



The Paraná-Etendeka Continental Flood Basalt Province: A historical perspective of current knowledge and future research trends

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ABSTRACT

The development of ideas concerning Continental Flood Basalt Provinces is not new, and many studies were completed on specific provinces before the advent of plate tectonics. The Paraná-Etendeka Province is not an exception, and actually is an example of a province that has been thoroughly studied for >100 years. In this work, I present a brief summary of various aspects of this province from a rather general point of view, including many references of difficult access to a reader not versed on the Portuguese language. Key features include the presence of alkaline volcanism along the edges of the main basin, before and after a markedly tholeiitic event, the uneven spatial distribution of eruptive products relative to the location of continental rapture, the apparent lack of a pattern of temporal activity across the whole province and the close relationship between the structure of the underlying sedimentary basin and the distribution of volcanic rocks. By bringing together information relevant to all of those key features, an evolutionary model emphasizing the role played by the changing local structure is outlined. This model is an example of how key observations (many of which were overlooked for >50 years) provide the required impetus for the completion of future research that has the potential to substantially change the form in which this province has been visualized for at least the past 30 years.

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1. Introduction

Flood-basalt or Plateau-lavas have been described on the scientific literature for more than one century. Their large spatial extent, relatively flat topography, and occurrence of an apparently homogeneous and continuous sequence of lava flows, are three characteristics that were highlighted on those provinces from the earliest reports (e.g., Geikie, 1885; Richthofen, 1868; Tyrrell, 1937; Washington, 1922). The form in which those characteristics have been incorporated into the definition of Flood-basalt provinces, and actually the form in which the provinces themselves have been perceived and studied, however, has not remained constant throughout the years.

The form in which Flood-Basalt Provinces (FBPs) have been approached can be roughly divided in three main stages. On the first stage, description of their physical features and general characteristics were dominant, with particular interest on the identification of chemical or petrographic aspects that could serve to distinguish them from other examples of volcanic activity (the so called cone volcanoes). On the second stage, a strong association with FBPs and mantle plumes became dominant, and emphasis was made on establishing the origin of the magma that fed those provinces; interest on the physical characteristics of the associated products decreased notably during this time. On

the third stage, a renewed interest on the physical aspects of the rocks found on those provinces has started to take place, and many of the strong associations made during the second stage are being re-examined. The just described tendencies apply equally to FBPs visualized either collectively or as individual cases, and certainly there are individual works that do not fit into the general tendencies of their time. Nevertheless, this simplified context provides an adequate explanation of the origins of some controversial topics that remain present until this date, and also serves to understand why is it that very often knowledge of one specific FBP appears to be incomplete, at least in some critical topics.

An objective of the present review, and of the special issue in which this review is included, is to reduce the fragmentation that in my opinion characterizes current knowledge of what is now known as the Paraná-Etendeka Large Igneous Province (PELIP). This is accomplished here in part by providing a historic perspective illustrating how ideas about this particular province have changed over time, and also by showing how some old ideas might promote new interpretations when examined to the light of cumulative information. In Section 2, I present a brief summary of relevant work completed on the PELIP for more than a century with some emphasis on the oldest published works. Sections 3 and 4 present a selection of subjects that from my personal point of view open the possibility for an alternative evolutionary perspective of this province, and in Section 5 such an alternative

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evolutionary scheme is outlined. A general review from a more marked-ly geodynamic context is provided by Foulger (2017).

2. The Paraná-Etendeka before plate tectonics

Relevant literature describing some aspects of the PELIP before the 1950's has been summarized by Licht (2014). As he pointed out, many of those documents are of difficult access, not only because of their age, but also because several were originally written in Portuguese, therefore limiting their diffusion only to a community versed on that language. As it turns out, Licht's review is also limited to an audience capable to read Portuguese, and therefore, his work also remains as inaccessible for a large part of the present day international community as any of the oldest documents that he examined. In order to ameliorate this situation, I provide in this section a brief summary of Licht's review, with the occasional elaboration in some topics which I found particularly interesting, or on documents for which I had direct access.

According to Licht (2014), the first references to the igneous rocks of the Paraná were made by Jesuit missionaries and other Europeans that settled on Brazil, Paraguay and Argentina during the XVI and XVII centuries. Those references focused on the presence of an iron-rich soil produced by the alteration of basalt, called itacurú in Guaraní language, probably equivalent to plinthite, and that was used for construction and processed to obtain iron. Additional mention to rocks that could be related to the flood-basalts were made by various travellers during the XIX century, but overall, those documents provide only vague descriptions that might be difficult to understand in the present context due to differences in the use of terms and the ambiguity of some descriptions, and therefore, none of those works is further discussed here.

In more modern terms, probably the first description of the stratigraphic contact of igneous rocks with the underlying sands on the state of Paraná was made by Derby (1878), and the first description about the wide geographical distribution of those igneous rocks was probably due to Oliveira (1916). Three years later, Branner (1919) published the first comprehensive geologic map of Brazil. According to the text accompanying that map, the extension of the extrusive igneous rocks is very large, but on the map proper, the area displaying igneous rocks is relatively reduced, including only parts of the southern states of Santa Catarina and Rio Grande do Sul, and a long but narrow strip along the Paraná River (Fig. 1). Consequently, the map published by Branner conveys a graphic image of a relatively small igneous province, and this image prevailed unless the reader was willing to be immersed in lengthy descriptions distributed across many pages.

The image about the extension of this province started to change radically with the publication of the map provided by Baker (1923), in which the extent of the basalt flows is outlined in a form that is closer to present estimates (Fig. 1). In that work, Baker indicates that the total area of the basalt cover is around 800,00 km², with an average thickness of 1000 ft (~300 m). He also pointed out the presence of an extraordinary number of dikes and sills intruding the sediments surrounding the lava flows, especially to the east, therefore considering that the area covered by those sediments should also be included in the estimation of the total area originally covered by the lava flows. As for the thickness of the lava pile, he mentioned a few estimates on several places, indicating that the thickest flow cover was achieved at Santa Catarina, Paraná and Rio Grande do Sul states. Although this estimate later become proved to be wrong, it is in his work where the large dimensions of the PELIP start to be really appreciated.

The insights of Baker (1923) did not stop with the estimation of the actual dimensions of the province, but included other observations that proved to be very influential (if not necessarily all correct) in later works. For example he described the intercalation between sandstones and some lava flows, an apparent lack of pyroclastic material, and even suggested the possible correlation of this province with an African counterpart (the Karoo lavas), highlighting the temporal association of those lavas with a continental break up. Although his age estimate proved



Fig. 1. Map showing the different extensions assigned to igneous rocks in south Brazil by Branner (1919) – orange color and Baker (1923) – area enclosed by the solid line. Names of Brazilian States mentioned throughout the text are also included for reference.

later to be wrong (he considered the age of the Paraná lavas to be ~200 Ma, more consistent with current estimates of the age of the Karoo Province in western South Africa than with the Etendeka province as currently established), his work represents an excellent summary of many important features of that province even if regarded with present day standards.

Although Baker (1923) distinguished various types of rocks within the province based on the presence or absence of olivine, the general descriptions up to that time considered a uniform composition across the basin. Among the first authors to provide evidence suggesting otherwise, Walther (1927) distinguished two main types of rocks, that he referred to as “doleritos” and “porfiritos”. Very soon, Guimaraes (1933) identified 5 divisions combining petrography and field appearance: Basalts without olivine, Diabases, Dolerites, Melaphyres, and Spilites. The exact meaning of those divisions in present day terminology is somewhat difficult to establish. The difficulty resides in the different meaning that some terms had at the time, as exemplified by the 2-group division of *basalts* (one group with 46%–55% SiO₂ and the second with SiO₂ content between 61 and 66%) proposed by Leinz (1949). Nevertheless, it is clear that by the 1950's there was enough evidence to suggest that the composition of the products was not really homogeneous across the PELIP, and even that a strong bimodality could be appreciated. The latter statement is justified by considering that Guimaraes (1933) seems to have been among the first authors to have identified regional differences in the composition of the lavas, by reporting a decrease on the magnetite content of the products from north to south, an idea that was later elaborated by Piccirillo et al. (1988) among many others.

Washburne (1930) made important contributions to the knowledge of the Paraná igneous Province, but unfortunately, all of Washburne's observations were published as part of a work devoted to petroleum

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