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PROPOSALS FOR TIME CLASSIFICATION AND CORRELATION OF PRECAMBRIAN ROCKS AND EVENTS IN CANADA AND ADJACENT AREAS OF THE CANADIAN SHIELD

PART 2: A PROVISIONAL STANDARD FOR CORRELATING PRECAMBRIAN ROCKS

R.J.W. DOUGLAS

Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

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FOREWORD

This report was prepared by the author shortly before his untimely death on November 1, 1979, in an attempt to bring some order to time classifications presently in use for Precambrian successions. The impetus came from the need for systematic correlation in compiling the 1:1 million geological atlas of Canada, a project for which Dr. Douglas was the co-ordinator and general editor.

The proposed classification is in essence that proposed by C.H. Stockwell in the 1960s with subsequent modifications, but Douglas' scheme emphasizes type areas of limited extent rather than the geological province usage proposed by Stockwell. Time intervals are established based on stratigraphic successions, orogenic and nonorogenic events and paleomagnetic considerations. Stockwell has prepared an extensive compilation of isotopic age determinations and of published discussions of ages of Precambrian rocks and orogenic episodes. This will be published separately by the Geological Survey as a paper series report in 1981.

The extensions proposed by Douglas and Stockwell to the existing Precambrian nomenclature used by the Geological Survey have not as yet been accepted for general use but both are being published in order to make the proposals known to a wide audience, and to generate discussion which may enable a consensus to be reached on which a formal classification can be based.

D.J. McLaren
Director General
Geological Survey of Canada

OTTAWA, June 1980

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PART 2: A PROVISIONAL STANDARD FOR CORRELATING THE PRECAMBRIAN ROCKS OF THE CANADIAN SHIELD

Abstract

In 1964 the Geological Survey published a Precambrian time scale based on isotopic age determinations which quantified and somewhat elaborated the then existing fourfold division. The Survey is currently compiling a 64-sheet, 1:1 million Geological Atlas and this has emphasized the need for a revised standard of Precambrian time to enable correlation between different map areas and to describe more clearly geological relationships. In this report modifications are proposed to the 1964 standard, "type" assemblages are designated and the possible use of magneto-chronological units is examined. The units are described in order of increasing age in terms of Magnetic Intervals and isotopic age.

It is proposed that the Archean be divided into three eras and that the youngest of these be divided into two suberas. It is further proposed that the Aphebian be divided into three suberas, that the Neohelikian be divided into three suberas, that the Paleohelikian also be divided into three and that the Hadrynian be divided into two suberas. New names are proposed for some of these divisions.

Résumé

En 1964, la Commission géologique a publié un Tableau des temps géologiques du Précambrien basé sur la datation isotopique et qui ajoutait une dimension quantifiée, tout en l'élaborant, à la division à quatre phases qui existait alors. La Commission procède actuellement à la compilation d'un Atlas géologique composé de 64 feuilles à l'échelle de 1/1 000 000. La Commission constate la nécessité d'une norme révisée dans la datation du Précambrien afin de permettre d'établir une corrélation entre différentes zones cartographiées et pour mieux décrire les relations géologiques. Dans le présent rapport, les auteurs proposent certaines modifications à la norme de 1964, ils définissent des assemblages "types" et ils examinent l'utilisation possible d'unités magnéto-chronologiques. Les unités sont décrites de manière à refléter davantage les intervalles magnétiques et la datation par les isotopes.

Les auteurs proposent de diviser l'Archéen en trois ères et que la plus récente de celles-ci soit à son tour divisée en deux sous-ères. Ils proposent ensuite de diviser l'Aphébien en trois sous-ères, le Néohélikien en trois sous-ères, le Paléohélikien en trois sous-ères également, tandis que l'Hadrynien serait divisé en deux sous-ères. De nouveaux noms sont suggérés pour certaines de ces divisions.

INTRODUCTION

Accompanying most of the compilation maps that form the 1:1 million Geological Atlas of Canada are geotectonic correlation charts. These convey in graphic form the stratigraphic and temporal relationships of the rock units that appear on the map, and the geological events that affected them, either more clearly, or in more detail, than the legend and map are able to do. They show, in particular, the assemblages of rock units that typify certain parts of the area embraced by the map and the tectonic events that prevailed in that sector of the earth's crust. They give the nomenclature, characteristic lithology and typical facies of the rock units, as well as their general equivalence with the rock units of other sectors and other maps. The column (or group of columns) cannot convey, however, exactly the area for which it is relevant – that must be seen on the map, and of course some aspects of the geology summarized on the chart could be deduced by a close inspection of the map and legend. The geotectonic correlation chart is, in effect, the justification for the map representation, the basis for all the correlations implicit or inherent in the preparation of the compilation map.

Correlation is fundamental to any geological map, whether it be the correlation of rocks in kind or in time, and whether it be in the course of detailed mapping or in the preparation of compilation maps. The fewer the number of categories of rocks that are identified and the longer the units of geological time that are recognized, the greater is the ease of assignment, and fewer the number of problematical rocks. By the same token however, many significant geological relationships may be lost or obscured. The converse is equally obvious and particularly relevant to the need for age designations for Precambrian rocks. As knowledge of the age of Precambrian rocks increases so must the system of age designations be expanded and refined in order to convey this knowledge adequately, just as advances in biochronology have led to refinements in, and improvements to, the Phanerozoic time scale.

Not so long ago a threefold division of Precambrian time into Early, Middle and Late, or a fourfold division into Archean and Early, Middle and Late Proterozoic, were considered useful in conveying concepts of the relative ages of Precambrian assemblages. With the advent of isotopic age determinations quantification of these Precambrian time units became possible. The fourfold division was formalized further by C.H. Stockwell and defined both geologically and geochronologically, mainly in the course of preparing the Tectonic Map of Canada (Stockwell, 1964, 1970a, 1970b). He proposed the era terms Aphebian, Helikian and Hadrynian for subdivisions of the Proterozoic Eon, the subera terms Paleohelikian and Neohelikian, and the names of the terminal orogenies for the Archean, Aphebian and Helikian (Fig. 1). He used histograms of isotopic age determinations, mainly by the K-Ar method, to determine the time of the orogenies and utilized the limits of their effects as one of the criteria to establish the boundaries of structural provinces and subprovinces in the Canadian Shield. Stockwell's proposals have profoundly affected the interpretation of the geology of the Canadian Shield for more than a decade and have provided the now firmly established framework within which the significance of new chronological and geological data have been assessed.

Stockwell's standard was used by J.C. McGlynn (1970) in the preparation of the first overall correlation chart for the Precambrian of the Canadian Shield. The five age designations were also used on the Geological Map of Canada (Douglas, 1969a) and, where geological relationships so indicated, they were supplemented by a numerical ordering of the Helikian rocks, a division of the Aphebian into lower, middle and upper parts, and a threefold division of the Archean into relatively older and relatively younger parts. The latter concept was extended somewhat on a small scale tectonic map of Canada (Douglas, 1974b) in separating parts of the Superior, Slave and Nutak provinces that were affected by the Kenoran Orogeny from those parts affected by the Kenoran and older orogenies.

Some time will elapse before compilation of all the Atlas sheets covering the Canadian Shield will be complete. In preparing these maps, the significance of all available data, both old and new, will be assessed by the compilers, not the least of which will be the meaning of various geological relationships with respect to the age of the rocks and the correlation of rock units between sheets or within each sheet. Undoubtedly a better job will be done as the compilations near completion and, ideally, the methods which could be employed then to correlate the Precambrian rocks and to designate their age should be applied now. The purpose of this paper, accordingly, is to propose additions to Stockwell's standard for Precambrian time and to present the author's reasons for doing so. The objectives of the modifications are to establish for the 1:1 million Geological Atlas of Canada whatever subera time units are useful now in order to correlate as closely as possible, to indicate the temporal order of rock units and stratigraphic sequences, and to convey these aspects by use of appropriate symbols on the maps, thereby restricting the broad age assignments currently available to the rocks for which it is not possible to be more precise.

TIME AND ROCK

During the evolution of the earth from its primeval state, three sequential series of events have occurred which establish the temporal relationships of rocks – the evolution of organisms, the decay of radioactive elements, and the orientation of the earth's magnetic pole relative to particular continents or regions. Study of plant and animal fossils by paleontologists has produced time-stratigraphic and biochronological standards for the Phanerozoic Eon. Physicists and chemists have, in recent years, provided increasingly precise measurements of various isotopic ratios that serve to relate or discriminate the age of rocks far back into Precambrian time. The study of the temporal variations in the orientation and polarity of remanent magnetism in the rocks of coherent crustal plates has provided yet another method whereby the relative ages of the rocks may be established.

Time-stratigraphic Units

For better understanding and greater clarity, a distinction needs to be made between the time-stratigraphic Phanerozoic time scale and what is possible for the Precambrian[1]. The Phanerozoic time-stratigraphic system of nomenclature is based more on biochronological ordering than on stratigraphic ordering (McLaren, 1970). It is dependent primarily on the record of evolving organisms indigenous to rock-stratigraphic units and their local stratigraphic ordering, but it is the ability of the paleontologist to correlate that creates the Phanerozoic time scale. The radiometric time scale established by the Geological Society of London (Harland et al., Ed., 1964) is an additional one. It is primarily a temporal ordering of rocks that serves to

EON	ERA	SUBERA		GEOLOGICAL EVENT THAT DEFINES TIME UNIT	ESTIMATED AGE OF BOUNDARY (M a) U-Pb—K-Ar	Rb-Sr
				Cambrian	ca 570	ca 570
PROTEROZOIC	HADRYNIAN		late		ca 620	ca 620
PROTEROZOIC	HADRYNIAN		early	Avalonian Orogeny		
PROTEROZOIC	HADRYNIAN		early	epi-Grenvillian (cooling period)	1000	1000
PROTEROZOIC	HELIKIAN	NEOHELIKIAN	late	GRENVILLIAN Orogeny		
PROTEROZOIC	HELIKIAN	NEOHELIKIAN	late	epi-Elzevirian (cooling period)	1200	1180
PROTEROZOIC	HELIKIAN	NEOHELIKIAN	early	Elzevirian Orogeny		
PROTEROZOIC	HELIKIAN	NEOHELIKIAN	early	epi-Elsonian (cooling period)	1400	ca 1400
PROTEROZOIC	HELIKIAN	PALEOHELIKIAN	late	ELSONIAN Disturbance	ca 1500	ca 1550
PROTEROZOIC	HELIKIAN	PALEOHELIKIAN	early	Killarnean Orogen		
PROTEROZOIC	HELIKIAN	PALEOHELIKIAN	early	epi-Hudsonian (cooling period)	ca-1750	1755
PROTEROZOIC	APHEBIAN		late	HUDSONIAN Orogeny		
PROTEROZOIC	APHEBIAN		late	epi-Moranian (cooling period)	1870	1850
PROTEROZOIC	APHEBIAN		middle	Moranian Orogeny	ca 2140	2140
PROTEROZOIC	APHEBIAN		early	Blezardian Orogeny		
PROTEROZOIC	APHEBIAN		early	epi-Kenoran (cooling period)	2520	ca 2515
ARCHEAN		late		KENORAN Orogeny		
ARCHEAN		late		epi-Laurentian (cooling period)	2670	2660
ARCHEAN		late middle		Laurentian Orogeny	2900	2880
ARCHEAN		early middle		Wanipigowan Orogeny	3400	ca 3500
ARCHEAN		early		Uivakian Orogeny		

GSC

Figure 1. *Detailed (formal and informal) time units and estimated ages of boundaries (C.H. Stockwell, personal communication, December, 1977).*

[1] Previously partially expressed by the writer at the Penrose Conference held in Wyoming in 1970 by the Geological Society of America, and in Douglas (1969b).

quantify or calibrate the time-stratigraphic and biochronological standards. The absolute time-span of the components is established by isotopic ages of biochronologically dated rock units, or of rocks of igneous origin that are closely bracketed in time by such rock units. The double standard serves to correlate igneous rocks not otherwise relatable geologically to each other, or to the standard, and also serves as a check on the validity of some geological conclusions, but it needs reappraisal of the isotopic ages used in integrating the standards. In general, the Phanerozoic system of nomenclature works regardless of the additional radiometric time-scale, albeit more meaningfully with it. The system conveys concepts of the age of Phanerozoic rocks for local or worldwide correlation and for representing the age of rocks on legends and geological maps at any scale.

Time-rock Units

The Precambrian time-scale, depends on the intrinsic physical attributes of the rocks rather than on their fossil organic content, and on a temporal ordering of intrusive igneous rocks rather than on the law of superposition of sedimentary strata. The relationship between isotopically-determined time and the rocks so dated is more accurately described as time-rock than as time-stratigraphic. Stratigraphic ordering and temporal ordering are commonly considered synonomous, but this is true only for stratigraphic successions of sedimentary and volcanic rocks for a temporal ordering can be established independently of stratigraphy and only a temporal ordering is possible for isotopically dated igneous rocks (Fig. 2). For the Phanerozoic orogenic and tectonic events and their isotopic ages are related to the biochronological standard derived from the stratigraphic sequence, whereas for the Precambrian the isotopic ages of tectono-magmatic events are the standard, bracketing in time the stratigraphic sequences.

The second-order components of the Precambrian time-scale, the eras, are dependent primarily on determinations of the isotopic age of the products of orogenic events, mainly the intrusive granitoid rocks, but also partly on regional metamorphic effects. These are synchronous or overlapping synchronous throughout the world. The orogenies bracket in time the supracrustal successions and assemblages which, accordingly, owe their age assignments to the geological relationships they exhibit with respect to the dated rocks. Closer identification of the age of the supracrustal rocks is contingent on identification of additional orogenic events as done by Stockwell (1981) or on dating the nonorogenic, hypabyssal, basic intrusions and the volcanic assemblages themselves as proposed herein. A true time-stratigraphic scale for the Precambrian could be developed from isotopic

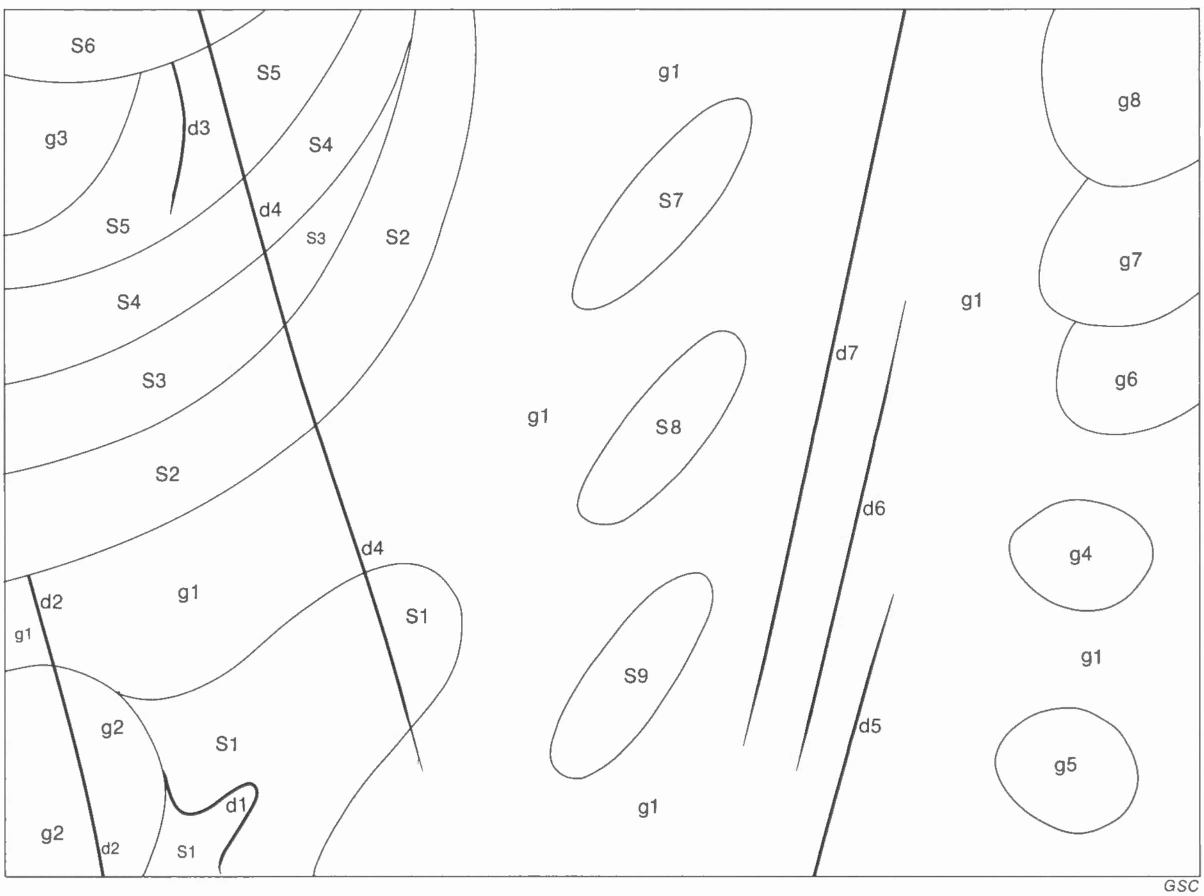


Figure 2. Schematic geological map to illustrate the distinction between stratigraphic and temporal orderings for Precambrian rocks. Both a stratigraphic and temporal ordering can be established for the sequence of sedimentary and volcanic rocks S2 to S6. A mutual intergration of temporal and stratigraphic orderings can be established for the strata S1-S6, the granites g1-g3, and the gabbro dykes d1-d4, with an uncertainty as to the relative ages of g3 and d3. A temporal ordering, but no stratigraphic ordering, can be established for the strata of the sequence and S1, but for d1, g2 and d2 intrusions, and for the granites g6 to g8. A temporal ordering can only be established radiometrically or paleomagnetically for the strata S7, S8 and S9, the granites g4, g5, and g6-g8, and for the gabbro dykes d5, d6 and d7.

age determinations of the time of deposition or penecontemporaneous diagenesis of the sedimentary rocks themselves, but there has been some difficulty in obtaining reliable numbers, and currently their reliability is assessed with reference to orogenically defined standards, rather than the converse. It could also arise from paleontological investigations of the fossil record of Precambrian organisms, but for the Canadian Shield these have not been used to establish temporal subdivisions, nor have they contributed significantly to correlation of the strata. It would seem, furthermore, that the potential is rather limited for obvious reasons. A third possibility arises from the use of paleomagnetic data, which has the most potential.

We mean different things when we say that rocks of different origin have the same age. The geological age of sedimentary rocks is their time of deposition. For volcanic rocks it is the time of their extrusion or their ejection and accumulation as volcanogenic materials. The geological age of other igneous rocks is the time of intrusion and/or crystallization to the solid state. Metasedimentary, metavolcanic and meta-igneous rocks are given age designations according to their original times of deposition, extrusion or intrusion, regardless of their degrees of metamorphism, or the number of times they have been deformed and recrystallized, or what their isotopic age may be except when they have been so reconstituted that their origin can no longer be determined, and their true age, accordingly, is unknown. They are then designated according to igneous rock nomenclature and have a younger geological age. Similarly, for intrusive rocks that have been metamorphosed or involved in later orogenies – the isotopic age may not reflect the time of intrusion. The common feature of all methods of isotopic age determination is that they establish limits to the age of the rock, which in some cases corresponds closely with the actual time of formation of the rock, whether it be sedimentary, volcanic, igneous or metamorphic. The number is just another way of expressing the measured concentrations of certain isotopes and is the time that has elapsed since a particular physical-chemical environment was established. It needs to be translated into meaningful terms with respect to the time of formation and mode of origin of the minerals involved, and then translated again with respect to the mode of origin of the rock itself. Of course, complications arise from changes in the geological environment which produce a differential loss or enrichment of the parent or daughter elements with the result that the computed age is greater or less than the real geological age; some discrepancies, however, establish a meaningful subsequent or previous geological history for the rock; some other anomalous ages are as yet inexplicable.

Even though all isotopically derived numbers must have a meaning we may not know the full meaning of them all. We need, therefore, a standard with which to relate the numbers in order to test the validity of the mineralogical-geological arguments that link the age determination to the geological age for the rock. For the Phanerozoic we have such a standard – the biochronological standard. For the Precambrian we lack such a standard and have to depend on the combination of our concept of the geological framework, and an empirical, isotopically-derived standard that must be initially assumed to be valid, for example that of Stockwell, 1964. We are dependent on the numbers alone, each being a separate entity and related to the other numbers by virtue of its magnitude or by similar relevant mineralogical-geological relationships. We cannot check with certainty one isotopic age by another method simply because the other method relates to a different mineralogical-geological concept, nor can we ascertain whether similar or different numbers from different or isolated bodies of rock are meaningful without recourse to preconceived geological concepts.

Magneto-chronological Units

The recent advances in paleomagnetic studies of Precambrian rocks (Irving, 1964) raise the possibility of developing a time-stratigraphic standard comparable in principle to that of the Phanerozoic. Paleomagnetic studies can ascertain the orientation of the ambient earth's magnetic pole within the rocks, and its polarity, at the time the rocks formed relative to their present position with respect to the pole of rotation of the earth. Determinations of the variations in paleomagnetic pole positions within stratigraphic sequences, whether sedimentary or volcanic, reflect the relative movement of that sector of the earth's crust in time, which when plotted on projections of the surface of the globe, give rise to what is known as the apparent polar wandering path. The path is calibrated by isotopic age determinations either of the sedimentary and volcanic rocks comprising the stratigraphic sequences, or of the intrusive rocks that bracket the sequences and which themselves may yield paleomagnetic pole positions.

Precambrian rocks exhibiting identifiably stable, primary, remanent magnetism represent a fair range of lithologies, especially the ferruginous sediments such as redbeds, the mafic volcanic and intrusive rocks, and their metamorphic aureoles. Most other rocks are generally low in ferromagnetic minerals and have a low magnetic intensity. Some, however, such as the acidic plutonic rocks, may develop a metamorphic aureole within which a secondary magnetism can be related to the time of intrusion. Accordingly, rocks of different origin but exhibiting the same paleomagnetic pole positions can be correlated within the same crustal plate and, if the isotopic age of the rocks of one origin were to be determined, that age could reasonably be applied to all. The magnetization direction evident in the rocks is analyzed and studied and also related mineralogically and petrologically to the processes of formation of the rocks in order to delineate different magnetization directions and their time of formation relative to the time of formation of the rocks and to subsequent events.

The apparent polar wandering path, as for example those shown in Figure 3 taken from Irving and McGlynn (1976a) and Fahrig (1978), although varying considerably so that it lies in unique positions for certain times, also overlaps or nearly overlaps for certain other times. Coincident pole positions cannot always be used to indicate a direct correlation or a particular age as several different ages may be indicated where the tracks overlap. Although there are considerable difficulties involved in establishing and calibrating the apparent polar wandering path and the validity of the loops, the rate of change in position of the pole appears more rapid at certain times and, accordingly, the resolution of the method should be more precise, whereas the resolution is less where the pole position appears to be nearly static for a relatively long time. Furthermore, where a lack of coincidence of paleomagnetic pole positions from rocks of different regions that are considered to have the same isotopic age occurs, the conclusion may be drawn that they did not lie originally within the same crustal plate, or that subsequent differential movement between the plates has occurred.

Paleomagnetic pole positions on apparent polar wandering paths are of two types: those that are derived from stratigraphic sequences, and those that are derived from intrusive igneous rocks and their metamorphic aureoles. The former type of pole traces a path that has an ordering which is both stratigraphic and temporal. This path, which is a temporal sequence of pole positions, is derived from a superimposed sequence of strata and it is valid, within the limits of accuracy of the method, regardless of the ages assigned to the rocks or the time span of the sequence because of the stratigraphic ordering of the rocks. The isotopic ages serve to calibrate the path and, depending on whether they were derived from the sequence itself, or the associated intrusive rocks, either fix or bracket the pole positions in time. From these data it is possible to define magneto-stratigraphic and magneto-chronological time intervals for Precambrian rocks in the same sense that time-stratigraphic and biochronological intervals are established for the Phanerozoic (Oriel et al., 1976). Furthermore, such minor variations as may be evident in the paleomagnetic pole positions relative to a generalized path (i.e. a smoothed, broad curvilinear path; see Fig. 3), and short spaced reversals in polarity, can reasonably be expected to be of temporal significance because they are recorded from stratigraphically ordered rocks, assuming site sampling is sufficient to average out the secular variations.

On the other hand, the intrusive igneous rocks, unless bearing observable geological relationships to isotopically dated stratigraphic sequences or exhibiting crosscutting relationships with themselves, yield an apparent polar wandering path that is dependent solely on the validity of isotopic ages for the relative position and, accordingly, for the temporal sequence of pole positions. If the age assignments are changed by virtue of better precision or a different method, the relative position of the pole positions may be changed and the apparent polar wandering path changed. The path so derived is less securely fixed in time and position because it lacks the stability inherent from a stratigraphic ordering of the rocks from which the poles are derived. In addition, little temporal significance can be attributed to minor variations in pole positions from a generalized or smoothed path, and such reversals in polarity as may be evident in the rocks of about the same age could be one or several. This is mainly because with igneous intrusions the significance of small differences in geological age is not known unless the rocks are also temporally ordered via geological relationships (Fig. 2). The numbers by themselves do not establish unequivocally whether the igneous intrusions represent a succession of events of a certain time span or a geologically "instantaneous" single event. Accordingly it is not possible with paleomagnetic data derived solely from intrusive igneous rocks to define magneto-stratigraphic intervals nor to establish magnetochronological intervals the way that term is currently defined (Oriel et al., 1976), that is as the time unit equivalent to a magneto-stratigraphic unit established within a stratigraphic succession. The paleomagnetic intervals that can be derived from intrusive rocks should also be embraced by the concept of magneto-chronological intervals however, for they arise from the joining of paleomagnetism and geochronology and, although not definable in the same manner as magneto-stratigraphic units, they are capable of being defined as magneto-intrusive units, a term that should be used to make the distinction. They have been shown to be valuable in the correlation of rocks that might not be correlatable by other means, or as easily correlated, and may also provide time brackets for other rocks whether of sedimentary, volcanic, intrusive or metamorphic origin. Such magneto-intrusive units should only serve until they can be converted into magneto-stratigraphic units, bearing in mind that for the Precambrian some may never find equivalence within stratigraphic sequences.

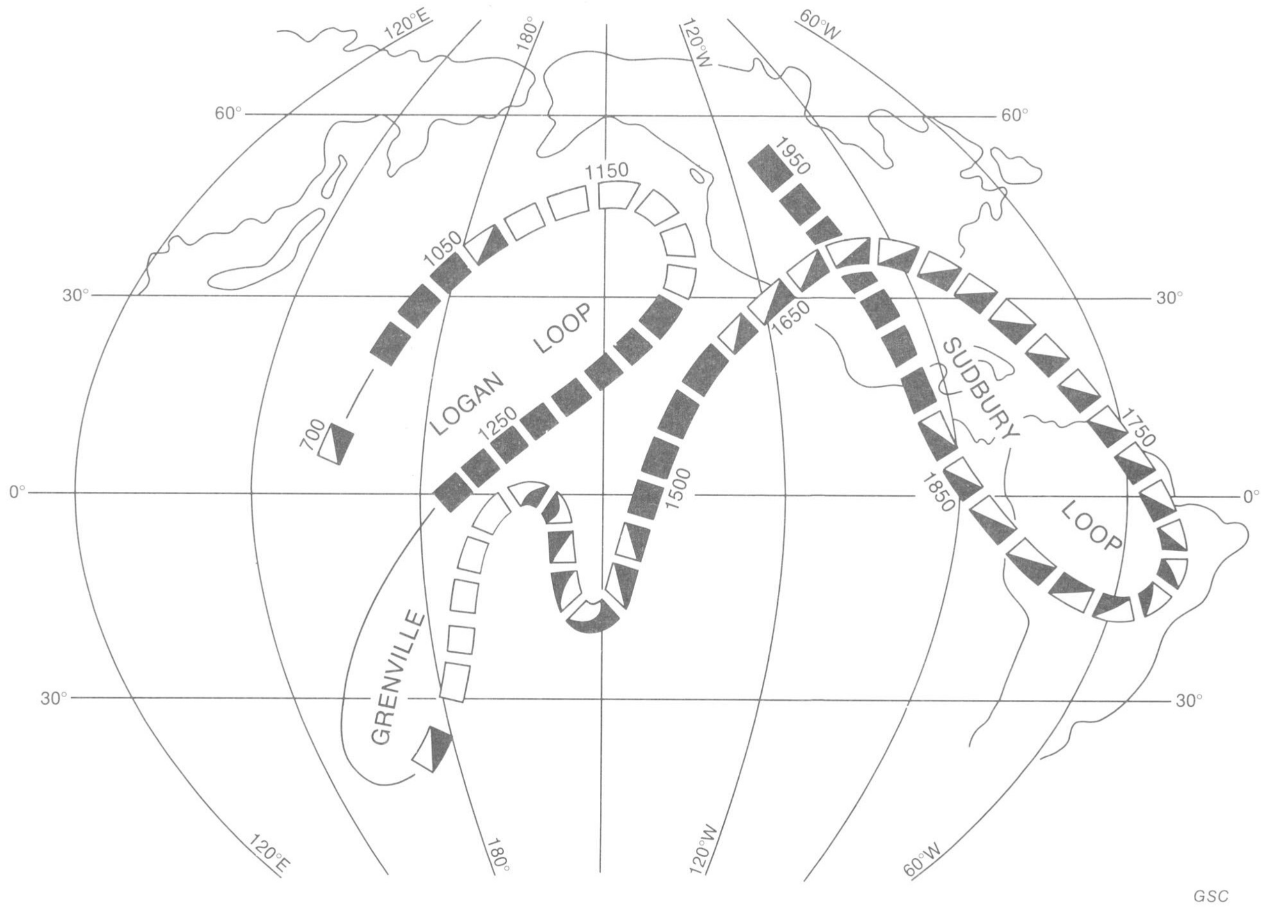


Figure 3. *Apparent polar wandering path for the Precambrian of the Canadian Shield. [From Irving and McGlynn (1976a); Fahrig (1978)]*

STANDARDS FOR PRECAMBRIAN TIME

Even though they are related in various ways to stratigraphic successions, and to sequences of geological events, the existing time scales for the Precambrian rocks of the Canadian Shield (Stockwell, 1964, 1970b, 1973), those by Goldich (1968), and the system for the Geological Map of the United States (King and Beikman, 1974) are time classifications, not time-stratigraphic classifications. Stratigraphic relationships are involved as one of several criteria invoked to define the limits of the geological provinces, and so would appear to be embraced in the definition of Stockwell's era-terminating orogenies. However, only a very few of the rocks yielding the isotopic ages used in establishing the time of the orogeny bear any stratigraphic or spatial relationship with the unconformity beneath overlying limiting stratigraphic successions. The time of the orogeny is derived by Stockwell from rocks within the Grenville, Churchill and Superior provinces that have yielded isotopic ages, each of which is accepted or rejected as having been produced in, or affected by, the orogeny. It matters not what the method used may have been to acquire the numbers, the principle remains the same. Stockwell's original system established broad time categories for what are essentially lithotectonic assemblages, one in which the plutonic assemblages are categorized according to an orogenic interval with a span of a few hundred million years and the supracrustal assemblages by the era according to the relevant orogenic brackets. However, once a numerical limit is allocated to an era, thereby defining the time of the end of an orogeny, certain rocks must then be designated a certain age according to whether they have a greater or lesser number, not by whether they constitute a certain lithotectonic assemblage or bear a certain geological relationship to other rocks. That is why a type succession of rocks and events becomes essential.

The desire of Goldich (1968) for "a simple system" or to divorce the isotopic ages from the rocks from which they were derived avoids the problems inherent in defining and revising a geological time scale for the Precambrian, but it does not accommodate the geologist who has to deal with the age of rocks in a practical way. If for no other reason, a geological time scale (i.e. one with named units of time) is essential to identify the age of Precambrian rocks on geological maps by a system of single or dual letter designations (see e.g. King and Beikman, 1974). Names for geological time units convey more than simple numerical limits; they also denote the concepts and relationships inherent in their definition. In this way they are comparable to many other names that are used to express multiple, collective or all-embracing geological attributes – for example, those for formations, groups, orogenies, intrusive suites, geological provinces, and the like. Another aspect is that, by using a geological age for stratigraphic sequences, assemblages of volcanic rocks, or for intrusive rocks, a span of time connotation is conferred and the misconception inherent in identifying rocks only by their numerical isotopic age is avoided.

Of the various modifications proposed herein to Stockwell's Precambrian time scale, all have designated assemblages of rocks. Only two can be construed as being time-stratigraphic units (the middle Neohelikian and the Huronian), and of these one is also a magneto-stratigraphic unit. Some others are almost definable as time-stratigraphic or magneto-stratigraphic units, but not quite adequately as understood by this writer; a significant deficiency for example, is the lack of knowledge of the time span of the stratigraphic succession or igneous event. Almost all are based on nonorogenic igneous events, particularly the basic igneous intrusions, from which their isotopic fixes are derived. The rock units selected have some or all of the following characteristics which are shown in Figures 5-7.

1. a temporal ordering of associated rocks, derived mainly from a stratigraphic ordering.
2. they are fixed in time by Rb-Sr and U-Pb age determinations that are reasonably reliably related to a sequence of geological events.
3. paleomagnetic characteristics that have been closely related to the time of formation of the rock.
4. they provide meaningful limits to the age of other rocks or, being widespread themselves, warrant being closely identified as to age.

The geological time terms employed on the provisional standard for the 1:1 000 000 Geological Atlas geotectonic correlation charts (in pocket; shown in abbreviated form as Fig. 4) include the conventional terms currently in use by the Geological Survey of Canada for the Precambrian – the Archean and Proterozoic eons, the Aphebian, Helikian and Hadrynian eras, and the Paleohelikian and Neohelikian suberas. The map symbols are indicated for these and the proposed names and subdivisions. These time terms are supplemented by the time-rock terms for orogenic and nonorogenic events. The orogenic events are those previously established by Stockwell (1964) and those that he has currently recognized and defined (Stockwell, 1981; Fig. 1). Of the latter orogenies, the Uivakian and Wanipigowan are used herein to divide the Archean Eon into the unnamed Early and Middle Archean eras, and the Laurentian Orogeny is used to divide the Late Archean into the Keewatian and Timiscamian suberas. The additional subdivisions of the Proterozoic Eon are derived from nonorogenic rock units. For the Hadrynian, the beginning of the Late Hadrynian is considered to be marked by the intrusion of the Coronation sills in the Coppermine Homocline of Bear Province. The Neohelikian is divided into the Early, Middle and Late Neohelikian suberas, the Middle Neohelikian being defined as the interval of reverse polarity that is recognized in the Keweenawan lavas and Logan sills in the Lake Superior Basin of Southern Province. The end of the Early Aphebian, or Huronian Subera, is defined as the time of intrusion of the Nipissing diabase, the Late Huronian being represented by the strata of the Cobalt Group. Several other rock units are also incorporated into the standard and may be used in less formal ways and as time-rock fixes for greater ease in correlating other rocks either paleomagnetically or by general geological relationships.

Completing the standard is a column showing the paleomagnetic polarities of the nonorogenic time-rock units, and a linear scale calibrated in millions of years. The time span of the polarity intervals shown on the standard are all arbitrary as the time spans of the rocks in which they were recorded are not known and only one limit may have been established. The polarity is indicated on the standard and on the rock units shown in Figures 5, 6 and 7 as a solid vertical bar for reverse (R), diagonal ruling for mixed (M) and no ornamentation for normal (N) polarities. All age determinations by the Rb-Sr method stated in this paper, and shown on Figures 5, 6 and 7, are converted to the ^{87}Rb decay constant $\lambda = 1.42 \times 10^{-11} a^{*-1}$ (the number and error limits as published are given in brackets). Some age determinations by the U-Pb method have also been converted to new decay constants as appropriate, courtesy of R.K. Wanless.

The geological relationships and temporal ordering of the rock units that illustrate parts, or that have been used in defining parts, of the standard are shown in Figures 5, 6 and 7, together with some relevant data on the isotopic ages, paleomagnetic pole positions and polarities that have been obtained from the rocks. This is analogous to charts illustrating faunal zones and ranges of individual organisms for the Phanerozoic. The paleontologist, as his ability to correlate has increased through the years, has periodically

*a is the SI abbreviation for year.

revised and redefined the limits of the time-stratigraphic units making up his standards, and subdivided them even more. Similarly, the standard for the Precambrian should not stay static, for as the data base expands with new geological relationships, new isotopic age determinations, and more precise fixing of the polar wandering path, then more rocks will be correlated and there will be a need to convey this new

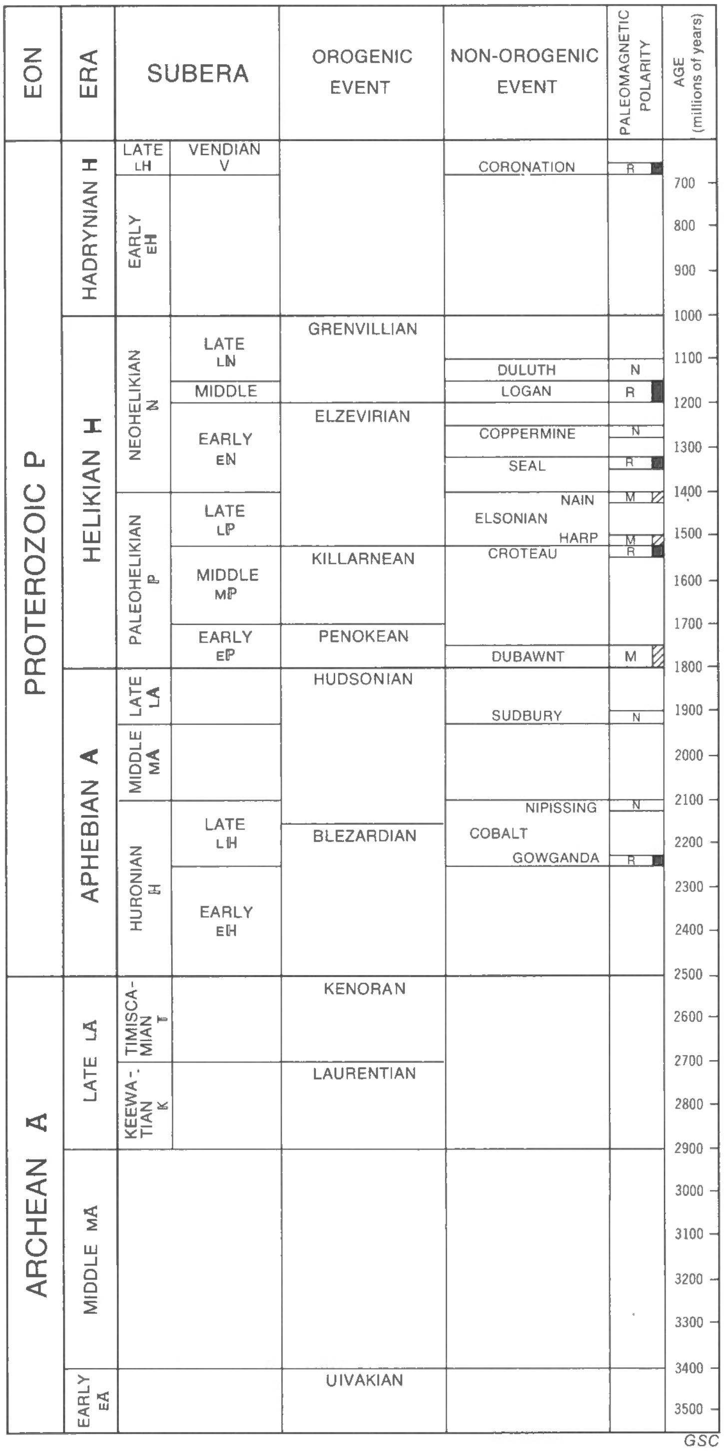


Figure 4. *Provisional standard for correlating the Precambrian rocks of the Canadian Shield.*

information in terms of more precise geological age assignments. In the various columns of Figures 5, 6 and 7, rock units and tectonic events have been assembled in a minimum of space and so not all stratigraphic and temporal relationships have been shown. The graphic system and symbols used are the same as for the geotectonic correlation charts in "Geology and Economic Minerals of Canada", 5th Edition (see e.g. McGlynn, 1970). It should be noted particularly that all horizontal lines which limit the rock units in time are correlations to the standard only, and that three degrees of reliability are indicated: solid lines of all types mean correlations are "established"; broken lines mean correlations are "uncertain"; and broken lines with a query mean correlation is "unknown", the rock unit being placed arbitrarily relative to preceding and succeeding rock units and events.

Hadrynian

Widespread Late Hadrynian basic intrusions – sills, dykes and sheets, extend across the northern part of the Canadian Shield from Bear Province in the west to Baffin Island on the east. The variously named intrusions have been grouped together as the Franklin diabases by Fahrig et al. (1971) and used to define the Franklin Magnetic Interval with a mean pole position of 8°N, 167°E, at least one reversal, and a mean age of 675 Ma. It is a magneto-intrusive interval of indefinite time span. The Coronation sills component is considered herein to constitute the rock standard, rather than the whole Franklin intrusive assemblage (Fig. 5, column 6). The sills are intrusive into the Hadrynian Rae Group, the uppermost of the stratigraphic sequence constituting the Coppermine Homocline of northern Bear Province (Baragar and Donaldson, 1973) and is accordingly unequivocally temporally related to the earlier Mackenzie Magnetic Interval recorded in the Helikian part of the sequence (Robertson and Fahrig, 1971). The Coronation sills also constitute a magneto-intrusive interval, one of lesser duration than the Franklin, and one that could be directly related to the magneto-stratigraphic intervals that might be recorded in the strata of the Rae Group. Data from other components of the Franklin intrusions are considered as establishing a correlation to the standard, and the extent of the variations accepted as being embraced by the concept of the Franklin Magnetic Interval.

As calculated by Robertson and Baragar (1972) the pole position for the Coronation sills alone is 01°S, 163°E. The sills have a consistent reverse polarization and an average K-Ar age of 647 Ma. Since all components of the Franklin Magnetic Interval are recorded from intrusive igneous rocks lacking a geologically established temporal ordering, it is not known whether the Coronation reverse pole position is preceded or succeeded by the other Franklin pole positions which are both normal and reverse, nor is it known whether there is more than one reversal and what the time span of all the intrusions may be. For instance, the Baffin dykes (Fahrig and Schwartz, 1973) which occur in several subparallel swarms, record two polarity intervals, axiomatically indicating a difference in age. Those with reverse polarity have a pole position of 6.0°N, 168.3°E, and those with normal polarity have a pole position of 6.6°N, 167.5°E. With the presently available data it is not unreasonable to correlate the Baffin and Coronation reversely magnetized intrusions and to consider the normally magnetized Baffin intrusions approximately coeval, even though the differences are greater between the two reverse poles than between the reverse and normal poles. Correlation to a standard is involved, a fact not self-evident in the practice of relating the mean pole position for all the intrusions to their average or mean isotopic age in order to obtain a "more precise" point on the polar wandering path.

The mean age of the Coronation sills of 647 Ma, with an arbitrary range of 25 Ma is used to define the Late Hadrynian Subera on the standard at 675 to 570 Ma. Possibly this should be extended to 700 Ma as noted by Fahrig et al. (1971) to allow for probable argon loss and the scatter of K-Ar age determinations for the Franklin intrusions. The Late Hadrynian so defined is equivalent to the Vendian of the U.S.S.R. (Sokolov, 1972) given as 680 ± 20 Ma to 570 ± 10 Ma, and considered here to be of period-system rank. Characteristically, the Vendian of Eurasia includes rocks of glacial origin, an origin also attributed to some parts of the Hadrynian successions throughout Cordilleran Orogen (e.g. Gabrielse, 1972). If correlated on the basis of synchroneity of glaciations, the Hadrynian of the Cordillera would be Late Hadrynian and represented by very thick and extensive successions whereas on the northern Canadian Shield any possible Hadrynian sediments are intruded by the Franklin diabases and would be Early Hadrynian. Furthermore, some of the underlying strata in the Cordillera, particularly in the north, generally referred to the Helikian (e.g. Douglas, 1969a) more properly should be referred to the Helikian and/or Hadrynian.

The pre-Late Hadrynian is termed Early Hadrynian as present data are insufficient to suggest further division. The Coronation pole position and its polarity are relevant to all of the Canadian Shield, but not directly to the bordering Phanerozoic orogenic belts as the Hadrynian in the Cordilleran, Appalachian and Innuitian orogens is allochthonous in various ways with respect to the Canadian Shield and its cratonic extensions.

Helikian

During the Neohelikian, basic igneous events in the southern and northwestern parts of the Canadian Shield, particularly the Bear Province, the Lake Superior Basin of Southern Province, and the Naskaupi Fold Belt of eastern Grenville Province, are represented by the extrusion of thick sequences of lavas, the intrusion of sills, and several dyke swarms.

Lake Superior Basin

Extensive paleomagnetic studies of the volcanic and intrusive rocks of Lake Superior Basin, commencing with the pioneering work of DuBois (1962), have established three major paleomagnetic polarity intervals – normal, reverse, normal (Books, 1972) and distinctive pole positions which permit the temporal ordering and correlation of a large part of the volcanic successions throughout the basin (Fig. 5, columns 1 to 5). The reverse polarity interval is used herein to divide the Neohelikian into three parts – Early, Middle and Late, the Middle Neohelikian comprising the rocks exhibiting the reverse polarity. Of the many possible ways that the Neohelikian could be divided this seems to provide distinctive age designations for a large number of rock units in both Southern and Bear provinces insofar as present data indicate, and offers some potential for additional refinements in the future.

The time span of the Middle Neohelikian reverse polarity interval is not precisely established; it is shown provisionally on the standard as 1150 to 1200 Ma. The mean of K-Ar ages from the Logan sills is given at 1150 Ma by Fahrig (1978) and 1160 Ma by Irving and McGlynn (1976a). A recent Rb-Sr errorchron of 1200 Ma was obtained from the basal contact zone (Wanless and Loveridge, 1978). Hanson and Malhotra (1971) reported a K-Ar age of 1300 Ma from the sill at Suomi. An U-Pb age of 1200 Ma is reported by Cumming et al. (1955) from pitchblende in veins in the Archean basement close to the overlying reversely polarized lavas at Alona Bay (Fig. 5, column 5). The reverse polarity interval is recorded in the lower part of the North Shore lava succession which is intruded by the coeval to younger Duluth gabbro complex and other bodies yielding a U-Pb age on zircons of 1115 ± 15 Ma (Silver and Green, 1963), and Rb-Sr isochrons of 1091 (1115 ± 14)[1] and 1069 (1092 ± 15) Ma (Faure et al., 1969). The pole for the North Shore lavas with reverse polarity is given at 45.8°N, 161.4°W (Books, 1968), that for the overlying normally polarized lavas at 32.6°N, 176.9°W (Books, 1972), and for the Duluth gabbro, normal, at 32.5°N, 160°W (Beck, 1970). The pole for the Logan sills, at 41°N, 140°W (Robertson and Fahrig, 1971), is an important point on the Logan Paleomagnetic Loop in the apparent polar wandering path (Fig. 3). Probably an earlier part of the reverse polarity interval is represented by the upper part of the South Trap lava succession, which lies in a different fault block than the North Shore succession, and which is stratigraphically underlain by normally polarized lavas (Books, 1972). The pole position for the South Trap lavas, reverse polarity, is 28.0°N, 127.5°W (Books, 1968), somewhat different from that for the Logan sills and lower North Shore lavas, and the pole positions for the earlier, underlying normally polarized South Trap lavas is 9.8°N, 160.4°W (Books, 1972), similar to other Early Neohelikian poles as represented by the Mackenzie Magnetic Interval. The reversely polarized parts of the South Trap and North Shore lava successions as indicated in Books (1968, 1972) are taken as defining the lower and upper boundaries of the Middle Neohelikian in the sense of a time-stratigraphic unit, and as a magneto-stratigraphic interval. The upper boundary coincides with the top of the Lower Keweenawan of some authors (e.g. DuBois, 1962; Green, 1972).

Other reversely polarized rocks of Lake Superior Basin, such as those at Mamainse Point (Robertson, 1973), Alona Bay, Cape Gargantua and the lower Osler Group (Palmer, 1970), and the Northern Prong of the Duluth complex (Beck, 1970) record similar or intermediate positions and are considered to fall within the Middle Neohelikian. The alternation of reverse and normal polarities of Mamainse Point is thought by Robertson (1973) to be caused by fault repetition.

Also included on the standard are the Duluth intrusions which provide the most reliable chronological fix for the volcanic sequences presently available (averaged at 1091 Ma; smoothed to 1100 Ma). They mark the close of the main episodes of intrusion and extrusion on the North Shore which is the end of the Middle Keweenawan of some authors, although Goldich (1972) extends the "Keweenawan igneous activity" to the interval 1000 to 1200 Ma, that is to the end of the Late Neohelikian. Books (1972) also concluded that the uppermost Portage Lake lavas of Michigan and on Isle Royale were somewhat younger than the youngest North Shore lavas. The northeast trending Thunder Bay dyke swarm of Robertson and Fahrig (1971), the Logan dykes of some authors, intrude the Logan sills. They have a mean pole position of 35°N, 179°W, almost coincident with that for the upper North Shore lavas. Recent mapping of the swarm by Geul (1973) shows that some northwest trending porphyritic diabase dykes are crosscutting; they may include the northwest trending dyke found reversely polarized by Robertson and Fahrig (1971). The irregularly trending Mount Mollie layered gabbro is also relatively younger than the Thunder Bay dykes; it has yielded a K-Ar age of 1045 ± 40 Ma (Geul, 1973).

The youngest lavas known are on Michipicoten Island (Annels, 1974) where the Mamainse Point lavas are intruded by quartz porphyries and unconformably overlain by the Michipicoten Island Formation (Fig. 5, column 4). Rb-Sr isochrons from the porphyries and the Michipicoten Island lavas are 1004 (970 ± 62) Ma and 918 (886 ± 74) Ma

[1] Rb-Sr ages are given in this paper converted to $\lambda = 1.42 \times 10^{-11} a^{-1}$; the number as published is bracketed.

respectively (Wanless and Loveridge, 1978). The Michipicoten Island Formation should, accordingly, be designated earliest Hadrynian, for although it could be latest Neohelikian allowing for the analytical error, an Early Hadrynian age designation is more informative. All the lavas and porphyries have normal polarization and a composite mean pole position of 29°N, 181°W, like other parts of the Late Neohelikian (Palmer, 1970).

Coppermine Homocline

The Early Neohelikian rocks of Bear Province (Baragar and Donaldson, 1973; Irvine, 1970), record sequentially the intrusion of the Muskox ultramafic complex into the Hornby Bay sandstones, the deposition of the Dismal Lake sediments, and the extrusion of the Coppermine River lavas which intertongue with redbeds in their upper part (Fig. 5, column 6). The northwest trending Mackenzie dykes, considered coeval in Bear Province with the Muskox intrusion and Coppermine lavas, extend in major swarms from the Arctic Ocean southeastward across the western Shield into Southern Province. All of the igneous rocks are normally polarized and record similar to identical paleomagnetic pole positions; they constitute the Mackenzie igneous episode and the quasi-static Mackenzie paleomagnetic interval (Fahrig et al., 1965; Robertson, 1969; Fahrig and Jones, 1969; Fahrig, 1978).

The time span of the Mackenzie igneous episode is not well established. Fahrig (1978) gives the mean age as 1250 Ma. Irving and McGlynn (1976) assign a span of 1200 to 1300 Ma. The close of the igneous events may be indicated by the Rb-Sr isochron of 1257 (1214 ± 45) Ma obtained on selected samples of the Coppermine River lavas (Baragar in Wanless and Loveridge, 1972). As some of the other samples lie off that chord, Baragar suggested that a hydrothermal event occurred at 1108 (1070) Ma associated with an interval of faulting. Almost all K-Ar ages from the lavas, intrusion and dykes are younger than 1200 Ma (Fahrig and Jones, 1971), with a few, considered unreliable, being in the range 1300 to 1360 Ma. Although subject to some uncertainty, the end of the extrusion of the Coppermine lavas is used as a fix on the standard at 1250 Ma. How much earlier the Muskox intrusion occurred, and what the time span of the Mackenzie dyke intrusions may be, are not known.

The Muskox intrusion cuts and metamorphoses the Hornby Bay sandstones, but does not appear to have affected the dolomites of the nearby Dismal Lake Group (Irvine, 1970). Irvine also noted that tridymite, a mineral that forms at pressures equivalent to less than 1 km depth, occurs in both the Muskox granophyre and the Hornby Bay contact aureole. He concluded therefore that the Muskox was emplaced prior to the deposition of the Dismal Lakes Group, under a relatively thin blanket of Hornby Bay sandstones. A Rb-Sr errorchron of 1231 (1189) Ma has been determined by Wanless (in Baragar and Robertson, 1973). It does not provide an early limit to the igneous events, but suggests that the Coppermine and Muskox were not long separated in time.

The paleomagnetic pole position for the Coppermine River lavas (Baragar and Robertson, 1973) is 2°N, 180°E. The Muskox intrusion has a pole position of 4.7°N, 191.2°E (Robertson, 1969). The latter is shown in Figures 5 and 6 below an arbitrary interval allocated to post-Muskox erosion and the deposition of the carbonates of the Dismal Lake Group. The interval for intrusion of the Mackenzie dykes may extend somewhat earlier as well as later but not much, or else some would presumably record the reverse polarity and different pole position of the Seal event (Fig. 6, column 1). The mean pole position calculated for the Mackenzie dykes alone is 8°N, 177°W (Fahrig and Jones, 1969), and in combination with the Muskox intrusion and Coppermine River lavas is 4°N, 171°W (Fahrig, 1978) but, as pointed out by Baragar and Robertson (1973) a single paleomagnetic pole is not really warranted.

The Mackenzie Magnetic Interval is only partially anchored in the stratigraphic succession and as a magnetostratigraphic interval it is limited to the Coppermine component which is incorporated into the standard at 1250 Ma. Its time span is not precisely known, nor is its continuity through the strata of the Dismal Lakes Group established. As a magneto-intrusive interval including the Mackenzie dyke swarm it is provisionally considered to extend from the reverse polarization recorded in the Seal Lake Group noted in the following paragraphs to the beginning of the Middle Neohelikian reverse polarization interval. A great many of the basic igneous rocks of the Canadian Shield that might not otherwise have been related either geologically or isotopically have been correlated paleomagnetically by reference to the Mackenzie Magnetic Interval. They can be designated as Early Neohelikian, possibly late Early Neohelikian.

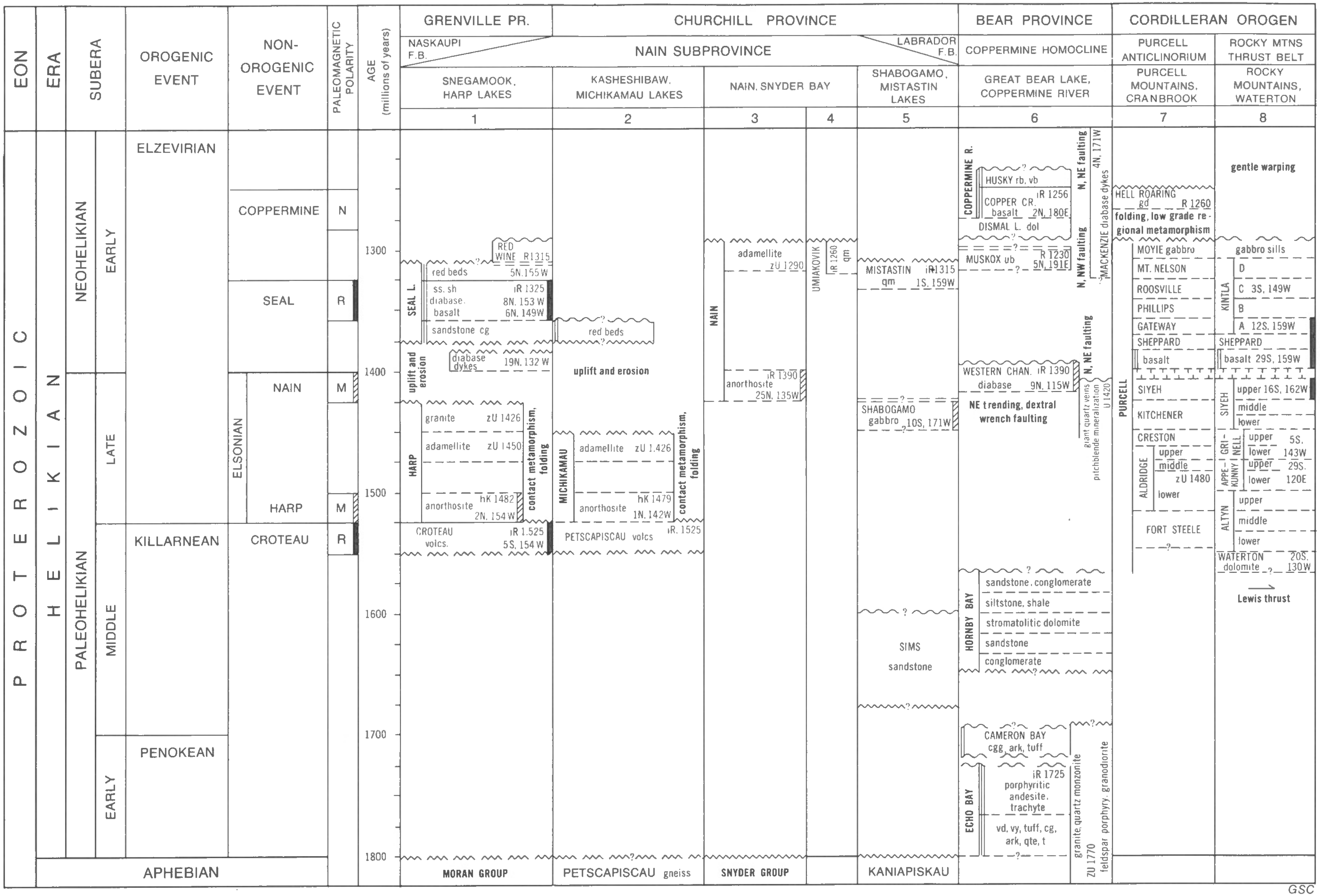
Nain and Naskaupi Subprovinces

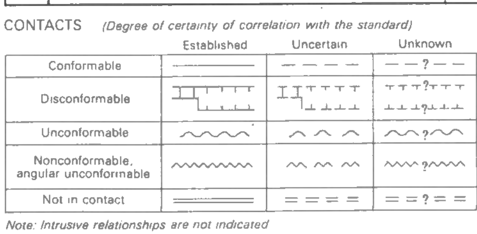
Early Neohelikian rocks in the Naskaupi Fold Belt of eastern Grenville Province are termed the Seal Lake Group (Fahrig, 1959). They unconformably overlie the Harp Lake anorthosite complex to the north, one of the Late Paleohelikian Elsonian intrusions characterizing the Nain Subprovince of eastern Churchill Province (Fig. 6, column 1). The Seal Lake Group has been recently found overlying the Middle Paleohelikian Croteau (Bruce River)[1] Group by Smyth et al. (1975), although generally the two groups are in fault contact (Fahrig, 1959). The relative age of the Harp Lake anorthosite and Croteau volcanics is unknown. This assemblage of rocks constitutes a temporally ordered, partly stratigraphically ordered, sequence that is considered herein to constitute the rock standard for a part of the Helikian.

The Seal Lake Group consists of redbeds, basalt and diabase sills, divided into five formations. The igneous rocks have yielded a Rb-Sr isochron of 1323 (1278 ± 92) Ma (Wanless and Loveridge, 1978). The pole position for the volcanics, combined from two formations is 6°N, 149°W, and that for the diabase sills is 8°N, 153°W (Roy and Fahrig, 1973). The sills are mainly in the intervening formation and are possibly coeval with the upper volcanics but are younger than the lower volcanics. Both sills and volcanics are reversely magnetized. The uppermost formation, composed of redbeds, possibly could be much younger, but is considered conformable with the underlying beds by Brummer and Mann (1961). These strata are normally polarized and have two pole positions, the dominant being 5°N, 205°E (Roy and Fahrig, 1973) which is close to that of the Muskox intrusion, a possible early component of the late Early Neohelikian, Mackenzie Magnetic Interval. The end of the extrusion of the Seal Lake volcanics is taken as a fix on the Standard at 1325 Ma. The beginning of the Seal event is not known, but it could be taken to include the possibly coeval, but normally polarized Harp dykes which are discussed below.

Adamellites and granites from the Harp Lake complex have yielded nearly concordant U-Pb zircon ages of 1450 and 1426 Ma respectively (Wanless in Irving et al., 1976). These bodies intrude the somewhat older anorthosite which records mixed normal and reverse polarities with a mean pole position of 1.6°N, 153.7°W (Irving et al., 1976). The K-Ar age of hornblende from the marginal gabbro is 1482 Ma, and from the contact aureole is 1449 Ma. The bordering country rocks have a pole position of 14.1°N, 144.2°W, mainly normal, which is considered by the authors to have been acquired during a later magnetization, at a time of uplift and cooling of the general region. This possibly should be

[1] "Croteau Group" of this paper is used in the sense of Roy and Fahrig (1978), and is equivalent to the Bruce River Group of Smyth et al. (1975).





ABBREVIATIONS

ark	*arkose*	sh	*shale*
cg	*conglomerate*	ss	*sandstone*
cgg	*conglomerate with granite clasts*	t	*chert*
gd	*granodiorite*	ub	*ultrabasic*
qm	*quartz monzonite*	vd	*andesite*
qte	*quartzite*	volcs	*volcanics*
		vy	*trachyte latite*

Figure 6. *Selected Paleohelikian and Early Neohelikian sequences of rocks and events.*

considered earliest Neohelikian but could be Late Paleohelikian. The Harp diabase dykes, which intrude the complex, are normally polarized and have a mean pole position of 18.6°N, 131.9°W. The dykes are probably slightly older than the Seal Lake Group on stratigraphic grounds as clasts of the dykes appear in the conglomerates or they may be partly contemporaneous, being chemically and petrologically similar to the volcanics and diabase (Myers and Emslie, 1977); they are considered Early Neohelikian. Comparable data are available from the nearby Michikamau anorthositic intrusion (Emslie et al., 1976), the relatively younger adamellite component yielding a U-Pb age for zircons of 1460 Ma (Krogh and Davis, 1973), and the anorthositic rocks recording normal polarization and a mean pole position of 1°N, 142°W. The K-Ar age of hornblende from the marginal gabbro is 1479 Ma. The pluton is overlain in the north by unnamed redbeds (Emslie, 1970), possibly a Seal Lake equivalent.

The ignimbritic volcanic rocks of the Croteau Group yield a Rb-Sr isochron of 1526 (1474 ± 42) Ma (Wanless and Loveridge, 1972). The rocks are reversely polarized and have a mean pole position of 5°S, 154°W (Roy and Fahrig, 1973). They were folded or tilted prior to the deposition of the Seal Lake Group and folded again in the Grenvillian Orogeny (Smyth et al., 1975). The Petscapiskau Group, which is intruded by the Michikamau anorthosite, exhibits amphibolite facies regional metamorphism as well as contact metamorphism (Emslie, 1970). The volcanics have yielded a Rb-Sr isochron of 1525 (1473 ± 60) Ma (Wanless and Loveridge, 1978). Emslie suggested in the accompanying discussion (op. cit.) that the Petscapiskau and Croteau volcanics could be extrusive equivalents of the nearby anorthosites.

In more northerly parts of Nain Subprovince the adamellite plutons have somewhat younger ages. As in the south, they are generally younger and intrusive into the anorthositic components, or form separate bodies. The Mistastin adamellite has yielded a Rb-Sr isochron of 1318 (1346 ± 15) Ma (Marchand and Crockett, 1974) and the Umiakovik an isochron of 1290 (1246 ± 36) Ma (Wanless and Loveridge, 1978). The Nain adamellite has a U-Pb age on zircons of 1290 Ma (Krogh and Davis, 1973). The age of the Nain anorthosite itself may be closely limited by the Rb-Sr isochron of 1388 (1418 ± 25) Ma from a late crystallizing, probably contaminated, anorthositic pegmatite (Barton, 1974). Emslie (1970) suggested that the "too young" isotopic ages from the adamellites are the result of the magmas being derived by partial melting of isotopically inhomogenous deep crust.

The spread between the times of intrusion (crystallization) of the Nain anorthosite and adamellite is 98×10^6 years, and may possibly have been more as the younger limit is determined on zircons and the older limit by the Rb-Sr method. A similar time span might be inferred for the Harp Lake and Michikamau complexes. The U-Pb ages of zircons in the adamellite components are 1450 and 1460 Ma respectively. The K-Ar ages of hornblende in the marginal zone of the Harp Lake anorthosite are 1449 and 1482 Ma, and from the Michikamau is 1479 Ma. These K-Ar numbers should reflect cooling of the anorthosite bodies to below the temperature for argon retention prior to the intrusion of the adamellite, and presumably reflect some unknown lapse of time after cooling to temperatures that would have been recorded by U-Pb systematics in the anorthosite, such as they might be. Constraints on the beginning of intrusion of the Harp Lake and Michikamau anorthosites are provided by the Rb-Sr isochrons of about 1525 Ma from both the Croteau and Petscapiskau volcanics. If cogenetic, 1525 Ma would be about the beginning of intrusion of the anorthosites; if not, the number still provides a temporal limit as the Michikamau anorthosite is relatively younger geologically. The limit of the Late Paleohelikian is taken, accordingly, as 1525 Ma but alternatively could be 1550 Ma to embrace the Croteau and Petscapiskau volcanics. The end of the Late Paleohelikian is taken as fixed by the Nain anorthosite at 1400 Ma (smoothed from 1388 Ma). This definition limits the Late Paleohelikian to the time of intrusion of the Elsonian anorthosites in Nain Subprovince and does not include all of the acidic intrusions. According to present data the Elsonian adamellite and granitic components were intruded in the 170 Ma interval 1460 to 1290 Ma, that is mainly in the Early Neohelikian and partly in the Late Paleohelikian.

Current concepts (Morse, 1977; Emslie, 1978) envisage the Elsonian event as being an anorogenic, bimodal, magmatic event consisting of multiple intrusions into a stable cratonic crust, the successive small mafic types rising through the crust and coalescing into larger bodies, with the coexisting to subsequent acidic magma types being produced by partial melting of the lower crust. The writer holds no particular brief for designating the Elsonian either as an "orogeny" (Stockwell, 1964) or as a "magmatic event" (Emslie, 1978). The deformation and metamorphism that accompanied the intrusions and that which followed extrusion of the Croteau and Petscapiskau volcanics must be considered to be Late Paleohelikian deformation and metamorphism whether or not it represents an "orogeny". The Elsonian event may be unlike other orogenies or magmatic events, but then other orogenies and magmatic events are not all the same either.

The writer is concerned, however, that Nain Subprovince be retained as the type region for the definition of the boundary between Paleohelikian and Neohelikian (Douglas, 1972), for the tectonics associated with the Elsonian do affect that definition. An alternative to that proposed above, of placing the close of the Paleohelikian at the end of the known Elsonian adamellite intrusions, i.e. at 1290 Ma, would place the Seal Lake Group, by virtue of its isotopic age, in the Late Paleohelikian. That number could be considered "too old", but placing the Seal event much later than 1290 Ma would crowd the Mackenzie igneous events; they probably do not overlap as their paleomagnetic polarities are opposite. Moreover, the Seal Lake Group should be construed as "type" Neohelikian for it is the only supracrustal succession that is both younger than a "type" Elsonian intrusion and which has been folded in the Grenvillian Orogeny.

In the extension of the Elsonian Plutonic Belt into the Grenville Province where the intensity of the Grenvillian Orogeny makes the age relationships of the rocks uncertain, it does not seem unreasonable to treat the unique anorthositic suite as a lithotectonic assemblage indicative of the Late Paleohelikian, and to so use it to designate other rocks as being older or younger according to relative intrusive relationships. Other components, the gabbro, adamellites and granites are much less distinctive. Both Paleohelikian and Neohelikian gabbros are known in the Nain and Naskaupi subprovinces and the presently known range in age of the adamellites and granites approaches the limits of the Killarnean and Elzevirian orogenies of western Grenville Province at 1550-1500 and 1200-1180 Ma respectively (Stockwell, personal communication, 1977; Fig. 1), from which they may not be easily separable.

There seem to be insufficient data to establish rocks as definitely Middle Paleohelikian in age. The Sims Formation of southern Labrador Fold Belt (Fig. 6, column 5) which is bracketed by the Hudsonian Orogeny and the intrusion of the Shabogamau gabbro, generally considered part of the Elsonian Intrusions, is also deformed in the Grenvillian Orogeny (Wynne-Edwards, 1961). The temporal relationship of the Sims to the Croteau and Petscapiskau groups is not known. No age determinations have been made on the Shabogamau gabbro, but it has been found to be reversely polarized, with a pole position of 10°S, 171°W by Fahrig et al. (1973). The Thelon Formation of Western Churchill Province (Fig. 7, column 1) is bracketed by the Mackenzie dykes and is accordingly, Paleohelikian and/or Early Neohelikian. The Hornby Bay Group of Bear Province (Fig. 6, column 6) is bracketed by the Western Channel diabase which has a K-Ar age of 1400 Ma and a Rb-Sr isochron of 1392 (1345 ± 48) Ma (Wanless and Loveridge, 1978) and the upper Echo Bay volcanics which have yielded a Rb-Sr isochron of 1733 (1770 ± 30) Ma (Robinson and Morton, 1972); it is Middle or Late Paleohelikian.

Elzevirian and Killarnean Orogenies

The two new Helikian orogenies to be defined by Stockwell (Stockwell, personal communication, 1977; Fig. 1) are within western Grenville Province. The Elzevirian Orogeny, with a terminal age of 1180 to 1200 Ma, most probably relates to the Early Neohelikian. It serves as a lower age limit to the Flinton Group which unconformably overlies the deformed Grenville Supergroup and the Elezevir batholith, which has an age of 1250 ± 25 Ma (Moore and Thompson, 1972). The Flinton Group has been deformed and metamorphosed by the Grenvillian Orogeny, the nearby Deloro pluton yielding a Rb-Sr isochron of 1125 (1095 ± 46) Ma (Wanless and Loveridge, 1972). The Flinton Group, accordingly, is bracketed as being Middle Neohelikian. The Killarnean Orogeny with a terminal age of 1500 to 1550 Ma affects Huronian rocks at the boundary between Grenville and Southern Provinces near Sudbury, but may not be recognized yet within Helikian sequences.

Cordilleran Orogen

Most of the Purcell Supergroup of the Cordilleran Orogen was probably deposited in the Late Paleohelikian and Early Neohelikian (Fig. 6, columns 7 and 8). The available isotopic age determinations are from the succession in Purcell Mountains whereas the available paleomagnetic data are from the Rocky Mountains some distance to the east; correlations of rock units shown are those of Price (1964), modified slightly. The younger age bracket is the time of intrusion of the Hellroaring Stock at 1260 Ma (Ryan and Blenkinsop, 1971). It is somewhat uncertain as a limit, as the stock intrudes the Aldridge Formation, low in the succession. The older age bracket is derived from the time of formation of the Sullivan orebody which D.R. Shaw (oral presentation, Kingston, 1978) considered to have formed synchronously with deposition of the uppermost beds of the lower Aldridge Formation, at the interface with the seawater 1430 Ma ago. The paleomagnetic data shown are from Black (1963) and Evans et al. (1975); there is only a vague correspondence paleomagnetically with rocks of the same general age on the Canadian Shield. The Cordilleran sequences, however, have been thrust laterally several hundred kilometres during the Jura-Cretaceous and Tertiary orogenies, possibly accompanied by some rotational movement of the thrust sheets. The sequences may also have been displaced at other times far from their original locus of accumulation along the border of the craton.

Aphebian

Hudsonian Orogeny

The end of the Hudsonian Orogeny, and by definition the close of the Aphebian Era, is placed at 1750 to 1755 Ma by Stockwell (personal communication, 1977; Fig. 1). This includes in the Late Aphebian the lower part of the Dubawnt Group (Wright, 1967) of western Churchill Province and the coeval, post-kinematic Nueltin granites (Eade, 1974) of the Ennadai Fold Belt. These rocks have yielded three Rb-Sr isochrons (Wanless and Loveridge, 1972), one from the Dubawnt volcanics of 1785 (1725 ± 4) Ma and two from the Nueltin plutons of 1760 (1700 ± 16) and 1775 (1715 ± 59) Ma. The Dubawnt Group has been included previously in the Paleohelikian (Stockwell, 1964, 1970a, 1970b, 1973; Douglas, 1969a,b) as it is nearly flat lying and rests unconformably on Hudsonian deformed and metamorphosed basement. The Nueltin plutons have also been considered to be post-orogenic (Eade, 1974; Davidson, 1972).

The apparent inconsistency arises from the fact that Stockwell designates the Churchill Province as the type region for the Hudsonian Orogeny and so the numbers selected in establishing the temporal limit of the orogeny are derived mainly from rocks that have no established relationship to younger stratigraphic successions. The same situation does not occur with the Grenvillian Orogeny, and probably not with the Kenoran, Wanipigowan and Uivakian orogenies, but it does with the Laurentian. In a region as large as the Churchill Province it would be unrealistic to suppose that deformation would culminate and end at the same time; there could be places where the Hudsonian Orogeny terminated relatively early and so there could be late-orogenic to post-orogenic sedimentation and volcanism that would be Aphebian in age. Elsewhere the latest phases of the orogeny could have extended into the Paleohelikian, that is, even later than the 1750 Ma limit. This could well occur in Eastern Churchill Province as isotopic age determinations of the effects of the Hudsonian Orogeny there are rather meagre. Also, it is the easterly parts of the province, in the Circum-Ungava geosyncline, that the thickest Aphebian successions occur and possibly the youngest supracrustals that accumulated prior to the onset of the Hudsonian Orogeny. Furthermore the terminal orogeny in Southern Province (see later section), generally also called Hudsonian, may be of a different age as may possibly be the orogeny in Bear Province (Robinson and Morton, 1972; Fig. 6, column 6). The writer is of the opinion that orogenic events in different mobile belts have different attributes and involve different geological concepts (Douglas, 1969b) and accordingly they should be embraced and expressed by different names, even though they may be of the same age or nearly so.

There are two alternatives: 1) to set the limit of the Aphebian at the youngest isotopic ages attributed to the Hudsonian Orogeny in Churchill Province; or 2) to define the limit of the Aphebian in a region where there is stratigraphic control and the ages of post-orogenic deposits are known.

The latter alternative is adopted herein and incorporated on the standard (Fig. 4). It treats the geological relationships in the Ennadai Fold Belt (Douglas, 1974a) as indicative of the effects of the Hudsonian Orogeny on Aphebian strata and Archean basement (Eade, 1971, 1973, 1974; Bell, 1971; Davidson, 1970), designates the rocks of the Dubawnt Group and the Nueltin intrusions as the record of the immediate post-orogenic events, and accepts the isotopic age determinations on these rocks (Wanless and Loveridge, 1972, 1978; Wanless and Eade, 1975) as bracketing the Aphebian-Helikian era boundary at 1800 Ma (Fig. 7, column 1).

In this region, the principal Aphebian stratigraphic succession, the Hurwitz Group, lies with regional angular unconformity on the Late Archean Henik and Kaminak groups, and an early Aphebian post-orogenic swarm of northerly trending diabase dykes, also termed Kaminak. Much of the Hurwitz Group is open-folded, broken by thrust and normal faults and little metamorphosed. It is locally unconformably underlain by the Montgomery Lake Group, possibly early Aphebian in age, and overlain unconformably by the Ennadai Group. Quartz latite relatively high in the succession has yielded a Rb-Sr isochron of 1872 (1808 ± 22) Ma and amphibole from gabbro sills low in the succession a K-Ar age of 1815 ± 116 Ma (Wanless and Eade, 1975). These ages are considered to reflect some modification of the rocks prior to or during the Hudsonian Orogeny. Quartz monzonite plutons intrude the Hurwitz Group; one of these has yielded a Rb-Sr isochron of 1834 (1772 ± 22) Ma (Wanless and Eade, 1975), and in northwestern Ennadai belt Aphebian sediments and Archean basement have been subjected to penetrative deformation, amphibolite grade metamorphism and migmatization. These plutonic rocks are unconformably overlain by the redbeds and potassic volcanics of the Dubawnt Group. In more southerly parts of the belt the coeval Nueltin, post-kinematic, epizonal, fluorite-bearing, porphyritic granite plutons intrude the Hurwitz and Ennadai groups and the Archean basement. The three age determinations of 1872, 1834 and 1815 from the Aphebian-Hudsonian assemblage and the three from the Dubawnt-Nueltin assemblage of 1786, 1775, and 1760 bracket in time the Aphebian-Helikian era boundary; it is taken as being at 1800 Ma.

Late Aphebian – Early Paleohelikian

As noted previously few rocks can be definitely assigned to the Middle Paleohelikian, but there are many that have yielded isotopic ages of about 1700 Ma or greater. That number, accordingly, is proposed as the boundary between the Early and Middle Paleohelikian (Fig. 4).

The age of the Dubawnt volcanics at 1786 Ma constitutes an important chronological fix for paleomagnetic correlation of Early Paleohelikian rocks; the Dubawnt succession is provisionally assigned to the interval 1750 to 1800 Ma on the standard (Fig. 7, column 1). It consists of four formations (Donaldson, 1965): the South Channel conglomerate, the Kazan redbeds, the Christopher Island trachytic to andesitic volcanics, and the Pitz quartz feldspar porphyries. The succession is intruded by the coeval Martell syenite plugs. A mean pole position of 7°N, 83°W with mixed polarity has been determined by Park et al. (1973). The data have been calculated (Irving and Hastie, 1975) as yielding a mean pole position of 1°N, 83°W for the Kazan Formation, and 19°N, 85°W for the overlying Christopher Island Formation. The latter is reversely polarized except for some probably younger dykes which are normal, and the Kazan Formation is of mixed polarity, exhibiting three reversals (Park et al., 1973). The Martin Group of the Tazin Belt (Fig. 7, column 2) is probably also Early Paleohelikian (see later text). It has a mean pole position of 9°S, 72°W and mixed polarity (Evans and Bingham, 1973).

Less precisely dated Late Aphebian to Early Paleohelikian assemblages in Western Churchill Province, which are generally considered to be late orogenic to post-orogenic, have been studied paleomagnetically – the Late Aphebian, Nonacho Group by McGlynn et al. (1974); and the Paleohelikian Et-Then Group by Irving et al. (1972). The Et-Then unconformably overlies the deformed strata of the Great Slave Supergroup, several formations of which have also been studied paleomagnetically (Evans and Bingham, 1976; Bingham and Evans, 1976; McMurray et al., 1973). The paleomagnetic pole positions for these various assemblages fall on the part of the apparent polar wandering path associated with the Hudsonian Orogeny (Irving and McGlynn, 1976a) spreading generally latitudinally east and west from the Dubawnt pole positions, but the age of the rocks and some of the times of magnetization as well as the polar wandering path itself are subject to some uncertainties.

In Southern Province, the plutonic rocks and metamorphic effects attributed by some authors to the Penokean Orogeny fall within the Early Paleohelikian. The age of the Cutler granite is probably about 1715 (1750 ±) Ma (Weatherill et al., 1960); zircons from granitic orthogneiss at the Grenville Front are 1730 Ma old (Krogh et al., 1971), and the remobilized Murray granite offshoots No. 1 and 2 are about 1777 (1815 ±) and 1695 (1733 ±) Ma old respectively (Gibbins and McNutt, 1975). The isochron of 1684 (1720 ± 30) Ma from the sediments of the Whitewater Group, and the Onaping scatterchrons (Fairbairn et al., 1968) reflect this event. The Bell Lake granite with a zircon age of 1550 Ma (Krogh et al., 1971) is referred to the Killarnean Orogeny of Stockwell (1981, Fig. 1).

Middle and Late Aphebian

There are few age determinations on which to base a boundary between the Middle and Late Aphebian as so few Aphebian rocks have yielded numbers other than the limiting Hudsonian Orogeny; provisionally it is drawn at 1925 Ma which may mark the onset of the Hudsonian Orogeny in the Tazin Belt (Fig. 7, column 2), a region of intense deformation forming part of the crustal block adjoining Ennadai Fold Belt on the northwest (Douglas, 1974a). The Archean or Early Huronian Tazin Group is penetratively deformed and migmatized, subsequently mylonitized and broken by wrench and normal faults and unconformably overlain by the Martin Group (Tremblay, 1972). Age determinations of the several syngenetic and epigenetic uranium mineralizations at Beaverlodge which bracket the supracrustal rocks in time have been summarized by Koeppel (1968), together with those by other methods and for nearby regions.

The first episode of syngenetic uranium and thorium mineralization in pegmatites in the Tazin Group occurred at about 2185 (2200) Ma (Robinson, 1955), and the second at about 1900 Ma (Koeppel, 1968). These episodes are similar to the ages of zircons and Rb-Sr isochrons from the plutonic rocks of northeastern Alberta (Baadsgaard and Godfrey, 1972). The post-orogenic Martin Group is limited by the first epigenetic pitchblende mineralization, given at 1754 (1790 ± 20) Ma (Koeppel, 1968) and probably by the K-Ar age of 1830 ± 50 Ma (Wanless et al., 1966) from a post-orogenic gabbro dyke, although they are not in contact.

In the Southern Province, the Sudbury Nickel Irruptive provides an isotopic fix for Aphebian strata, establishing the Whitewater Group as Late Aphebian (Fig. 7, column 3). Recently, Gibbins and McNutt (1975) obtained various Rb-Sr ages and isochrons; those from the norite and sublayer indicate an age of intrusion and crystallization of 1915 (1956 ± 98) Ma; those from the micropegmatite of 1645 (1680 ± 30) Ma reflecting a subsequent hydrothermal greenschist facies metamorphism, which also affected the Whitewater Group, are attributed to the Penokean Orogeny. The Sudbury Irruptive intrudes the suprajacent Onaping tuff, considered by some to be the extrusive and effusive equivalent (Williams, 1956). In Figure 7, column 3, this relationship is shown graphically. If the Onaping tuff and Sudbury Irruptive are not treated as cogenetic then the irruptive provides a terminal age limit rather than an initial age limit for the Whitewater Group, which would then be designated Middle Aphebian. The Sudbury Irruptive has a mean pole position of 47°N, 107°W and is normally polarized (Sopher, 1963).

The thick stratigraphic successions characteristic of the Circum-Ungava geosyncline (Dimroth et al., 1970) and the Marquette Range Supergroup in the western Southern Province in the United States (Cannon and Gair, 1970) can only be designated as Aphebian. Of these, the Kaniapiskau Supergroup is illustrated graphically in Figure 7, column 4, as spanning the Middle Aphebian and also extending into the Early and Late Aphebian. It is included in this way until more precise age brackets are established for the various

Circum-Ungava successions to serve as a lithological standard so that rocks that are customarily correlated on a lithological basis can be placed in their appropriate relative position on the different correlation charts which accompany adjoining 1:1 000 000 Atlas sheets, even though none can be directly related to the standard. An obvious example is the need to show the Wabush Lake iron formation and other formations of the Gagnon Group on correlation charts for the eastern Grenville Province sheets in the same positions as the Ferriman Group for sheets covering the Kaniapiskau Supergroup. The Animikie Group of Southern Province is placed in such a position for lack of a better place (see Fig. 7, column 3).

Early Aphebian-Huronian

The time of intrusion of the Nipissing diabase has generally been accepted as the limiting age of the Huronian succession of eastern Southern Province (Robertson et al., 1969). The sills and dykes intrude, most significantly, the youngest of the Huronian groups, the Cobalt Group. The K-Ar age of 2095 Ma was reported by Lowden et al. (1962), and Rb-Sr ages of 2109 (2155 ± 80) Ma by Van Schmus (1965) and 2116 (2162 ± 27) Ma by Fairbairn et al. (1969). It is proposed that 2100 Ma be taken as the boundary between the Middle Aphebian and Early Aphebian suberas and that Huronian be used as the name for the latter subera. Huronian is currently used as a rock-stratigraphic term of supergroup rank with designated reference sections of the component stratigraphic units (Robertson et al., 1969). It has been proposed as a time-stratigraphic term (Church and Young, 1970) and as a time term (Alcock, 1934). It is considered herein to be a time term of subera rank, an alternative to Early Aphebian, spanning the interval from the end of the Archean, taken as 2500 Ma, to the end of the Nipissing intrusions, taken as 2100 Ma. A time connotation is often associated with Huronian, both in its use orally and in the literature; the duality of usage is no more ambiguous than the duality of the Phanerozoic period-system nomenclature. Moreover, it seems better to use Huronian than to propose a new term as it is such a long standing Canadian term known the world over. Should the need for a distinction be considered imperative, then deletion of the temporal suffix yields Huron Supergroup.

The use of Huronian as a time-stratigraphic term as advocated by Church and Young (1970) is not at variance with this proposal, although this writer considers that only the part of the Huronian succession represented by the Cobalt Group can be defined in a time-stratigraphic sense at present. The Late Huronian, spanning the interval 2250 to 2100 Ma, is represented by the strata of the Cobalt Group and by the Nipissing intrusions. The earlier limit is derived from a Rb-Sr isochron of 2240 (2288 ± 87) Ma (Fairbairn et al., 1969) from the Gowganda, the basal formation of the Cobalt Group. The paleomagnetic characteristics of the Gowganda and the Nipissing have been determined, the latest study being by Roy and Lapointe (1976). Other rocks elsewhere can be correlated, accordingly, with the Late Huronian either isotopically, paleomagnetically, or lithologically. The Upper Huronian as a time-stratigraphic unit is represented by the strata of the Cobalt Group as presently constituted whether or not all of Late Huronian time is recorded by the sediments, and it would also include whatever strata might have been deposited during the time of intrusion of the Nipissing diabase.

The Nipissing intrusions are included in the Late Huronian rather than in the Middle Aphebian because of their close geological and spatial relationship with the Huronian sediments. The time span of the intrusions is not known. They could be geologically "instantaneous" but are arbitrarily assigned a span of 25 million years, as in the case of the other igneous events. The assigned interval, 2125 to 2100 Ma, also approximates the range of the available isotopic ages. The isotopic age for the Gowganda Formation appears to be a geologically reasonable age, accepting the validity of the Nipissing ages, but is subject to some uncertainty as other Rb-Sr age determinations made from stratigraphically older Huronian formations were younger than the age of the Nipissing (Fairbairn et al., 1967). Accordingly, 2250 Ma for the boundary between the Early and Late Huronian is considered provisional. It is customarily cited as being the time of first appearance of redbeds in the geological column (e.g. Frarey and Roscoe, 1970) which is interpreted by some to reflect the evolution of the earth's atmosphere from a nonoxidizing, possibly reducing state, to an oxidizing state (e.g. Rubey, 1955). Included in the Late Huronian would be the Blezardian Orogeny of Stockwell (1981; Fig. 1), with a limiting age of 2140 Ma.

Paleomagnetically, the Gowganda and Nipissing record several magnetizations (Roy and Lapointe, 1976). The authors conclude that the reverse pole position of 67°N, 158°E was acquired by the Firstbrook Member of the Gowganda Formation shortly after deposition, and that the normal pole position of 42°N, 258°E found in the Nipissing diabase and its contact aureole was acquired during cooling following intrusion. Roy and Lapointe also suggested paleomagnetic correlation of the Otish gabbros of eastern Grenville Province (Fahrig and Chown, 1973) with the Nipissing; the Otish Mountains Group, host to the gabbro intrusions has been correlated lithologically with the Cobalt Group (Frarey and Roscoe, 1970). The Abitibi dykes of central Superior Province (Larochelle, 1966), the Molson picritic dykes of western Superior Province (Ermanovics and Fahrig, 1975), the Big Spruce complex (Irving and McGlynn, 1976b), and the Indin dykes (McGlynn and Irving, 1975) of Slave Province are late Huronian or early Middle Aphebian.

Although the Huron Supergroup includes three distinctive groups below the Cobalt Group, no data are available to permit correlation with them individually other than on a lithological basis or the general age bracket of 2500 to 2250 Ma. The early part of the Early Huronian includes one or more igneous episodes in widely separated regions which suggests the possibility of making the division of the Huronian subera threefold rather than twofold. This would however, discard the relatively simple expression "Early Huronian" for the pre-Cobalt part of the Aphebian.

The volcanic rocks of the Mugford Group of Nutak Province have a whole rock Rb-Sr age of 2340 (2390) Ma (Barton, 1975). Murthy and Deutsch (1972) reported a mean pole position of 49°N, 143°W. The Kaminak diabase dykes of Western Churchill Province (Fig. 7, column 1) intrude Archean volcanic terrane, are truncated at the unconformity beneath the Aphebian, Hurwitz Group, and are metamorphosed in the Hudsonian Orogeny (Davidson, 1970). The unmetamorphosed dykes have an average K-Ar age of 2370 Ma, a mean pole position of 23.8°S, 122.3°W, and mixed polarity (Christie et al., 1975). In central Superior Province, the northerly trending Matachewan olivine diabase dyke swarm is possibly Early Huronian. Some dykes cut the Kenoran-deformed Timiskaming Group near Kirkland Lake and some are unconformably overlain by the Cobalt Group. The Matachewan dykes have yielded a K-Ar age of 2485 Ma (Wanless et al., 1965), the oldest of several K-Ar ages, and a Rb-Sr whole rock age of 2633 (2690 ± 93) Ma (Gates and Hurley, 1973). Although these numbers indicate or suggest an Archean age, the Matachewan event is shown in Figure 7 within the Early Huronian in its geologically preferred position. The most recently determined paleomagnetic pole position is given by Irving and Naldrett (1977) as 44°N, 60°E; polarity is mixed. The Dogrib dykes of Slave Province have a comparable apparent conflict between their isotopic age and that of the rocks they intrude (McGlynn and Irving, 1975). The dykes have yielded K-Ar ages of 900 to 2310 Ma (Leech, 1966) and a Rb-Sr whole rock age of 2635 (2692 ± 80) Ma (Gates and Hurley, 1973). The dykes are normally polarized with a mean pole position of 35°S, 50°W (McGlynn and Irving, 1975).

Archean

In addition to the Kenoran Orogeny, which marks the close of the Archean Eon, Stockwell currently recognizes three other Archean orogenies – the Uivakian, Wanipigowan and Laurentian (Stockwell, 1980; Fig. 1). The Uivakian and Wanipigowan orogenies, with terminal ages of 3500 to 3400 and 2900 to 2880 Ma respectively, serve to divide the Archean into three unnamed parts, each of era rank – Early, Middle and Late Archean. On the standard the respective limits are taken as 3400, 2900 and 2500 Ma.

The Laurentian Orogeny, with a terminal age of 2670 to 2660, serves to divide the Late Archean into two suberas for which it is proposed that the names Keewatian and Timiscamian be used, the boundary to be drawn at 2700 Ma. In concept this differs little from the former practice of treating the rock-stratigraphic units of the Archean as if they were time-stratigraphic units and accordingly referring the relatively older, predominantly volcanic assemblages to the "Keewatin" and the relatively younger, predominantly sedimentary assemblages to the "Timiskaming". It differs in that Keewatian and Timiscamian would refer to units of geological time having certain numerical limits. Insofar as presently available data suggest most assemblages previously designated "Keewatin" or "Timiskaming" would have the corresponding temporal designation. Where this distinction of relative age cannot be made on geological or geochronological grounds, the rocks would have to be designated Late Archean or Archean. The alternative to using Keewatian and Timiscamian as geological time terms is to employ such cumbersome terms as "Early Late Archean" and "Late Late Archean", or even "Late Early Late Archean" granite to designate a Late Keewatian granite.

These two additional subera names and the threefold era subdivision are minimal for the Archean. It is anticipated that in the course of preparation of the 1:1 000 000 Atlas maps that several gross lithotectonic assemblages will be established which, even though not adequately isotopically dated everywhere, could be reasonably initially inferred to be of the same age and which then would provide a geological framework to be tested with additional age determinations. Furthermore such a geologically conceived relative temporal ordering of the rocks may be essential to appraise the significance of some Archean age determinations.

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