Challenges of Gondwanan marine–nonmarine correlations – a palynological perspective

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Abstract – Marine–nonmarine correlations of the Permian of Laurussia are recently addressed using integrated sedimentological-palaeontological-geochemical signatures aiming to refine existing correlation schemes. However, for Gondwana such efforts are still in an early stage with first studies on single localities and within distinct basins. Palynology is seen to be the key discipline to tackle this challenge and recent efforts to use climatic signatures recorded in palynomorph assemblages for cross-basin and interbasinal correlations of Karoo-aged basins in southern Africa are very promising. Their near continuous basin fill from the Pennsylvanian to the Early Jurassic captures the most prominent climate change in the Phanerozoic. Postglacial coal-bearing successions of Permian and Triassic age in the Main Karoo Basin of South Africa enable detailed studies of changing vegetation on land. Marine black shales capture changes in paleoceanographic conditions as reflected in marine phytoplankton assemblages and changing terrestrial input of pollen grains and spores, enabling precise correlation of terrestrial coals and marine shales. Ongoing research aims to establish the use of climate signals recorded in terrestrial and marine palynofacies for correlation on a Gondwana-wide, interregional scale.

Keywords: Marine–nonmarine correlation, palynology, paleoclimate, Permian, Gondwana

INTRODUCTION

Marine–nonmarine correlations of the Permian of Laurussia are recently addressed using integrated sedimentological-palaeontological-geochemical signatures aiming to refine existing correlation schemes (Schneider et al., 2014). In the southern hemisphere, research on Gondwanan successions and their interregional correlation is still incomplete with regard to high-resolution regional biozonations, interregional correlation schemes, and integrated bio-, chemo- and sequence stratigraphic approaches. Most of the existing zonations are local, were established independently and are in most cases not calibrated by radiometric data, hampering interregional comparison. A review of the progress in Permian palynostratigraphy of Gondwana within a global context was provided by Stephenson (2016).

A recent attempt to tackle the challenge of high-resolution correlation of continental and marine deposits within the Main Karoo Basin of South Africa using climate signatures recorded in palynomorph assemblages (Ruckwied et al., 2014) showed the huge potential of this approach for inter-Gondwanan correlation based on palynofacies analysis. Detecting marine transgressive events within coal-bearing successions characteristic of Gondwana's postglacial history was addressed by Götz and Ruckwied (2016) and Ruckwied and Götz (2016) for the Main Karoo Basin providing additional correlatable timelines. From this background and based on the recent interest in marine–nonmarine correlation also with respect to its application to fossil energy resource exploration (coal, shale gas, etc.), we here present the recently tested South African correlation model and outline future tasks and challenges to establish high-resolution marine–nonmarine correlation schemes for the Permian of Gondwana.

CLIMATE SIGNATURES AS CORRELATION TOOL IN THE MAIN KAROO BASIN

The Permian postglacial climate history of Gondwana represents the most prominent climate amelioration in the Phanerozoic, ranging from severe icehouse conditions in the Pennsylvanian to extreme hothouse conditions in the Triassic (Scheffler et al., 2006; Montañez et al., 2007; Isbell et al., 2008; Sun et al., 2012; Scotese, 2016). Vegetation changes recorded in palynomorph assemblages related to climate change are thus of particular significance for reconstruction of Gondwana's climate history. Permian postglacial Gondwana coals of the Main Karoo Basin have been extensively studied mainly for resource exploration rather than for academic purpose (Hancox and Götz, 2014) and different palynostratigraphic zonation schemes have been developed for identification and correlation of coal seams (Falcon et al., 1984; Aitken, 1994; Millsteed, 1999). However, the most detailed palynostratigraphic study was conducted by Anderson (1977) in the northern Karoo Basin who erected seven biozones for the Permian. Later, Backhouse (1991) used this extensive database for a comparison and correlation with palynological biozones established in the Western Australian Collie Basin and this work provides so far the most robust correlation between Western Australia and southern Africa. The composition of Early Permian (Cisuralian) assemblages in other parts of central Gondwana (e.g., Pakistan, India) are similar to those of southern Africa in that monosaccate pollen grains and trilete spores are the dominant elements, and these are succeeded by more diverse assemblages containing non-taeniate and taeniate bisaccate pollen grains, cycad pollen grains, and fern spores. From the Guadalupian, the assemblages of Pakistan and India (Balme, 1970; Tiwari and Tripathi; 1992) begin to diverge from those of the more southerly central part of Gondwana most probably because of more rapid climate warming related to their lower latitude position and additional rapidly northward move.

Coals are unique climate archives and the palynological record of coal deposits of the Main Karoo Basin in South Africa has been recently studied with respect to climate signatures (Götz and Ruckwied, 2014; Ruckwied et al., 2014; Wheeler and Götz, 2016; 2017). Furthermore, the Main Karoo Basin is well suited to establish marine–nonmarine correlation schemes based on palynology, since fluvio-deltaic coals of the north-eastern basin are replaced by marine black shales in the central and southern basin parts (Götz and Ruckwied, 2016; Ruckwied and Götz, 2016). High terrestrial input is characteristic of the Permian (Ecca) shales and enables precise correlation with distinct coal seams and their inter-seam clastic successions (Fig. 1). So far, basin-wide correlation was limited due to the use of mainly nonmarine vertebrates (tetrapods) of low time resolution and the lack of absolute age controls. Recently published radiometric dates (Fildani et al., 2009; Rubidge et al., 2013; Day et al., 2015; Gastaldo et al., 2015; McKay et al., 2015) have improved the existing biostratigraphic correlation scheme. Still, the problem of marine–nonmarine correlation can only be solved by precise palynostratigraphic data such as recently obtained from fluvio-lacustrine coal deposits and marine black shales (Ruckwied et al., 2014). Evidence of a major transgression event ("Whitehill event") by peak abundance of marine phytoplankton during the deposition of the early Guadalupian (Roadian) Whitehill shales (Götz and Ruckwied, 2016; Ruckwied and Götz, 2016) provides an additional correlatable timeline corresponding with the occurrence of marine plankton in siltstones and glauconitic sandstones on top of the No. 5 Coal Seam of the north-eastern basin. Palynostratigraphic control makes this marine signature a powerful tool for cross-basin correlation (Fig. 2). However, more radiometric data are necessary to pinpoint this event on highest precision which then would enable to interpret cyclic patterns of the marine black shales and coal deposits on a Milankovitch to sub-Milankovitch scale. For the Main Karoo Basin thus ongoing research within the KARIN (Karoo Research Initiative) project focusses on the integration of palynostratigraphic and cyclostratigraphic data based on new radiometric data from ash beds in marine Ecca shales of the southern basin parts. Climate signatures recorded in palynomorph assemblages are seen as the most powerful tool for marine–nonmarine correlation and from the recent works by Götz and Ruckwied (2014), Ruckwied et al. (2014), Götz (2015), and Wheeler and Götz (2016, 2017) the shift from icehouse to cooling greenhouse conditions during the Artinskian/Kungurian, and major warming during the Guadalupian has been well documented in the Main Karoo Basin. Furthermore, recent studies of Permian palynomorph assemblages of Mozambican coal successions in the eastern Tete Province reveal exactly the same signatures (Götz et al., 2017a) and thus support the palynological approach using icehouse-greenhouse signals for interregional correlation.

APPLICATION TO OTHER GONDWANA BASINS

The Main Karoo Basin of South Africa represents a retro-arc foreland basin (Catuneanu et al., 1998) with a nearly continuous basin fill from the Pennsylvanian to Early Jurassic (Johnson et al., 2006) including terrestrial and marine deposits (Götz and Ruckwied, 2016; Ruckwied and Götz, 2016) and is thus very well suited to establish new correlation schemes based on climate signatures. In other parts of central Gondwana (e.g. Mozambique), studies on climatic signatures recorded in palynomorph assemblages and their use for intra- and interbasinal correlation are in progress (Götz et al., 2017a), however so far without radiometric age control. Karoo-aged basins of other parts of sub-Saharan Africa (Kenya, Zambia, Zimbabwe, Tanzania, Botswana) contain Permian successions where local palynozonations were previously established (Hart, 1960; 1963; Falcon, 1975; 1978; Hankel, 1987; 1992; Nyambe and Utting, 1997; Stephenson and McLean, 1999; Modie, 2007; Modie and Le Hérissé, 2009), however in the view of interregional correlation these basins have to be revisited and future studies are necessary to provide a more robust correlation scheme for entire southern Africa. For Indian coal-bearing successions the approach is seen as very promising based on first studies including palaeoclimate interpretation using palynomorph assemblages (e.g., Aggarwal and Jha, 2013; Pauline Sabina K and Jha, 2014) and future studies on well selected reference sections with ideally continuous Permian successions (e.g., Godavari Graben; Mukhopadhyay et al., 2010) are suggested. For the South American basins of western Gondwana this approach is seen as most promising since palynostratigraphic schemes are well developed e.g. for the San Rafael Basin in central western Argentina and in the Paraná Basin in southern Brazil with radiometric data already available (Césari and Gutiérrez, 2000; Souza and Marques-Toigo, 2003; Césari, 2007; Soledad Vázquez and Césari, 2017). Whereas in the eastern part of Gondwana, Australian basins seem to be most challenging due to their tectonic disturbance, incomplete basin fill history, different latitude positions, presence of rare marine intervals in the Permian, and significant endemism, with the result that separate palynozonations were developed in the western and eastern Australian basins (Kemp et al., 1977; Balme, 1980; Backhouse, 1991; Price, 1983; 1997) and the precise relationship between these schemes and the ages of the biozones still remains speculative. Recent studies by Laurie et al. (2016) and Phillips et al. (2018) provide new radiometric data from zircons of ash beds in Permian successions of the Sydney, Gunnedah, Bowen and Galilee basins in eastern Australia, and drillcore in the Canning Basin in Western Australia. These data, together with associated palynostratigraphic determinations, are crucial for the direct calibration of the Price (1997) scheme to the numerical timescale, and provide an excellent base for refining Australian palynostratigraphy including climate signatures. Furthermore, focusing again on studies of acritarch acme events which were previously detected in the eastern Australian basins (Evans, 1962; Norvick, 1981; McMinn, 1985; McLoughlin, 1988; Price, 1997) and coincide with transgressive events, may be useful in further refining the interbasinal correlation schemes (Wheeler et al., 2017). For Antarctica, the works by Farabee et al. (1990), Larrsson et al. (1990) and Lindström (1995a,b), and more recently the study by Lindström and McLoughlin (2007) applying Australian palynostratigraphy to Antarctica, rather than develop local palynostratigraphic schemes, provide an ideal base to establish integrated correlation schemes in the future as it is at present developed for southern Africa.

CONCLUSIONS AND OUTLOOK

The recent attempt to develop a high-resolution marine–nonmarine correlation scheme for southern Africa integrating climate signatures recorded in Permian palynomorph assemblages and palynofacies patterns, is seen as a very promising approach to refine intra-Gondwanan correlations. The Main Karoo Basin of South Africa is a pilot basin with continuous Permian successions of terrestrial and marine deposits and thus the here gained database will guide future efforts in tackling interregional correlations.

A major task for the future is to obtain radiometric age control for reference sections in Gondwanan basins from the western, central and eastern parts of Gondwana. Once these reference sections have been identified, existing palynostratigraphic zonations can be refined based on the identification and time calibration of major climate shifts and cross-basin transgressive events.

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FIGURES

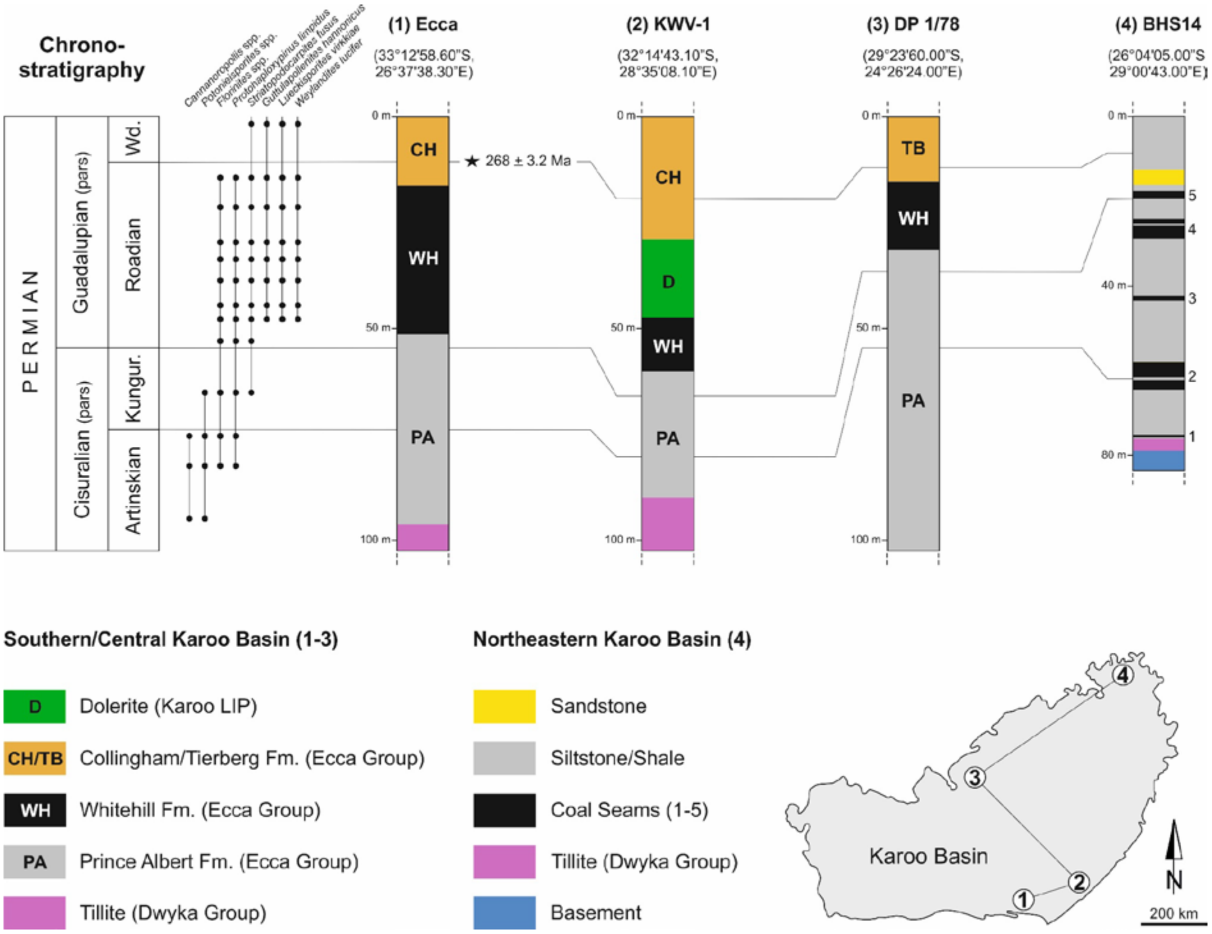

Figure 1. Permian reference sections of the southern, central and north-eastern parts of the Main Karoo Basin, South Africa, used for cross-basin correlation: (1) Ecca Pass section (outcrops along the regional road R67 between Grahamstown and Fort Beaufort, Eastern Cape Province), (2) KARIN borehole KWV-1 (drilled in 2015 within the framework of the research programme KARIN in an abandoned quarry 10 km E of the town Willowvale, Eastern Cape Province), (3) SOEKOR exploration borehole DP 1/78 (drilled NE of the town Hopetown, Northern Cape Province), (4) coal exploration borehole BHS14 (drilled SW of the town Witbank (Emalahleni), Mpumalanga Province). Palynomorph assemblages suggest a late Cisuralian (Artinskian–Kungurian) to early Guadalupian (Roadian) age for the fluvio-deltaic coal deposits of the north-eastern basin and can be correlated with the marine black shales of the southern and central basin (Prince Albert, Whitehill, basal Collingham/Tierberg formations). First radiometric ages from the Ecca Pass section were recently published by McKay et al. (2015) and revealed an early Guadalupian (Roadian) age for the lowermost Collingham Formation (marked by star).

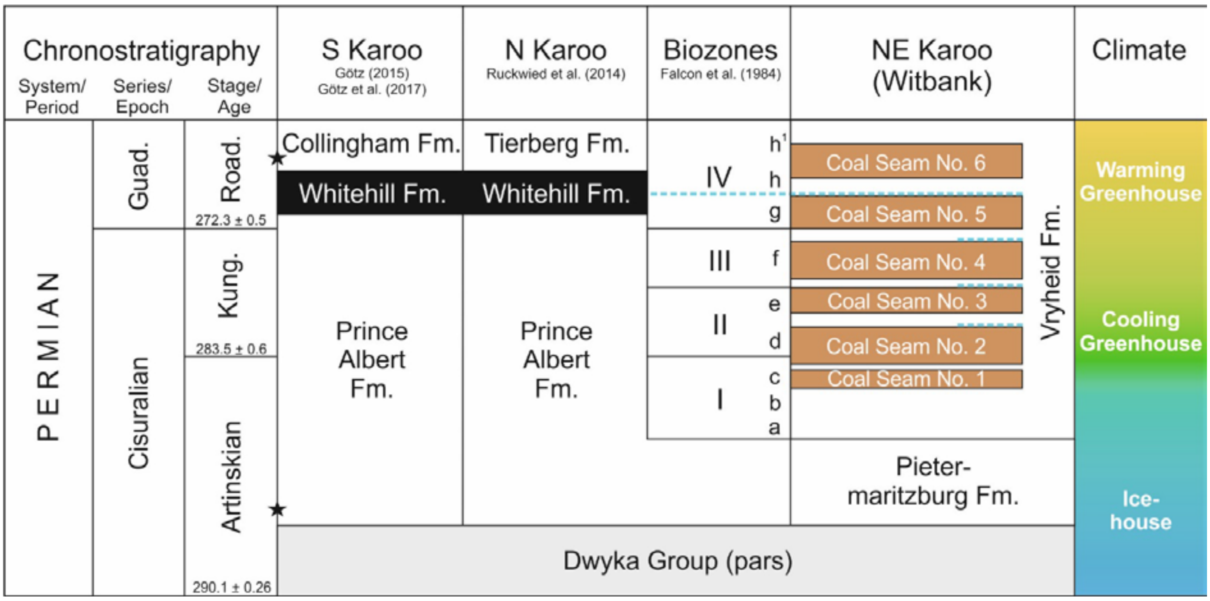

Figure 2. Karoo cross-basin correlation of marine black shales and fluvio-deltaic coal deposits based on palynology and major climate shifts. The shift from icehouse to cooling greenhouse conditions is documented in Coal Seam No. 2 and in the black shales of the Prince Albert Formation (Götz and Ruckwied, 2014; Ruckwied et al., 2014; Wheeler and Götz, 2016, 2017). Significant warming is reflected in Coal Seam No. 5 and in the black shales of the Whitehill Formation (Götz and Ruckwied, 2016; Ruckwied and Götz, 2016), preceding Late Permian–Triassic hothouse conditions (Scotese, 2016). Maximum flooding surfaces are highlighted by dashed blue lines on top of coal seams. A major flooding event related to climate warming occurred within the Whitehill Formation ("Whitehill event"; Götz and Ruckwied, 2016; Ruckwied and Götz, 2016; Götz et al., 2017b). Radiometric ages for the base of the Prince Albert Formation (marked by star, 288 ± 3 Ma) from Bangert et al. (1999), and base Collingham Formation (marked by star, 268 ± 3.2 Ma) from McKay et al. (2015), corresponding to a base Collingham age of 270 ± 1 Ma published by Stollhofen et al. (2000) from Namibia. Permian timescale from Shen et al. (2013).