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Review

Key paleomagnetic poles and their use in Proterozoic continent and supercontinent reconstructions: A review

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A R T I C L E   I N F O

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A B S T R A C T

Key paleomagnetic poles are poles that are well defined and precisely dated. The rock unit from which the pole is derived must have a precise (usually U–Pb) age and the pole itself must be demonstrated primary with a rigorous field test. The use of key poles is essential in defining reliable apparent polar wander paths (APWPs) and establishing continental reconstructions. Many hundreds of Proterozoic paleopoles have been published from around the globe, but only ~45 are from large craton interiors and pass the key pole criteria. Most key poles are from mafic dykes and sills in the Superior craton (pre-1.83 Ga) or Laurentia (post-1.80 Ga) or Baltica. As a result, with occasional exceptions, it is difficult to define or compare reliable APWP segments in order to test Proterozoic continental reconstructions. However, there are now sufficient age matches or approximate age matches for pairs of key poles from a number of cratons to help constrain their relative locations. In this analysis, Proterozoic key poles are identified and their use in constructing APWPs and testing continent and supercontinent reconstructions is discussed. This key pole database establishes a well constrained Superior craton-Laurentia APWP for much of the Proterozoic that can be used as a reference track against which a growing number of individual key poles from other cratons can be compared. There is now a robust Baltica–Laurentia reconstruction for ~330 m.y. between 1.59 and 1.26 Ga using this approach and potentially for ~570 m.y. between 1.83 and 1.26 Ga if additional key and non-key poles from well-dated units are considered. Key pole comparisons for several other cratons yield preliminary constraints on the relative movement of cratons (e.g., Slave and Superior cratons in the Paleoproterozoic) or on specific elements of continental reconstructions (e.g., Amazonia and Baltica in the Mesoproterozoic, South China craton and Australia in the Neoproterozoic, or Baltica and Laurentia also in the Neoproterozoic).

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1. Introduction

Key paleomagnetic poles are poles that are well defined and precisely dated (Buchan et al., 2000; Buchan, 2007b). In the Precambrian, key poles are a prerequisite for establishing reliable apparent polar wander paths (APWPs) and testing continent and supercontinent reconstructions. Many if not most non-key poles are so poorly constrained, especially in age, that they cannot be reliably sequenced along APWPs. Only about a dozen years ago, most key Precambrian poles were derived from Laurentia (post-1.80 Ga) and the Superior craton (pre-1.83 Ga) or Baltica. There were few key pole age matches making it difficult to attempt paleocontinental reconstructions. Since then the database of key poles has expanded to include poles from a significant number of the large cratons around the world, as well as a significant number of key pole age matches.

Although the importance of key paleopoles is acknowledged in many recent publications, most attempts to use paleomagnetic data to reconstruct Precambrian continents rely heavily or even almost entirely on non-key poles. As a result of the large uncertainties in many of these poles, especially in their ages, numerous quite discordant reconstructions have been proposed. Only occasionally have reviews of Precambrian reconstructions focused largely on key paleopoles (Buchan et al., 2000, 2001; Evans and Pisarevsky, 2008).

In this review the current database of Proterozoic key poles is catalogued and analyzed to determine what constraints can be placed on APWPs and continent/supercontinent reconstructions. To aid in the discussion several non-key poles are considered in order to clarify or support reconstructions based on key poles. They are from well-dated, unmetamorphosed rock units but lack a primary field test, or are precisely dated virtual geomagnetic poles (VGPs) that may not average out secular variation.

2. Key paleomagnetic pole criteria

There are two basic criteria for a key paleopole (Buchan, 2007b):

(1) *The age of the paleopole is precisely determined*. In particular, the pole must be demonstrated primary with a field test (see Section 3) and the rock unit precisely dated. Only U–Pb or occasionally Ar–Ar ages are sufficiently precise. Most key paleopoles catalogued in this review have ages that have been determined within ±10 m.y., although a maximum uncertainty of ±20 m.y. is permitted. As noted by Buchan (2007b), it should in future be possible to significantly tighten this latter uncertainty.

(2) *The paleopole is of good quality*. In particular, the primary remanence must be properly isolated using paleomagnetic cleaning techniques such as stepwise alternating field or thermal demagnetization, and secular variation largely averaged out. In addition, it is important that the remanence is corrected for the effects of structural rotation. As a result, it is usually best to avoid cratonic margins where complicated deformation may be difficult to resolve. In sedimentary rocks, the remanence may need to be corrected if inclination shallowing has occurred either during deposition or later compaction (Kodama, 2012). Inclination shallowing is greatest (up to 15 or 20°) for sediments deposited in intermediate latitudes and decreases progressively to zero for deposition at the geomagnetic equator and pole. The presence of inclination shallowing can be determined by comparing data from coeval sedimentary and igneous rocks, by comparing fine-grained and coarse-grained sediments which experience different degrees of shallowing, or with more sophisticated rock magnetic experiments summarized in Kodama (2012).

It should be noted that the key pole age criteria are more stringent than criteria used in other quality tests. For example, the most widely cited pole quality ranking in use today is the Q index of Van der Voo (1990) which does not require that the remanence is demonstrated primary or that the age of the rock unit is precisely determined.

3. Field tests for primary remanence Q2

Field tests are critical to determining if a remanence is primary. They are often poorly understood and frequently misused. Tests which indicate that a remanence is primary are summarized below, and those which do not establish a remanence as primary are outlined in Section 4.

3.1. Baked contact test

A classic baked contact test (Everitt and Clegg, 1962; Buchan, 2007a) involves sampling an igneous unit and sampling both the baked and unbaked zones of nearby host rocks. The test is positive and the remanence of the igneous unit is considered to be primary if the igneous rock and its baked host carry similar stable remanence directions, whereas the unbaked host a short distance away carries a significantly different stable direction. Diabase dykes that cross-cut older diabase dykes, sills or mafic volcanics often yield excellent tests. On the other hand, felsic host rocks frequently carry unstable remanences which are unsuitable for baked contact tests. There is the possibility of a “false positive” if, for example, chemical alterations occurred along the contact of the igneous unit long after its emplacement and locally reset the remanence direction on either side of the contact, while not affecting the remanence farther away. Such chemical alterations can usually be detected by comparing the magnetic characteristics of the host rock in the baked and unbaked zones, or by comparing the magnetic directions of the margin and