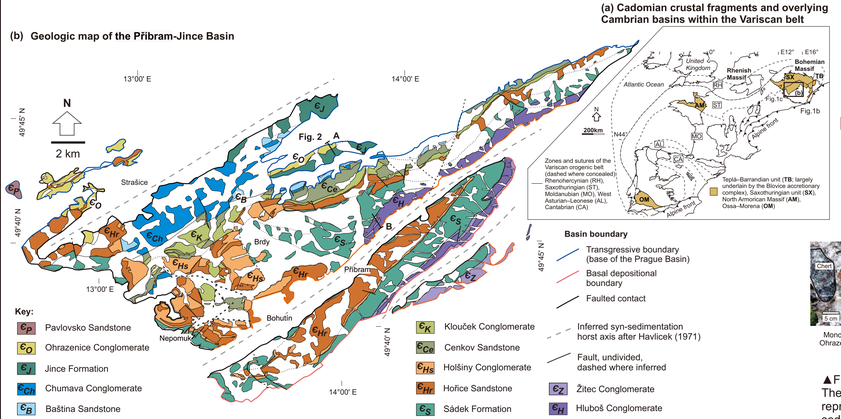
Basin evolution during incipient rifting of ribbon terranes: an example from the Bohemian massif

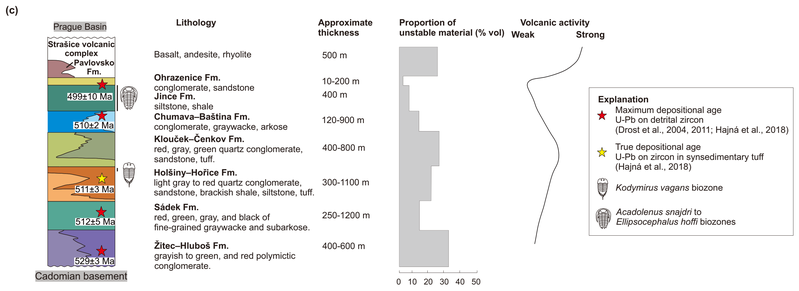
Reza Syahputra[1,2], Jiří Žák[1]

[1]Institute of Geology and Paleontology, Faculty of Science, Charles University, Albertov 6, Prague, 12843, Czech Republic
[2]Department of Geoscience, Faculty of Mathematics and Natural Sciences, University of Indonesia, Depok Campus, 16424, Jakarta, Indonesia

Introduction

A transition from active to passive margin during the late Ediacaran to early Cambrian occurred along the Avalonian–Cadomian orogenic belt. This transformation was characterized by a continuous transition from subduction to extension and rifting (e.g., Nance et al., 2002; 2008). The extension was recorded by vigorous magmatic activity and by the development of sedimentary basins (e.g., Chlupáč et al., 1998; Dörr et al., 2002; Žák et al., 2013). The Cadomian subduction stopped at ca. 540 Ma in the Armorican Massif and Saxothuringia but continued in the Ossa Morena Zone (Iberian Massif) and Teplá–Barrandian unit (Bohemian Massif) until at least the early to middle Cambrian. The most preserved and less affected by younger deformation example of Cambrian sedimentary basin is the Příbram–Jince basin in the Teplá–Barrandian unit (e.g., Kukal, 1971), which recorded the initial rifting of ribbon continent with associated volcanic and plutonic complexes, and briefly interrupted by marine transgression (Dörr et al., 2002; Kukal, 1971; Zulauf et al., 1999). We combine the sedimentary record observation from mesoscale with paleocurrent analysis from the anisotropy of magnetic susceptibility as a testpiece scenario to unravel the timing and evolution of the basin.





▲Figure 1. (a) Distribution of Cadomian terrane with sedimentary Cambrian basins along the Variscan orogenic belt in Europe. The most preserved and undeformed Cambrian basin by younger deformation is the Příbram-Jince basin in the Teplá–Barrandian unit within the center of the Bohemian Massif. (b) Geological map of the Příbram-Jince basin (Kukal, 1971; Czech Geological Survey). The rock formation is downdip and getting younger to the NW. (c) Stratigraphy of the Příbram-Jince basin related to its thickness, percentage of unstable material, and volcanic activity. Compiled from Fatka and Szabad (2014), Hajná et al. (2018), and Kukal (1971).

Methods

Inferred paleocurrent from mesoscale measured from the down-dip planar and through cross-stratifications obtained from 15 outcrops (out of 74 stations documented in total). Anisotropy of magnetic susceptibility (AMS) was used here to analyze quantitatively the symmetry, intensity, and orientation of 'invisible' magnetic fabrics in sandstones to obtain independent quantitative information on paleocurrent directions (e.g., Felletti et al., 2016; Hrouda et al., 2009). To remove the effect of post-depositional tectonic deformation (bedding tilt), the paleocurrent vectors have been rotated to horizontal about a rotation axis represented by strike of the bedding by an angle equal to bedding dip.

Results

The paleocurrent directions inferred from the magnetic lineations in most cases show a good match with those obtained from mesoscopic cross-stratification. Different direction in the paleocurrent could be as the result of (1) the statistical distribution of individual specimens and may easily flip by ~180°, and (2) fine-grained magnetic particles that may align systematically either parallel or perpendicular to flow lines during deposition, depending on the velocity gradient and depositional mechanism (e.g., Rees, 1965, 1975; Taira and Scholle, 1979; Stachowska et al., 2020 and references therein).

Ohrazenice Fm.: monomictic conglomerate, massive–thickly bedded, poorly sorted with quartz pebbles layer. Clasts compose of quartz and chert up to 5–20 cm.

Jince Fm.: siltstone and sand, massive bedded, fine-scale lamination with bedding-parallel cleavage. Clasts compose of silt and shale (sub/graywacke).

Chumava–Baština Fm.: monomictic conglomerate, massive–thickly bedded, poor–moderately sorted with quartz pebbles layer. Clasts compose of quartz and chert (sub/graywacke) with size up to 10–20 cm.

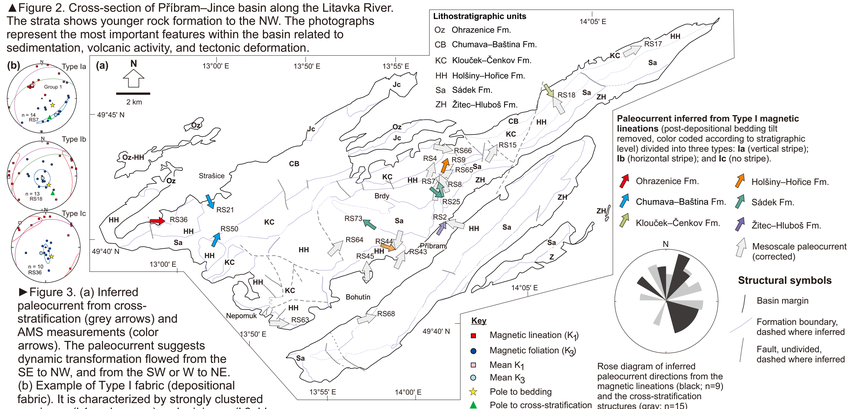
Klouček–Čenkov Fm.: quartz sandstone conglomerate, thin–thickly bedded, moderately sorted with quartz pebbles layer and cross-stratification. Clasts compose of quartz and chert (sub/graywacke) with size up to 1–5 cm.

Holšiny–Hořice Fm.: quartz sandstone conglomerate, massive–thickly bedded, moderately sorted with cross-stratification. Clasts compose of quartz and chert (sub/graywacke) with size up to 1–10 cm.

Sádek Fm.: sandstone, siltstone,shale; massive–thinly bedded. Has a mud strips with cross-stratification. Dominated by: fine-grained quartz sand (subarkose).

Žitec–Hluboš Fm.: polymictic conglomerate, massive–thickly bedded, chaotic with cross-stratification. Clasts compose of quartz, chert, granite, rhyolite, plagio-granite with size up to 20-30 cm.

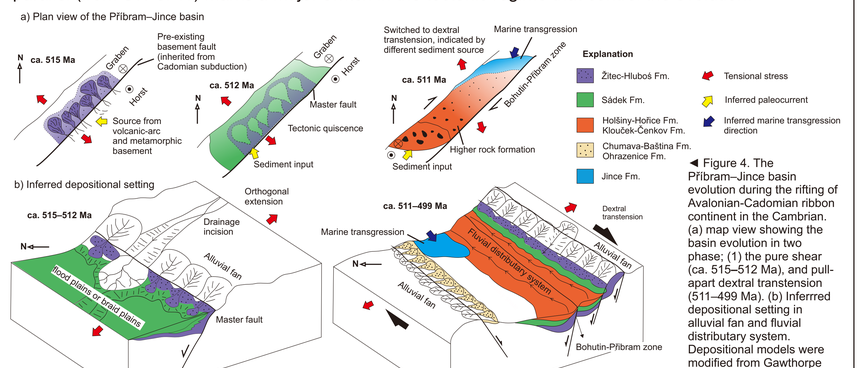
▲Figure 2. Cross-section of Příbram–Jince basin along the Litavka River. The strata shows younger rock formation to the NW. The photographs represent the most important features within the basin related to sedimentation, volcanic activity, and tectonic deformation.



►Figure 3. (a) Inferred paleocurrent from cross-stratification (grey arrows) and AMS measurements (color arrows). The paleocurrent suggests dynamic transformation flowed from the SE to NW, and from the SW or W to NE. (b) Example of Type I fabric (depositional fabric). It is characterized by strongly clustered maximum (k1; red square) and minimum (k3; blue circle) principal susceptibilities, shape parameter scattered across both the oblate and prolate fields, and has a low degree of anisotropy.

Discussion

It is apparent that the deposition in the Příbram–Jince basin was syn-tectonic. We suggest that the previous described provenance changes indicate a change in tectonic regime during deposition, also controlling the basin fill thickness and volcanic activity. We interpret that the basin evolved kinematically in two main phases. The first phase involved gravel accumulation in the SE with the basin fill younging toward the NNW. Then, a short period of tectonic quiescence may be assumed on the basis of an abrupt change from gravel to fine-grained basin fill as represented by the areally extensive Sádek Formation (at 512 ± 5 Ma). Later, faulting became active again and created a northwesterly facing half-graben system. This first phase of the basin evolution was controlled by pure shear (orthogonal) NW–SE extension. The second phase involved the sediment transport from basin-axis-oblique (from the SE) to basin-axis-parallel (from SW or W) marks a major switch in the tectonic regime that control the evolution.



◄ Figure 4. The Příbram–Jince basin evolution during the rifting of Avalonian-Cadomian ribbon continent in the Cambrian. (a) map view showing the basin evolution in two phase; (1) the pure shear (ca. 515–512 Ma), and pull-apart dextral transtension (511–499 Ma). (b) Inferrred depositional setting in alluvial fan and fluvial distributary system. Depositional models were modified from Gawthorpe and Leeder (2000)

Conclusion

The Teplá–Barrandian unit recorded Cadomian subduction until ca. 527–524 Ma (Hájna et al., 2018). The Příbram–Jince basin was initiated at ca. 515 Ma and filled with alluvial and fluvial deposits.The inferred fault geometry and kinematics and geometry of basin fill suggest that the Příbram–Jince basin developed as a dextral transtensional pull-apart basin with multiple depocenters during the initial rifting of ribbon terranes. The volcanic activity (usually bimodal) was delayed and short-lived, lasting only from ca. 500 Ma to 485 Ma.

Acknowledgement

We would like to appreciate this research achievement to Charles University Grant Agency (GAUK). Financial support by the grant No.952220 of the Charles University Grant Agency given to Reza Syahputra (Ph.D student) is gratefully acknowledged.

References

Chlupáč, I., Havlíček V., Kříž, J., Kukal, Z., Štorch, P., 1998. Palaeozoic of the Barrandian (Cambrian-Devonian). Geol Survey, Prague, pp 1–183
Dörr, W., Zulauf, G., Fiala, J., Franke, W., Vejnar, Z., 2002. Neoproterozoic to Early Cambrian history of an active plate margin in the Teplá–Barrandian unit - a correlation of U–Pb isotopic-dilution-TIMS ages (Bohemia, Czech Republic). Tectonophysics 352, 65–85.
Drost, K., Linnemann, U., McNaughton, N., Fatka, O., Kraft, P., Gehmlich, M., Tonk, C., Marek, J., 2004. New data on the Neoproterozoic - Cambrian geotectonic setting of the Tepla-Barrandian volcano-sedimentary successions: geochemistry, U-Pb zircon ages, and provenance (Bohemian Massif, Czech Republic). International Journal of Earth Sciences 93, 742-757.
Fatka, O., Szabad, M., 2014. Cambrian biostratigraphy in the Příbram-Jince Basin (Barrandian area, Czech Republic). Bulletin of Geosciences, 413-429.
Felletti, F., Dall'Olio, E., Muttoni, G., 2016. Determining flow directions in turbidites: An integrated sedimentological and magnetic fabric study of the Miocene Marnoso Arenacea Formation (northern Apennines, Italy). Sedimentary Geology 335, 197-215.
Gawthorpe, R.L., Leeder, M.R., 2000. Tectono-sedimentary evolution of active extensional basins. Basin Research 12, 195-218.
Hajná, J., Žák, J., Dörr, W., Kachlík, V., Šláma, J., 2018. New constraints from detrital zircon ages on prolonged, multiphase transition from the Cadomian accretionary orogen to a passive margin of Gondwana. Precambrian Research 317, 159–178.
Hrouda, F., Krejci, O., Potfaj, M., Stranik, Z., 2009. Magnetic fabric and weak deformation in sandstones of accretionary prisms of the Flysch and Klippen Belts of the Western Carpathians: Mostly offscraping indicated. Tectonophysics 479, 254-270.
Kukal, Z. 1971. Sedimentology of Cambrian deposits of the Barrandian area (Central Bohemia). Journal of Geological Sciences, Geology 20, 53–100.
Nance, R.D., Murphy, J.B., Keppie, J.D., 2002. A Cordilleran model for the evolution of Avalonia. Tectonophysics 352, 11–31.
Nance, R.D., Murphy, J.B., Strachan, R.A., Keppie, J.D., Gutiérrez-Alonso, G., Fernández-Suarez, J., Quesada, C., Linnemann, U., D'Lemos, R., Pisarevsky, S.A., 2008. Neoproterozoic–early Palaeozoic tectonostratigraphy and palaeogeography of the peri-Gondwanan terranes: Amazonian v. West African connections, In: Ennih, N., Liégeois, J.P. (Eds.), The Boundaries of the West African Craton. Geological Society, London, Special Publications, pp. 345–383.
Rees, A. I., 1965. The use of anisotropy of magnetic susceptibility in the estimation of sedimentary fabric. Sedimentology 4, 257–271.
Rees, A. I. and Woodall, W. A., 1975. The magnetic fabric of some laboratory deposited sediments. Earth Planetary Science Letters, 25, 121-30.
Stachowska, A., Łuzinski, M., Śmigielski, M., Wysocka, A., Jankowski, L., Zilkowski, P., 2020. Anisotropy of magnetic susceptibility as an indicator for palaeocurrent analysis in folded turbidites (Outer Western Carpathians, Poland). Sedimentology 67, 3783-3808.
Taira, A. and Scholle, P. A., 1979. Deposition of resedimented sandstone beds in the Pico Formation, Ventura Basin, California, as interpreted from magnetic fabric measurements. Geological Society of America Bulletin 90, 952–962.
Žák, J., Kraft, P., Hajna, J., 2013. Timing, styles, and kinematics of Cambro-Ordovician extension in the Tepla-Barrandian Unit, Bohemian Massif, and its bearing on the opening of the Rheic Ocean. International Journal of Earth Sciences 102, 415-433.
Zulauf, G., Schitter, F., Riegler, G., Finger, F., Fiala, J., Vejnar, Z., 1999. Age constraints on the Cadomian evolution of the Teplá Barrandian unit (Bohemian Massif) through electron microprobe dating of metamorphic monazite. Zeitschrift der Deutschen Geologischen Gesellschaft 150, 627–639.