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PAPER

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U-Pb zircon dating of metaigneous rocks from the Nordbreen Nappe of Svalbard's Ny-Friesland suggests their affinity to Northeast Greenland

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Abstract

SIMS U-Pb zircon dating of metaigneous rocks of the Nordbreen Nappe from the West Ny-Friesland terrane (Eastern Basement Province of Svalbard) yields crystallization ages of 1,761 ± 4 Ma for a felsic metatuff and 1,373 ± 4 Ma for a metagabbro dyke. The Palaeoproterozoic age of the metatuff is similar to previously obtained ages for various felsic rocks from the study area, whereas the Mesoproterozoic age of the metagabbro has not been thus far documented on Svalbard. However, a similar age pattern has been reported from Northeast Greenland. Therefore, we conclude that the West Ny-Friesland terrane can be correlated with age equivalent units of Northeast Greenland. We also explore similarities and dissimilarities between the study area and other terranes of Svalbard and speculate on regional-scale correlations. Together, the presented new ages provide critical piercing points in palaeogeographic reconstructions of the relatively poorly understood circum-Arctic region.

1 | INTRODUCTION

Comparison and possible correlation of Precambrian rock units in Svalbard with those observed in the Greenland and Scandinavian Caledonides relies on robust geochronological data tied to accurate palaeogeographic reconstructions of the High Arctic. The presence of Tonian granites and Cryogenian glacial diamictite-bearing sedimentary successions in the Eastern Basement Province (Nordaustlandet terrane) of Svalbard (Figure 1) has been used to restore eastern Svalbard to the East Greenland margin prior to widespread deformation during the mid-Palaeozoic Caledonian Orogeny (Gee & Tebenkov, 2004; Harland, 1997). However, a correlation of basement rocks in the westernmost exposures of the Eastern Basement Province (West Ny-Friesland terrane) and other regions of Svalbard remains less certain (Harland, 1997).

The West Ny-Friesland terrane is dominated by the Atomfjella Complex composed of felsic orthogneiss that is interpreted as basement to a poorly understood overlying metasedimentary succession.

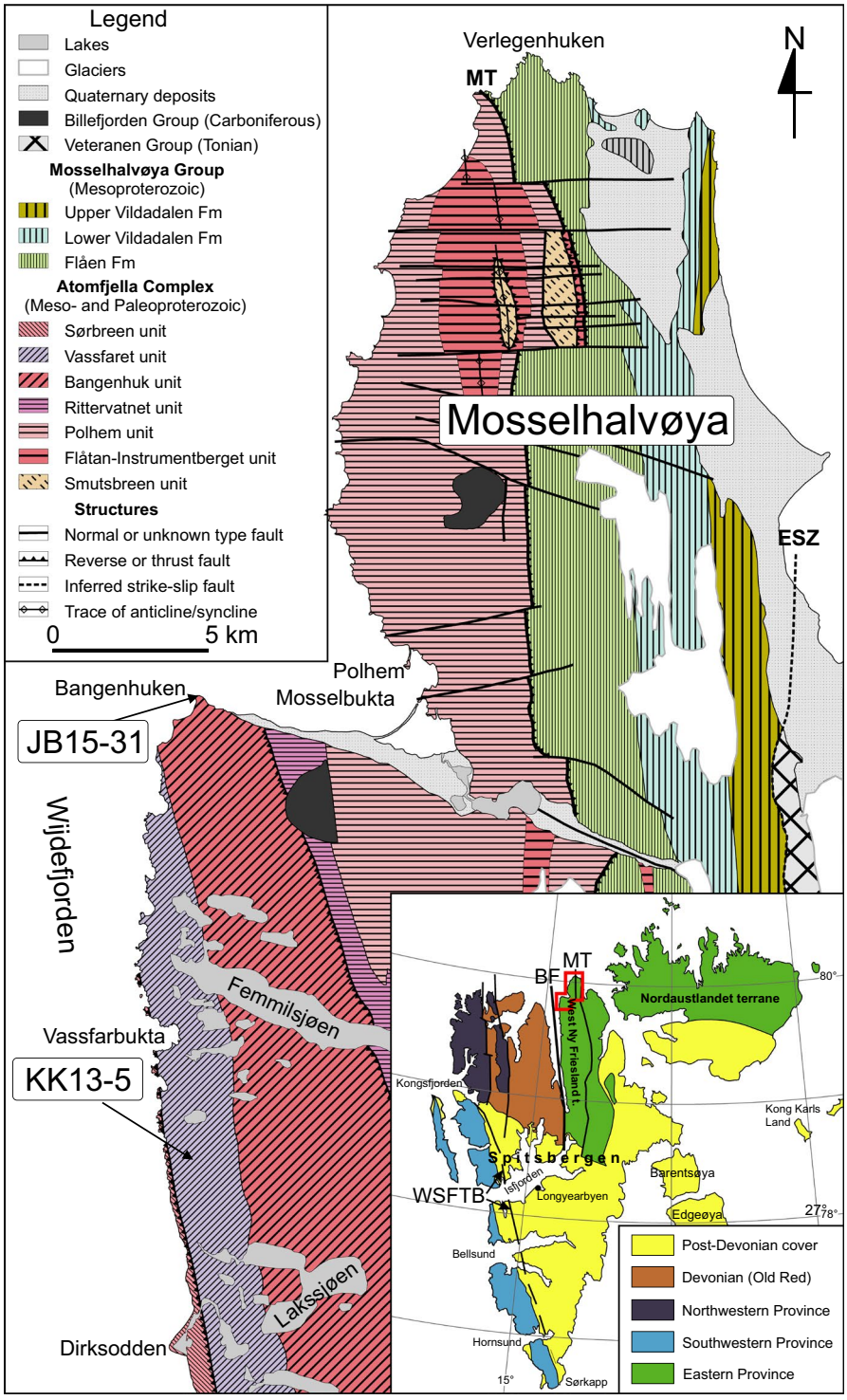

FIGURE 1 Geological map of west Ny-Friesland (after Elvevold & Dallmann, 2011, simplified), MT, Mosselhavøya Thrust; ESZ, Eolussletta Shear Zone. Bottom right corner: schematic geological map of the Svalbard Archipelago (modified from Gee & Tebenkov, 2004), BF, Billefjorden Fault Zone; WSFTB, West Spitsbergen Fault and Trust Belt, the red frame indicates the area of research [Colour figure can be viewed at wileyonlinelibrary.com]

During the Caledonian Orogeny, a nappe stack of four west-directed thrust-sheets was formed, including the Nordbreen Nappe, that was folded during a later phase of the Caledonian Orogeny to generate the Atomfjella Antiform (Witt-Nilsson, Gee, & Hellman, 1998). Previous isotopic age dating on quartzofeldspathic orthogneiss of the Atomfjella Complex suggested an age of ca. 1,750 Ma (e.g. Johansson, Gee, Björklund, & Witt-Nilsson, 1995), but the age of numerous mafic dykes and metatuff layers remain unknown. Here, we present new U-Pb zircon ages obtained using secondary ion mass spectrometry (SIMS) for a metagabbro which intrudes the Atomfjella orthogneisses and a metatuff layer within the overlying metasedimentary section of the Nordbreen Nappe, in order to elucidate the tectonic setting and age of these basement units. Together, the new data provide critical piercing points in palaeogeographic reconstructions of the relatively poorly understood circum-Arctic region.

2 | GEOLOGICAL SETTING

The pre-Devonian crystalline basement of the Svalbard archipelago forms three large tectonic provinces partly covered by the Devonian–Palaeogene sedimentary and volcanic units (Figure 1; Harland, 1997; Harland & Wright, 1979; Mazur et al., 2009; Ohta, Dallmeyer, & Peucat, 1989). The Northwestern, Southwestern and Eastern Basement provinces are separated by large Palaeozoic strike-slip fault zones (e.g., Gee & Tebenkov, 2004; Harland, 1985; Mazur et al., 2009), and regional metamorphic events recorded in the basement are interpreted to reflect tectonism associated with the Caledonian Orogeny (e.g., Gee et al., 1992; Harland, 1985; Majka & Kośmińska, 2017). The Eastern Basement Province is separated from the other provinces by a large strike-slip shear zone called the Billefjorden Fault Zone (e.g. Gee & Tebenkov, 2004; Harland, 1997; Michalski, Lewandowski, & Manby, 2012; Figure 1), while the boundary between the Northwestern and Southwestern Basement Provinces is marked by the front of the West Spitsbergen Fold and Thrust Belt (Dallmann, Andresen, Bergh, Maher, & Ohta, 1993; Harland & Horsfield, 1974).

Svalbard's Eastern Basement Province is subdivided into the Nordaustlandet and West Ny-Friesland terranes. The Nordaustlandet terrane is dominated by ca. 970–950 Ma augen gneiss-dominated basement (McClelland, Gosen, & Piepjohn, 2019) that is inferred to be depositionally overlain by Tonian to Ordovician shallow-water sedimentary rocks, all of which are locally intruded by Silurian felsic to intermediate plutonic rocks (Gee, Johansson, Larionov, & Tebenkov, 1999; Halverson, Hoffman, Schrag, Maloof, & Rice, 2005; Harland, 1997; Johansson et al., 2000; Johansson, Larionov, Tebenkov, Ohta, & Gee, 2002). The basement and younger cover were variably metamorphosed, from anchimetamorphic to locally amphibolite facies conditions during the Caledonian Orogeny (Johansson, Maluski, & Gee, 2001).

Low-grade Neoproterozoic rocks of the Nordaustlandet terrane extend westward across Hinlopenstretet to Mosselhalvøya, Ny-Friesland, where they are tectonically juxtaposed with the Mosselhalvøya Group (Figure 1), a sequence of higher-grade metasedimentary rocks previously referred to as the Planetfjella Group (Wallis, 1967). The Mosselhalvøya Group is bound to the west by the Mosselhalvøya fault, which may mark the tectonic boundary between the Nordaustlandet and West Ny-Friesland terranes (Witt-Nilsson et al., 1998). Other interpretations place this boundary at the contact between the Planetfjella (Mosselhalvøya) and Veteranen groups referred to as the Eolussletta (or Sorgfjorden) Shear Zone (ESZ; Lyberis & Manby, 1993; Manby & Lyberis, 1991; Nathorst, 1910) or Veteranen Line (Harland, Scott, Auckland, & Snape, 1992). Manby and Lyberis (1991) described the ESZ as a vertical, sinistral shear zone up to 3 km wide.

The structure of West Ny-Friesland terrane is dominated by the Atomfjella Antiform (Witt-Nilsson et al., 1998), a ~150 km long north-south-trending structure that consists of orthogneiss and psammitic metasedimentary rocks of the Atomfjella Complex (Witt-Nilsson et al., 1998). The four Caledonian thrust sheets in the Atomfjella Antiform are, from bottom to top, the Finlandveggen, Rekvika, Nordbreen and Dirksodden nappes (Figure 2; Gee & Tebenkov, 2004; Hellman, Gee, & Witt-Nilsson, 2001; Witt-Nilsson et al., 1998). They are all interpreted to be composed of similar Palaeoproterozoic basement consisting of ca. 1750 Ma granitic gneiss (Johansson & Gee, 1999; Johansson et al., 1995; Larionov, Johansson, Tebenkov, & Sirotkin, 1995) and non-conformably overlying metasediments. In the east, the Atomfjella Antiform is interpreted to be overthrust by the Mosselhalvøya Nappe consisting of metasediments of the Mosselhalvøya Group (Figure 2; Gayer et al., 1966; Gee & Tebenkov, 2004; Hellman et al., 2001; Witt-Nilsson et al., 1998).

The structurally lowest Finlandveggen Nappe includes gneisses of the Eskolabreen unit that have yielded zircon U-Pb Thermal Ionization Mass Spectrometry (TIMS) ages of 1,749 ± 18, 1,748 ± 21 and 1,734 ± 5 Ma (Johansson & Gee, 1999; Larionov et al., 1995). The Instrumentberget gneiss occurs as the basal unit of the overlying Rekvika Nappe and yielded a U-Pb TIMS age of 1,745 ± 13 Ma (Hellman, Gee, Johansson, & Witt-Nilsson, 1997).

The Nordbreen Nappe includes metaigneous basement rocks of the Bangenhuk unit and an inferred cover metasedimentary sequence referred to as the Vassfaret unit (Figure 2). The Bangenhuk unit includes penetratively deformed granitic gneiss whose age has been estimated using U-Pb TIMS in range from 1,766 to 1,724 Ma (Johansson et al., 1995). The latter study also reported U-Pb TIMS ages on titanite from several samples of the Bangenhuken unit that yielded upper intercept ages of ca. 1,750 Ma (Johansson et al., 1995). These basement rocks are also known to include ca. 2,709 Ma quartz monzonitic orthogniess (Hellman et al., 2001). The Vassfaret unit overlies the Bangenhuk unit and includes semipelite, amphibolite, quartzite and metatuff. Metagranites of the Bangenhuk unit clearly intrude the lowermost metasedimentary rocks of the Vassfaret unit at some localities, making the inferred depositional relations suspect. U-Pb detrital zircon provenance studies of quartzites from the Vassfaret unit yielded a minimum deposition age of ca. 1,740 (Bazarnik, McClelland, Majka, Kośmińska, & Piepjohn, 2017). Both

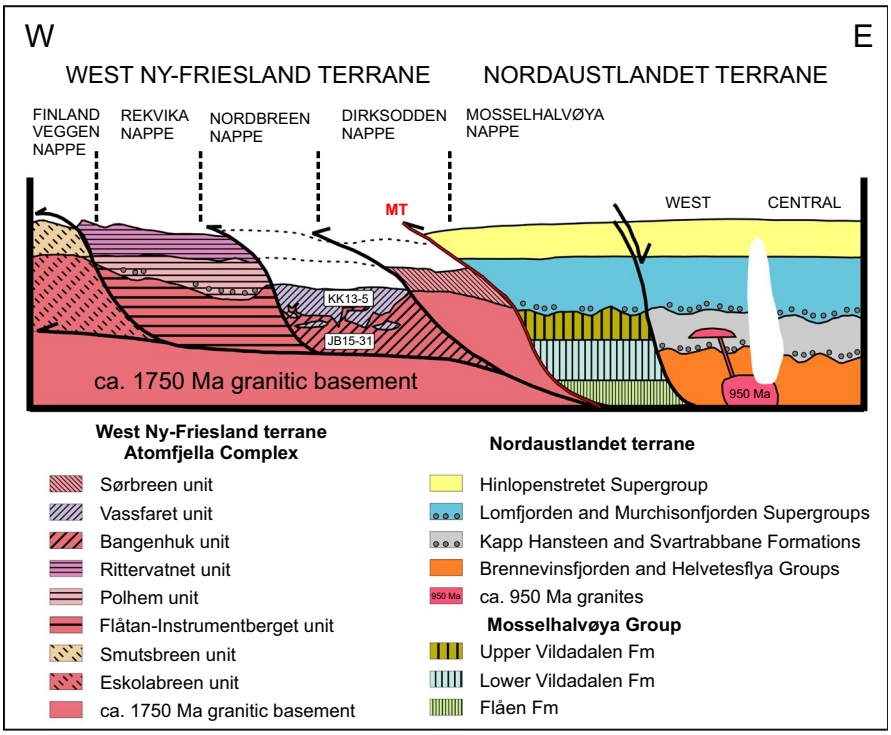

FIGURE 2 Schematic pre-Caledonian configuration of the Ny-Friesland thrust sheets, indicating a minimum of 80 km E-W lateral shortening (modified after Witt-Nilsson et al., 1998), MT, Mosselhavøya Thrust [Colour figure can be viewed at wileyonlinelibrary.com]

the basement and metasedimentary units are intruded by mafic dykes of unknown age.

3 | DATING RESULTS

Zircon was separated from samples of a metatuff of the Vassfaret unit and a mafic dyke in the Bangenhuk unit using conventional techniques, imaged using cathodoluminescence (CL) and analysed using SIMS using SHRIMP IIe/MC at the Polish Geological Institute—NRI in Warszawa. Petrographic description of the dated samples and detailed methodology as well as geochronological data are presented in Supporting information and in Figures S1, S2 and Tables S1, S2.

The metatuff (Figure 1; KK13-5) yielded euhedral oscillatory zoned zircon grains (Figure 3a). Most of the grains have CL-light cores, although some exhibit CL-dark cores. Analyses of 49 grains define a weighted mean $^{207}Pb/^{206}Pb$ age of 1,761 ± 4 Ma (MSWD = 0.9; Figure 4a,b, Table S1).

The metagabbro (Figure 1; JB15-31) yielded fragments of euhedral zircon with oscillatory zoning and partially patchy CL zoning (Figure 3b). The results obtained from 30 fragments yielded weighted mean $^{207}Pb/^{206}Pb$ age of 1,373 ± 4 Ma (MSWD = 1.1; Figure 4c,d, Table S2).

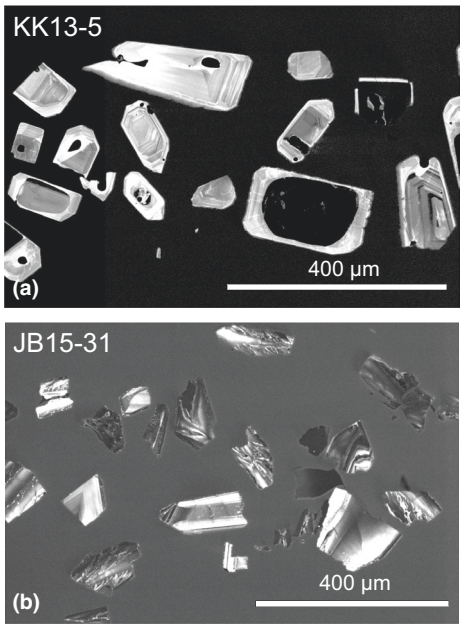

FIGURE 3 Cathodoluminescence images of zircon grains from the samples KK13-5 (a) and JB15-31 (b)

4 | DISCUSSION AND SUMMARY

The new U-Pb SIMS zircon age of 1,373 ± 4 Ma presented herein significantly refines the previously published ideas about the absolute age of the mafic dykes, based solely on field relations and available for host rocks and late metamorphic overprint. These previous studies suggest that the mafic suite must be younger than both the orthogneiss basement and the vast majority of the paragneiss units of the four thrust sheets of the West Ny-Friesland terrane. Hence, the age of emplacement of these mafic rocks has been anticipated to be post ca. 1,750 Ma but pre-Silurian because the whole succession bears evidence for deformation and metamorphism during the Caledonian Orogeny (e.g., Gee & Page, 1994; Johansson et al., 1995). Although

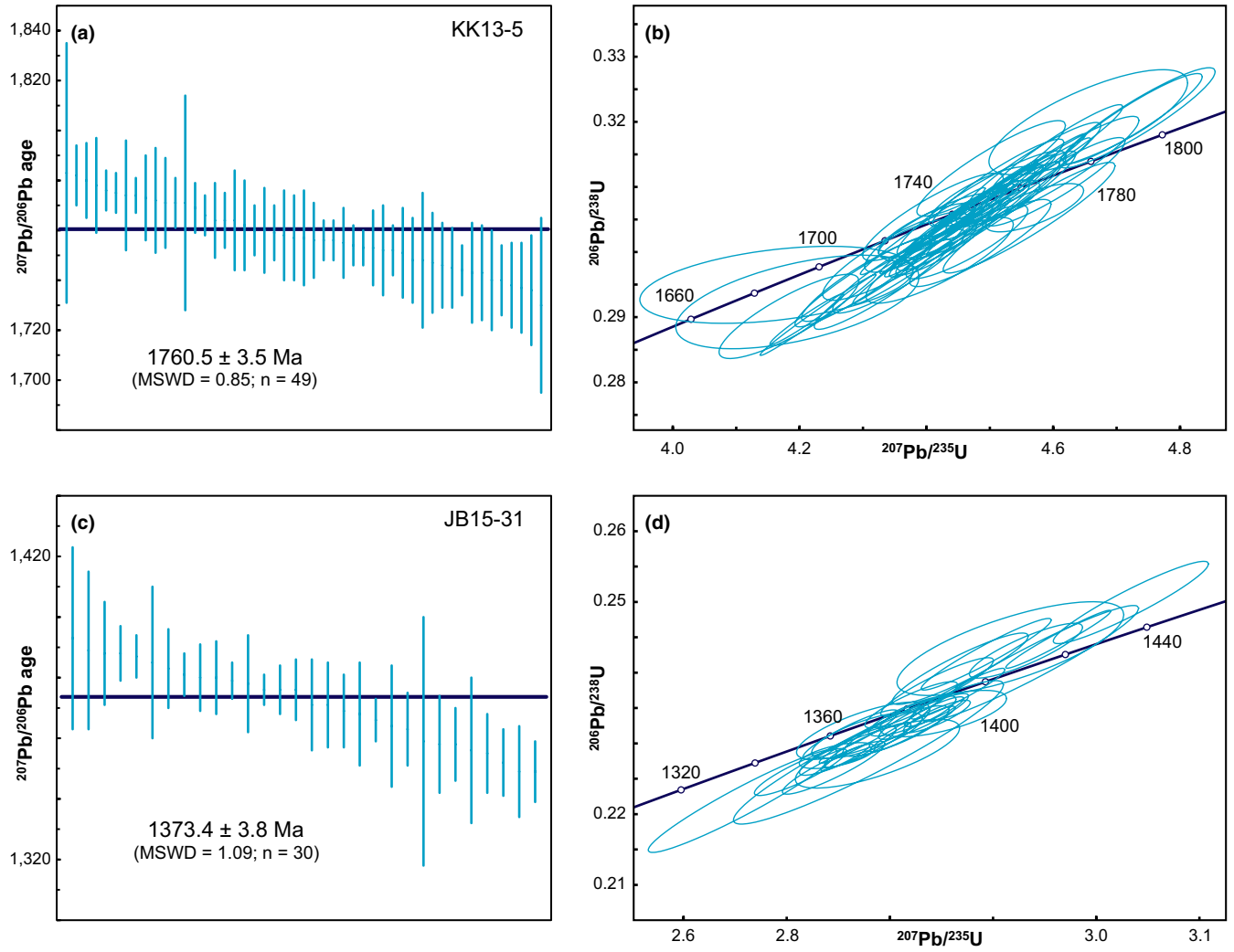

FIGURE 4 SIMS results shown on $^{207}Pb/^{206}Pb$ weighted mean and U-Pb Concordia diagrams for samples KK13-5 (a, b) and JB15-31 (c, d), data-point errors symbols for weighted mean and ellipses for concordia diagram are 1 σ and 2 σ respectively [Colour figure can be viewed at wileyonlinelibrary.com]

extrapolation of the ca. 1,370 age to all mafic dykes within the Atomfjella Complex is tenuous without further geochemical and geochronological studies, the new data provide the first geochronological evidence for magmatism of this age on the entire Svalbard archipelago.

The obtained age of 1,761 ± 4 Ma from the metatuff sample suggests that the deposition of sedimentary protoliths of the Vassfaret unit commenced contemporaneously with or before the final emplacement of granitic protoliths in the underlying Bangenhuken basement that are interpreted to be the plutonic equivalents of the dated metatuff. Importantly, the detrital zircon studies of the upper levels of the Vassfaret unit define the youngest zircon populations at ca. 1,740–1,735 Ma (Bazarnik et al., 2017; Hellman & Witt-Nilsson, 1999). Witt-Nilsson et al. (1998) report that the felsic orthogneiss locally intrudes the lowermost parts of the Vassfaret unit (see also Figure 2). Assuming these intrusions are coeval with the dated magmatism of the Bangenhuken unit and the metatuff reported herein, the basal parts of the Vassfaret unit must have been deposited before the emplacement of those felsic intrusives. Such interpretation has been already proposed by Gayer and Wallis (1966) and Hellman et al. (2001). Therefore, we postulate that the lowermost levels of the Vassfaret unit are indeed somewhat older than its upper levels, but still Palaeoproterozoic in age. The ca. 1,373 Ma age of the dated metagabbro, if extrapolated to all other mafic units of the Atomfjella Complex, brackets the sedimentation of the cover units between Palaeoproterozoic and Mesoproterozoic.

Palaeoproterozoic felsic intrusive and extrusive rocks have been previously recognized in all four thrust sheets of the West Ny-Friesland terrane, and their age was estimated to ca. 1,750 Ma. The SIMS U-Pb zircon age of 1,761 ± 4 Ma of the metatuff presented in this study is similar to the oldest ages presented by Johansson et al. (1995). We suggest that Palaeoproterozoic felsic igneous activity in West Ny-Friesland culminated around 1,760 Ma and infer that the younger ages derived using whole grain techniques may either reflect Pb-loss or indeed indicate prolonged igneous activity until

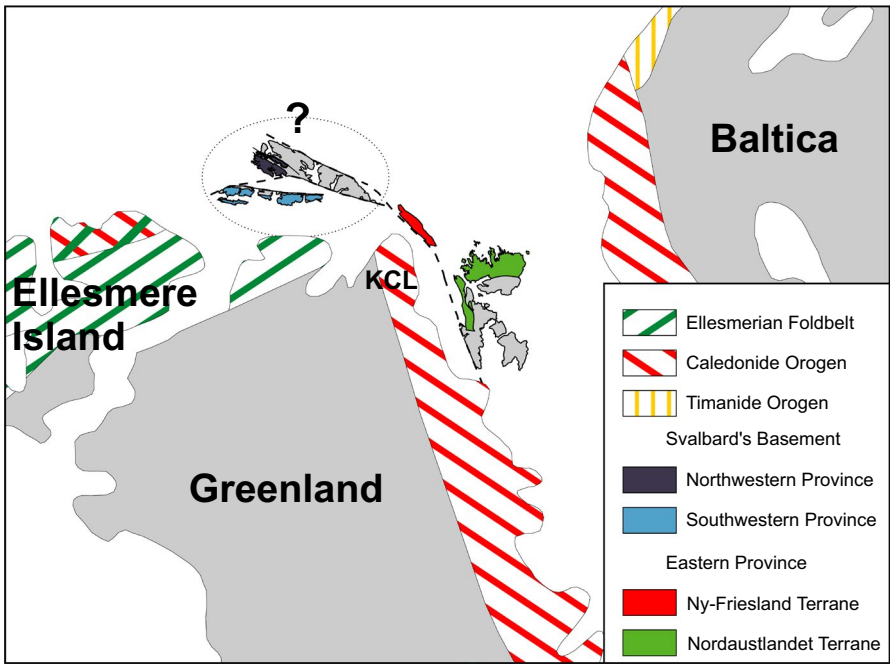

FIGURE 5 Proposed tectonic position of Svalbard's Basement Provinces in the latest Neoproterozoic. Note the uncertain position of the Northwestern and Southwestern provinces. Current range of the Timanian, Caledonian and Ellesmerian fold belts are marked by yellow, red and green straps. KCL, Kronprins Christian Land [Colour figure can be viewed at wileyonlinelibrary.com]

1,724 Ma (Johansson et al., 1995). Notwithstanding the latter, all these results can be explained by the same magmatic event, which is generally unknown from other Svalbard provinces. Hence, a need for a correlation with some other circum-Arctic terranes naturally emerges.

Numerous previous studies have linked different basement provinces of Svalbard to the Laurentian (Greenland) margin (e.g. Halverson, Porter, & Gibson, 2018; Harland, 1997; Michalski et al., 2012). These basement provinces are now displaced from their original positions and juxtaposed in present Svalbard. The Eastern Province has been traditionally correlated to central East Greenland (Halverson et al., 2018; Harland, 1997; Hoffman et al., 2012). Similarities of the Eleonore Bay Supergroup (Greenland) and Lomfjorden and Murchisonfjorden supergroups (East Ny-Friesland and Nordaustlandet, Svalbard) suggest close links between Neoproterozoic tillite-bearing clastic sections and overlying Cambro-Ordovician carbonates in these two regions (Gee, Fossen, Henriksen, & Higgins, 2008; Gee & Tebenkov, 2004; Malone, McClelland, Gossen, & Piepjohn, 2014). Tonian metaigneous rocks have also been cited as a basis of comparison between Nordaustlandet and East Greenland (Gee & Tebenkov, 2004), but differences in the 970–950 Ma and 950–915 Ma magmatic ages observed from two regions respectively, suggest that the Nordaustlandet terrane did not originate just immediately adjacent to East Greenland (McClelland et al., 2019).

The ca. 1,760 Ma and ca. 1,380 Ma ages obtained from the Atomfjella Complex combined with a distinct lack of Tonian magmatism show a substantially different provenance for the West Ny-Friesland terrane than for the Nordaustlandet terrane. Palaeoproterozoic metaigneous intrusive rocks in both the foreland and overlying thrust sheets in the East Greenland Caledonides define an extensive ca. 1,750 Ma basement province extending ~800 km north of 73°N along the east coast of Greenland (e.g. Kalsbeek, Higgins, Jepsen, Frei, & Nutman, 2008; Kalsbeek et al., 1999). Felsic metavolcanic rocks of ca. 1,740 Ma age are also known from the Hekla Sund and Aage Berthelsen Gletscher formations of the Independence Fjord Group in Kronprins Christian Land (KCL on Figure 5), the northernmost part of the East Greenland Caledonides (Kalsbeek et al., 1999). The metavolcanic rocks are intercalated with a 2 km thick package of siliciclastic rocks of inferred Palaeoproterozoic age (Collinson, Kalsbeek, Jepsen, Pedersen, & Upton, 2008; Higgins, 2015). Locally, the entire package of felsic metavolcanic rocks and metasedimentary units is cut by mafic rocks referred to as the Midsommersø Dolerites and dated to 1,382 ± 2 Ma (Pb-Pb baddeleyite age based on three samples, Upton et al., 2005).

Based on the similarity in the timing of mafic magmatism, we proposed that the Nordbreen Nappe in the West Ny-Friesland terrane is correlative with the basement-cover succession exposed in the northern East Greenland Caledonides. It must be noted that the ca. 2,000 Ma basement known from Northeast Greenland (Kalsbeek, Nutman, & Taylor, 1993) has not yet been found in the West Ny-Friesland terrane; nevertheless, datasets from both regions allow for their mutual correlation and more importantly, highlight potential differences between the West Ny-Friesland and Nordaustlandet terranes of Svalbard's Eastern Basement Province. This suggests that the two terranes of the Eastern Basement Province may have been originally separated and juxtaposed later along the regional-scale Caledonian sinistral strike-slip zones (e.g., Eolussletta Shear Zone, Billefjorden Fault Zone) which play a major role in the late-to-post-Caledonian assembly of Svalbard's basement provinces (e.g. Harland, 1997; Mazur et al., 2009; Michalski et al., 2012).

A pre-Caledonian northerly location reconstruction for the West Ny-Friesland terrane in proximity to Northeast Greenland requires revisiting the original locations of terranes currently residing west

of West Ny-Friesland, namely the Northwestern and Southwestern Basement Provinces. The former was traditionally correlated to the Nordaustlandet terrane (e.g., Gee & Tebenkov, 2004) based mainly on the occurrence of ca. 950 Ma magmatism within both tectonic units, whereas the latter to the Pearya Terrane of northern Ellesmere Island based mainly on the occurrence Ordovician blueschist and eclogite complexes and their potential link to the M'Clintock Complex of the Pearya Terrane (e.g. Gee & Tebenkov, 2004; Kośmińska *et al.*, 2014; Mazur et al., 2009; Majka et al., 2015). Especially, the recent discovery of ca. 950 Ma metaigneous rocks overprinted by the Torellian (ca. 640 Ma) and Caledonian subduction-related metamorphism within the Southwestern Province (Majka et al., 2015) as well as documentation of other lithologies metamorphosed during the Torellian event (e.g. Majka, Mazur, Manecki, Czerny, & Holm, 2008; Majka, Czerny, Larionov, Pršek, & Gee, 2012) show close similarities of this province to at least parts of the Northwestern Province, namely the Richarddalen Complex, where there is a record of Tonian magmatism followed by formation of ca. 640 Ma partial melts and Caledonian high pressure metamorphism (e.g., Gromet & Gee, 1996). Thus, both the Northwestern and Southwestern provinces could have formed one composite terrane located preferentially somewhat north of Ny-Friesland close to Laurentia (Figure 5; in the vicinity of the Pearya Terrane of Ellesmere Island). However, an alternative position of these terranes close to the Baltican margin in the vicinity of the Timanides (the idea based on the widespread evidence for Torellian metamorphism in the Southwestern Province) cannot be rejected at this stage of research. Notwithstanding the above speculation, our tentative model for post-Caledonian assembly of Svalbard's basement suggests a close link between the Northwestern and Southwestern provinces in the late Neoproterozoic and their juxtaposition with the West Ny-Friesland terrane originally located in the direct proximity to Northeast Greenland (Figure 5). Similarly, the West Ny-Friesland and Nordaustlandet terranes were juxtaposed along the same left-lateral strike system (Figure 5). Although the relative position of these two terranes is uncertain, the data presented herein support a Laurentian origin for both terranes. Additional isotopic age data are required to significantly advance discussions of mechanisms and timing of assembly of Baltica- vs. Laurentia-derived terranes along the sinistral strike-slip system observed within the crystalline basement of Svalbard.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Data S1. Petrographic description of the dated samples, detailedmethodology and geochronological data.

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