all of the oceans were enlarged by the sinking or broadening of their basins, and all the continents were more or less reëlevated. These latter are the "critical periods" in the history of the earth and are marked by the following features (somewhat modified from LeConte, 1900):

(1) By widespread deformation of the earth's crust, transmitted from place to place. This leads to the elevation of many and widely separated mountain ranges, followed by long intervals of erosion and mountain removal, and therefore by almost universal unconformities. Because of the long-enduring intervals of lost record, the subsequent faunas are not only very different, but appear as if suddenly or at least quickly evolved. Each revolution or critical period is named after one of the prominent mountain ranges formed at the time designated, for example, Laramide and Appalachian revolutions. The subsequent interval is the transition period from one era to the next.

(2) By widespread changes in the physical geography. That is, there are at these times a highly diversified or young topography, decided alterations in the continental outlines, the making of new or the breaking down of old land connections (the land bridges which permit intercontinental organic migrations), and marked changes in the oceanic currents, all of which also lead to marked variations of temperature and often to actual glacial periods.

(3) By marked and widespread destruction of the previously dominant, prosperous, and highly specialized organic types. This is produced partly by the physical changes and partly by the extensive migrations that are more conspicuous at these times and that therefore invite the spread of death-dealing parasitic diseases.

(4) By the marked evolution of new dominant organic types out of the small sized and less specialized stocks, and by the development of hordes of new species.

The last or Cascadian revolution is so recent that the record of it is not lost, and a study of this enables us better to comprehend the changes wrought by the earlier revolutions. LeConte regards it "as the type, as the best proof of the fact of critical periods, and as throwing abundant light on the true character of such periods, and especially on the causes of the enormous changes in organic forms during such times" (1895).

The periods usually take their names from the geographic area where the system of rocks was first considered to be of period value. Thus the Cambrian, Ordovician, Silurian, and Devonian systems were first discerned in England and Wales and take their names from ancient peoples living in these countries, or from the district itself in which the rocks are best developed. Permian is from the Province of Perm in the Urals of Russia, while Jurassic comes from the Jura mountains. Mississippian directs attention to the Mississippi valley, where these rocks are well developed; Pennsylvanian, to the greatest coal state in North America; and Comanchian (1887), to the home of the Comanche Indians in Texas. With regard to the last division, however, Shastan (1869) is an older name, having reference to the Shasta mountains of California. Triassic has reference to the tripartite development of these rocks in Germany, and is an heirloom from the days of geology when the science had not worked out the principle that formations and periods must be based upon type areas. Cretaceous is a still older inheritance from the days of mineral geology, before there was much stratigraphy, the name being based upon the chalk deposits of western Europe. Should this petrographic term be objectionable, the geographic name Platte

(1876) from the river of that name in Kansas and Wyoming could take its place in America.

The geologic time-table.—The time is not yet at hand for a complete evaluation of the minor diastrophic movements, because the recorded geologic succession in the different countries is by no means the same. For instance, the chronology of Africa south of the Sahara desert is in the main one of erosion, with a wonderful record of continental deposits and glacial formations. In other words, this continent throughout time has generally stood well above the pulsating oceans, and owing to reëlevation in recent geologic periods now stands at an average elevation of 2000 feet above sea-level. North America, on the other hand, lay near sea-level throughout the Paleozoic, was often in part submerged, and therefore has recorded in its rocks the most complete history of this era; but during the Mesozoic the greater eastern half of the continent was continually above the sea. The Mesozoic marine sedimentary record is in consequence restricted to a narrow strip along the Atlantic, to a wider area along the Gulf and Pacific margins, and to the Great Plains country, over which there flowed great inland seas from Mexico to the Arctic in Cretaceous time. To find the Mesozoic history in greater perfection we must look to the countries to the north of the Mediterranean. On the other hand, the Ordovician period is closed in America by the *Taconic disturbance* (named from the Taconic mountains of eastern New York), when low mountains were thrown up from Virginia to Newfoundland; whereas this movement is hardly registered in Europe outside of Great Britain. And again, the Silurian throughout western Europe is closed by the *Caledonian disturbance*, when mountains were raised from Ireland and Scotland through Norway into arctic Spitzbergen; while in America no marked elevation then took place. In early and middle Devonian time, however, all northeastern North America was in the throes of mountain-making and decided volcanic activity; this is the *Shickshock disturbance* so well seen in the mountains of the same name in southern Quebec and Gaspé.

Because of these unsatisfactory conditions in our present knowledge of the earth's history, we are not in a position to state that the periods in our table are the only ones that will eventually be recognized in North America. On the contrary, we confidently expect to see evidence developed to show that the Mississippian period embraces two diastrophic cycles or periods (Tennesseian and Waverlian); the Ordovician has certainly two and apparently four (Cincinnatian, Champlainian, Canadian and Ozarkian); while the Cambrian has three (Croixian, Acadian, and Waucobian). To keep these movements or probable diastrophic cycles of period value before geologists, we have placed their names in the fourth column of the table.

In conclusion, we may truthfully say that there is now a good deal of harmony among geologists in their use of the theory that the surface of the earth is periodically and rhythmically in motion, and that this diastrophic action is the basis of chronogenesis, developing not only cycles of sea invasion and land emergence, and cycles of erosion, but as well cycles of organic evolution. Although the eras are clearly recognizable everywhere, nevertheless, until the geologic geography of Europe is worked out in detail, we shall not be able to say that the various periods in current use are all established in nature, and it will therefore be doubtless advisable for America to continue to work out her own geologic chronology.

Part II. Pre-Cambrian Time (J. B.).

When the International Committee in 1905 proposed a nomenclature for the pre-Cambrian rocks of the Lake Superior region, it may have seemed to some at that time that the larger relations had become fixed, and that future work, while not altering the classification, would serve to develop details. The classification then proposed represented in fact a large advance upon that apparent hopelessness of solution of the pre-Cambrian which in previous decades had been summed up in the name of the "Basement Complex," but the growth of knowledge regarding this earliest division of earth history has kept on during the past decade with equal pace, and has been perhaps as great as in any field of geology. It has revealed more clearly a distant perspective of earth history analogous on a larger scale to that vista of prehistoric human history which has been developed during this same decade in Europe. The meeting of the International Geological Congress at Toronto in 1913 was the stimulus which determined that a revision of the pre-Cambrian classification should be made, with the object of making it express more exactly the present points of view. This revision, however, like that of 1905, must be regarded as provisional only, another step toward a larger and more accurate knowledge of the long eons which preceded the fossiliferous record. At least four somewhat different classifications were proposed, but, although showing some radical differences, they nevertheless hold much in common. For the purposes of this table, that of Coleman has been most largely followed, but the views of Adams, Collins, Lawson, and M. E. Wilson have also been of use.

In arranging tables of geologic chronology, it has been customary to show the sequence of stratified formations only.

Periods of deformation have not found recognition except as events closing periods of sedimentation. Periods of erosion have not been named, and if noted at all in the historic sequence have been represented in tables only by a line of unconformity. In the pre-Cambrian history it is necessary for any adequate representation to give to periods of deformation and periods of wide-spread erosion name and place comparable to the periods represented by known sedimentary record. The incorporation of these principles is a feature of this table. Periods of igneous invasion and crustal revolution are shown on the right, periods of sedimentary record on the left. The lesser erosion intervals resulting in the breaks which separate periods are shown by narrow spaces, the great intervals by wide spaces. Even this magnification, however, probably continues to minimize the duration of the great erosion intervals. The arrangement of the table which results serves to make prominent the most significant and distinctive features of the pre-Cambrian,—on the one hand the wide-spread crustal revolutions characterized by vast upwellings of molten rocks; on the other, the profound depth to which erosion has planed, revealing broadly at the surface, levels of the crust once subjected to regional metamorphism at depths measured in miles. In this high average attitude of the lands with respect to the sea, indicated by mountain-building and erosion, the pre-Cambrian resembles the Cenozoic more than it does the Paleozoic and Mesozoic. The completion of the present cycle of erosion will remove wide areas of sedimentary rocks of Mesozoic and Paleozoic age now lying above sea-level, and greatly broaden the exposures of pre-Cambrian rocks. The continental record of the present, like that of the pre-Cambrian, will become one dominantly of diastrophism and erosion, with sedimentation in geosynclines, but all on a lesser scale of magnitude.

To note in descending order certain of the problems presented in the present table: the attention may be turned first to the use of the names Proterozoic and Archeozoic, with their popular rendition as the Age of Primitive Marine Invertebrates and the Age of Unicellular Life. The reason for this usage is the desire for conformity with the system of classification used for the later geologic ages. The Proterozoic, however, is broken here into an early and a late division, separated by a period of profound diastrophism, following a use made by Coleman in the Dana Memorial Lectures on the Silliman Foundation, given at Yale University in December, 1913, and to be published during 1914 by the Yale University Press. The limitations of these divisions are thus structural rather than biologic, but this is true in a measure also of the later eras, as argued by

Chamberlin.* As the names of successive great divisions of earth history, to be applied in widely separated regions, these terms Archeozoic and Proterozoic imply a less definite correlation than the more localized terms of Paleolaurentian, Neolaurentian, and Algonkian, used here for the Canadian Shield. For this reason these "zoic" names appear to have real value, as well as for the fact that by their use harmony is maintained through the whole scheme of geologic chronology. The nature of the faunas of the Proterozoic and Archeozoic is unknown, as is also the time in earth history when the Metazoa first rose to dominance over the Protozoa. The dividing line therefore cannot be drawn from biologic evidence; but even if a fair knowledge of the life of these times was possessed, it is probable that it would be found gradational to a considerable degree, and these broad names as here used could still apply without doing violence to the biotas of the Paleo- and Neolaurentian.

In this table the name Huronian has been restricted to the series originally studied by Logan. The Animikie, often called the Upper Huronian, is separated by a wide-spread unconformity and in its wider regional extent is distinct from the original Huronian. On the other hand, many of the areas formerly called Lower Huronian are composed of rocks which are separated by a crustal revolution and a following great erosion interval from the true Huronian. Three distinct series have thus become linked in past decades under one name, but the tendency of modern classification is in just the opposite direction. That which is here still called Huronian is no doubt susceptible of division, but there would be questionable value in introducing such subdivisions in this table and it would involve correlations which only those personally familiar with the fields should undertake.

The first great advance in the understanding of the Laurentian, the basal Archean, lay in the recognition that the gneisses were largely of igneous origin and were younger than certain lavas and sediments which rested upon them. It became apparent that vast domes and irregular bodies of molten rock had welled up from the unknown depths, had displaced and engulfed the older foundations of the crust, and had permeated and altered the surficial rock cover which still remained. These great masses of igneous rock are known as batholiths. In the invasion and injection of the older rocks they have absorbed material into themselves and added their emanations to the enveloping rocks. Mountain-making pressures also came into play and combined their action with that of igneous

* Van Hise and Leith, Pre-Cambrian Geology of North America, Bull. 360, U. S. Geol. Surv., 1909, p. 21.

invasion. Batholithic mountains and regional metamorphism were the result.

The greatest additional advance in recent years regarding the pre-Cambrian classification is doubtless the differentiation of the Laurentian igneous invasion and crustal disruption into two distinct crustal revolutions separated by a long era of erosion and sedimentation. Such a difference in age in the Laurentian base is discussed by Van Hise and Leith (op. cit., p. 28), part of the fundamental granites being regarded as intrusive in the Algonkian. The term Laurentian they recommend to be restricted to the older granites intrusive into the Keewatin, but not into younger rocks, and they point out the confusion which results when the determination of the age of the granite is neglected.

When in 1889 it was proposed by the United States Geological Survey to classify the pre-Cambrian rocks into two great divisions, the Archean and Algonkian, it was not known that the granitic base held any important masses of sediments; and the Archean, represented mostly by Keewatin basaltic lavas and Laurentian intrusive granites, both in altered forms, that is, greenstones and gneisses, was looked upon as a primal igneous eon. The Algonkian in contrast was thought to consist dominantly of sediments, though including much igneous material. Later work has largely broken down this distinction. The enormously thick Grenville series and the Sudburian were once widely spread, but have been mostly swallowed in the rising granites. Important intrusions cut also the Huronian and Animikian. In view of this intermeshing of what were once thought to be two kinds of dominant terrestrial activity, distinctly separated in time, the term Algonkian has largely lost its usefulness. If used at all, it should apparently be restricted to the rocks laid down after the second of the wide-spread granitic invasions which disrupted the foundations of the Canadian Shield.

The first of the granites, Lawson in his recent paper continues to call the Laurentian, the second great invasion he has named the Algoman, and he places it after the Huronian. Other writers, however, place the second before the Huronian; Coleman, moreover, considers it probable that the Laurentian of Logan's original area belongs to the later invasion, not the earlier, and the name refers more properly therefore to the later of the two. Such a conclusion leaves the earlier granite and gneiss nameless. In order to avoid confusion until more definite knowledge is attained, the writer proposes to call the older the *Paleolaurentian*, the later the *Neolaurentian*. Probably much of the fundamental granite gneiss for a long time, if ever, cannot be classified positively into either the one or the other division. For such areas the general name of Laurentian will continue to apply, and may include rocks of two widely different ages. Thus the field geologist is not faced by the difficulty of indicating the age and relations of the basement rock of the Canadian Shield before such are known in his locality.

The presence of vast batholithic invasions is not now regarded as so distinctively a process related to earth origin as it was formerly, though in the Laurentian it does seem to have occurred on a grander scale than in any later era and in that respect is doubtless related to the earlier stages of the earth. The metamorphic province of the Appalachians, for example, has been intruded by granite gneisses in the Paleozoic, the extent of their exposure being shown by the blotches of red on the geologic map of North America published by the U. S. Geological Survey in 1911. The areas of concealed granites and gneisses are without doubt of far wider extension, connecting in depth what are now seen as isolated areas. If erosion were to plane as deeply in the metamorphic regions of the Appalachians, it would doubtless reveal there a basement complex of Paleozoic and older rocks comparable in character to the Laurentian. The Cordilleran Province is also widely underlain by igneous rocks, but these are mostly of post-Paleozoic date. In the Sierras and Coast ranges they have become broadly exposed by erosion, and a deeper planation would there also widen and unify the exposures of igneous rock.

The recognition of at least two great periods of batholithic invasion in the pre-Cambrian raises the question whether there may not be more, and whether the basal fundamental gneiss in different parts of the world, as Van Hise has previously noted, may not have varying ages. With increase of knowledge this seems more strongly a possibility and should serve as a caution against hasty correlations of widely different regions. Lawson puts the great Algoman igneous irruption and the following Eparchean interval between the Huronian and Animikian. Others regard the greater break as below the Huronian. If, however, batholithic invasion should be found to occur widely at this horizon, it might result in a division of the pre-Cambrian of the Canadian Shield into four, in place of the present three divisions, as these in turn now tend to supplant the older usage of a two-fold division into Archean and Algonkian.

Molten rock accumulates in reservoirs deep in the crust and the higher intrusions and extrusions are given off from these. But while standing quiescent, the fluid acts like an unstable emulsion. On the one hand, the lime, iron, and magnesia tend to segregate more or less together, retaining less than the average per cent of silica. This dominance of metallic oxides gives basic magmas, fluid at lower temperatures and more thinly fluid than those which are richer in silica. The common solidified forms are the basaltic surface rocks and, at greater depths, the diabases and gabbros; rocks rich in hornblende, pyroxene, and olivine. On the other hand, the alkaline oxides, soda and potash, tend to separate from the heavier metallic oxides and keep with them most of the silica, the acid radicle of the common rock minerals. They thus give rise to the acidic magmas, solidifying into rocks dominated by alkaline feldspar and quartz. Such rocks are, however, difficult to melt and become pasty rather than fluid, when heated in the furnace. But in the laboratory of nature the fusion takes place at great depths in the crust and the magmas are surcharged with gases which, because of the pressure of the overlying rock, cannot escape. Their presence in various degrees of concentration gives all degrees of fluidity and consequent capacity for intrusion. As a whole, however, the basic magmas are probably more fluid even at depth, and are markedly more fluid on approach to the surface. The acid magmas at the surface betray their viscous nature in pumice, obsidian, and rhyolite; at depth, on the contrary, they give rise to granites and to the slightly more basic forms known as granodiorites. In thin injection sheets and in the vein-like nature of pegmatite dikes they there betray a high local fluidity, but in the greater masses the structural phenomena not uncommonly suggest a higher viscosity and therefore a lessened capacity to rise through overlying rocks.

The maintained fluidity of basic magmas makes easy their extrusion in enormous volume, in spite of their high density. In some regions the great lava fields of Cenozoic date show no evidence as to whether more acidic phases of the regional magmas are concealed beneath, but where erosion in the Cordillera has exposed the granite sand granodiorites to view, the latter are commonly seen to have been preceded in the same regions by great extrusions of lavas and breccias, mostly of intermediate or basic nature. A period of great batholithic invasion may therefore be connected genetically with a preceding period of lava and breccia outpourings. The Neolaurentian batholithic invasion was preceded by very basic lava flows and tuffs, as is seen in the upper parts of the Sudbury series. The Paleolaurentian invasion was preceded by the vast basaltic flows of the Keewatin.

These facts concerning the recurrence here and there through geologic time of regional igneous activity, volcanic phenomena culminating in subcrustal foundering and the cradling of the surface rocks upon newer foundations, when taken in conjunction with the widely separated ages of the Paleo- and Neolaurentian invasions, show that it is no longer safe to regard the Keewatin and Laurentian as parts of a primal igneous eon.

They are distinctive in their wide-spread extent and seem to have developed on a scale and with an intensity that are characteristic of those early ages, but are not unique in time.

This point of view suggests the possibility of a still more distant vista of geologic history. The Coutchiching of Lawson, long doubted but determined recently to have in part a real existence, lies conformably beneath the Keewatin lavas. The Grenville, perhaps the thickest of known sedimentary series, is torn and injected by granite and is generally agreed to have preceded the Paleolaurentian revolution. There is no certainty as yet, however, regarding its relation to the Keewatin. Miller and Knight in the Madoc area have found a series of rocks resembling the Grenville and overlying a series of greenstone schists correlated with the Keewatin greenstones. As the Canadian investigators have pointed out, however, the Grenville is so generally separated from the Keewatin of the Lake Superior succession by a belt of batholiths that no convincing general correlation between the two regions is yet possible. In either case, whether older or younger than the Keewatin, the vast thickness and sedimentary character of the Grenville series would seem to mark out those rocks as the records of a period or era which should ultimately be separated from the Keewatin. The Grenville shows how very far removed in time is the following Laurentian crustal disruption from the origin of the earth. Before that recurrence of the reign of fire, the orderly processes of air and water had been in operation for ages, making and depositing sediments whose thickness is measured by many tens of thousands of feet. The limestone in the Grenville, estimated at more than nine miles in thickness, and by far the greatest in amount of any known pre-Cambrian formation, testifies further to the efficiency of chemical weathering, a process frequently inefficient in later pre-Cambrian ages.

The Grenville everywhere floats upon and is torn to pieces by younger igneous rocks. Its original floor may be everywhere destroyed. Deep erosion has now removed all but the more downsunken troughs or included masses. The interior forces generated in the depths of the earth and the external forces born of the ancient sun thus limit, as if to a glimpse between two curtains, our vision of this oldest known period of the earth. But the history which the Grenville records shows that even this is not the primal eon. That is hidden, perhaps forever, from vision and from hammer.

GEOLOGIC CHRONOLOGY FOR NORTH AMERICA.

(1) Classification based on Superposition of Strata, and Erosion Intervals.

CORRELATION BY MEANS OF FOSSILS.

Eras	Major Divisions	Periods	Epochs		Advances in Life	Dominant Life
PSYCHOZOIC			Recent (Alluvial or Post-Glacial)	Cascadian Revolution	Rise of world civilization The era of mental life	**AGE OF MAN**
CENOZOIC (MODERN LIFE)	QUATERNARY	Glacial	Pleistocene		Periodic glaciation Extinction of great mammals	**AGE OF MAMMALS AND MODERN FLORAS**
	TERTIARY	Late Tertiary (Neogene)	Pliocene		Transformation of man-ape into man	
			Miocene		Culmination of mammals	
		Early Tertiary (Paleogene)	Oligocene		Rise of higher mammals	
			Eocene		Vanishing of archaic mammals	
MESOZOIC (MEDIEVAL LIFE)	LATE MESOZOIC	Epi-Mesozoic Interval		Laramide Revolution	Rise of archaic mammals	**AGE OF REPTILES**
		Cretaceous	Lance		Extinction of great reptiles	
			Montanian Coloradian		Extreme specialization of reptiles	
		Comanchian			Rise of flowering plants	
	EARLY MESOZOIC	Jurassic			Rise of birds and flying reptiles	
		Triassic			Rise of dinosaurs	

[Continued on the next page.]

GEOLOGIC CHRONOLOGY FOR NORTH AMERICA.

(1) Classification based on Superposition of Strata, and Erosion Intervals.

CORRELATION BY MEANS OF FOSSILS.

<table>
<tr><th>Eras</th><th>Major Divisions</th><th>Periods</th><th colspan="2">New Periods</th><th>Advances in Life</th><th>Dominant Life</th></tr>
<tr><td rowspan="13">PALEOZOIC
(ANCIENT LIFE)</td><td rowspan="5">LATE PALEOZOIC
OR
CARBONIFEROUS</td><td colspan="2">Epi-Paleozoic Interval</td><td rowspan="3">Appalachian Revolution</td><td>Extinction of ancient life</td><td rowspan="5">AGE OF AMPHIBIANS AND LYCOPODS</td></tr>
<tr><td>Permian</td><td></td><td>Rise of land vertebrates
Rise of modern insects and ammonites
Periodic glaciation</td></tr>
<tr><td>Pennsylvanian</td><td></td><td>Rise of primitive reptiles and insects</td></tr>
<tr><td rowspan="2">Mississippian</td><td colspan="2">Tennesseian</td><td>Rise of ancient sharks</td></tr>
<tr><td colspan="2">Waverlian</td><td>Rise of Echinoderma</td></tr>
<tr><td rowspan="2">MIDDLE PALEOZOIC</td><td>Devonian</td><td colspan="2"></td><td>Rise of amphibians
First known land floras</td><td rowspan="2">AGE OF FISHES</td></tr>
<tr><td>Silurian</td><td colspan="2"></td><td>Rise of lung-fishes and scorpions</td></tr>
<tr><td rowspan="6">EARLY PALEOZOIC</td><td rowspan="3">Ordovician</td><td colspan="2">Cincinnatian</td><td>Rise of land plants and corals</td><td rowspan="6">AGE OF HIGHER (SHELLED) INVERTEBRATES</td></tr>
<tr><td colspan="2">Champlainian</td><td>Rise of armored fishes</td></tr>
<tr><td colspan="2">Canadian
Ozarkian</td><td>Rise of nautilids</td></tr>
<tr><td rowspan="3">Cambrian</td><td colspan="2">Croixian</td><td>Rise of shelled animals</td></tr>
<tr><td colspan="2">Acadian</td><td>Dominance of trilobites</td></tr>
<tr><td colspan="2">Waucobian</td><td>First known marine faunas</td></tr>
</table>

PRE-CAMBRIAN HISTORY.

Archean of earlier authors.

(2) Classification based on sequence rocks, crustal movements, and cycles of erosion. Order of events according to Coleman.

CORRELATION WITHOUT THE AID OF FOSSILS.

Eras	Major Divisions	Periods: Recorded dominantly by surface deposits (Sedimentary and igneous)	Periods: Recorded dominantly by internal structures (Intrusion and diastrophism)	Physical Characters	Dominant Life (Inferred)
LATE PROTEROZOIC (PRIMITIVE LIFE)	ALGONKIAN	**Great Epi-Proterozoic Interval. Over much of the earth the unconformity extends to Neolaurentian Revolution**			**AGE OF PRIMITIVE MARINE INVERTEBRATES** (Fossils almost unknown. Delimitation of base of this age indefinite)
		Keweenawan		Continental sediments and basic volcanics. Metalliferous deposits in older rocks	
		Animikian (Upper Huronian)		Sediments dominant Great Iron Series	
				The Eparchean Interval of Lawson	
		Huronian (Lower)		Aqueous and glacial deposits Oldest known fossils (Archæocyathinæ)	

EARLY PROTEROZOIC (PRIMITIVE LIFE)	ARCHEAN OF LATER AUTHORS	NEO-LAURENTIAN	Epi-Neolaurentian Interval. Peneplanation of mountains and continents			AGE OF UNICELLULAR LIFE PROTOZOA AND PROTOPHYTA (Fossils wholly unknown)
				Neolaurentian Revolution	Batholithic mountain-building Metamorphism and igneous invasion of Sudburian and older rocks	
			Sudburian		Basic lava flows in upper part Conglomerates and quartzites dominant (Temiscaming, Pontiac, etc.)	
ARCHEOZOIC (PRIMAL LIFE)		PALEO-LAURENTIAN	Epi-Paleolaurentian Interval. Profound erosion of mountains and continents			
				Paleolaurentian Revolution	Batholithic mountain-building Igneous invasion of Keewatin Crustal disruption	
			Keewatin Coutchiching Grenville ?		Basic volcanics and iron formations Coutchiching schists and gneisses Grenville calcareous sediments	

THE UNRECOVERABLE BEGINNING OF EARTH HISTORY

COSMIC HISTORY