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Article abstract

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Paleomagnetism of Precambrian Rocks of Laurentia

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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 bougé 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,
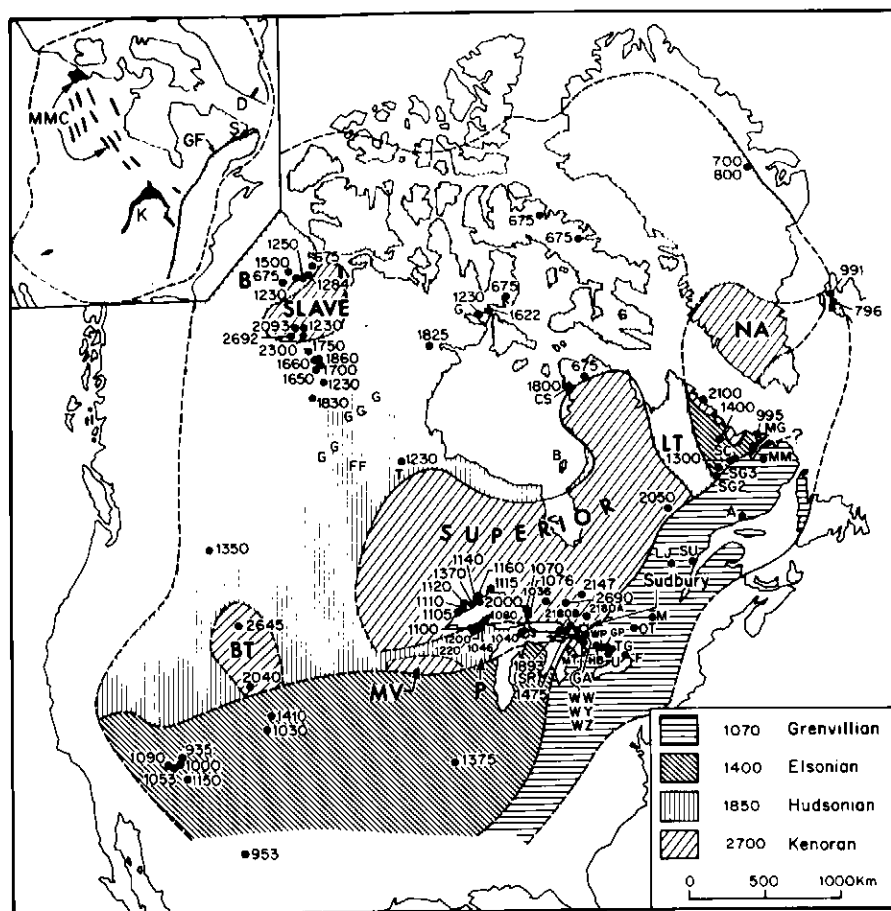
Figure 1
Structural provinces of Laurentia and
paleomagnetic sampling localities. Rock
units sampled are listed in the appendix.
The mean ages at which four major
subdivisions of Precambrian terrain were
stabalized are from Stockwell (1972). **P** is
the Penokean fold belt stretching from
Sudbury to 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 10⁸ 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
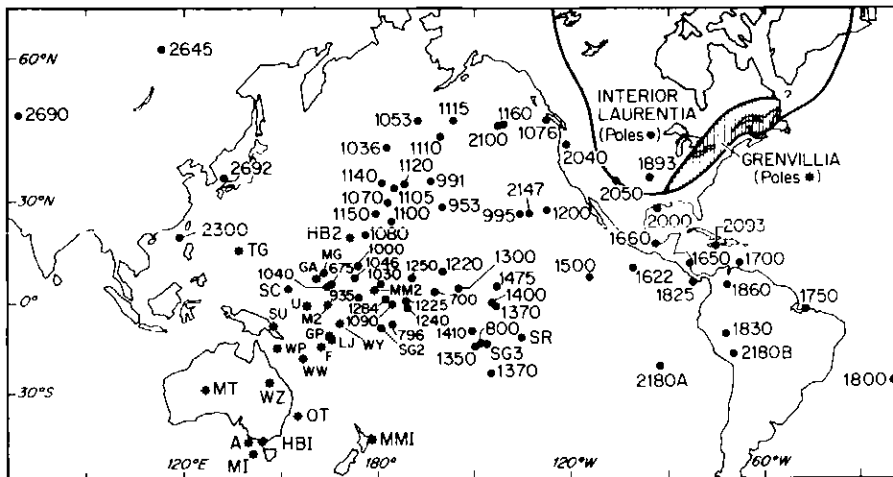a lapse of about 10⁸ years (note the

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
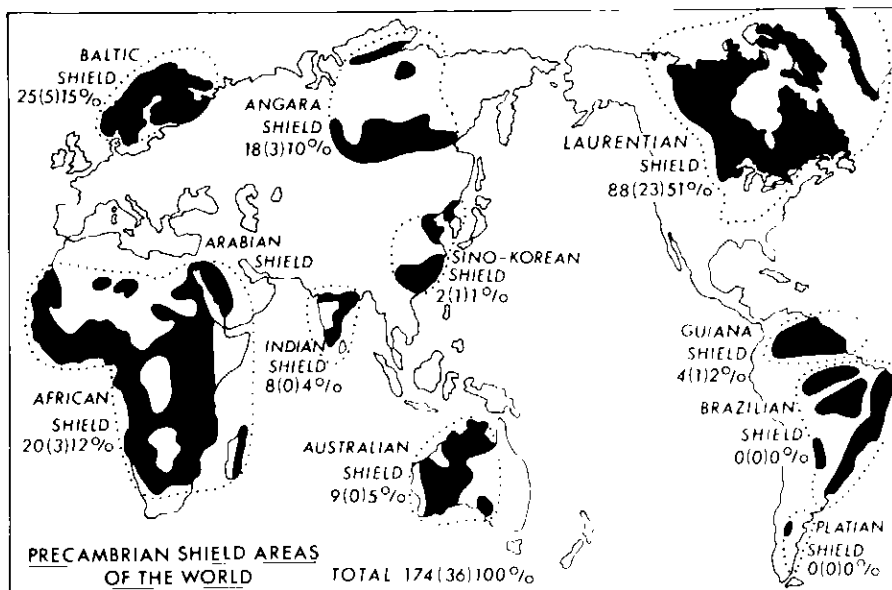units from which the poles were obtained
are listed in the appendix.

PRECAMBRIAN SHIELD AREAS
OF THE WORLD   TOTAL 174(36)100%

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 10⁶ 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 reconstruction. 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 undocu-
mented variations are present, or that
the existing poles are in error, or are
wrongly dated. A kink and question-
mark 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
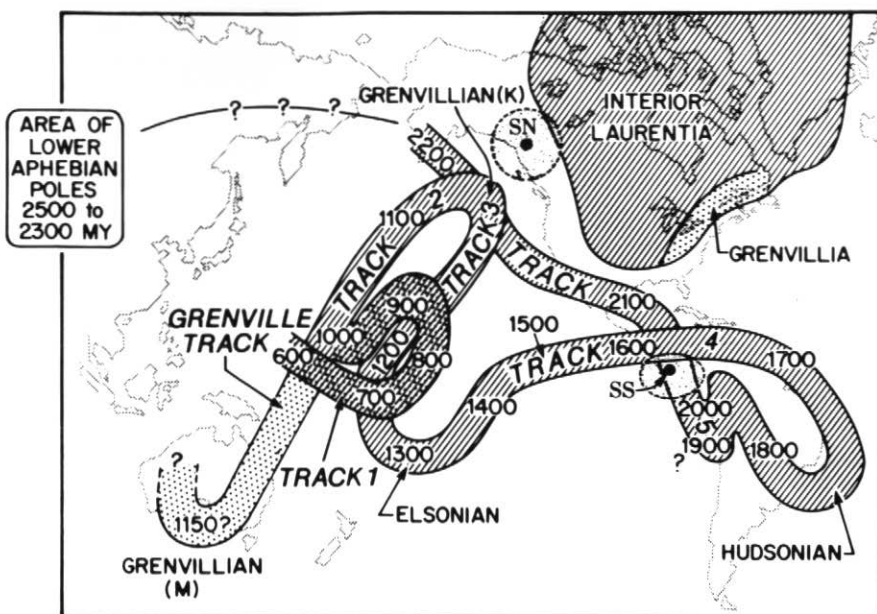features: (1) A single continent in

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 10^8 years. The
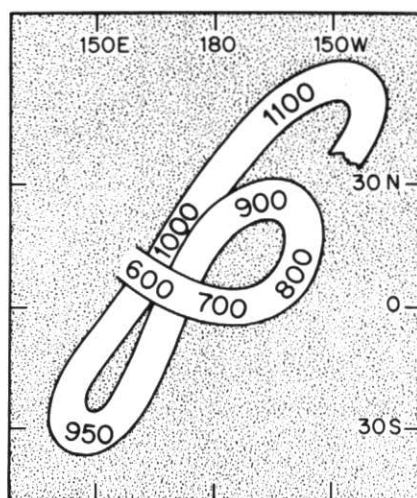hairpins are named by the orogeny to which
they are thought to correspond. The poles
for the Sudbury nickel irruptive are SS
(south range) and SN (north range), both
without structural correction, are from
Sopher (1963).

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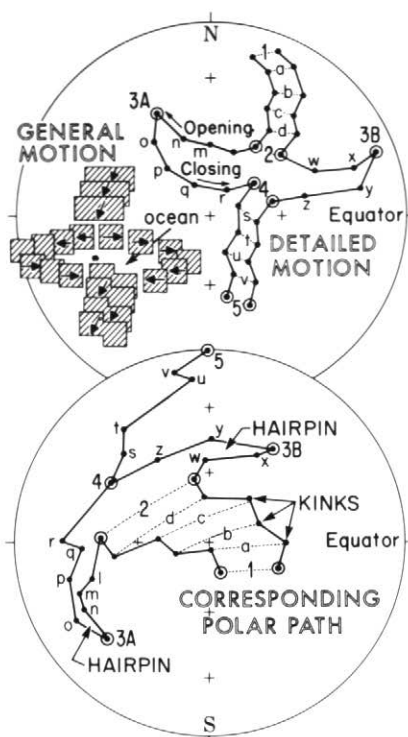interval −1100 to −600 m.y.

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
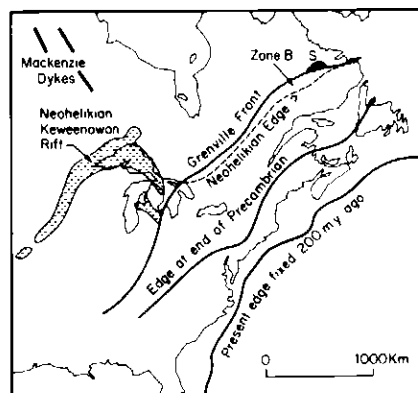

Figure 7
Successive southeastern margins of North America. Zone B is explained in text. The late Precambrian boundary is from Williams and Stevens (1975). The Seal Lake rift system (S), the Mackenzie dyke system and related Coppermine-Muskox volcanism (—1250 m.y.), and the Keweenawan rift filled with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

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.

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.
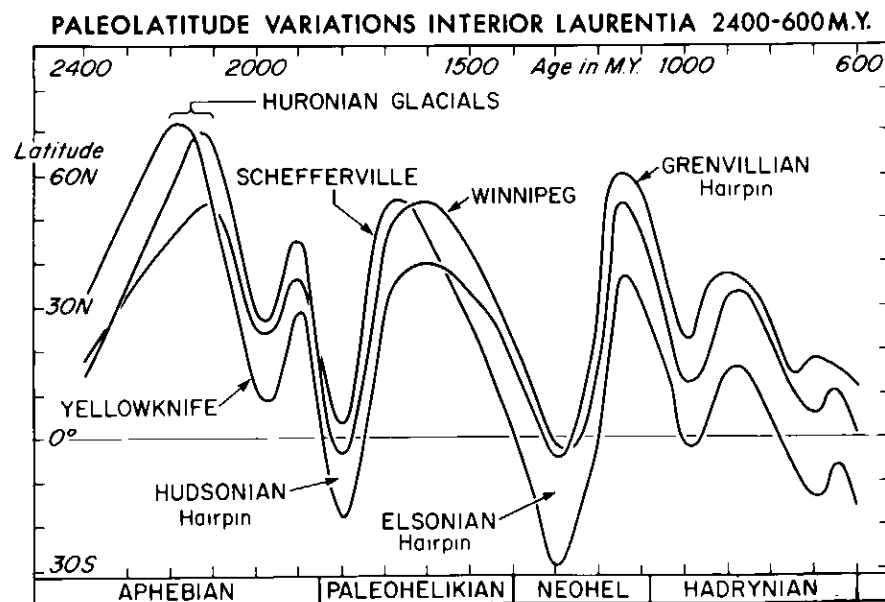
PALEOLATITUDE VARIATIONS INTERIOR LAURENTIA 2400-600 M.Y.

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

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).*

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.

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
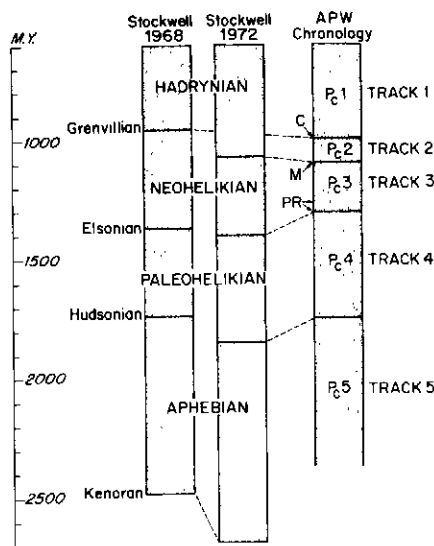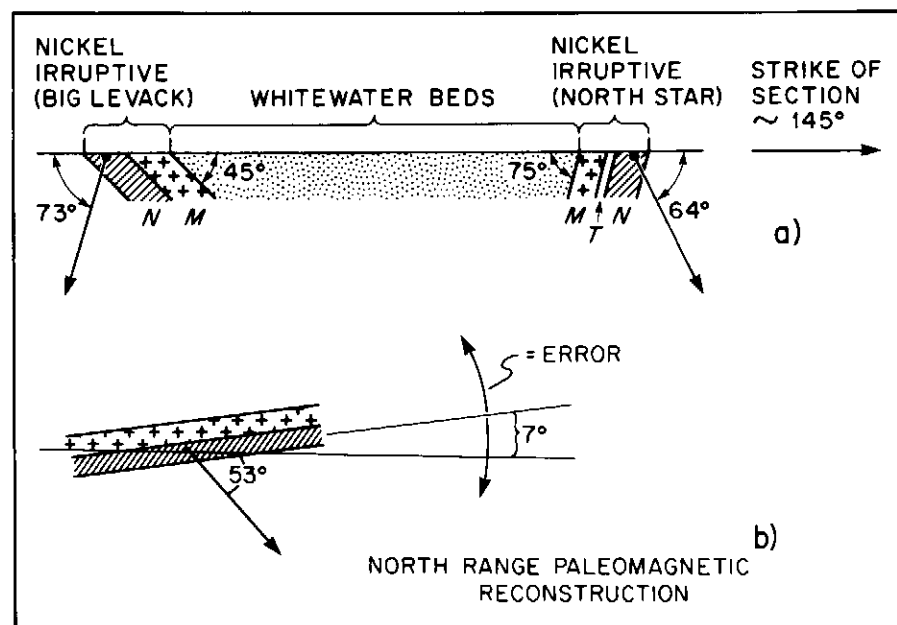which in this region ended about -1600

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

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