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Palaeomagnetic evidence for Proterozoic continental development

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The palaeomagnetic record of continental drift during the Proterozoic is reasonably complete for North America (including Greenland and the Baltic Shield), less complete for Africa and Australia, and fragmentary elsewhere. Palaeomagnetic poles of similar age from different cratons or structural provinces of any one continent tend to fall on a common apparent polar wander path (a.p.w.p.), indicating no major ($\gtrsim$ 1000 km) intercratonic movements. On this evidence, Proterozoic orogens and mobile belts are essentially ensialic in origin. However, the palaeomagnetic record has systematic gaps. In highly metamorphosed orogens (amphibolite grade and above), remagnetization dating from post-orogenic uplift and cooling is pervasive. Collisional and ensialic orogenesis cannot then be distinguished. Palaeopoles from different continents do not follow a common a.p.w.p. They record large relative rotations and palaeolatitude shifts. A recurrent pattern appears in the late Proterozoic drift of North America. At approximately 200 Ma intervals (at about 1250, 1050, 850 and 600 Ma B.P.), the continent returned to the same orientation and (equatorial) latitudes from various rotations and high-latitude excursions. Lacking detailed a.p.w.ps. from other continents, it is not possible to say if these motions represent Wilson cycles of ocean opening and closing in the Phanerozoic style, but they do require minimum drift rates of 50–60 mm/a, comparable to the most rapid present-day plate velocities.

1. INTRODUCTION

The principal uncertainty associated with a Precambrian palaeomagnetic pole is not in its position but in its age. There are three distinct problems.

(i) Error limits on radiometric dates increase in proportion to the age.

(ii) Both isotopic and magnetic recorders are 'overprinted' or partially reset by metamorphism, but to different extents. Deciding which magnetic overprints and mineral or whole-rock ages are pre-orogenic and which are post-orogenic, and correctly matching ages to magnetizations, is a formidable task (see, for example, Buchan *et al.* 1977).

(iii) Overprints date from the uplift and slow cooling phase of orogeny. Since the 'blocking temperatures' for magnetic and isotopic systems differ, radiometric dates may lead or lag magnetization ages by tens of millions of years (Berger *et al.* 1979; Dunlop *et al.* 1980).

Tie points for Precambrian apparent polar wander paths (a.p.w.ps) come either from lightly metamorphosed formations that post-date stabilization of a craton or from those few metamorphosed formations whose pre-orogenic and post-orogenic magnetizations have been identified from laboratory and field studies (e.g. contact or fold tests) and are confidently dated. Syn-orogenic palaeopoles from active orogens and mobile belts are rare. Generally the nature of orogeny must be deduced from palaeopoles that predate or postdate the deformational phase of orogeny. Often the data are not from the orogen of interest but from neighbouring stable cratons.

These difficulties are manifest in the examples in the present paper, most of which are drawn from the Proterozoic of North America. Broader and more detailed analyses are found in

Briden (1976), Irving & McGlynn (1976, 1979), Irving (1979), McElhinny & Embleton (1976), McElhinny & McWilliams (1977), McWilliams (1980), Morris *et al.* (1979) and Piper (1974, 1976*a*, *b*).

2. Africa

There are now of the order of 40 dated palaeopoles for the Proterozoic of Africa. About half fall in the interval 2.3–1.8 Ma B.P., illustrated in figure 1. Poles from the west African and Kaapvaal cratons form a coherent set between 2.3 and 2.2 Ma B.P. and the single pole from the Congo craton agrees reasonably well with poles of similar age from the other two cratons.

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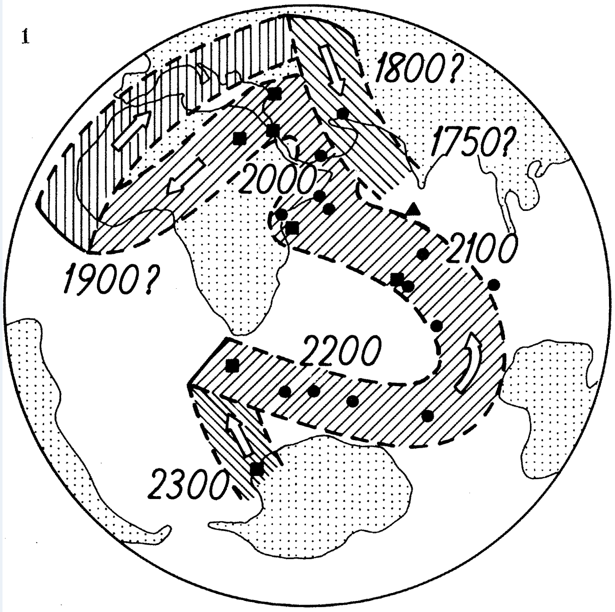

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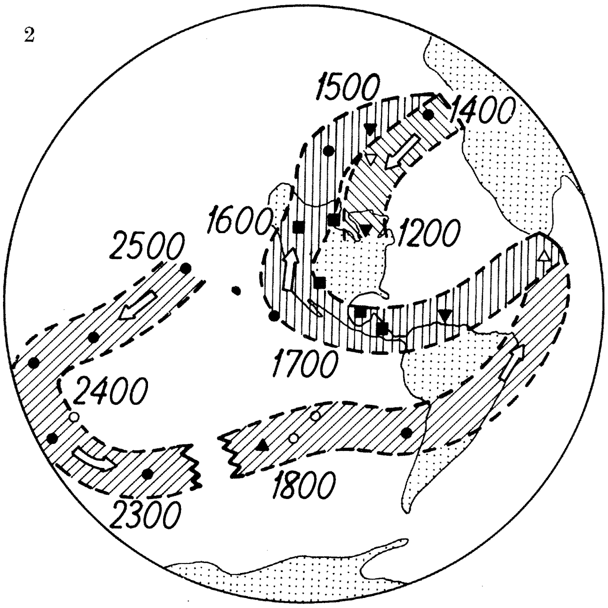

Figure 1. Early Proterozoic a.p.w.p. for three African cratons: west African (●); Congo (▲); Kaapvaal (■). Although ovals of confidence are not given for individual palaeopoles, uncertainty is reflected in the width of the a.p.w.p. Numbers along the a.p.w.p. are ages in millions of years. (Redrawn from McElhinny & McWilliams (1977) with the addition of the 1900–1750 Ma B.P. loop proposed by Piper (1974, 1976*a*). Individual poles are identified in these papers.)

Figure 2. Early and middle Proterozoic a.p.w.p. for seven Australian tectonic blocks: Yilgarn craton (●) Pilbara craton (○); Kimberley basin (▲); Pine Creek mobile belt (△); Gawler craton (■); Mount Isa mobile belt (▼); Musgrave mobile belt (▽). Note the gap in the a.p.w.p. between 2300 and 1800 Ma B.P. (Redrawn after McElhinny & Embleton (1976), where individual poles are identified. Some secondary magnetization poles of unknown age have been omitted.)

The west African and Kaapvaal cratons must have been in their present relative positions (apart from a possible difference in palaeolongitude, which is undetermined palaeomagnetically) 2.3–2.2 Ga ago and the Congo craton must have been in its present position relative to the other two cratons by 2.1 Ga B.P. at the latest. There are gaps in the a.p.w.p., during which the cratons could have drifted independently. If they did so, they must have returned to their pre-drift positions after each period of relative drift. This has not been a usual consequence of Phanerozoic seafloor spreading. Even allowing that the tectonic régime in the Proterozoic may not have been one of plate tectonics as we understand it, periodic reassembly of disrupted cratonic elements, always in the same configuration, is improbable.

The uncertainties in palaeopole positions (reflected in the width of the a.p.w.p.) and their ages are such that opening and closing of small oceans, 500 or even 1000 km in width, or relative shears of similar magnitude cannot be ruled out (see §4.3). However, the simplest hypothesis is that the Precambrian cratons of Africa have occupied their present relative positions since at least 2.3 Ga B.P. and that later orogenies in the intervening fold belts had an ensialic origin.

3. AUSTRALIA

The Australian a.p.w.p. for the Proterozoic (figure 2) is based on rather sparse data from seven cratons and fold belts. Palaeopoles about 2.4 Ga in age from the Pilbara and Yilgarn blocks of western Australia are in agreement. The intervening 1.7 Ga Ophthalmian mobile belt is therefore likely ensialic.

The nature of 1.8–1.7 Ga B.P. orogenic events elsewhere in Australia is uncertain, since the a.p.w.p. has a gap between 2.3 and 1.8 Ga B.P. Poles about 1.8 Ga in age from the Pilbara, Yilgarn and Kimberley blocks are in approximate agreement, as are poles about 1.7 Ga old from the Yilgarn, Gawler and Mount Isa blocks. The major cratonic elements of the Australian Shield were therefore assembled by 1.7 Ga B.P. Whether they were assembled by large-scale displacements just before 1.8 Ga B.P. or whether they had stabilized long before will not be known until pre-orogenic magnetizations are discovered in rocks outside the Pilbara and Yilgarn cratons.

The only strikingly discordant 1.8–1.7 Ga B.P. pole, requiring a large excursion in the a.p.w.p., comes from volcanics of the Pine Creek geosyncline of the north Australian coast. This region is possibly the product of marginal tectonics that continued after 1.7 Ga B.P.

4. LAURENTIA

4.1 *Kenoran orogeny*

The most recent major reactivation of Archaean rocks of the Superior, Slave and Beartooth tectonic provinces of the Canadian Shield (figure 3*a*) occurred in the Kenoran orogeny, which culminated 2.7–2.6 Ga ago. Archaean structural trends have been recognized in basement rocks of other provinces (notably the Grenville) but any magnetization of Kenoran or Archaean age has been overprinted by later metamorphism.

Within the Superior, Slave and Beartooth provinces, the regional grade of metamorphism resulting from the Kenoran orogeny is greenschist, the greenstone belts or subprovinces having lower-than-average grade and the intervening gneiss belts having higher-than-average grade. Only in the Superior province have Archaean magnetizations tentatively been identified. Palaeopoles W, S, Q_2 and A in figure 3*b* are respective average poles for formations in the Wabigoon and Shebandowan–Wawa volcanic belts and the Quetico gneiss belt of the western Superior province (Dunlop 1979) and the Abitibi volcanic subprovince of the central Superior province (Schutts & Dunlop 1979). Poles K and D refer to individual formations within the Abitibi subprovince (Irving & Naldrett 1977).

These poles may be *about* 2.8 Ga old, in which case they demonstrate the probable integrity of much of the Superior craton before the Kenoran orogeny. (Alternatively, some or all of these poles may represent 1.25 Ga B.P. overprints; see §4.3.) Without Archaean data from the other

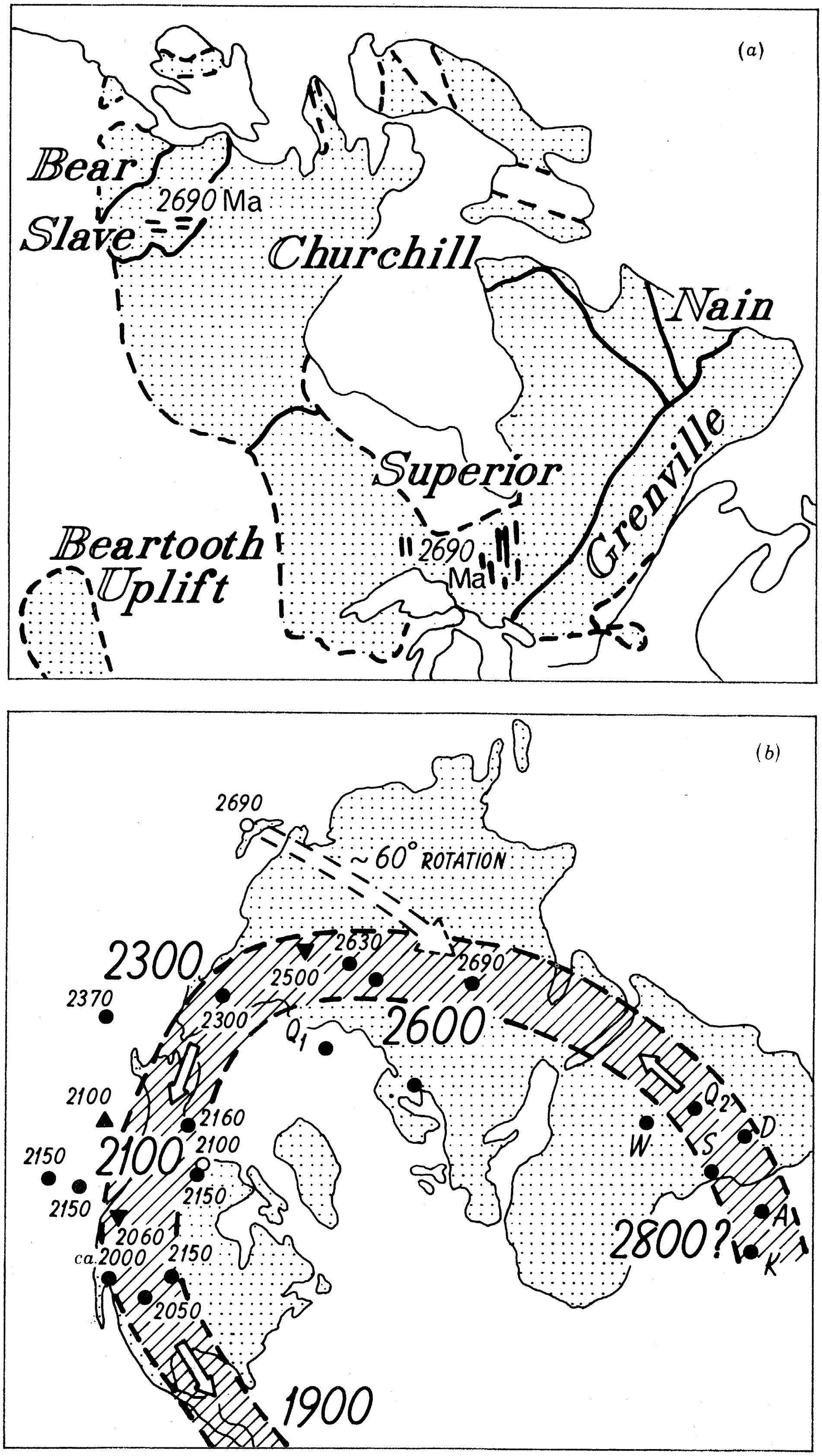

Figure 3. For description see opposite.

provinces, nothing can be said about possible intercratonic movements during the Kenoran event.

Superior and Beartooth poles dating from the close of the Kenoran orogeny form a group in figure 3*b*, from which the 2690 Ma B.P. pole for the Dogrib dikes of the Slave province (McGlynn & Irving 1975) diverges significantly. A 60° clockwise rotation of the Slave province, with little palaeolatitudinal change (and unknown palaeolongitudinal shift), would bring the Dogrib pole into coincidence with the pole of the probably correlative 2690 Ma B.P. Matachewan dikes of the Superior province (Irving & Naldrett 1977). A large rotation (about 90°) would be required to align dyke trends in the two provinces (figure 3*b*).

The Slave province may be a displaced terrain (Irving 1979) that reached its present

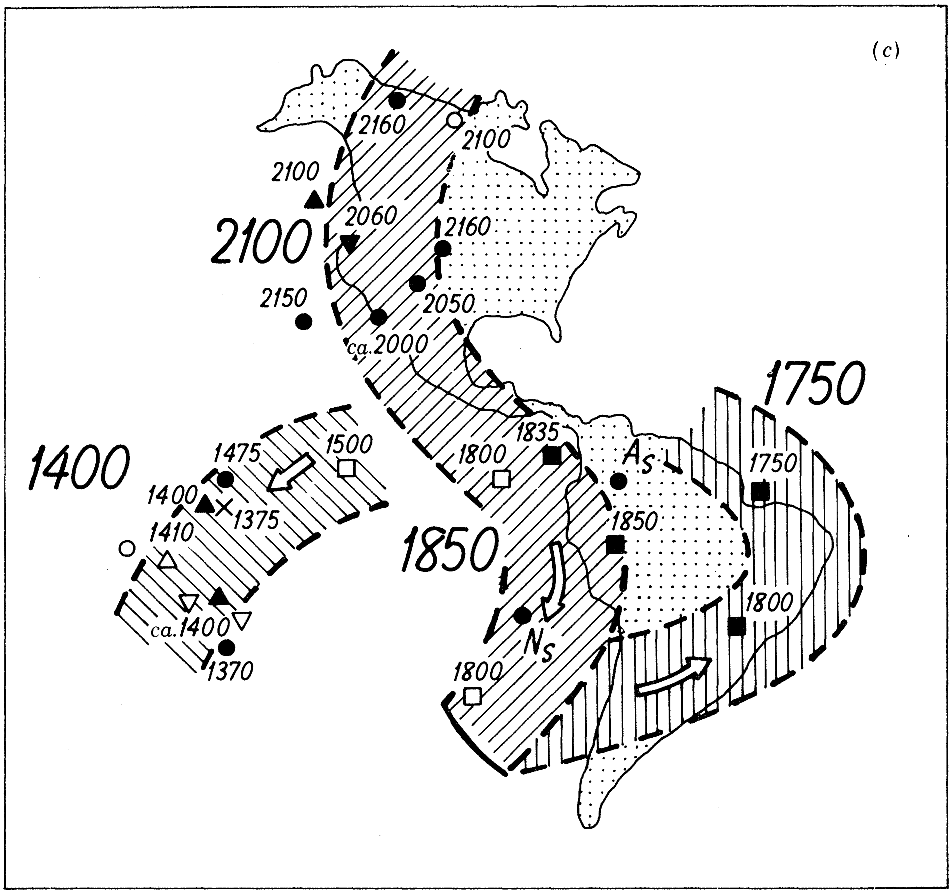

FIGURE 3. (*a*) Tectonic map of the Canadian Precambrian Shield. Trends of 2690 Ma B.P. diabase dykes in the Slave and Superior provinces are indicated schematically. Outlying Laurentian exposures in western North America, Greenland and northern Europe are not shown.

(*b*) Late Archaean and early Proterozoic a.p.w.p. for four structural provinces of Laurentia: Superior (including Southern) (●); Slave (○); Nain (▲); Beartooth (▼). A 60° rotation of the Slave province about an Eulerian pole in the western shield reconciles 2690 Ma B.P. poles from Superior and Slave provinces, as shown. Labelled Archaean poles are identified and discussed in the text. Dated Proterozoic poles are referenced in Irving & Naldrett (1977) and Irving (1979).

(*c*) Middle Proterozoic a.p.w.p. for nine Laurentian structural provinces or outliers: ●, ○, ▲, ▼, as in (*b*); Churchill (■); Bear (□); Front Range, Colorado (△); Belt, Montana and Alberta (▽); St François mountains, Missouri (×). A_s, N_s are secondary (overprint) poles for Abitibi basin rocks and Nipissing diabase respectively. Poles referenced in Irving & McGlynn (1979) and Irving (1979).

location with respect to the Superior after 2500 Ma B.P. but not later than 2160 Ma B.P., by which time Slave and Superior province poles coincide (figure 3*b*). It is also possible that the Dogrib magnetization is a later overprint.

4.2 *Hudsonian orogeny*

The 1.8–1.7 Ga B.P. mobile belts of Australia have North American counterparts in 2.0–1.7 Ga B.P. geosynclines and fold belts within the Bear and Churchill structural provinces (figure 3*a*). In these same provinces, and to some extent elsewhere in the shield, older basement rocks were reactivated and magnetically overprinted in the 1.85–1.75 Ga B.P. Hudsonian event.

There is convincing coherence of poles from the Superior, Slave, Nain and Beartooth provinces between 2160 and about 2000 Ma B.P. (figure 3*b*, *c*) and from the Superior, Slave, Nain and Belt provinces and Precambrian outliers in Colorado and Missouri between 1475 and 1370 Ma B.P. (figure 3*c*). These results bracket the Hudsonian event in time and space. The entire shield, except perhaps the Grenville province (§4.4), had been assembled at the latest 250 Ma after the end of the Hudsonian event. Furthermore, even before the event, four of the stable cratonic areas encircling the main Hudsonian orogen had the same relative positions as they do today.

Although we lack pre-orogenic poles from the Churchill province that could demonstrate beyond doubt pre-Hudsonian integrity of the central shield, it is difficult to imagine a plate tectonic mechanism of introducing all or part of the Churchill from afar without disrupting the encircling cratons. The Bear province, consisting of the 2.0–1.7 Ga B.P. Coronation geosyncline and younger cover rocks, is not so encircled and could have formed via marginal tectonics (Hoffman 1980).

Schutts & Dunlop (1979) report evidence for orogenic overprinting of Abitibi subprovince rocks, dated by ^{40}Ar/^{39}Ar ages of felsic and mafic mineral separates (Hanes & York 1979) at 1.8–1.7 Ga B.P. Both the Abitibi overprint pole and undated overprints from the 2160 Ma B.P. Nipissing diabase, also from the Superior province, fall on the 1850–1750 Ma B.P. a.p.w.p. defined by Churchill and Bear province poles (figure 3*c*). Thus by about 1.8 Ga B.P., orogen and adjacent 'stable' craton were in their present relative positions. The Hudsonian orogeny was almost certainly an ensialic event occurring within the fixed framework of the Superior, Slave and Nain cratons.

Piper (1974, 1976*a*, *b*) has proposed the existence of a Proterozoic Pangaea on the basis of matching Laurentian and African a.p.w.ps. A comparison of figures 1 and 3 demonstrates that, unless the Laurentian a.p.w.p. is more complex or the African a.p.w.p. is simpler than we now believe, no match is possible between 2.3 and 1.75 Ga B.P. An explicit comparison is given by Irving (1979, figure 13), using Piper's suggested reconstruction of the two continents. A post-1.1 Ga B.P. match is conceivable, but, throughout most of the Proterozoic, Laurentia, Africa and Australia drifted independently.

4.3 *Mackenzie igneous event*

In §4.1, Superior province palaeopoles W, S, Q$_2$, A, K and D (figure 3*b*) were provisionally considered to be Archaean. They could equally well record partial overprinting of magnetization on a regional scale during the 1.25 Ga B.P. Mackenzie igneous event. Their antipoles fall near the Laurentian a.p.w.p. between 1.3 and 1.25 Ga B.P. (figure 4*a*) and many are indistinguishable at the 95% confidence level from poles of Mackenzie dykes and lavas from the Superior, Churchill, Slave and Bear provinces.

Three observations favour a primary Archaean magnetization.

(i) Formations sampled come from areas where few or no Mackenzie dykes are known.

(ii) In the Abitibi subprovince, positive contact tests demonstrate that poles A and K are older than 2690 Ma B.P. Matachewan dikes (Irving & Naldrett 1977; Schutts & Dunlop 1979).

(iii) The group of poles cuts across the trend of the a.p.w.p. in figure 4*a*, rather than spreading out along the path.

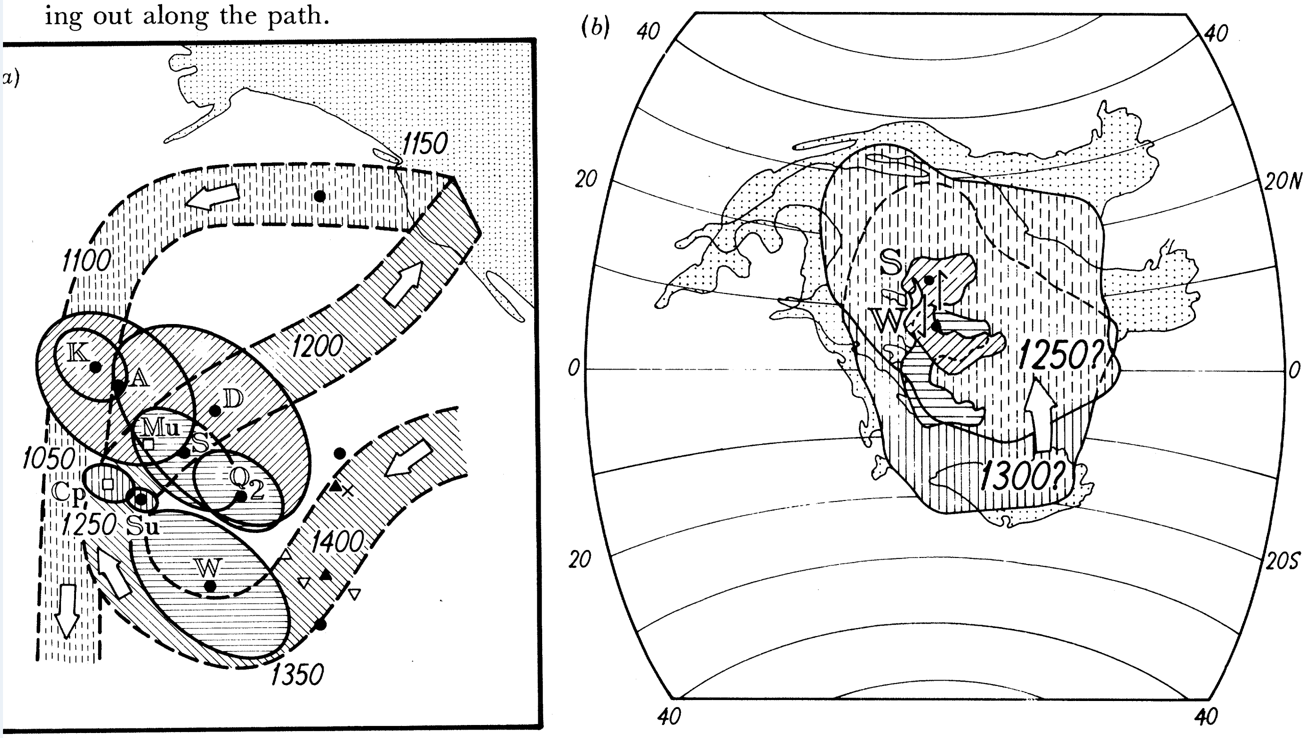

FIGURE 4. (*a*) Laurentian a.p.w.p. for the late middle Proterozoic, showing that antipoles of poles W, S, Q_2, A, K and D (figure 3*b*) are consistent with widespread remagnetization of Archaean terrains in the Superior province during the 1250 Ma B.P. Mackenzie igneous event; 95% confidence ovals about the primary Mackenzie poles Mu (Muskox intrusion) and Cp (Coppermine lavas), both of the Bear province, and Su (Sudbury dikes, Superior province) are much tighter than ovals enclosing the possible overprints. Unlabelled poles (as in figure 3*c*) and Mu, Cp, Su are referenced in Irving & McGlynn (1976, figure 6).

(*b*) Continental reconstructions implied by poles W and S of (*a*). The Superior province is shown within the framework of the Laurentian Shield (including its inferred extension under later cover). The two reconstructions can be interpreted as differing either in time (successive positions of the entire shield at 1300 and 1250 Ma B.P.) or in space (relative drift between Shebandowan (S) and Wabigoon (W) subprovinces, and presumably other units of the shield as well, viewed at 1250 Ma B.P.). Arrows indicate the 800 km of shear necessary to restore W and S to their present relative positions, if the second interpretation is correct.

On the other hand, three other results favour Mackenzie-age overprinting.

(i) Results tend to degroup if structurally corrected (Dunlop 1979; Schutts & Dunlop 1979), implying that magnetization post-dated Kenoran deformation.

(ii) Where a magnetization of this type and a known Kenoran overprint coexist in the same rock (e.g. Q_2 and Q_1 in figure 3*b*), the Kenoran overprint has higher blocking temperatures and, on a thermal model, is older.

(iii) ^{40}Ar/^{39}Ar dating of feldspars demonstrates reheating of one of the Quetico subprovince formations about 1.1 Ga ago (Berger & York 1979). Despite this abundance of evidence, a choice between the two possible ages of magnetization remains difficult.

Palaeopoles from the Shebandowan–Wawa volcanic belt and the correlative Abitibi belt are indistinguishable (see for example, figure 4*a*), but both are significantly different at the 95% level from the pole of the more northerly Wabigoon greenstone belt. The continental reconstructions implied by the Shebandowan and Wabigoon poles (figure 4*b*) are slightly rotated with respect to each other, but the major difference is one of 8° in palaeolatitude.

There are two possible tectonic models. The first model imagines that poles W and S differ in age and record the positions of the Superior province (and presumably the rest of the shield) at about 1300 Ma B.P. and 1250 Ma B.P. respectively. The second model imagines that poles W and S record the same time, but the two subprovinces were at that time shifted 8° in relative palaeolatitude (cf. figure 4*b*). About 800 km of left-lateral shear between these presently east–west trending belts would have been needed to bring them to their present relative positions.

The latter model is not particularly likely, since it would tend to degroup older (Kenoran) poles, but it serves to illustrate the limitations in the resolving power of the palaeomagnetic method. Poles W and S are just barely distinct. They record equatorial palaeolatitudes, where a geocentric, axial dipole field (assumed throughout this paper) is most sensitive to changes in latitude. Even under these ideal conditions, a relative shear less than 800 km would have been unresolved. Furthermore, an ocean of any size opening or closing between the belts would go unrecorded, since only palaeolongitude would change. Relative rotations near the equator (as in figure 4*b*) are recorded via large segments of a.p.w.p. but rotations at the pole are not recorded at all.

Three points need to be emphasized.

(i) The palaeomagnetic method has an inherent ambiguity, since palaeolongitude is not recorded.

(ii) The minimum amount of drift or rotation recorded has a lower limit that increases with palaeolatitude.

(iii) A continent reconstruction must be made for each case of interest. Ambiguities and limits of resolution cannot readily be judged from a.p.w.ps.

4.4 *Grenvillian orogeny*

The Grenville province (figure 3*a*) is a marginal orogen of generally high-grade (amphibolite to granulite) metamorphism. Orogenic overprinting of magnetization is pervasive, obscuring the record of the Grenvillian event.

Two-component magnetizations in the Haliburton intrusions gave palaeopoles $\mathrm{Hb_A}$ and $\mathrm{Hb_B}$ (figure 5), which were at first interpreted (Buchan & Dunlop 1973, 1976) as recording independent motion of 'Grenvillia' (the Grenville exclusive of the reactivated zone north of an unidentified collisional suture) before its convergence with 'Interior Laurentia' (the remainder of the stable Laurentian craton) about 1050 Ma ago. Recent $^{40}\mathrm{Ar}/^{39}\mathrm{Ar}$ dating of separated minerals from the Haliburton rocks (Berger *et al.* 1979) shows that in reality $\mathrm{Hb_A}$ and $\mathrm{Hb_B}$ are both post-orogenic, with respective ages of 980 Ma and 820 Ma. They define a Grenville loop in the Laurentian a.p.w.p. that is largely unrecorded by rocks from other provinces, but they have nothing to say about the Grenvillian orogeny.

The search for pre-orogenic magnetizations has turned to the Thanet, Tudor and Cordova gabbros (figure 5, inset), located in an area of relatively low-grade (low-amphibolite to high-greenschist) metamorphism. The $^{40}\mathrm{Ar}/^{39}\mathrm{Ar}$ hornblende age of the Thanet gabbro is 1200 Ma

(Berger & York 1981), the oldest K/Ar age ever measured for the Grenville and indistinguishable from the U/Pb zircon formation age of the nearby Umfraville gabbro. Since K/Ar ages were not totally overprinted in this area, perhaps the same holds true for magnetizations.

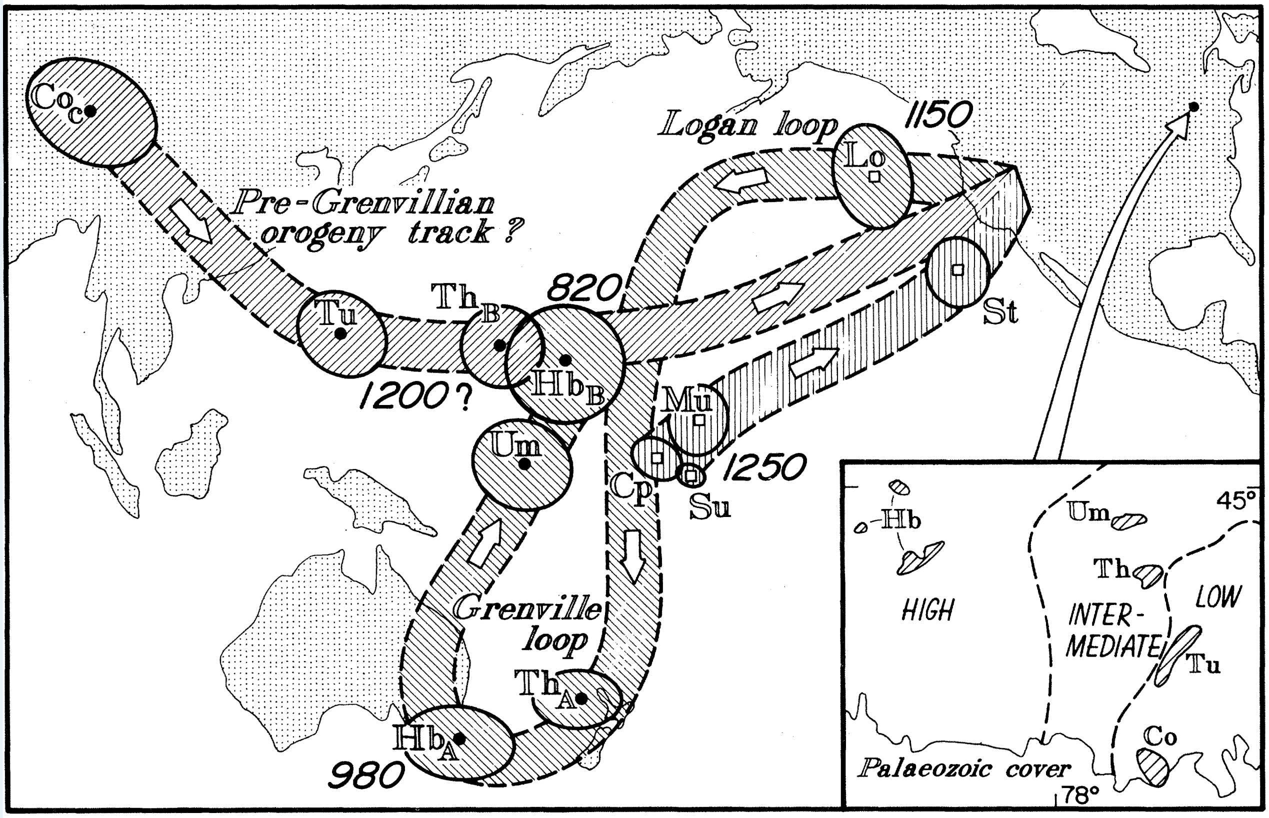

Figure 5. Selected Grenville province palaeopoles (●) from a region of locally low metamorphic grade (inset). $\mathrm{Co_c}$ (Cordova gabbro C component), Tu (Tudor gabbro) and $\mathrm{Th_B}$ (Thanet gabbro B component) may define a pre-Grenvillian orogeny track in the a.p.w.p., converging with the Logan loop of Interior Laurentia (□) about 1150 Ma B.P. The juncture would mark the onset of orogeny in Grenvillia and Keweenawan rifting in Interior Laurentia. St (South Trap Range Lavas) and Lo (Logan diabase) are representative 1200–1150 Ma B.P. Keweenawan poles. Mackenzie-age poles Mu, Cp and Su are as in figure 4. $\mathrm{Th_A}$ (Thanet gabbro A component), $\mathrm{Hb_A}$, $\mathrm{Hb_B}$ (Haliburton intrusions A and B components) and Um (Umfraville gabbro), in time sequence, define the Grenville loop of a united Laurentia. Poles referenced in Irving & McGlynn (1976), Irving (1979) and Dunlop *et al.* (1980).

Palaeopoles $\mathrm{Co_C}$, Tu and $\mathrm{Th_B}$ (figure 5) from the Cordova, Tudor and Thanet bodies define a southeast-trending a.p.w.p. not recorded elsewhere in the Grenville province. These poles could be late Precambrian or early Palaeozoic overprints (cf. figure 7). However, if $^{40}\mathrm{Ar}/^{39}\mathrm{Ar}$ dating should prove them to be 1200 Ma old or older, they would define a pre-orgenic a.p.w.p. for Grenvillia that converges with the Logan loop of Interior Laurentia not later than 1050 Ma B.P. and (as imagined in figure 5) perhaps as early as 1150 Ma B.P. If this should be the case, the Grenvillian orogeny would be a collisional event, bracketed in time between 1150 and 1050 Ma B.P.

Corresponding continental motions are sketched in figure 6. The long pre-orogenic a.p.w.p. segment of figure 5 implies a 90° rotation of Grenvillia but little latitude change. Grenvillia and Interior Laurentia unite by 1150 Ma B.P. (at the earliest) and then undergo three latitude shifts of 50–60° toward and away from the equator, with negligible rotation, between 1150 and 820 Ma B.P. The average drift rate must have been at least 50–60 mm/a.

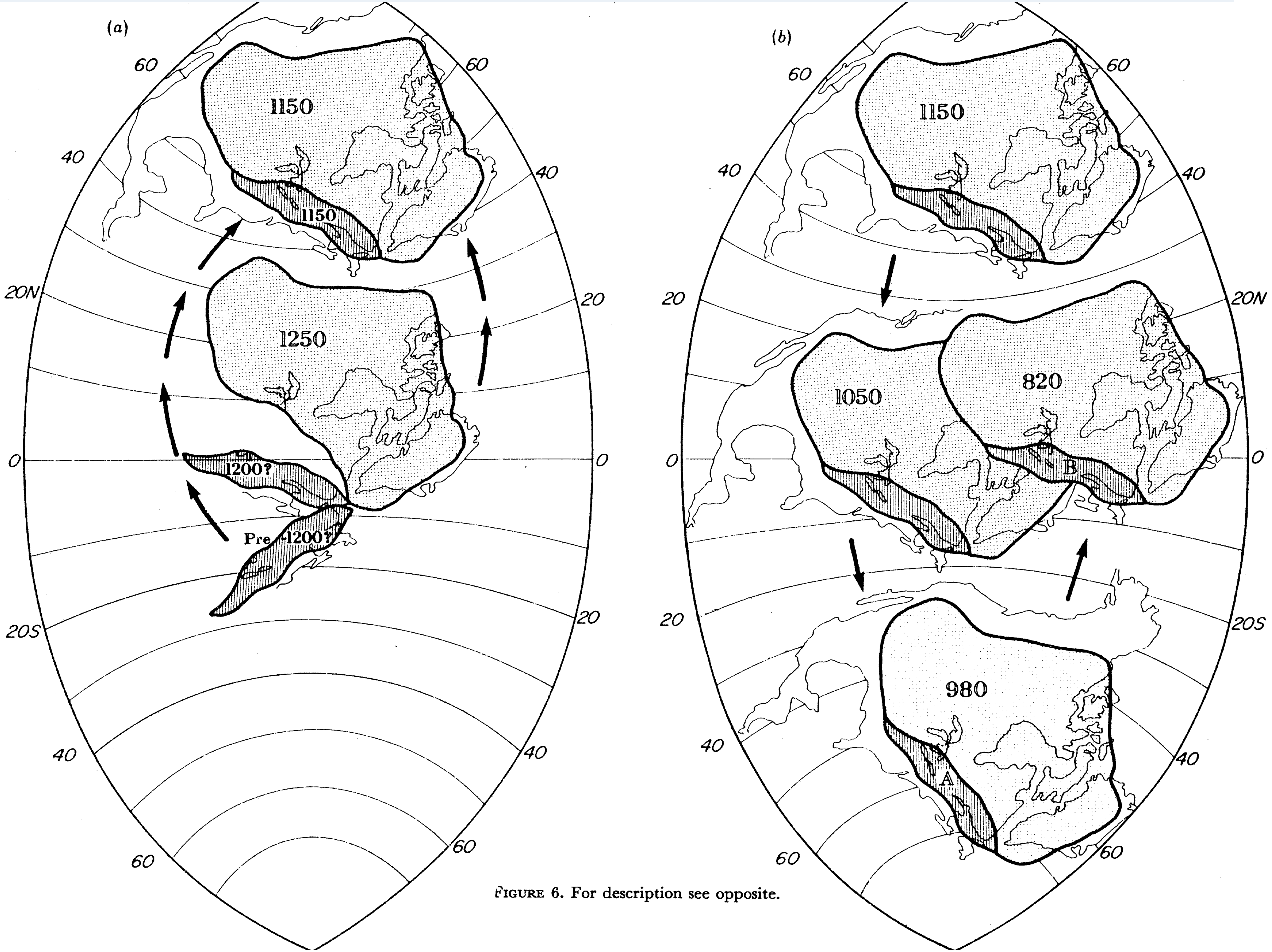

FIGURE 6. For description see opposite.

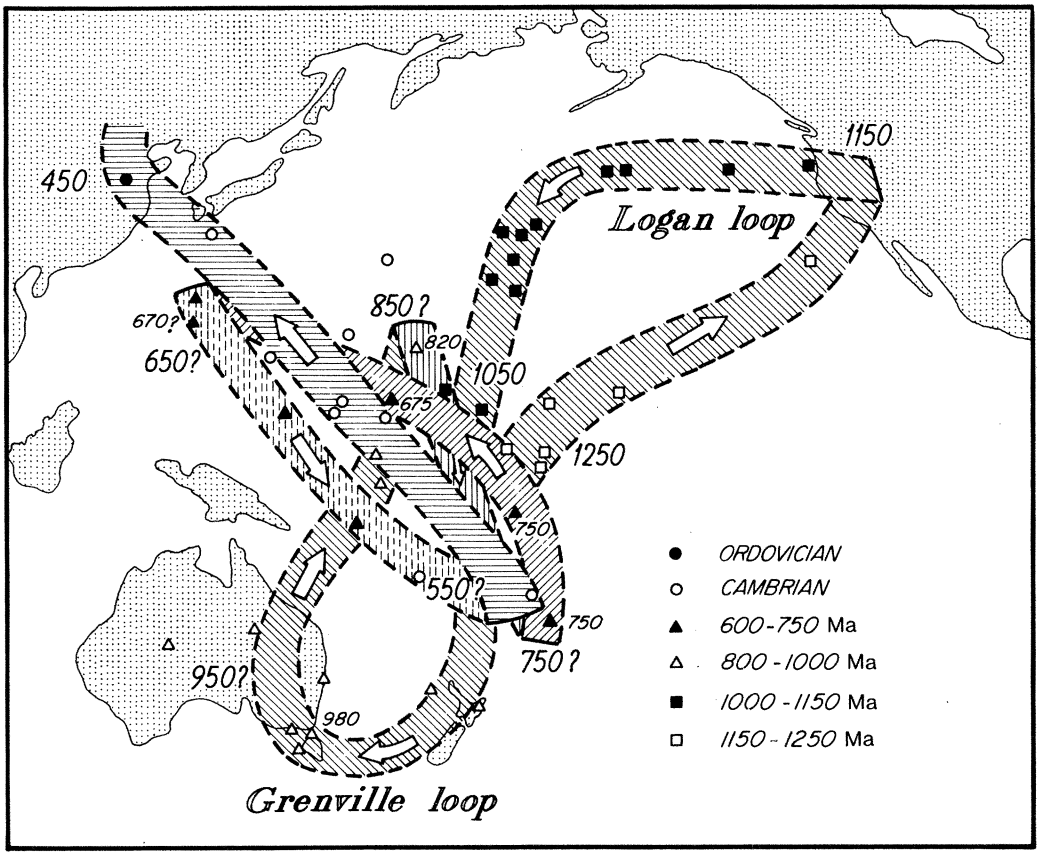

Figure 7. One possible version of the Laurentian a.p.w.p. between 1250 and 450 Ma B.P. Only the more reliable poles are included. For a complete inventory of palaeopoles, see Irving (1979, figures 8, 9). Better dating of poles could conceivably simplify the a.p.w.p. between 850 and 450 Ma B.P., but at least one loop is certain (lower Cambrian tie points).

4.5 *Hadrynian and Cambrian events*

Laurentia was equatorial and rotated about 90° from its present aspect 1250 Ma ago and again 1050 and about 850 Ma ago. In the intervening 200 Ma intervals, the continent moved to higher latitudes with little rotation (figure 6). The polar signature of these motions is a periodic return of the a.p.w.p. to a point near 180°E, 0°N.

In Hadryrian (post-Grenvillian) and Cambrian time, the a.p.w.p. returned at least once to this area, and perhaps several times (figure 7). The best-documented return is between 600 and 550 Ma B.P., the tie points being a number of lower Cambrian poles. Whereas the Grenville and Logan loops record major drift of Laurentia, the repeated post-850 Ma B.P. polar excursions of figure 7 record rotations with little accompanying latitude change.

Lacking detailed a.p.w.ps. from neighbouring continents, we do not know if these excursions are the signature of Wilson cycles of ocean opening and closing. Some periodic tectonic phenomenon certainly seems to be recorded.

Figure 6. Continental reconstructions over the interval 1250 to 820 Ma B.P. implied by figure 5. (*a*) Collision of Grenvillia and Interior Laurentia implied by converging a.p.w.ps $\mathrm{Co_C}$–Tu–$\mathrm{Th_B}$–Lo and Su–Cp–Mu–St–Lo (figure 5). (*b*) Drift of united Laurentia implied by a.p.w.p. Lo–$\mathrm{Th_A}$–$\mathrm{Hb_A}$–Um–$\mathrm{Hb_B}$. (Tie-point poles at 1050 Ma B.P. were not shown in figure 5. They fall between $\mathrm{Hb_B}$ and Cp.)

5. CONCLUSIONS

On the present palaeomagnetic evidence, African, Australian and Canadian Precambrian shields were largely assembled as we know them today by early Proterozoic times. The African, Australian and Laurentian a.p.w.ps individually record substantial continental drift during the Proterozoic, but, apart from possible occasional 'jostling', the three continents drifted independently. Drifts rate were high at times ($\geqslant$ 50–60 mm/a) but never unreasonably so.

In Africa, the Congo, Kaapvaal and West African cratons were assembled by 2.1 Ga B.P. at the latest. In Australia, the Pilbara and Yilgarn blocks in the west were assembled by 2.4 Ga B.P., the Kimberley block in the northwest was added by 1.8 Ga B.P. and the Gawler and Mount Isa blocks in the east were added no later than 1.7 Ga B.P. Until magnetizations predating 1.8–1.7 Ga B.P. orogenic events are recovered from the northern and eastern blocks, it will not be possible to determine whether successive blocks were added between 2.4 and 1.7 Ga B.P. to the margin of an older continental nucleus in the west or whether the entire shield is very old and all the 1.8–1.7 Ga B.P. mobile belts are ensialic. The 1.7 Ga B.P. Ophthalmian belt of western Australia is certainly ensialic, as are post-1.7 Ga B.P. fold belts elsewhere.

In Laurentia, few Archaean palaeopoles are available and the nature of the 2.7–2.5 Ga B.P. Kenoran orogeny is unrecorded. The Superior, Slave, Nain and Beartooth provinces were assembled by 2.1 Ga B.P. and the Churchill and Bear provinces were added no later than 1.8 Ga B.P. Despite the lack of pre-orogenic magnetization in the Churchill province, the 1.85–1.75 Ga B.P. Hudsonian event must have been ensialic because of the constraint of preassembled encircling cratons. The Bear province is not constrained in this fashion and may have accreted marginally between 2.0 and 1.7 Ga B.P. Small relative motion of sub-provinces within the Superior craton is permitted by palaeomagnetic data at the time of the 1.25 Ga B.P. Mackenzie heating event but is improbable because of the proven integrity of Superior, Churchill, Slave and Bear provinces at this time. The Grenvillian orogeny erased practically all pre-existing magnetization throughout the Grenville orogen, but poles from formations in a local 'window' of lower metamorphic grade may record marginal accretion of Grenvillia at 1.15–1.05 Ga B.P. If so, these poles are the earliest magnetic record of ocean closing, possibly marking the onset of Wilson cycles in the style of Phanerozoic plate tectonics.

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