Earth-Science Reviews 181 (2018) 144–152

Contents lists available at ScienceDirect

Earth-Science Reviews

journal homepage: www.elsevier.com/locate/earscirev

Discussion

Comment on "Paleozoic reactivation structures in the Appalachian-Ouachita-Marathon foreland: Far-field deformation across Pangea, by J. Craddock, D. Malone, R. Porter, J. Compton, J. Luczaj, A. Konstantinou, J. Day, and S. Johnston [Earth Science Reviews 169 (2017), 1–34]

Boerboom T.J.[a], Bornhorst T.J.[b], Cannon W.F.[c], Hinze W.J.[d], Jirsa M.A.[a], Runkel A.C.[a,*], Schulz K.J.[c], Steenberg J.R.[a], Woodruff L.G.[e]

[a] Minnesota Geological Survey, 2609 Territorial Road, St. Paul, MN 55114-1057, USA
[b] A. E. Seaman Mineral Museum, Michigan Technological University, 1404 E. Sharon Avenue, Houghton, MI 49931, USA
[c] U.S. Geological Survey, Mail Stop 954 National Center, Reston, VA 20192, USA
[d] Purdue University, Department of Earth, Atmospheric, and Planetary Sciences, 30 Brook Hollow Lane, West Lafayette, IN 47906, USA
[e] U.S. Geological Survey, 2280 Woodale Drive, St. Paul, MN 55112, USA

ARTICLE INFO

Keywords:
Comment
Paleozoic
Proterozoic
Reactivation
Midcontinent Rift
Craddock

1. Introduction

The recent paper *Paleozoic reactivation structures in the Appalachian-Ouachita-Marathon foreland*: *Far-field deformation across Pangea* by John P. Craddock et al. (2017), (https://doi.org/10.1016/j.earscirev.2017.04.002) describes a number of anomalous structures in the generally flat-lying Paleozoic strata throughout the midcontinent region of the U.S., and ascribes them to far-field effects of the Appalachian-Ouachita orogeny. The paper appears to serve a useful purpose in highlighting and summarizing these widely-distributed structures and proposing a unified origin for them. Our comments do not pertain to that aspect of the paper, and in fact we are not experts on many of these structures. However, we do take strong exception to many aspects of the discussion of the Midcontinent Rift System (MRS). The Craddock et al. (2017) description of the nature and origin of the rift contains a very large number of factual errors, incorrect representations and omissions of published literature, and interpretations contrary to many well established geological relationships. In addition, the paper presents several drastically new interpretations of aspects of the rift that have not been subjected previously to peer review, and thus seem inappropriate to appear for the first time in a review paper. For example, their proposed Kapuskasing-Keweenaw fault system is a newly interpreted feature that they propose was a significant influence both in development of the MRS and in its later inversion. They also contend that possibly a major part of rift inversion and related reverse faulting occurred in the Late Paleozoic. Readers of their paper should be aware that these interpretations have not been adequately vetted in peer-reviewed publications, and are flawed by numerous errors. Because of these issues, we feel compelled to write this discussion to provide a counterpoint to both the errors and to new interpretations that we believe are inadequately supported.

2. Kapuskasing-Keweenaw fault system (KKF)

Craddock et al. (2017) present a review of the periodic reactivation of the MRS since the termination of extension and volcanism in the Mesoproterozoic approximately 1085 my ago. This is a significant topic because of the impact of reactivation on the structure and related geology, including mineral and hydrocarbon resources of the overlying Mesoproterozoic and Phanerozoic sedimentary rocks. A review is

* Corresponding author.
E-mail address: runke001@umn.edu (A.C. Runkel).

https://doi.org/10.1016/j.earscirev.2018.02.003
Received 7 November 2017; Accepted 4 February 2018

therefore warranted, but there are a number of significant flaws in the Craddock et al. (2017) summary of this topic.

Craddock et al. (2017) state in four separate places that the MRS has 5 failed rift arms. This proposal for 5 failed arms is attributed to Sutcliffe's (1991) Fig. 16.2 (not Fig. 2 as stated in the text), although nowhere in the Sutcliffe figure or text is there any reference to '5 failed arms' for the MRS. On page 652 of Sutcliffe's (1991) article, there is a discussion of an early suggestion by Burke and Dewey (1973) that the Kapuskasing structure may have been a failed arm of the MRS, but the next sentence indicates that Percival and Card (1983) refute this, and suggest that the Nipigon area was a more reasonable candidate for a third failed arm. The idea of 5 failed rift arms for the MRS seems to be completely a construct of Craddock et al. (2017) for which we are aware of no supporting evidence.

One of the most questionable conclusions reached in Craddock et al. (2017) relates to what they identify as the Kapuskasing-Keweenaw fault system (KKF), a system of faults they claim extends from near James Bay on the north to Kansas on the south. Critical to this conclusion is the nature, if not the very existence, of faults that connect the Kapuskasing structure southwestward beneath Lake Superior to the Keweenaw fault. In their Fig. 2 they show two faults, the Mamainse Point fault and Montreal River fault crossing the lake. On the figure the Montreal River fault forms the direct connection between the Ivanhoe Lake fault and Keweenaw fault. These faults were originally proposed by Manson and Halls (1994, 1997) who used a variety of information derived from geological and geophysical mapping. They speculated that faults on trend with the Archean to Paleoproterozoic Kapuskasing horst structure (not a suture as stated multiple times by Craddock et al. (2017)) extend from the exposed Archean rocks on the eastern shore of Lake Superior into the pre-rift basement rocks beneath the eastern Lake Superior segment of the MRS. Further, Manson and Halls (1994, 1997) proposed that these faults influenced the development of the MRS in eastern Lake Superior, particularly during the late compression. Craddock et al. (2017) have appropriately referenced these publications in support of their proposed KKF, but have not explained their interpretive nature. We accept that the Mamainse Point and Montreal River faults beneath Lake Superior are permissible interpretations from geophysical data, but they are not unique interpretations. Other studies (i.e., Mariano and Hinze, 1994) using the same data concluded that there is no support for large scale thrusting in eastern Lake Superior. In particular, both proposed faults are crossed by three seismic reflection lines. Manson and Halls (1994) show the projected position of the Mamainse Point fault on all three lines. Although a fault with small offset seems permissible on these lines, it also seems clear that there is no fault with major offset comparable to the Ivanhoe Lake and Keweenaw faults on any of the lines. Inspection of these same lines relative to the presumed location of the Montreal River fault also reveals little or no offset of reflective units in the subsurface. We therefore strongly question a connection between the Ivanhoe Lake fault of the Kapuskasing structure and the Keweenaw fault of the MRS given that geophysical data do not support the existence of a fault with comparably large offset connecting the two. We do not argue against the existence of thrusts with relatively small displacement, but object to a proposal for major rift-inversion along the Mamainse Point and Montreal River faults.

These faults also seem unlikely to have had strong influence on extension during formation of the MRS. The rift basin, now filled with a thick sequence of basalt flows, extends across the faults at a nearly right angle with little or no change in character and continues for about 600 km to the southeast (e.g., Hinze et al., 1975). Consequently, these faults clearly did not strongly influence opening and filling of the rift.

Craddock et al. (2017) present no evidence to support their interpretation that pre-Keweenawan faulting extends from the western end of Lake Superior to Kansas. This interpretation is particularly questionable in that their KKF system transects basement ranging from the Archean Superior craton in Lake Superior to younger accreted Paleoproterozoic terranes (1760 Ma and younger Yavapai and Mazatzal terranes) in Iowa and Kansas.

Craddock et al. (2017) state several times that the total length of the KKF is 4000 km, but the actual distance of their KKF system as shown in a number of figures is on the order of only 2500 km. The longer distance appears to include the eastern branch of the MRS that extends to the southeast towards Detroit, but it is unclear how Craddock et al. (2017) relate the eastern branch of the rift system to their KKF system. Their treatment of the eastern arm of the MRS is cursory and inaccurate, yet no theory of the origin of the rift and its inversion is complete without an explanation for it. In Figs. 1 and 2 of Craddock et al. (2017) the eastern branch is indicated only by a single thrust fault with thrusting up to the west along what is generally mapped as the western margin of the eastern branch of the MRS. In their Figs. 18 and 19C, the eastern extension of the MRS is completely missing, perhaps because the authors state on page 19 that …*the Kapuskasing-Keweenaw fault became a single inverted fault boundary 4000 km in length that is parallel to the Grenville and younger Appalachian orogens (Fig. 1)*. The eastern extension of the MRS being perpendicular to the Grenville front as shown in their Fig. 21 is questionable. Potential field data, deep drilling, and seismic reflection profiling by numerous investigators over a half century (Hinze et al., 1975; Hinze et al., 1992; Fowler and Kuenzi, 1978; Zhu and Brown, 1986) fails to support their interpretation of a KKF structure as presented in these figures and described in the text. Fig. 21 of Craddock et al. (2017) does show a more conventional location for the MRS except that they extend the rift system from eastern Lake Superior across a gap in the positive gravity anomaly to the Kapuskasing feature. It is unclear what is being mapped by Craddock et al. (2017) along this segment.

We also note that in contrast to the evidence presented by Allen et al. (1997) (not referenced in this paper), Craddock et al. (2017) connect the Douglas and Isle Royale faults in western Lake Superior in their Figs. 1 and 2. Allen et al. (1997) provide an analysis of the structure of the Lake Superior western segment of the MRS, including possible controls on the faulting that are not considered by Craddock et al. (2017) in their description of the rifting. Craddock et al. (2017) present geological and velocity profiles across this branch of the MRS in Fig. 16, but they do not provide the color key to the velocities, the source of the figure, and the location of the profiles on Fig. 20 as stated in the caption of Fig. 16. The schematic depiction of a 'KKF' structure in the figures as a substitute for the well-documented map pattern of the MRS and related faults is potentially detrimental as it could result in false assumptions by readers who are not familiar with the regional geology.

2.1. Additional errors in presentation of the KKF

(1) Page 1: *The Kapuskasing suture has a long history of fault reactivation.…*

Here and many times later in the paper the authors refer to the Kapuskasing as a **suture**. Although Wilson (1968) suggested that the Kapuskasing Structural Zone may be a suture between the western and eastern Superior Province, subsequent work has shown that interpretation to be incorrect (Percival and West, 1994). Note that on page 19 the authors also identify the Trans-Superior and Quetico fault zones as sutures, which they are not.

(2) Page 1: *The Kapuskasing suture….is interpreted by Manson and Halls (1994, 1997) to continue to the southwest as the Keweenaw-Lake Owen-Hastings thrust fault system in Michigan, Wisconsin, Minnesota, Iowa, Kansas, and Oklahoma thereby forming a single thick-skinned, reverse fault system from near James Bay, Ontario, Canada to central Oklahoma, USA.*

Manson and Halls (1994, 1997) do make the case that Midcontinent Rift System (MRS) rifting may have been facilitated by regionally weakened crust in the Lake Superior region and that individual rift boundary faults may be inherited, pre-Keweenaw structures. However, they do not suggest that a thrust fault system extends from James Bay to