Geoscience Canada

Paleomagnetism of Precambrian Rocks of Laurentia

E. Irving and P. L. Lapointe

Volume 2, Number 2, May 1975

URI: https://id.erudit.org/iderudit/geocan2_2art03

See table of contents

Publisher(s)

The Geological Association of Canada

ISSN

0315-0941 (print)
1911-4850 (digital)

Explore this journal

Cite this article

Irving, E. & Lapointe, P. L. (1975). Paleomagnetism of Precambrian Rocks of Laurentia. *Geoscience Canada*, *2*(2), 90–98.

Article abstract

If the paleomagnetic poies from the Grenville Province are excluded it is possible to construct a relatively simple path of apparent polar wander relative to the Precambrian shield of North America, Greenland, and NW Scotland ("-Laurentia) during the Proterozoic. This indicates (but does not prove) that during this time the main body of Laurentia has remained approximately intact and that the geosynclines in the Churchill Province were formed without large-scale (plate-style) dismemberment of Laurentia. Although it is possible to integrate the results from the Grenville into this path, it is not easy to do so, indicating that the southern part of the Grenville Province moved independently of the main body of Laurentia becoming sutured to it at -1000 my The path of apparent polar wandering can be divided into five tracks, providing a useful stratigraphie tool, and the data are consistent with Stockwell's stratigraphie scheme for the Proterozoic. Results from Sudbury indicate that the north range irruptive was horizontal when intruded.

Paleomagnetism of Precambrian Rocks of Laurentia

E. Irving and P. L. Lapointe
Earth Physics Branch
Energy Mines and Resources
Ottawa, Ontario K1A 0E4

Summary
If the paleomagnetic poles from the Grenville Province are excluded it is possible to construct a relatively simple path of apparent polar wander relative to the Precambrian shield of North America, Greenland, and NW Scotland (= Laurentia) during the Proterozoic. This indicates (but does not prove) that during this time the main body of Laurentia has remained approximately intact and that the geosynclines in the Churchill Province were formed without large-scale (plate-style) dismemberment of Laurentia. Although it is possible to integrate the results from the Grenville into this path, it is not easy to do so, indicating that the southern part of the Grenville Province moved independently of the main body of Laurentia becoming sutured to it at -1000 m.y. The path of apparent polar wandering can be divided into five tracks, providing a useful stratigraphic tool, and the data are consistent with Stockwell's stratigraphic scheme for the Proterozoic. Results from Sudbury indicate that the north range irruptive was horizontal when intruded.

Résumé
Si on exclut les pôles paléomagnétiques provenant de la province de Grenville, on peut construire un tracé simple, relatif au socle précambrien de l'Amérique du Nord, du Groenland, et du nort-ouest de l'Ecosse (Laurentia), de la dérive apparente des pôles, pour la durée du Protérozoique. Ceci indique que, dans cet intervalle, le bloc principal de Laurentia est resté approximativement intact et que les géosynclinaux de la province de Churchill ont été formés sans démembrement à grande échelle (style des plaques) du socle de Laurentia. Puisqu'il est possible d'integrer les résultats du Grenville dans cette courbe, cependant non sans quelques difficultés, ces résultats indiqueraient que la partie sud de la province du Grenville a bouge indépendamment du bloc principal du Laurentia se rattachant à lui à – 1000 m.a. Le tracé de la dérive apparente des pôles peut être divisé en cinq segments produisant ainsi un outil stratigraphique utile et les données sont consistentes avec le schème stratigraphique de Stockwell pour le Protérozoique

Introduction
The geomagnetic field is caused by dynamo action in the highly conducting fluid core of the earth. When averaged over periods of about 10^4 years the field approximates to that of a geocentric axial dipole, the mean magnetic pole coinciding within a few degrees with the rotational pole. The average field direction and corresponding pole (the paleomagnetic pole) can be calculated from the remanent magnetism in rock units, the "age" of the pole being the time at which the magnetism was acquired. The pole obtained in this way is found to vary with time at rates of about 0.3° per m.y. This variation is called apparent polar wander (APW), and is generally attributed to motion of the observing locality relative to the mantle, that is to continental drift. In this article APW, as it has been observed in Precambrian rocks of Laurentia, is reviewed, but first some general comments about the difficulties peculiar to Precambrian paleomagnetic studies are made.

Traditionally, paleomagnetic evidence has been obtained from rocks that have been little altered, in the belief that their remanent magnetization reflects the direction of the earth's field at the time rocks were formed. Lavas that contain pure fine-grained single-domain magnetite, and which cool quickly, will acquire their magnetization at about 550°C. The corresponding temperature for hematite, which is the other common carrier of remanent magnetism in rocks, is about 650°. However, if cooling (and this may be initial cooling or cooling following subsequent reheating events) occurs very slowly, then magnetization is acquired at much lower temperatures. This is the phenomenon of magnetic viscosity by which magnetization processes are enhanced with time (Néel, 1949). For example, the magnetization of a rock containing single-domain magnetite may be expected to reach equilibrium with the geomagnetic field at about 200°C if that temperature is applied for 10^6 years. The corresponding temperature for hematitie is thought to be about 300°C. Most Precambrian rocks have undergone heating to temperatures of a few hundred degrees over long periods so that their original magnetization is commonly lost, and has been replaced by one or more secondary magnetizations each marking different thermal events. Complex techniques are required to separate these magnetizations properly, and in not more than a third of paleomagnetic studies, many of which are over 10 years old, have these techniques been fully applied.

The second difficulty in Precambrian paleomagnetic work is the uncertainty in the time basis of results. Differences of 10° in paleomagnetic poles can be measured, and 10° of APW usually occurs in about 30 m.y. Now there are very few Precambrian age determination that are so accurate, so that in addition to the considerable technical difficulties of retrieving old magnetizations that may be obscured by later magnetizations, there are the difficulties of relating a result to its correct time basis. In this review the Precambrian results are assembled in the age sequence we regard as most reasonable in the light of the present evidence. Because of the inadequacies of the existing record it is to be expected that this sequence will be substantially revised in the near future.

Laurentia comprises the Precambrian shields of North America and Greenland, and the Lewisian Platform (Fig. 1). It contains five archean elements (the Superior, North Atlantic and Slave Structural Provinces,

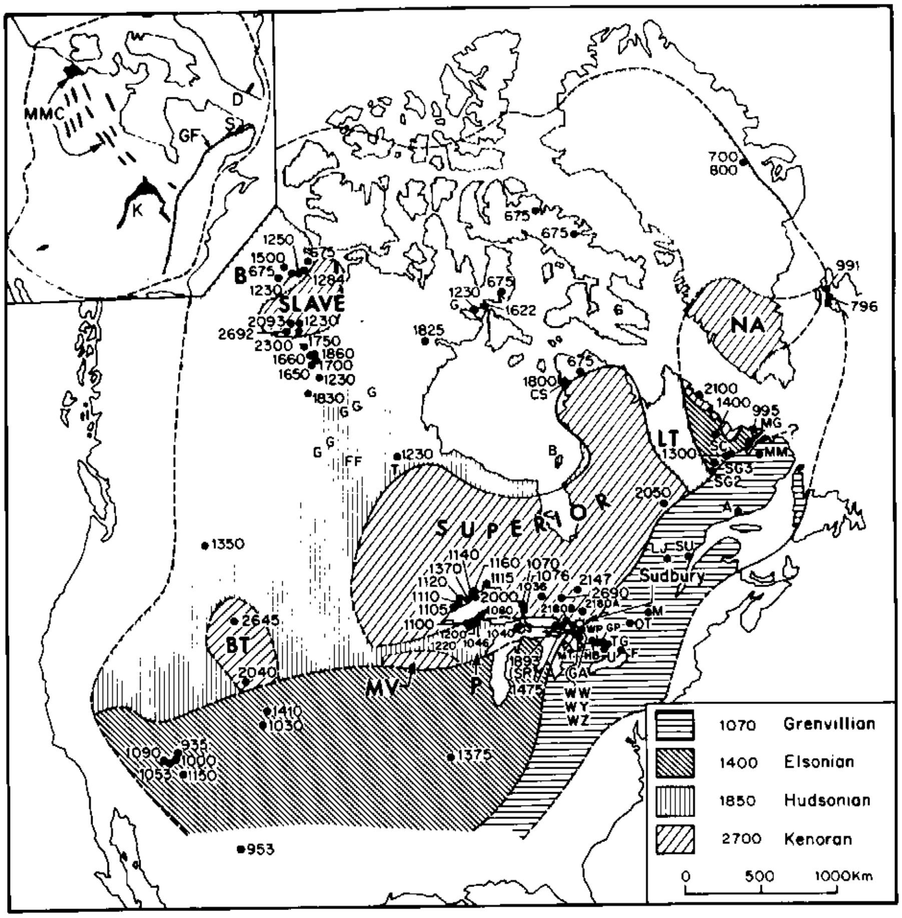

Figure 1
Structural provinces of Laurentia and paleomagnetic sampling localities. Rock units sampled are listed in the appendix. The mean ages at which four major subdivisions of Precambrian terrain were stabalized are from Stockwell (1972). **P** *is the Penokean fold belt stretching from Sudbury to Minnesota.* **BT** *is the Bear-tooth uplift,* **MV** *is the archean terrain of the Minnesota Valley, and* **NA** *is the North Atlantic Craton.* **BP** *is the Bear Province. Internal geosynclines containing basic igneous rocks are marked as follows:* **FF** *- Flin Flon,* **T** *- Thompson Belt,* **LT** *- Labrador Trough,* **CS** *- Cape Smith Belt,* **B** *- Belcher Islands. Greenland and the Lewisian of NW Scotland are rotated back to their positions at the end of the Precambrian. Base map compiled from Stockwell* et al *(1970) and Bridgwater* et al *(1973). In the inset the Grenville Front (GF) and the pre-Grenville rift magnetism are shown compiled mainly from Baragar see Geoscience Canada v. 1, no. 3, p. 56 (K - Keweenawan, D - Gardar, MMC - Muskox-Mackenzie diabase-Coppermine lavas, S - Seal volcanics).*

the Bear-tooth uplift in Colorado and Montana, and the archean terrain of the Minnesota valley). These are separated by terrain stabilized during the Hudsonian orogeny which culminated about 1700 m.y. Within this "Hudsonian" terrain there are several geosynclines (the internal geosynclines of Fig. 1) and extensive areas of reworked archean rocks. The Bear Province was also deformed during the Hudsonian, but it is marginal to Laurentia. On the southeast is the Grenville Structural Province, separated by the Grenville Front from the remainder of Laurentia. Laurentia without the Grenville Province is referred to as Interior Laurentia.

Results

The first collections of rocks from Laurentia for paleomagnetic study were made in NW Scotland by S. K. Runcorn and E. Irving (Cambridge University) in June 1951. These were the first red sediments to be studied paleomagnetically, and it was the first time fossil magnetism was shown faithfully to record the Precambrian geomagnetic field. The following year collections were made by the late J. W. Graham (Carnegie Institution, Washington) from two diabase dikes in Baragar County, Michigan. Work on the Precambrian of Laurentia, however, began in earnest when P.M. DuBois and S. K. Runcorn (Cambridge University) made extensive collections from Keweenawan rocks and the Precambrian of Arizona in the summer of 1954. Du Bois in particular made this the main topic of his research and in 1955 he returned to North America and continued work at the Geological Survey of Canada in Ottawa, making his more delicate observations on equipment at what was then the Dominion Observatory (now the Earth Physics Branch). His work culminated in an important paper (Dubois, 1962) which laid the foundations for the work which is now reviewed.

The localities sampled for paleomagnetic work are plotted in Figure 1. No result is included which is based on fewer than 10 samples and in which the error in the mean direction exceeds 20°. The corresponding poles are plotted in Figure 2. The polar errors, which are generally about 10°, are listed in the appendix, but are not plotted to avoid confusion. These poles are given relative to Laurentia, and their relationship to other continents is not known. Other continental outlines are given for reference only. Many rock units have been studied repeatedly, and in this compilation average values are given. For example, there are nine determinations from the Portage Lake lavas of the Middle Keweenawan, four studies of the Franklin diabase, and four of the Mackenzie diabase. Such results can be considered to be of very high reliability. Of the 88 results from Laurentia, 23 are based on two or more studies. The data published up to August 1974 from other Precambrian shields are shown in Figure 3. Half the results, and by far the largest number of replicate observations, are from Laurentia.

Figure 2 has several notable features. Poles in the same time interval of about 10^6 years fall within areas with dimensions of several thousand kilometres (e.g., poles in the age range -1150 to -950 m.y.). Within these areas there occur arcuate or quasi-linear polar sequences (e.g., 1100, 1050, 1000), and the pole returns to approximately the same place after a lapse of about 10^8 years (note the

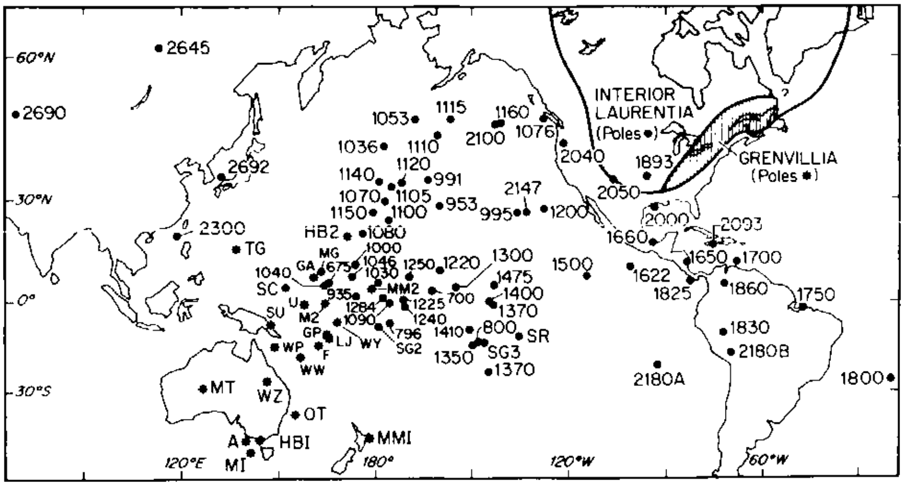

Figure 2
Paleomagnetic poles from Laurentia. The poles from Interior Laurentia are indexed by their estimated ages, poles from in and near the Grenville Province by letters. The rock units from which the poles were obtained are listed in the appendix.

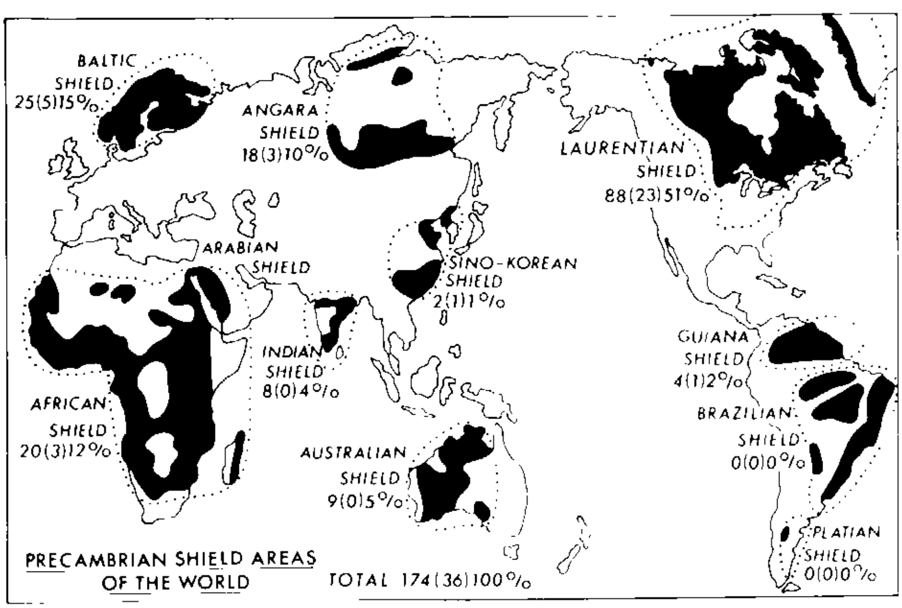

Figure 3
Precambrian shields of the world and the number of paleomagnetic results available from them. Only well-described data based on 10 or more samples are having an error 20° or less are counted. The number of results based on replicate studies is given in brackets, followed by the percentage of the whole.

proximity of poles 1250, 1050 and 675). These features indicate that the polar path has a loop-like form with amplitudes of about 50° and periods of the order 10^8 years. Finally, poles from the Grenville Province form a separate group; some overlap with poles from Interior Laurentia, but most are near what is now Australia.

In Figure 4 a reconstructed path of apparent polar wander (APW) is given. This has been obtained by linking the poles together in a time sequence, without abusing either the age or magnetic results. The path is divided by sharp bends (called hairpins) into five tracks which are numbered for reference. In this reconstruction the Grenville poles are arranged into a separate track. The rates of continental drift that this polar reconstruction implies are about 5 cm/yr, and comparable to present rates. Other reconstructions are possible (see Roy and Fahrig, 1973; Stewart and Irving, 1974; and Irving *et al.*, 1974), but these require additional loops and more rapid APW over certain intervals. An example is given in Figure 5 for the interval -1100 to -600 m.y., in which the Grenville poles are regarded not as a separate track but as an integral part of the APW path. This reconstruction requires rates of drift of 20 cm/yr between -1100 and -900 m.y., some four times greater than the reconstruction in Figure 4. Figure 4 is the "simplest" reconstruction in that it requires the shortest total polar path, that is, by-and-large, it demands the least amount of drift. The remainder of this review is based on the reconstruction of Figure 4. It is emphasized however, that other reconstructions are possible, and the curious reader must refer to the references cited for other opinions. There are large uncertainties in many parts of the rectonstruction. For example, the polar loop between -1000 and -600 m.y. (Track 1) is very poorly defined and may be much deeper than shown. Poles 2060, 1765 and 1725 are close together, and this means that drift of Laurentia was negligible during this interval, or that as yet undocumented variations are present, or that the existing poles are in error, or are wrongly dated. A kink and questionmark are added to Figure 4 at this point to denote this unsolved problem.

Model Curves

Obviously 88 results are too few to document satisfactorily the variations occurring over two billion years. However, given sufficient observations, there is no geometrical impediment to drawing an APW path unambiguously. The converse however is not true, that is, it is not geometrically possible to reconstruct continental motions unambiguously from a given APW path. As a first step in interpreting observed paths it is helpful to compare them with model paths calculated for hypothetical continental motions. Model paths for continents bordering an opening and closing ocean (the Wilson cycle) are shown in Figure 6. The generalized motion is given on the left. A single continent in motion first splits, then an intervening ocean is formed, and finally the fragments come together again. The actual motions will be more complex, perhaps comparable to the zig-zag trajectory shown on the top right of Figure 6. There are six main features: (1) A single continent in

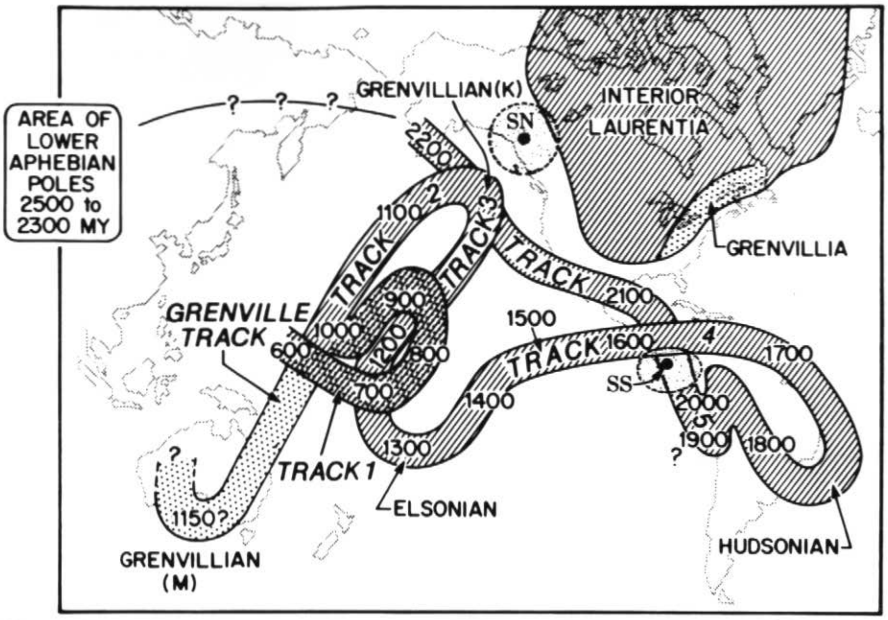

Figure 4
Suggested path of polar wandering from —2200 to —600 m.y. relative to Laurentia. The main tracks are numbered and calibrated at intervals of 10⁸ years. The hairpins are named by the orogeny to which they are thought to correspond. The poles for the Sudbury nickel irruptive are SS (south range) and SN (north range), both without structural correction, are from Sopher (1963).

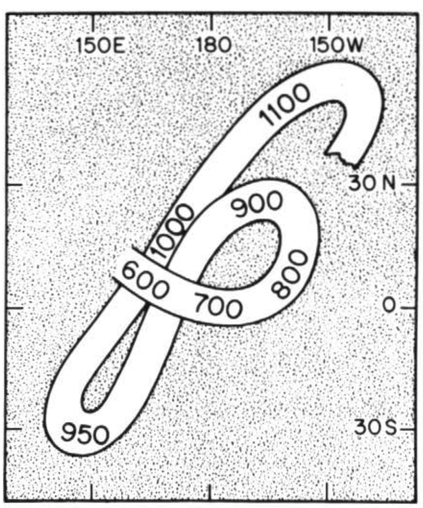

Figure 5
An alternative polar reconstruction for the interval —1100 to —600 m.y.

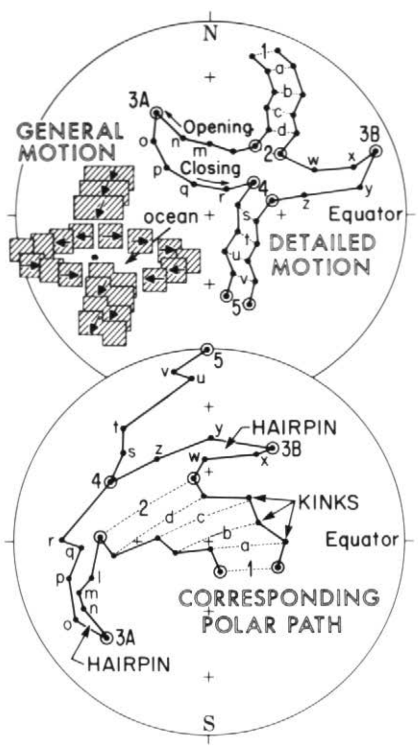

Figure 6
Model APW curves for the Wilson cycle. Continental motions are shown above and the corresponding APW below. Hairpins are numbered, and kinks are lettered. Equal-area projections are used.

motion produces a single polar path, and another continent in independent motion produces a separate path; (2) Large changes in direction produce large polar bends or hairpins; (3) Complementary loops are the polar signature of an opening and closing ocean; (4) Superimposed on these main trends are a series of kinks which correspond to the frequent minor changes in direction of continental motion; (5) Since the bordering continents are unlikely to return to exactly the same positions, the pre-rifting polar paths will have similar form but will not coincide; (6) Continental collisions are marked by polar junctures. Polar loops, hairpins and kinks appear to be the characteristic polar signatures of continents drifting in a plate-tectonic regime. Hairpins are large-scale effects signifying large changes in continental motions. They divided the polar path into a series of tracks, which spans intervals comparable to the time scale of plate tectonics, namely 10^8 years. The kinks occur more frequently, say every 10^7 years, and may be expected to reflect the detailed time-table of plate motions. With present experimental uncertainties kinks will not be positively identifiable in Precambrian studies, although such features as the bend in Track 4 and 5 could have this source.

Tectonic Aspects

The following discussion is, for the reasons given above, necessarily tentative. The conclusions are consistent with the paleomagnetic evidence, but they are not unambiguously demanded by it. The data are insufficient for firm conclusions to be drawn.

Between about -2200 and -1000 m.y., the paleomagnetic poles from Interior Laurentia can be combined into a single simple polar path (Tracks 2, 3, 4 and 5; Fig. 4). This is consistent with the idea that Interior Laurentia was approximately intact during that interval. There is as yet no paleomagnetic evidence for supposing that the archean fragments were ever much more widely dispersed than at present, and no evidence for subduction of large ocean plates *within* Hudsonian terrain. The paleomagnetic evidence is consistent with the idea that the geosynclines *within* Hudsonian terrain (internal geosynclines such as the Labrador Trough, Fig. 1) were formed from narrow rifts which never opened into wide oceans, and which were separated by archean terrain reactivated during the Hudsonian orogeny. These geosynclines appear to be intracratonic as McGlynn (1970) contended. The modern anologue of these early Proterozoic internal geosynclines could be the Red Sea-East African Rift system. The looped nature of the APW curve is consistent with the occurrence of plate-style motions of Interior Laurentia as a whole, and thus plate interactions marginal to Interior Laurentia are to be expected from the paleomagnetic evidence. Hoffman (1973) suggests that the Bear Province is a product of plate-style tectonics and it may be an example of such marginal plate interaction. Both internal and marginal orogenies correspond in time, within the accuracy of the observations, with the large changes in direction of motion of Interior Laurentia as a whole (with the Hudsonian hairpin of Fig. 4). This is to be expected since the internal deformations of a large plate which is not quite rigid will presumably respond to major changes in stress field over it.

For reasons that are rather complex and given elsewhere (Irving *et al.*, 1974) a good estimate of the age of the Grenville track is about -1150 to -1000 m.y. The difference in interval between Grenville poles and those from Interior Laurentia indicate that the two regions were once about 5000 km apart (Palmer and Carmichael, 1972; Palmer and Carmichael, 1973; Irving *et al.*, 1972). The convergence of the Grenville track and track 2 signifies the approach and collision of Grenvillia and Interior Laurentia (Buchan and Dunlop, 1973; Stewart and Irving, 1974). It is possible to reconstruct these motions and the map may be found in *Geoscience Canada* v. 1, no. 3, p. 60. In this argument a distinction is made between the Grenville Province and Grenvillia. Grenvillia is the Grenville Province minus zone *B* (Fig. 7), which is that part of Interior Laurentia deformed during the collision and which did not move along with Grenvillia.

Prior to about -1150 m.y. there is little or no paleomagnetic evidence for the Grenville Province, but there is evidence of very extensive rifting related to the Grenville Front at between -1250 and -1100 m.y. (the Pre-Grenville rift systems of Baragar, see *Geoscience Canada* v. 1, no. 3, p. 56). A further point is that the front is parallel to the late Precambrian edge and to the present continental shelf (Fig. 7). Their parallelism indicates that they might be the product of similar processes. Therefore it is possible, and fully consistent with the paleomagnetic data, that the central feature of the Grenville orogenic cycle is an open and closing ocean. It is possible that Grenvillia was broken from Interior Laurentia about -1250 m.y. at a time of the Pre-Grenville rifting, then moved away, and finally returned at -1000 m.y.

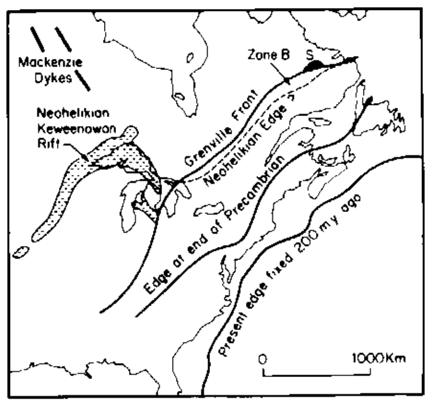

Figure 7
Successive southeastern margins of North America. Zone B is explained in text. The late Precambrian boundary is from Williams and Stevens (1975). The Seal Lake rift system (S), the Mackenzie dyke system and related Coppermine-Muskox volcanism (—1250 m.y.), and the Keweenawan rift filled with basic volcanic rocks 1200 to 1100 m.y.) are the Pre-Grenville rift system of Baragar.

Latitude Variations

The latitude variations of three reference towns in Interior Laurentia calculated from the APW curve of Figure 4 are shown in Figure 8. Interior Laurentia seems to have remained predominantly in the northern hemisphere, and does not appear to have moved randomly over the surface of the Earth. Although Laurentia has made several attempts to enter the southern hemisphere (notably at -1800, -1400, and -1000 m.y.) it never succeeds in doing so for any substantial length of time. The latitude was high about -2100 m.y., and this is consistent with the occurrence of glaciations in the Huronian at about this time. The late Aphebian iron deposits of Minnesota and Labrador seem to have been laid down in lowish latitudes at a time of sharply decreasing latitude. Without wishing to criticize the commonly accepted notion that the widespread deposition of iron at this time was triggered by a rapid increase in the oxygen content of the atmosphere, the evidence of Figure 8 does indicate that paleogeographic changes may also have been important.

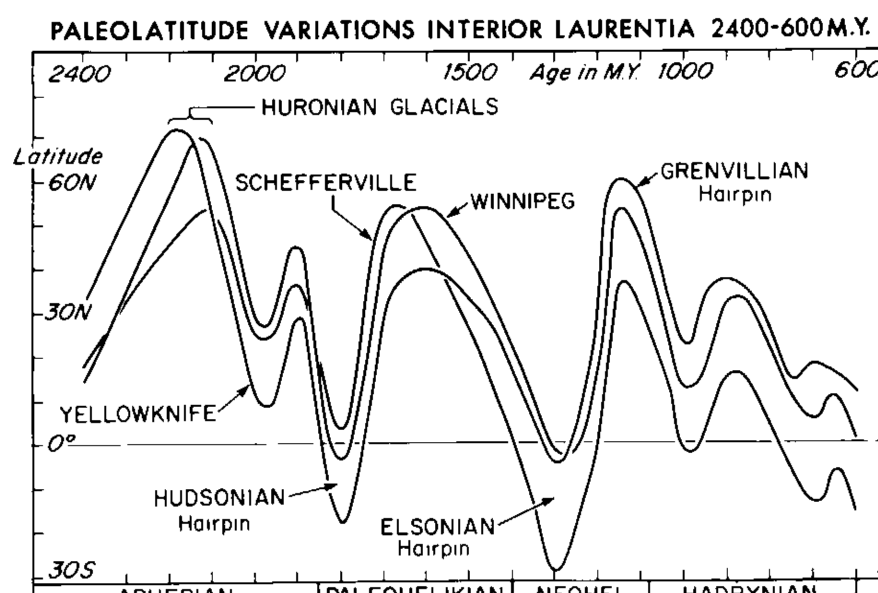

Figure 8
Latitude variations for Interior Laurentia. The variations at three reference towns are calculated from Figure 4.

APW Stratigraphy

Major changes in drift direction ought to correspond to the major orogenies, and the hairpins do in fact correspond in time approximately to the boundaries (which are the major orogenies) of Stockwell's four subdivisions of the Proterozoic. A tentative chronology of hairpins, which define a sequence of diastrophic intervals (Pc 1 to 5), is given in Figure 9. This chronology bears an obvious resemblance to Stockwell's scheme. The APW information may be capable of refining some of the less certain features of Stockwell's scheme. For example, Stockwell originally used K-Ar ages to define the Neohelikian-Hadrynian boundary at -950 m.y., but later using ages provided by Rb-Sr and U-Pb methods obtaining -1050 m.y. (Fig. 9). The paleomagnetic evidence, as interpreted in Figure 4, suggests that these are, in fact, two distinct tectonic events. The older age is the beginning of the convergence of Grenvillia and Interior Laurentia, and the younger age marks their collision. Obviously this suggestion is speculative, but if it is confirmed by future results, then there would be justification to revert to Stockwell's initial definition of the Neohelikian, and to define a Late and Early Neohelikian, corresponding to the diastrophic intervals Pc 3 and 2, and the opening and closing phase of the Grenvillian cycle respectively. The time is perhaps not far distant when we shall have a generalized stratigraphy for the Proterozoic, combining APW with the radiometric and general geological evidence employed by Stockwell, and by means of which it will be possible to place rocks, not only in their time frame, but also in their correct kinematic relationships.

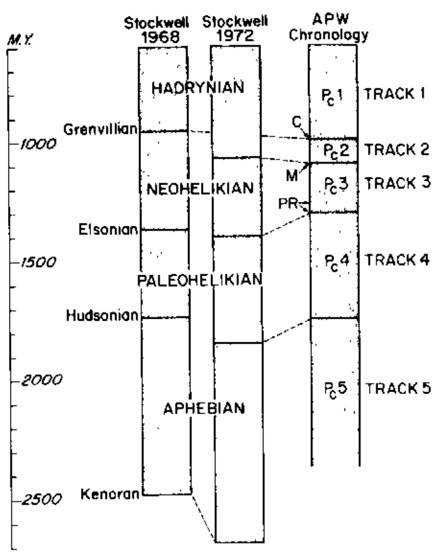

Figure 9
Tentative APW Stratigraphy for Laurentia. The chronologies of Stockwell based on mean ages of orogenies are given. On the left is an early version based on K-Ar mineral ages. In the centre is Stockwell's latest version based mainly on Rb-Sr isochron ages. The boundaries of the diastrophic intervals Pc1 etc. are defined by hairpins and the intervals themselves correspond to the main polar tracks (Fig. 4). PR is the average time of initiation of Pre-Grenville rifting, M is the main Grenville orogenic phase, and C is the collision as explained in text. Updated from Irving and Park (1972), and McGlynn et al. (1974).

Magnetization at Sudbury

The Sudbury nickel irruptive has a special place in Canadian geology, and moreover was one of the first Precambrian rock units to be studied paleomagnetically (Hood, 1958), but its magnetization has never been fully explained, and it is appropriate to comment here on this interesting problem and make some suggestions for its solution. The best current estimate of the age of the irruptive is 1844+3 m.y. based on U-Pb work on zircons (Krogh and Davis, 1975). The directions observed on the north and south ranges of the Sudbury structure are shown in section in Figure 10, and the corresponding poles in Figure 4. The inclinations are steep and directed outwards, so that if the irruptive is rotated into a common plane as if it were a single sill-like body the directions do not agree. The directions can be reconciled if it is assumed that the irruptive was intruded as an assymetrical lopolith but if this is done the resulting direction is essentially vertical and gives a pole at 53N, 115W which is grossly inconsistent with an age of about -1850 m.y. in the APW path of Figure 4. An important clue is provided by the study of the iron-minerals in the irruptive by Gasparinni and Naldrett (1972). The north range irruptive is unmetamorphosed, and the iron minerals have equilibrated at about 900°C, and there seems good reason to believe that the magnetization was acquired during cooling immediately following emplacement. The original attitude of the north range can therefore be reconstructed by rotating its paleomagnetic pole (SN of Fig. 4) into the pole position at 1850 m.y. on the reference APW curve, and adjusting its attitude accordingly. The north range irruptive then become essentially horizontal. The south range, however, was deformed and metamorphosed in the Penokean (=Hudsonian) orogeny which in this region ended about -1600

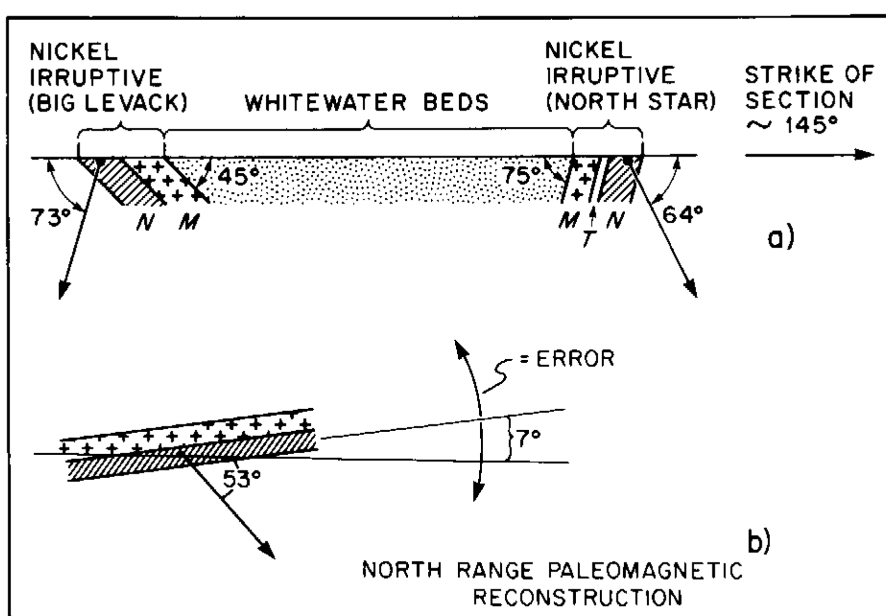

Figure 10
Section of Sudbury Basin showing directions of magnetization. Above are the directions in situ, compiled from Sopher (1963). Below the north range is reconstructed to make the magnetization agree with the pole position of —1850 m.y. N is the norite and M is the micropegmatite.

m.y. According to Gasparinni and Naldrett the iron minerals equilibrated at <600°C, and it is probable therefore that the magnetization was acquired long after emplacement during uplift following the Penokean orogeny. The magnetization directions in situ are actually observed to be consistent with a pole position (SS of Fig. 4) of -1600 m.y. This evidence indicates that the north range nickel irruptive was intruded as a quasi-horizontal sheet. The magnetization of the south range is apparently secondary, and therefore provides no information about the original attitude of the south limb. Whether modern paleomagnetic techniques can retrieve the original magnetization of the south range, and thus reconstruct the total original geometry of the irruptive remains to be seen.

Acknowledgements
We are grateful to J. L. Roy, J. C. McGlynn, R. F. Emslie and H. Ueno for many useful discussions, and to Patricia Anderson who produced Figure 6.

Appendix

Check-list of paleomagnetic poles

The rock units from which the poles were obtained are listed in order of increasing estimated age. It must be emphasized that these age estimates are approximate only, and are merely the best we can make of a woefully incomplete record. The errors associated with these age estimates vary from 10^7 to 10^8 years, and the final digit is not significant - these are given here in order to identify each result. The method of determining ages are indicated by letters: *K*-K-Ar ages, *R*-Rb-Sr ages decay constant 1.39 × 10^{-11} yr^{-1}, *Z*-U-Pb zircon ages, *S*-stratigraphic assignment, *U*-little age control. The error (P=0.05) in the pole is given in brackets in degrees, followed by the last three digits of the list number in the Ottawa paleomagnetic catalogue. The error is expressed either as a single value, which is the radius of the circle of confidence around the pole, or as two values, which are the semi-axes of an oral area of confidence. Further details may be obtained from the first issue of the Ottawa catalogue (Hicken *et al.*, 1972) and the second issue to appear in 1975.

Assigned age	Basis	Name	Error (P-0.05)	Ottawa number
675	*K*	Franklin diabase	(13)	313
700	*S*	Tillite Formation	(19 10)	056
796	*R*	Torridon Group	(6, 4)	001
800	*S*	Multicolored Series	(10, 5)	055
935	*K*	Rama diabase	(9, 5)	391
953	*R*	El Paso rocks	(6, 5)	167
991	*R*	Stoer Group	(9, 4)	422
995	*K*	Aillik dikes	(6)	353
1000	*K*	Nankoweap Formation	(8, 5)	396
1030	*R*	Pike s Peak granite	(8, 4)	155
1036	*K*	Nemegosenda carbonatite	(25, 24)	412
1040	*S*	Jacobsville sandstone	(3, 2)	302
1046	*K*	Freda and Nonsuch sandstone	(7, 4)	303
1053	*R*	Cardenas lavas, weathered	(14, 11)	398
1070	*R*	Mamainse lavas, normal	(8, 4)	394
1076	*R*	Mamainse lavas, reversed	(16, 14)	395
1080	*K*	Copper Harbour lavas	(10, 5)	304
1090	*R*	Cardenas lavas	(8, 5)	397
1100	*K*	Portage Lake lavas	(10, 6)	392
1105	*K*	North Shore volcanics, normal	(8, 4)	393
1110	*Z*	North Shore volcanics, reversed	(12, 9)	306
1115	*K*	Osler lavas	(14, 12)	147
1120	*K*	Keweenawan intrusive	(8, 6)	308
1140	*K*	Logan diabase	(7, 4)	268
1150	*K*	Gila diabase	(9, 6)	320
1160	*K*	Logan diabase, reversed	(10, 9)	309
1200	*K*	South Trap Range lavas, reversed	(8, 7)	150
1220	*S*	South Trap Range lavas, normal	(14, 8)	374
1230	*K*	Mackenzie diabase	(3, 1)	453
1250	*K, R*	Muskox intrusion	(5)	115
1284	*R*	Coppermine lava	(6, 3)	472
1300	*S*	Seal Group Red beds	(6, 3)	464
1350	*R*	Belt Series	(7, 4)	300
1370	*R*	Sibley Series	(13, 7)	473
1375	*R*	St Francois rocks	(8)	241
1400	*K*	Michikamau anorthosite	(10, 5)	205
1410	*R*	Sherman granite	(10)	172
1475	*R*	Crocker Island Complex	(11, 7)	129
1500	*K*	Western channel diabase	(6)	504
1622	*K*	Melville-Daly Bay metamorphics	(8, 6)	456
1650	*S*	Nonacho Group	(8, 4)	411
1660	*S*	Kahochello formation, secondary	(10, 8)	—
1700	*K*	Sparrow dikes	(9, 7)	410
1750	*S*	Et-Then Group	(10)	341
1800	*S*	Cape Smith volcanics	(2)	-
1825	*R, K*	Dubawnt Group	(7)	481
1830	*S, K*	Martin Formation	(12, 6)	468
1860	*S, R*	Kahochello Formation, primary	(9, 6)	-
1893	*R*	Spanish River complex	(25 24)	413
2000	*R*	Gunflint Formation	(17, 16)	191
2040	*K*	Wind River dikes	(23, 23)	326
2050	*S, K*	Otish gabbro	(9)	467
2093	*R, K*	Indin dikes	(12, 9)	492
2100	*R, K*	Mugford Basalt	(11, 9)	314
2147	*R, K*	Abitibi dikes major magnetization	(7, 6)	109
2180A	*R, K*	Nippissing diabase	(7, 4)	171
2180B	*R, K*	Nippissing diabase, Matinenda	(8, 5)	421
2300	*U*	X-dikes	(12, 6)	493
2645	*R*	Stillwater Complex	(13, 8)	244
2690	*R, K*	Matachewan dikes	(22)	107
2692	*R, K*	Dogrib dikes	(5, 3)	491
SR	*U*	Spanish River dike	(21, 11)	414

Check-list of Paleomagnetic Poles from the Grenville Structural Province and its near Vicinity

Age relationships are complex, and readers are referred to Palmer and Carmichael (1973), Roy and Fahrig (1973), Ueno *et al.* (1975) and Fahrig *et al* (1974) for discussions.

Basis	Name	Error (P=0.05)	Ottawa number
A	Lac Allard anorthosite	(10)	130
F	Frontenac dikes	(9, 6)	363
GA	Grenville anorthosite	(14, 9)	086
HB1	Haliburton basic rock	(10, 9)	399
HB2	Haliburton basic rock	(16, 8)	400
LJ	Lac St. Jean anorthosite	—	
M1	Morin complex (ht)	(10, 9)	482
M2	Morin complex (mt)	(12, 9)	483
MG	Michael gabbro	(2)	352
MM1	Mealy Mts. complex E	(9)	415
MM2	Mealy Mts. complex NW	(12)	417
MT	Magnetawan metasediments	(8)	
OT	Grenville metamorphic rocks	(8)	322
SC	Seal Croteau igneous rocks	(8, 5)	463
SG-2	Shabogamo gabbro	(32, 16)	419
SG-3	Shabogamo gabbro	(31)	420
SU	St-Urbain anorthosite	(16, 16)	409
TG	Tudor gabbro	(9, 5)	458
U	Umfraville intrusive	(9, 6)	043
WP	Wilberforce pyroxemite	(7, 5)	457
WW	Whitestone anorthosite (ht)	(11, 8)	500
WY	Whitestone anorthosite (mt)	(10, 6)	502
WZ	Whitestone anorthosite (ht)	(10, 8)	503

References

Bridgewater, D., A. Escher, G. D. Jackson, F. C. Taylor, and B. F. Windley, 1973, Development of the Precambrian Shield in West Greenland, Labrador and Baffin Island: *in* M. G. Pitcher, ed., Arctic Geology, p. 99-117, Amer. Assoc. Petroleum Geol.

Buchan, K. L. and D. J. Dunlop, 1973, Magnetization episodes and tectonics of the Grenville Province: Nature Phys. Sci. v. 246, p. 28-30.

Dubois, P. M., 1962, Paleomagnetism and correlation of Keweenawan rocks: Geol. Surv. Can. Bull. 71, 75 p.

Fahrig, W. F., K. W. Christie, and E. J. Schwartz, 1974, Paleomagnetism of the Mealy Mountain Anorthosite Suite and of the Shabogamo Gabbro, Labrador, Canada: Can. Jour. Earth Sci. v. 7, p. 18-29.

Gasparinni, E. and A. J. Naldrett, 1972, Magnetite and ilmenite in the Sudbury nickel irruptive: Econ. Geol. v. 67, p. 605-621.

Hicken, A., E. Irving, L. K. Law, J. Hastie, 1972, Catalogue of paleomagnetic directions and poles, first issue: Earth Physics Branch Publ. v. 45, no. 1, p. 1-136.

Hoffman, P., 1973, Evolution of an early Proterozoic continental margin: the Coronation geosyncline and associated aulacogens of the northwestern Canadian Shield: Phil. Trans. Roy. Soc. Lond. Ser. A., v. 273, p. 547-581.

Hood, P. J., 1958, Paleomagnetic study of some Precambrian rocks from Ontario: Univ. Toronto, Unpubl. Ph. D Thesis, 200 p.

Irving, E. and J. K. Park, 1972, Hairpins and superintervals: Can. Jour. Earth Sci., v. 9, p. 1318-1324.

Irving, E., J. K. Park and J. L. Roy, 1972, Palaeomagnetism and the origin of the Grenville front: Nature Phys. Sci., v. 236, p. 344-356.

Irving, E., R. F. Emslie and H. Ueno, 1974, Upper Proterozoic paleomagnetic poles from Laurentia and the history of the Grenville structural province: Jour. Geophys. Res., Dec. 1974.

Krogh, T. E. and G. L. Davis, 1975, The age of the Sudbury nickel irruptive: Carnegie Institution Year Book, in press.

McGlynn, J. C., 1970, *in* R. J. W. Douglas, ed., Geology and Economic Minerals of Canada: Geol. Survey Can., Econ. Geol. Rept. no. 1, p. 87.

McGlynn, J. C., G. N. Hanson, E. Irving and J. K. Park, 1974, Paleomagnetism and Age of Nonacho Group Sandstones and Associated Sparrow dikes District of Mackenzie: Can. Jour. Earth Sci., v. 11, no. 1, p. 30-42.

Néel, L., 1949, Théorie du trainage magnétique des ferromagnétiques en grains fins avec applications aux terres cuites: Ann. Géophys., v. 5, p. 99.

Palmer, H. C. and C. M. Carmichael, 1972, Grenville paleomagnetism and possible tectonic implications: Trans. Am. Geophys. Union, v. 53, p. 537.

Palmer, H. C. and C. M. Carmichael, 1973, Paleomagnetism of some Grenville Province rocks: Can. Jour. Earth Sci., v. 10, p. 1175-1190.

Roy, J. and W. Fahrig, 1973, The Paleomagnetism of Seal and Croteau rocks from the Grenville front, Labrador: polar wandering and tectonics implications: Can. Jour. Earth Sci., v. 10, no. 8, p. 1279-1301.

Sopher, S. R., 1963, Paleomagnetic study of the Sudbury irruptive: Can. Geol. Surv. Bull. 90.

Stewart, A. D. and E. Irving, 1974, Paleomagnetism of sedimentary rocks from N.W. Scotland and its comparison with the polar wandering path relative to Laurentia: Geophys. Jour., v. 37, no. 1, p. 51-73.

Stockwell, C. H., J. C. McGlynn, R. F. Emslie, B. V. Sanford, A. W. Norris, J. A Donaldson, W. F. Fahrig and K. L. Currie, 1970, Geology of the Canadian Shield: *in* R. J. W. Douglas, ed., Geology and Economic Minerals of Canada: Geol. Surv. Can., Econ. Geol. Rept. 1, (Fifth Edition), p. 44-150.

Stockwell, C. H., 1972, Revised Precambrian time-scale for the Canadian Shield: Geol. Surv. Can. Pap. 52, p. 1-4.

Ueno, H., E. Irving and R. H. McNutt, 1975, Paleomagnetism of the Whitestone anorthosite and diorite, and the Grenville polar track: Can. Jour. Earth Sci., in press.

Williams, M. and R. K. Stevens, 1975, Early Paleozoic continental margin of Eastern North America, C. H. Drake, ed., Springer-Verlag, New York, in press.

MS received December 5, 1974; revised January 20, 1975.