Publications of the Institute of Geophysics, Polish Academy of Sciences
Geophysical Data Bases, Processing and Instrumentation
vol. 452 (P-4), 2025, pp. 67–71
DOI: 10.25171/InstGeoph_PAS_Publs-2025-010
SVALGEOBASE II: Tectono-thermal evolution of Svalbard, geological workshop, Svalbard 2024

Current Paleomagnetic Database of Svalbard

Krzysztof MICHALSKI[1,✉], Geoffrey MANBY[2], Krzysztof NEJBERT[3],
Justyna DOMAŃSKA-SIUDA[3], and Szczepan BAL[1]

[1]Institute of Geophysics, Polish Academy of Sciences, Warsaw, Poland

[2]Department of Earth Sciences, Natural History Museum, London, Great Britain

[3]Faculty of Geology, University of Warsaw, Warsaw, Poland

✉ krzysztof.michalski@igf.edu.pl

1. INTRODUCTION

The paleomagnetic investigation of the Svalbard Archipelago can be divided into two distinct groups. Research on the Caledonian basement primarily focuses on testing hypotheses that before final Caledonian amalgamation Svalbard existed as separate crustal blocks – terranes, provinces. Paleomagnetic studies of Late Palaeozoic and younger rocks aim to quantify the paleogeographic position of Svalbard in relation to Baltica (Laurussia). In the latter case, Svalbard is considered as a single lithospheric block, consolidated during the Caledonian orogeny (sensu lato).

2. TESTING THE SCALE OF SEPARATION OF SVALBARD CALEDONIAN TERRANES

Harland and Wright (1979) proposed that before Caledonian consolidation, Svalbard existed as smaller lithospheric blocks dispersed along the eastern and northern margins of Greenland.

Here we adopt the nomenclature proposed by Harland (1997) for dividing Svalbard into the Caledonian Western, Central, and Eastern Terranes. The amalgamation of the Terranes was considered to have occurred in Late Devonian time (Harland and Wright 1979). Svalbard hosts large-scale, north-south trending mylonite zones that exhibit several horizontal kinematic indicators, such as Billefjorden Fault Zone, along which such crustal displacements could have occurred. However, the scale of postulated displacements is yet to be quantified.

The Proterozoic to early Palaeozoic successions present an ideal opportunity for palaeomagnetic experiments. There are, however, significant challenges. Unfortunately for two of the three Terranes (Western and Central) the primary palaeomagnetic record was entirely obliterated during Caledonian tectonogenesis, when metamorphic processes remagnetised the rocks (Burzyński et al. 2017; Michalski 2018; Michalski et al. 2012, 2014, 2017). Theoretically, if we assume that the amalgamation of terranes occurred only in the Late Devonian time and was linked to the activity of large-scale strike-slip faults, the scale of their separation should be measurable based on previously imposed secondary Caledonian remagnetisation, which is potentially associated with the main phase of the Caledonian collision in the Late Silurian. However, although both isotopic and palaeomagnetic records are based on the same fundamental process—the cooling of carrier minerals below their critical temperature—precisely determining the absolute age of secondary palaeomagnetic directions linked to metamorphism remains a significant challenge.

Ongoing palaeomagnetic studies suggest that the primary pre-Caledonian palaeomagnetic record may have been preserved only in selected areas of the Eastern Terrane that escaped Caledonian metamorphism. Maloof et al. (2006) identified three palaeopoles from Eastern Svalbard, which they interpreted as representing primary palaeomagnetic signals from 805–790 Ma (Fig. 1). They observed significant shifts of over 50° in the palaeomagnetic directions, which they attributed to a pair of true polar wander (TPW) events. However, the primary nature of at least one of these palaeopoles was questioned by Michalski et al. (2012, 2023), who pointed out that some of the sites sampled by Maloof et al. (2006) may have been affected by low-grade Caledonian metamorphism.

During palaeomagnetic expeditions to Eastern Svalbard in 2022 and 2023, the NEOMAGRATE project team collected an additional 400 independently oriented Neoproterozoic palaeomagnetic samples from 58 sites around Hinlopenstretet. These samples represent the Tonian Kapp Hansteen volcanics, the Veteranen Group carbonates and siliciclastics, the Akademikerbreen Group carbonates, as well as the Cryogenian carbonates and tillites of the Polarisbreen Group. The presence of a pre-Caledonian palaeomagnetic signal would suggest that this segment of the Caledonian belt was not subjected to east-directed over-thrusting. However, both Caledonian and Mesozoic remagnetization events have been identified in the region. The former may be linked to mineralization processes at the Caledonian orogenic front, while the latter could be associated with Cretaceous dolerite magmatism in eastern Svalbard.

Although the palaeomagnetic studies of eastern Svalbard alone will not verify the hypothesis of the Svalbard Caledonian Terrane separation, they are of significant for the paleogeographic reconstruction of the Rodinia supercontinent and the verification of the proposed Neoproterozoic True Polar Wander events.

3. QUANTIFICATION OF SVALBARD POST-CALEDONIAN PALEOGEOGRAPHIC POSITION

Most published palaeomagnetic results confirm that Svalbard has been part of Baltica at least since the Late Palaeozoic (Fig. 1). Palaeomagnetic data indicate the stabilisation of the Barents Sea platform and no significant displacement between Svalbard and continental Europe (within the resolution of the palaeomagnetic method) at least since the Devonian (Halvorsen 1989; Jeleńska and Lewandowski 1986; Nawrocki 1999; Watts 1985) or possibly even from the Silurian (Michalski et al. 2012). However, when analysing post-Caledonian Svalbard reconstructions based on palaeomagnetic results, it is important to be aware of the following limitations.

Due to post-orogenic uplift and erosion, no Silurian sedimentary cover is preserved on Svalbard. Consequently, the Silurian palaeomagnetic record is represented solely by secondary remanent magnetisation directions in pre-Silurian rocks. These likely formed during the exhumation of metamorphosed complexes, when ferromagnetic minerals cooled below their

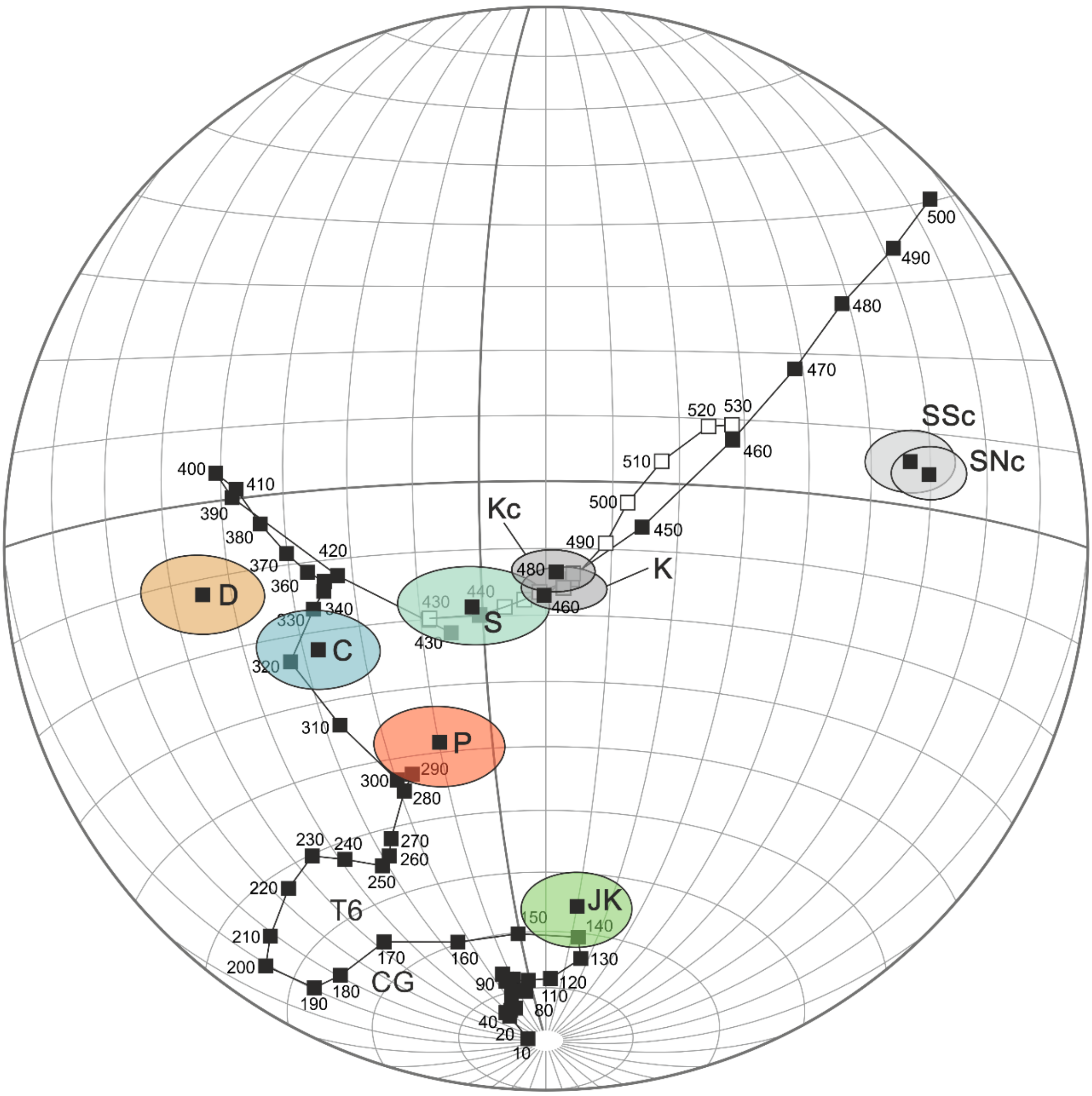

Fig. 1. Palaeopoles from Svalbard with their confidence limit ellipses (α95) plotted against Phanerozoic Apparent Polar Wander Paths (APWPs) of Laurussia (palaeopoles 0–430 Ma, filled squares), Baltica (palaeopoles 440–530 Ma, filled squares), and Laurentia (palaeopoles 440–530 Ma, open squares). The reference APWPs were derived from the GMAP 2012 database (Torsvik et al. 2012), with ages of specific points on the reference curve indicated. Symbols of palaeopoles identified in Palaeozoic and Mesozoic Svalbard formations: JK – Halvorsen (1989); P – Nawrocki (1999); C – Watts (1985); D – Jeleńska and Lewandowski (1986); S – Michalski et al. (2012) (note the coincidence of post-Caledonian Svalbard palaeopoles with their corresponding age segments on the reference curve). Palaeopoles identified by Maloof et al. (2006) in the Neoproterozoic succession of the Eastern Svalbard Terrane: K, Kc, SSc, SNc (note the coincidence of palaeopoles K and Kc with the Caledonian sector of the reference curve).

blocking temperatures. As mentioned earlier, precisely dating these secondary components using radiometric methods remains highly challenging (Michalski et al. 2012).

Palaeomagnetic studies of the red clastic deposits from the Devonian and Carboniferous of Spitsbergen have identified stable, potentially primary palaeomagnetic directions carried by hematite (Jeleńska and Lewandowski 1986; Watts 1985). So far, however, these studies do not include an inclination error correction, a well-known effect that leads to an underestimation of inclination due to the sedimentary deposition of ferromagnetic grains.

The paleomagnetic record in younger Permian and Triassic formations is based on less stable, medium- and low-coercivity grains of magnetite, titanomagnetite, and maghemite (Dudzisz et al. 2019; Nawrocki 1999). These minerals are prone to remagnetization, including that associated with the widespread Cretaceous magnetism on Svalbard. Finally, in the case of studies on Cretaceous dolerites (Halvorsen 1989), key challenges remain: the precise dating of individual magma intrusions, the elimination of secular variations, and the complex magnetization structure of igneous complexes formed through multiple stages of magma injection.

4. CONCLUSIONS

Palaeomagnetic studies of Svalbard play a crucial role in reconstructing the palaeogeography of the Arctic. Research on the Proterozoic successions of the Eastern Svalbard Terrane offers valuable insights into global full-plate models, particularly regarding the palaeogeography of the supercontinent Rodinia. In contrast, palaeomagnetic investigations of Svalbard's post-Caledonian rock sequences offer crucial information on the stability of the Barents Sea platform during the late Palaeozoic and Mesozoic.

One of the main challenges in palaeomagnetic studies of Svalbard is distinguishing between primary and secondary palaeomagnetic signals. A critical part of the palaeomagnetic workflow involves applying appropriate tectonic corrections for rotations linked to Caledonian, Svalbardian (?) and Eurekan contraction, as well as those associated with extensional processes related to opening of the North Atlantic and Eurasian Basin. In studies of sedimentary sequences, it is also essential to account for inclination shallowing corrections.

Acknowledgements. The presented study was partly funded by the PALMAG project 2012–2016: "Integration of palaeomagnetic, isotopic and structural data to understand Svalbard Caledonian Terranes assemblage", grant number: 011/03/D/ST10/0519 and the NEOMAGRATE project 2022–2026: "Rate of tectonic plates movement in Neoproterozoic – verification of Neoproterozoic True Polar Wander hypothesis", grant number: 2021/41/B/ST10/02390; both grants received funding from the Polish National Science Centre (NSC). The costs of participations in the SvalGeoBase II workshop was partly covered by project HarSval Bilateral initiative aiming at Harmonisation of the Svalbard cooperation; contract number: UMO-2023/43/7/ST10/00001. The activities were also partly funded from the means of the EEA and Norway Grants 2014–2021.

References

Burzyński, M., K. Michalski, K. Nejbert, J. Domańska-Siuda, and G. Manby (2017), High-resolution mineralogical and rock magnetic study of ferromagnetic phases in metabasites from Oscar II Land, Western Spitsbergen – towards reliable model linking mineralogical and palaeomagnetic data, *Geophys. J. Int.* **210**, 1, 390–405, DOI: 10.1093/gji/ggx157.

Dudzisz, K., K. Michalski, R. Szaniawski, K. Nejbert, and G. Manby (2019), Palaeomagnetic, rock-magnetic and mineralogical investigations of the Lower Triassic Vardebukta Formation from the southern part of the West Spitsbergen Fold and Thrust Belt, *Geol. Mag.* **156**, 4, 620–638, DOI: 10.1017/S0016756817001145.

Halvorsen, E. (1989), A paleomagnetic pole position of Late Jurassic/Early Cretaceous dolerites from Hinlopenstretet, Svalbard, and its tectonic implications, *Earth Planet. Sci. Lett.* **94**, 3–4, 398–408, DOI: 10.1016/0012-821X(89)90156-8.

Harland, W.B. (1997), *The Geology of Svalbard*, Geological Society Memoir, No. 17, The Geological Society, London, DOI: 10.1144/GSL.MEM.1997.017.01.26.

Harland, W.B., and N.J.R. Wright (1979), Alternative hypothesis for the pre-Carboniferous evolution of Svalbard, *Norsk Polarinst. Skri.* **167**, 89–117.

Jeleńska, M., and M. Lewandowski (1986), A palaeomagnetic study of Devonian sandstone from Central Spitsbergen, *Geophys. J. Int*. **87**, 2, 617–632, DOI: 10.1111/j.1365-246X.1986.tb06641.x.

Maloof, A.C., G.P. Halverson, J.L. Kirschwink, D.P. Schrag, B.P. Weiss, and P.F. Hoffman (2006), Combined paleomagnetic, isotopic and stratigraphic evidence for true polar wander from the Neoproterozoic Akademikerbreen Group, Svalbard, Norway, *Geol. Soc. Am. Bull*. **118**, 9–10, 1099–1124, DOI: 10.1130/B25892.1.

Michalski, K. (2018), Palaeomagnetism of metacarbonates and fracture fills of Kongsfjorden islands (western Spitsbergen): Towards a better understanding of late- to post-Caledonian tectonic rotations, *Pol. Polar Res*. **39**, 1, 51–75, DOI: 10.24425/118738.

Michalski, K., M. Lewandowski, and G.M. Manby (2012), New palaeomagnetic, petrographic and $^{40}Ar/^{39}Ar$ data to test palaeogeographic reconstructions of Caledonide Svalbard, *Geol. Mag*. **149**, 4, 696–721, DOI: 10.1017/S0016756811000835.

Michalski, K., K. Nejbert,, J. Domańska-Siuda, and G. Manby (2014), New palaeomagnetic data from metamorphosed carbonates of Western Oscar II Land, Western Spitsbergen, *Pol. Polar Res*. **35**, 4, 553–592, DOI: 10.2478/popore−2014−0031.

Michalski, K., G. Manby, K. Nejbert, J. Domańska-Siuda, and M. Burzyński (2017), Using palaeomagnetic and isotopic data to investigate late to post-Caledonian tectonothermal processes within the Western Terrane of Svalbard, *J. Geol. Soc*. **174**, 572–590, DOI: 10.1144/jgs2016-037.

Michalski, K., G.M. Manby, K. Nejbert, J. Domańska-Siuda, and M. Burzyński (2023), Palaeomagnetic investigations across Hinlopenstretet border zone: from Caledonian metamorphosed rocks of Ny Friesland to foreland facies of Nordaustlandet (NE Svalbard), *J. Geol. Soc*. **180**, 1, DOI: 10.1144/jgs2021-167.

Nawrocki, J. (1999), Paleomagnetism of Permian through Early Triassic sequences in central Spitsbergen: implications for paleogeography, *Earth Planet. Sci. Lett*. **169**, 1–2, 59–70, DOI: 10.1016/S0012-821X(99)00069-2.

Torsvik, T.H., R. Van der Voo, U. Preeden, C. Mac Niocaill, B. Steinberger, P.V. Doubrovine, D.J.J. van Hinsbergen, M. Domeier, C. Gaina, E. Tohver, J.G. Meert, P.J.A. McCausland, and L.R.M. Cocks (2012), Phanerozoic polar wander, paleogeography and dynamics, *Earth-Sci. Rev*. **114**, 3 –4, 325–368, DOI: 10.1016/j.earscirev.2012.06.007.

Watts, D.R. (1985), Palaeomagnetism of the Lower Carboniferous Billefjorden Group, Spitsbergen, *Geol. Mag*. **122**, 4, 383–388, DOI: 10.1017/S0016756800031824.

Received 13 February 2025
Accepted 18 February 2025