Open Research Europe

Open Research Europe 2024, 3:189 Last updated: 30 JUL 2024

Check for updates

RESEARCH ARTICLE

REVISED Implications of Timanian thrust systems in the Barents Sea and Svalbard on using paleontological constraints for plate tectonics reconstructions [version 2; peer review: 3 approved]

Jean-Baptiste P. Koehl[1,2]

[1]Earth and Planetary Sciences, McGill University, Montreal, Québec, H3A 0E8, Canada
[2]Geosciences, Universitetet i Oslo, Oslo, Oslo, 0371, Norway

v2 **First published:** 07 Nov 2023, **3**:189
https://doi.org/10.12688/openreseurope.16674.1
Latest published: 12 Jul 2024, **3**:189
https://doi.org/10.12688/openreseurope.16674.2

Open Peer Review

Approval Status ✓ ✓ ✓

	1	2	3
version 2 (revision) 12 Jul 2024	✓ view	✓ view	
version 1 07 Nov 2023	? view	? view	✓ view

1. **Alfonsa Milia**, National Research Council of Italy, Rome, Italy
2. **Esther Izquierdo-Llavall**, Instituto Geológico y Minero de España, Zaragoza, Spain
3. **Alexandre Kounov**, Basel University, Basel, Switzerland

Any reports and responses or comments on the article can be found at the end of the article.

Abstract

Background

The Svalbard Archipelago is commonly believed to have been located at comparable latitude and, possibly, to have been attached to Laurentia in the early Paleozoic (500–420 Ma) based on trilobite assemblage similarities. Trilobite assemblage differences and lack of mixing between Laurentia–Svalbard and Baltica were further used to propose that these continents were separated by the Iapetus Ocean at that time. However, recent structural correlation of Timanian (650–550 Ma) thrust systems throughout the Barents Sea show that Svalbard was already attached to Baltica in the latest Neoproterozoic and remained so during the Phanerozoic.

Methods

The present study presents a new interpretation of seismic reflection data from the DISKOS database, which were tied to nearby exploration wells. The study uses recently acquired knowledge of the seismic facies of intensely deformed pre-Caledonian rocks and principles of seismic stratigraphy to interpret the data.

Results

The present study reconciles the proximity of Svalbard and Laurentia with the early accretion of Svalbard to Baltica in the latest

Neoproterozoic. It also describes the influence of Timanian thrust systems on paleoenvironments and possible effects on trilobite assemblages, *e.g.*, the lack of mixing between those of Laurentia–Svalbard and Baltica.

Conclusions

The identification of elongate, emerged topographic highs in the Barents Sea and Svalbard in the late Neoproterozoic–early Paleozoic suggest that paleontological constraints should be considered with greater care when discussing continent separation since thrust systems may act as major faunal barriers within a single tectonic plate. Other factors to consider when discussing plate separation include paleoclimatic belts.

Plain language summary

Previous paleontological studies have used the differences in faunas (in the present case, now extinct fossil occurrences of trilobites) between two or more continental blocks (presently the Svalbard Archipelago, North America, and Scandinavia) to infer separation of these blocks by large distances up to several thousands of kilometers ca. 550 to 420 million years ago due to global plate tectonics processes. The present study shows that this method is biased because previous studies undermined factors such as climatic belts and (topographic) faunal barriers such as large, mountain-building cracks in the Earth's crust. The study builds on previous work on seismic data in the Barents Sea and Svalbard, which identified continuous, thousands of kilometers long, tens of kilometers thick networks of cracks extending from northwestern Russia to Svalbard and potentially northern Greenland, which formed 650 to 550 million years ago, therefore demonstrating a connection between all these continental blocks at 550-420 Ma.

Keywords

Svalbard, Laurentia, Baltica, Timanian Orogeny, Caledonian Orogeny, thrust, faunal barrier, trilobite, climate belt, faunal recruitment, Neoproterozoic, Cambrian, Ordovician

Corresponding author: Jean-Baptiste P. Koehl (jeanbaptiste.koehl@gmail.com)

Author roles: Koehl JBP: Conceptualization, Data Curation, Formal Analysis, Funding Acquisition, Investigation, Methodology, Project Administration, Visualization, Writing – Original Draft Preparation, Writing – Review & Editing

Competing interests: No competing interests were disclosed.

Grant information: This project has received funding from the European Union’s Horizon 2020 research and innovation program under the Marie Skłodowska-Curie Action fellowship (grant agreement No 101023439).

Copyright: © 2024 Koehl JBP. This is an open access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

How to cite this article: Koehl JBP. **Implications of Timanian thrust systems in the Barents Sea and Svalbard on using paleontological constraints for plate tectonics reconstructions [version 2; peer review: 3 approved]** Open Research Europe 2024, **3**:189 https://doi.org/10.12688/openreseurope.16674.2

First published: 07 Nov 2023, **3**:189 https://doi.org/10.12688/openreseurope.16674.1

REVISED **Amendments from Version 1**

The comments by Dr. Alfonsa Milia led to an update of the seismic interpretation in Figure 2b–c and Figure 3c–d. In addition, a few technical terms were updated throughout the manuscript (e.g., "sequence stratigraphy" into "seismic stratigraphy", "toplap" into "erosional truncation"). Also added a new Figure 1 with a paleogeographic reconstruction by Smethurst *et al.* (1998) showing the trilobite assemblages in the Early Ordovician of relevant continents.

On the suggestion of Dr. Esther Izquierdo-Llavall, a specification on the seismic data used for structural mapping in Koehl *et al.* (2022a) and Koehl and Stokmo (2024) was added. It would not be relevant for the present paper to include several figures published in previous manuscript (seismic dataset and magnetic anomaly map). Also added additional paragraphs to explain why none of the interpreted ifaults are normal faults and a paragraph about paleomagnetic data in the introduction. Additional specifications were added to the figures (e.g., location of the wellbores, scales) and figure captions.

A description of Svalbard's three terranes and minor modifications to Figure 1b were included on the suggestion by Dr. Alexandre Kounov.

Finally, the author of the present manuscript updated the literature list on the Cambrian fauna (trilobites and acritarch) of northern Greenland and added paleothermocline as a potential barrier to biological mixing based on the suggestion by Prof. John Peel (by email).

Any further responses from the reviewers can be found at the end of the article

Introduction

Paleontological constraints have been extensively used in trying to understand plate tectonics over the past 100 years, *e.g.*, von Ubisch (1921, 1928), Eckhardt (1922), Colosi (1925), and de Beaufort (1925) who were some of the first scientists to use paleontological records of South America and western Africa to support Wegener's Continental Drift theory (Wegener, 1929). It is now widely accepted that South America was juxtaposed to western Africa in the late Paleozoic–Mesozoic, forming part of the supercontinent named Pangea and, thus, explaining similar paleontological records in upper Paleozoic–Mesozoic sedimentary rocks on both continents (*e.g.*, Cisneros *et al.*, 2015; Modesto, 2006; Trewick, 2017). Similarly, faunal analyses already by Lemoine (1911) showed that Madagascar remained relatively close to eastern Africa until the mid-Cenozoic, while India had already been rifted away.

Later on, paleontological records were further used to infer land or sea connections between continents (*e.g.*, Hansen & Holmer, 2011) and, even in some cases, estimate the minimum distance between two continents and the width of oceanic domains. This is the case of the Iapetus Ocean between Baltica and Laurentia, which was estimated to reach a maximum width of up to 5000 kilometers in the Ordovician, based on paleomagnetic and paleontological data (Cocks & Torsvik, 2002; Domeier, 2016; Torsvik & Trench, 1991; Figure 1). This is yet to be supported by paleomagnetic data, which are sparse and of poor quality in Baltica and inexistent in Svalbard for that period (e.g., Torsvik & Rehnström, 2001). In addition, paleomagnetic data only yields information on the latitude position of continents and are worthless to resolve longitudinal movements, which have been dominating the most recent Wilson Cycle (E–W seafloor spreading in the Atlantic, Pacific, and central Indian oceans). The resolution of paleomagnetic data (550 km; Butler, 1992) and occasionally aberrant behavior (Abrajevitch & van der Voo, 2010) are other obstacles to the use of such data for paleogeographic reconstructions.

The use of faunal assemblages to infer the paleogeographic position of continental blocks is generally restricted to shallow-marine (*e.g.*, Ordovician trilobites in Svalbard, Baltica and Laurentia; Fortey, 1984; Fortey & Bruton, 2013; Fortey & Cocks, 2003) or terrestrial groups (*e.g.*, *Mesosaurus*; Modesto, 2006) since deep-marine faunas may spread over entire oceans (*e.g.*, conodonts; Bergström, 1983; Wright & Stigall, 2013). Terrestrial and shallow-marine faunas are more prone to allopatric speciation by vicariance, *i.e.*, the isolation of a population by (a) geographic barrier(s) such as mountain ranges (Trewick, 2017; Wright & Stigall, 2013). Such barriers are known to have broadly affected faunas in Laurentia in the Ordovician (*e.g.*, onset of Taconian Orogeny; Wright & Stigall, 2013). However, recent studies show that vicariance events may also affect marine faunas for tens of millions of years. For example, in the past 25 Myr, the configuration of the continents formed major barriers (Terminal Tethyan Event, Isthmus of Panama, East Pacific Barrier), which prevented and in places still prevent the exchange of tropical faunas between the main biogeographical regions (Cowman & Bellwood, 2013).

A key feature is the use made of Lower Cambrian and Lower Ordovician shallow water trilobite assemblages in Laurentia, Svalbard, and Baltica to infer terrane amalgamation and separation through time. In the early Cambrian, while Laurentia (Fritz, 1972; Poulsen, 1974) and southwestern Spitsbergen showed remains of Olenellus svalbardensis Kielan (Birkenmajer, 1978; Birkenmajer & Orlowski, 1977; Kielan, 1960; Major & Winsnes, 1955), the Cambrian trilobite record of Baltica was dominated by specimen of the Holmia, Schmidtiellus, and Kjerulfia genera (Holmiidea family, olenellid trilobite; Ahlberg *et al.*, 1986), together with ptychopariid trilobite (Ahlberg, 1980). Similarly in the Early Ordovician, Greenland and northeastern Spitsbergen were dominated by a bathyurid trilobite assemblage, Baltica showed primarily asaphid trilobites (Megistaspidinae and Ptychopygiinae), which were used to propose the presence of a broad oceanic domain, the Iapetus Ocean between Laurentia–northeastern Spitsbergen and Baltica in the Ordovician (Cocks & Torsvik, 2002; Domeier, 2016; Fortey & Bruton, 1973; Fortey & Bruton, 2013; Fortey & Cocks, 2003; Kröger *et al.*, 2017; Torsvik & Cocks, 2005; Figure 1). This model implies the presence of a major NE–SW-trending suture zone in the Barents Sea between Norway and Svalbard, which was suggested by previous

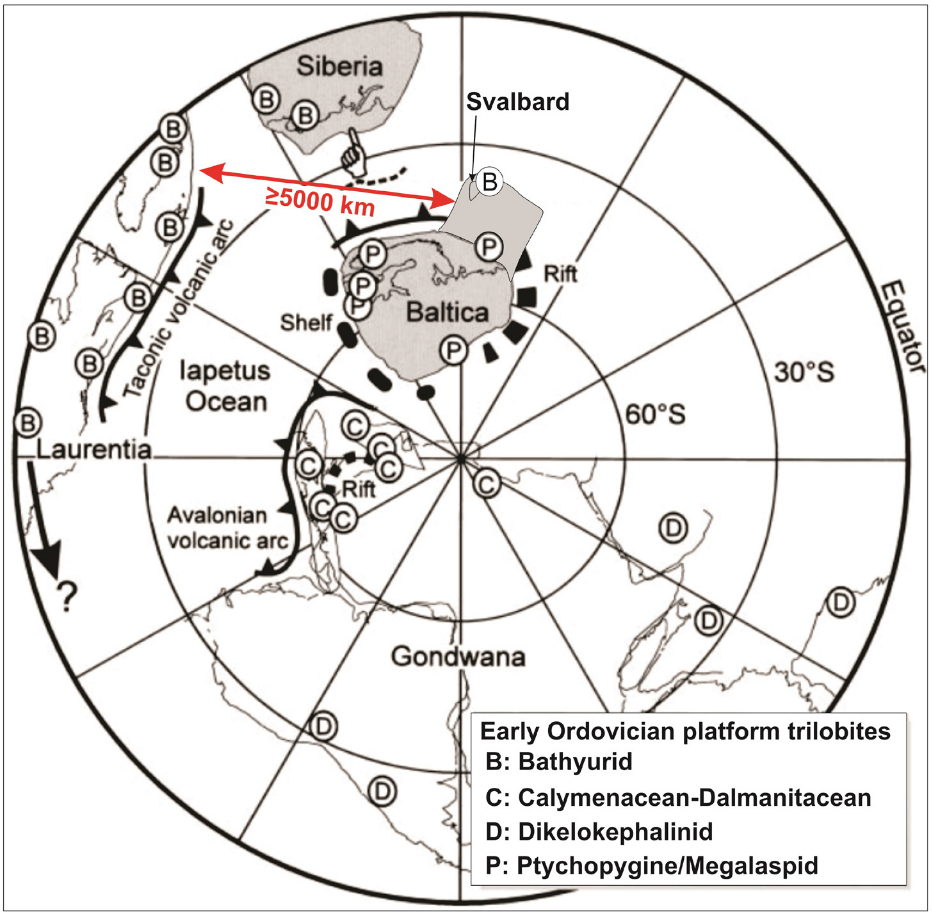

Figure 1. Paleogeographic and trilobite assemblages for relevant continents in the Early Ordovician modified after Smethurst *et al.* (1998). Notice the latitudinal change in the trilobite assemblages in Gondwana (including Avalonia), which is dominated by Calymenacean-Dalmanitacean trilobite in polar regions and by Dikelokephalinid at lower latitudes. The Svalbard Archipelago and the Barents Sea were added to Baltica based on the work by Koehl *et al.* (2022a) and Koehl *et al.* (2023). Also notice the c. 5000 km width inferred by previous works for the Iapetus Ocean between Baltica and Laurentia.

studies based on Ocean Bottom Seismometer data (Aarseth *et al.*, 2017; Barrère *et al.*, 2011; Breivik *et al.*, 2002; Breivik *et al.*, 2003; Breivik *et al.*, 2005; Gee & Teben'kov, 2004; Gee *et al.*, 2008; Gernigon *et al.*, 2014; Gudlaugsson *et al.*, 1998; Knudsen *et al.*, 2019; Krysinski *et al.*, 2013; Shulgin *et al.*, 2020). However, these monodisciplinary studies only considered the composition of the crust, and concrete evidence of such a major suture such as a fossil subduction zone and related structures (*e.g.*, fold and thrust systems) is lacking. In addition, other fossil assemblages, though they generally agree to a proximity of all Svalbard's basement terranes and North America, also show a similarity of fossil assemblages between Baltica and Laurentia in the Cambrian (Ahlberg *et al.*, 1986; Palmer & Peel, 1979; Poulsen, 1974; Babcock, 1994) and between Baltica and northeastern Svalbard in the Ordovician (Hansen & Holmer, 2011).

Recent analysis of seismic, magnetic, and gravimetric data throughout the Norwegian Barents Sea and the Svalbard Archipelago revealed the presence of several kilometers thick, deep, crustal-scale, hundreds–thousands of kilometers long, WNW–ESE-striking thrust systems, which display comparable top-SSW kinematics to and merge with Timanian fold and fault systems in the Russian Barents Sea, and onshore Novaya Zemlya and northwestern Russia (Koehl, 2020; Koehl *et al.*, 2022a; Koehl *et al.*, 2023; Figure 2a). Such orogenic systems are also found onshore–offshore northern Norway (Koehl & Stokmo, 2024). These thrust systems suggest that all terranes of the Svalbard Archipelago and the Barents Sea were already accreted to northern Norway at ca. 550 Ma and preclude the occurrence of large-scale strike-slip movements along major N–S-striking fault zones such as the Billefjorden Fault Zone during the Paleozoic (*e.g.*, Harland *et al.*, 1974; Harland *et al.*, 1992; Labrousse *et al.*, 2008) because these would truncate the late Neoproterozoic Timanian thrust systems. Furthermore, the presence of Timanian grain is thought to extend beyond the Svalbard margin into the Fram Strait (*e.g.*, Hovgård Ridge; Koehl, 2020), and possibly onshore northern Greenland (Estrada *et al.*, 2018a; Rosa *et al.*, 2016; Figure 2a).

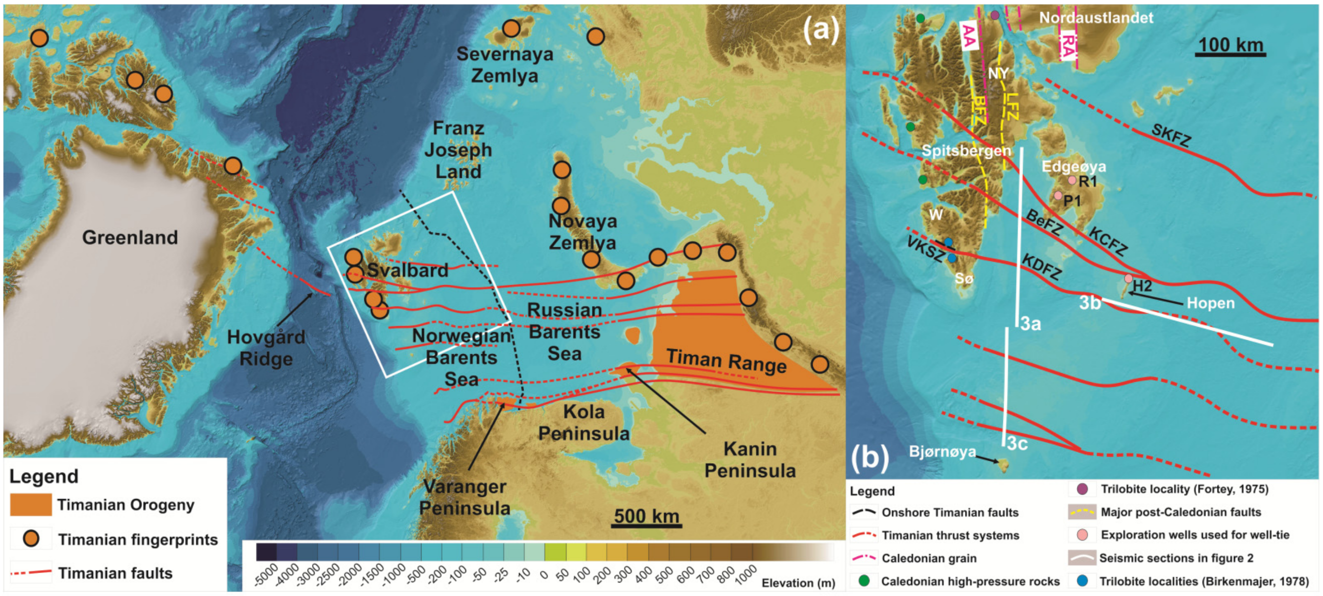

Figure 2. (**a**) Overview of Timanian thrust systems and fingerprints in the Norwegian Arctic showing the location of the study area (white frame). The dashed black line marks the boundary between the Russian and Norwegian Barents Sea. (**b**) Overview of the study area in the Norwegian Barents Sea showing major Timanian thrust systems and the location of seismic profiles displayed in Figure 3. Timanian thrusts are from Koehl *et al.* (2022a), Koehl *et al.* (2023), Koehl (2024), and Koehl & Stokmo (2024). The basemap is the International Bathymetric Chart of the Arctic Ocean from Jakobsson *et al.* (2012). Abbreviations: AA: Atomfjella Antiform; BeFZ: Bellsundbanken fault zone; BFZ: Billefjorden Fault Zone; H2: Hopen-2 exploration well; KCFZ: Kongsfjorden–Cowanodden fault zone; KDFZ: Kinnhøgda–Daudbjørnpynten fault zone; LFZ: Lomfjorden Fault Zone; NY: Ny Friesland; P1: Plurdalen-1 exploration well; RA: Rijpdalen Anticline; R1: Raddedalen-1 exploration well; SKFZ: Steiløya–Krylen fault zone; Sø: Sørkapp Land; VKSZ: Vimsodden–Kosibapasset Shear Zone; W: Wedel Jarlsberg Land.

The present contribution builds on the discovery of continuous Timanian thrusts throughout the Barents Sea and the Svalbard Archipelago by Koehl *et al.* (2022a) and discusses the importance of Timanian thrusts in these areas (Figure 2b) on the use of paleontological records in plate tectonics reconstruction, especially when used to estimate the distance between two continents and determine terrane amalgamation and separation. The present contribution explores the late Neoproterozoic–early Paleozoic history of the Svalbard and the Barents Sea through analysis of the seismic reflection data and discusses the role of tectonic structures as potential major biogeographical boundaries. For information on the geophysical data (which includes both 2D and 3D seismic reflection data, gravimetric and magnetic anomaly maps, and exploration wellbores, including well tie), the reader is referred to Koehl *et al.* (2022a) and Koehl & Stokmo (2024).

Geological setting

The lower Cambrian trilobite record of both southwestern Spitsbergen and Laurentia show comparable trilobite assemblages, including notably occurrences of Olenellus svalbardensis Kielan (Birkenmajer, 1978; Birkenmajer & Orlowski, 1977; Fritz, 1972; Kielan, 1960; Major & Winsnes, 1955; Poulsen, 1974), which belong to the Bonnia-Olenellus Zone of the Pacific trilobite province (Birkenmajer & Orlowski, 1977; Cowie, 1974). In Svalbard, such fossils occur in the in the Olenellusbreen Member of the Vardepiggen Formation and in the Flakfjellet Member of the Blåstertoppen Formation in Wedel Jarlsberg Land and Sørkapp Land (Birkenmajer, 1978; Birkenmajer & Orlowski, 1977; Fritz, 1972; Kielan, 1960; Major & Winsnes, 1955; Poulsen, 1974). Trilobite assemblages are supposedly different in Baltica and include mostly olenellid trilobites of the Holmiidea family (Holmia, Schmidtiellus, and Kjerulfia genera; Ahlberg *et al.*, 1986) and ptychopariid trilobites (Ahlberg, 1980), which typically define the Baltic trilobite province. It was therefore proposed that southwestern Spitsbergen was located close to Laurentia, but was separated from Baltica by large distances in the early Cambrian.

Similarly, based on trilobite fossil assemblage similarities, the northeastern terrane of Svalbard (*i.e.*, Ny Friesland and Nordaustlandet; see Figure 2b for location) is believed to have been located at comparable latitude and possibly adjacent to northeastern Greenland in the Ordovician (Cocks & Torsvik, 2002; Fortey, 1975; Fortey & Bruton, 2013; Fortey & Bruton, 1973; Fortey & Cocks, 2003; Kröger *et al.*, 2017; Smith & Rasmussen, 2008). Cocks and Torsvik (2002) and Fortey and Cocks (2003) further argue that the presence of bathyurid trilobites in both areas and their absence on Baltica, together with the presence of megistaspinid trilobites on Baltica and their absence in Laurentia–Svalbard suggest a broad separation of both continents in the Ordovician.

Moreover, the island of Bjørnøya in the Barents Sea shows Lower–Middle Ordovician sedimentary strata analogous to stratigraphic equivalents in northeastern Greenland (Smith, 2000;

Smith & Rasmussen, 2008). These overlie sedimentary rocks of presumed late Proterozoic age unconformably, thus suggesting a significant hiatus in the latest Neoproterozoic–earliest Ordovician, which is also comparable to the stratigraphic setting in northeastern Greenland (Smith, 2000; Smith *et al.*, 2004). These similarities are thought to reflect the proximity of Bjørnøya with northeastern Greenland in the Ordovician and, thus, that Bjørnøya was part of Laurentia at that time.

The Svalbard Archipelago (excluding Bjørnøya) is commonly believed to be divided into three terranes consisting of Proterozoic–early Paleozoic metamorphic rocks, which recorded different tectonothermal events (e.g., Harland, 1969; Harland *et al.*, 1992; Harland *et al.*, 1993). Svalbard's three terrane are commonly thought to have accreted during the early–mid Paleozoic Caledonian and Svalbardian orogenies through hundreds–thousands of kilometers long movements along major N–S-striking faults like the Billefjorden Fault Zone (Harland *et al.*, 1974; Harland *et al.*, 1992; Labrousse *et al.*, 2008). Similarly, the Barents Sea is thought to correspond to a composite continental terrane assembled and accreted with Baltica and Svalbard during the Caledonian Orogeny. The Iapetus Ocean suture is commonly thought to crosscut the Barents Sea in a NE–SW fashion between Svalbard and northern Norway as suggested mostly from Ocean Bottom Seismometer data (Aarseth *et al.*, 2017; Barrère *et al.*, 2011; Breivik *et al.*, 2002; Breivik *et al.*, 2003; Breivik *et al.*, 2005; Clark *et al.*, 2013; Gee *et al.*, 2008; Gee & Teben'kov, 2004; Gernigon *et al.*, 2014; Gudlaugsson *et al.*, 1998; Knudsen *et al.*, 2019; Krysinski *et al.*, 2013; Shulgin *et al.*, 2020). Although Ocean Bottom Seismometer data are reliable to discuss the composition of the crust and, therefore, to infer the possible presence of suture zones at depth (*e.g.,* Aarseth *et al.*, 2017; Breivik *et al.,* 2002; Breivik *et al.,* 2003; Breivik *et al.,* 2005), they do not provide much information about existing structures (including subduction-related structures such as folds and thrusts) and are not as reliable as interdisciplinary studies (*e.g.,* Klitzke *et al.,* 2019; Koehl *et al.,* 2022a). Notably, recent interdisciplinary works and reviews suggest that Svalbardian tectonism did not occur in Spitsbergen (Koehl, 2021; Koehl *et al.,* 2022b), that Svalbard's terranes and the Barents Sea were already amalgamated in the latest Neoproterozoic during the Timanian Orogeny at 650–550 Ma, and, thus, that the Iapetus suture is located in western Spitsbergen (Figure 2b), *i.e.*, significantly west of the Billefjorden Fault Zone (Koehl *et al.,* 2022a). Recent works also invalidated the occurrence of large-scale strike-slip movements along N–S-striking fault zone in Svalbard and the Barents Sea (Koehl & Allaart, 2021; Koehl *et al.*, 2022a).

The structural and tectonic study by Koehl *et al.* (2022a) provided for the very first time evidence of continuous, late Neoproterozoic (i.e., 650–550 Myr old) thrust systems throughout the Barents Sea and Svalbard, thus pinning these areas together since 650 Ma. The present study focuses on the implications of these thrust systems for paleontology and paleogeography and notably on the relationship between trilobite assemblages distribution and plate tectonic separation.

Methods

The present study is based on the interpretation of seismic reflection data in the northern Norwegian Barents Sea and Svalbard, which are all from the Norwegian National Data Repository for Petroleum Data (DISKOS database) of the Norwegian Petroleum Directorate. Seismic data were tied to exploration wells on Edgeøya (Raddedalen-1 and Plurdalen-1 wells; Bro & Shvarts, 1983; Harland & Kelly, 1997) and Hopen (Hopen-2 well; Anell *et al.*, 2014). See Koehl *et al.* (2022a, notably their method chapter) for detailed information on the well tie and for further discussion on the stratigraphy. Petrel (version 2021.3) was used to interpret the seismic reflection data, and CorelDraw (version 2017) was used to design the figures. Alternative open-source software are OpendTect and GIMP respectively.

The present study uses new knowledge in the seismic facies and structural character on seismic data of intensely deformed Proterozoic basement and lower Paleozoic metasedimentary rocks in the Barents Sea (see description of these successions in Koehl *et al.*, 2022a; Koehl *et al.*, 2023) and principles of seismic stratigraphy (e.g., erosional truncation, downlaps and onlaps; Mitchum *et al.*, 1977) to segregate them from overlying unmetamorphosed upper Paleozoic sedimentary successions. In order to be able to distinguish the various structures described in the present manuscript, high-resolution versions of the figures are found in *Underlying data* (Koehl, 2023).

Results

Proterozoic basement rocks

Proterozoic basement rocks typically show moderate–high-amplitude seismic reflections either arranged into up to 3–4 seconds (TWT) thick packages of moderately NNE-dipping reflections (see black lines in Proterozoic succession in Figure 3a–c), or into packages of gently undulating, typically poorly continuous reflections (see thin yellow lines in Proterozoic succession in Figure 3a–c and white lines in Proterozoic succession in Figure 4a). Reflections of the former packages terminate abruptly upwards within the Proterozoic succession or against lower–upper Paleozoic successions with erosional truncation geometries (see white half-arrows marking truncation by fuchsia reflections within Proterozoic succession in Figure 3a–c and Figure 4b). Reflections of the latter packages are either undulating gently with a similar wavelength as reflections of overlying lower Paleozoic succession (see thin yellow lines in Proterozoic succession in Figure 3a–c and Figure 4a), or truncated upwards by lower–upper Paleozoic successions (*e.g.*, white half arrows in Proterozoic succession in Figure 3c and Figure 4c). In places, the Proterozoic basement succession is characterized by moderate–high-amplitude, flat-lying reflections with relatively high continuity of up to 20–25 kilometers (see thick, flat-lying yellow lines in Proterozoic succession in the footwall of the Kongsfjorden–Cowanodden

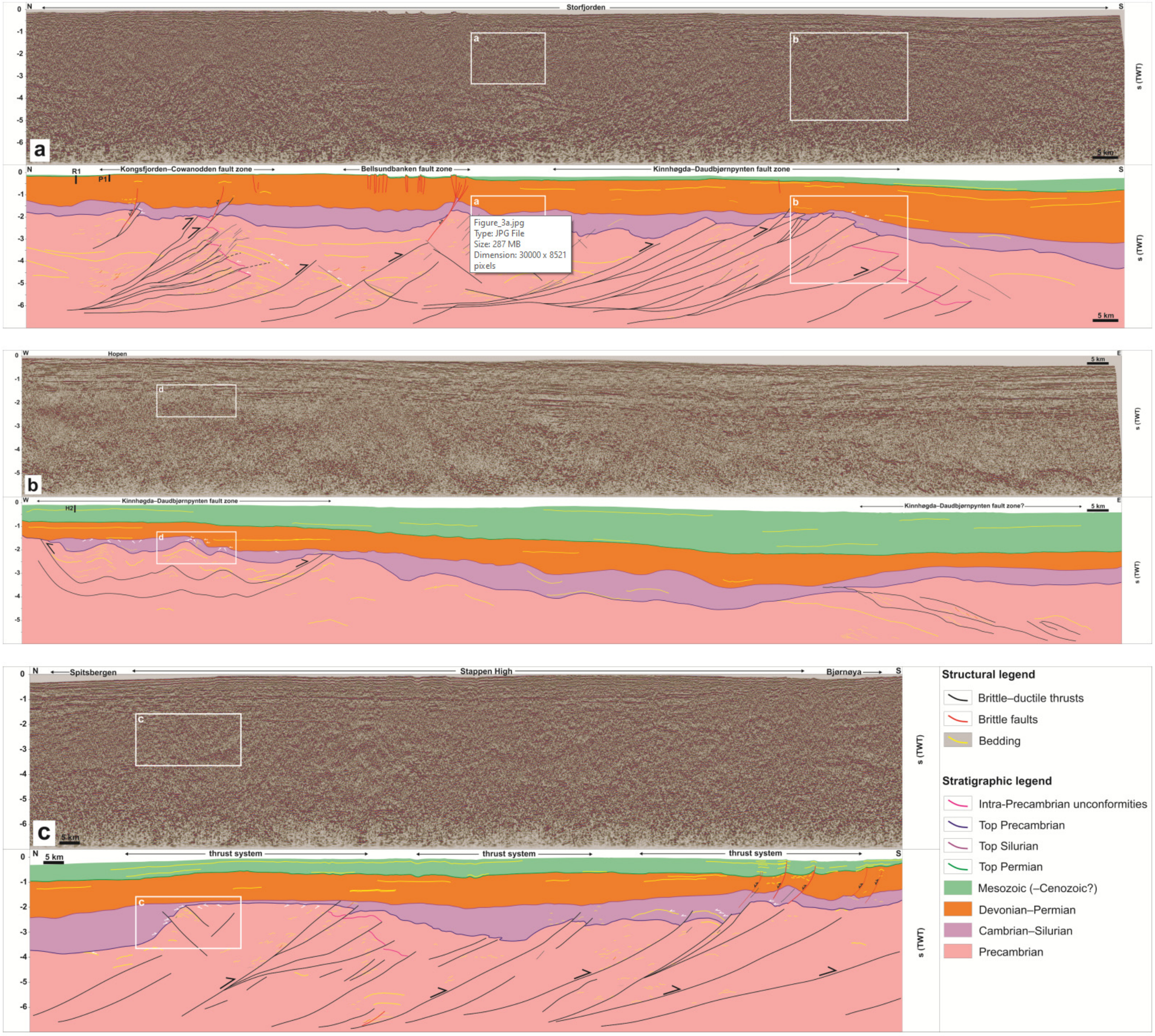

Figure 3. Seismic profiles (**a**) in Storfjorden, (**b**) south of Hopen, and (**c**) between Bjørnøya and Spitsbergen. The profiles show several kilometers thick, crustal-scale, dominantly NNE-dipping Timanian thrust systems (black lines) within Proterozoic basement rocks, and related overprints within lower Paleozoic, upper Paleozoic, and Mesozoic (–Cenozoic?) successions. The profiles also show major (erosional) unconformities between the Proterozoic basement, lower Paleozoic, and upper Paleozoic successions (white half-arrows). The projected location of exploration wells to which the interpretation was tied was added to (**a**) and (**b**). The projection was made along a WNW–ESE- to NW–SE-trending axis for the Raddedalen-1 and Plurdalen-1 wells in (**a**), i.e., parallel to the Kongsfjorden–Cowanodden fault zone, and along a NNE–SSW-trending axis for the Hopen-2 well in (**b**), i.e., perpendicular to Timanian fault systems. Note that the wells were drilled onshore above sea level. The depth of the projected traces of the wells is therefore not the same as the original well. However, the thickness of sediments penetrated by the wells is accurate and was time-converted to be directly compared with the interpreted seismic profiles (see Koehl *et al.*, 2022a their supplement S3 for more details). The white rectangles indicate the location of Figure 4a–d.

Fault Zone in Figure 3a). For a more detailed description of Proterozoic basement rocks and interpretation of thrust systems and related structures, the reader is referred to Koehl *et al.* (2022a).

Lower paleozoic rocks

The lower Paleozoic succession in the northern Norwegian Barents Sea and Svalbard Archipelago is typically 0.5–1 second (TWT) thick but reaches a thickness of c. 1.5 s (TWT)

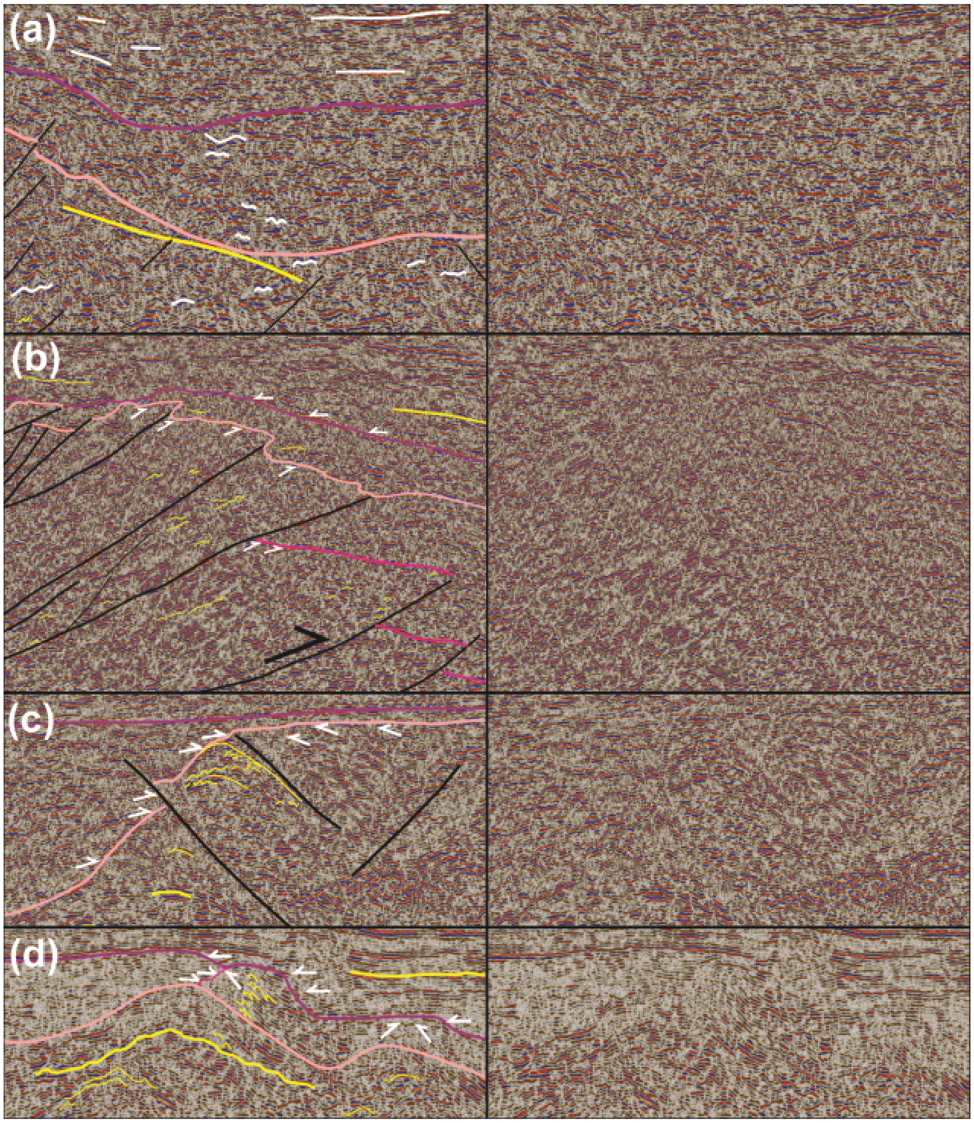

Figure 4. (**a**) Zoom in seismic data showing the undulating geometry of reflection characterizing Proterozoic basement and lower Paleozoic successions, whereas reflections within upper Paleozoic succession are relatively flat lying (white lines). (**b**) Zoom in seismic data showing erosional truncation geometries in moderately NNE-dipping reflections below the fuchsia and pink reflections in the north, and the onlapping character of reflections at the base of the upper Paleozoic succession over the lower Paleozoic reflection (white half-arrows). (**c**) Zoom in seismic data Between Bjørnøya and Sørkapp showing the onlapping character of reflections within the lower Paleozoic succession onto a Proterozoic basement paleo-high (white half-arrows) and early Paleozoic reactivation of an inherited Timanian thrust that offset the base of the lower Paleozoic succession in a reverse fashion. (**d**) Zoom in seismic data showing erosional truncation geometries near the top of the lower Paleozoic succession and onlap geometries at the base of the upper Paleozoic succession (white half-arrows). See location of (**a**–**d**) zooms in Figure 3. The legend is identical to Figure 3, except where specified otherwise. The location of (**a**–**d**) is shown as white rectangles in Figure 3a–c.

in places (*e.g.*, between Spitsbergen and Bjørnøya; Figure 3c). This succession consists of gently undulating, low–moderate-amplitude seismic reflections (see thin yellow lines within lower Paleozoic succession in Figure 3a–b and white lines within lower Paleozoic succession in Figure 4a). On E–W-trending seismic sections, some of these reflections are truncated upwards by flat-lying continuous reflections of the upper Paleozoic succession, thus resulting in erosional truncation geometries (see white half arrows in Figure 3b and Figure 4d). By contrast, erosional truncation geometries are sparse in this succession in N–S- to NNE–SSW-trending seismic sections. Instead, reflections within the lower Paleozoic succession appear to onlap Proterozoic basement rocks and, in places, they are laterally juxtaposed against or even partly overlain by Proterozoic basement rocks (*e.g.*, between Bjørnøya and Spitsbergen and in Storfjorden; Figure 3a and c and Figure 4c). Onlap geometries are consistently accompanied by thinning of the lower Paleozoic succession over Proterozoic basement highs, *e.g.*, between Bjørnøya and Spitsbergen where the succession shows a thickness << 0.5 second (TWT; Figure 3c and Figure 4c), or near Sørkapp and south of Hopen where it is completely absent in places (Figure 3a–b and Figure 4b and d).

Upper Paleozoic–Mesozoic sedimentary rocks

Upper Paleozoic–Mesozoic successions in the Barents Sea and Svalbard are characterized by relatively continuous and flat-lying reflections displaying both high and low amplitudes (Figure 3a–c and Figure 4a–b). The reflections either onlap Proterozoic–lower Paleozoic successions (white half arrows in upper Paleozoic succession in Figure 3a–b and Figure 4b and d), or parallel the Top lower Paleozoic reflection (Figure 3a–c and Figure 4a and c). Typical thickness of the upper Paleozoic succession is 1–1.5 second (TWT). The Mesozoic succession was largely eroded around the Svalbard Archipelago (Figure 3a) but it reaches a thickness > 2 seconds (TWT) towards the east and southeast (Figure 3b).

Discussion

Caledonian reactivation of Timanian thrusts and Proterozoic–early Paleozoic structural highs

Local erosional truncation geometries displayed by reflections within the lower Paleozoic succession against upper Paleozoic strata are interpreted as erosional unconformities and suggest that, in places, lower Paleozoic rocks in the northern Barents Sea were deposited and eroded prior to the Devonian (Figure 3b and Figure 4d). However, north of Bjørnøya, the lack of erosional truncation within the lower Paleozoic succession and the extremely thin character of this succession (much thinner than 0.5 second TWT) suggest that the area was likely a topographic high during most of the early Paleozoic (*i.e.*, non-deposition or deposition of a condensed succession; Figure 3c and Figure 4c). This is supported by the geometry of NNE- and SSW-dipping thrusts bounding the Proterozoic basement high. These thrusts propagate into overlying and adjacent lower Paleozoic rocks and offset the Top Proterozoic basement reflection, thus suggesting basement uplift due to minor top-SSW and top-NNE reactivation of Timanian thrust systems in the early Paleozoic (Figure 3c and Figure 4c). This episode of tectonism most likely reflects Caledonian reactivation–overprinting of Timanian thrust systems in this area, evidence of which are found throughout the Barents Sea and northern Norway (Koehl *et al.*, 2023; Koehl & Stokmo, 2024).

Similarly, offshore near Sørkapp, the lower Paleozoic succession is thinning dramatically and is even completely absent above portions of the Kinnhøgda–Daudbjørnpynten Fault Zone and does not show erosional truncation (Figure 3a–b and Figure 4b). In addition, basement-seated thrusts showing reverse offsets of the Top Proterozoic basement reflection transported slices of Proterozoic basement rocks onto lower Paleozoic rocks, thus indicating early Paleozoic thrusting and deposition of (part of) the lower Paleozoic succession into narrow foreland and piggy-back basins (Figure 3a and c and Figure 4b–c).

Reactivation of Timanian thrusts as sinistral-reverse faults during Caledonian contraction is also known from onshore southwestern Spitsbergen (Faehnrich *et al.*, 2020; Koehl *et al.*, 2022a; Mazur *et al.*, 2009). There, the Vimsodden–Kosibapasset Shear Zone segment of the Kinnhøgda–Daudbjørnpynten Fault Zone, which is associated to amphibolite facies metamorphism of Timanian age in nearby basement rocks (Majka *et al.*, 2008; Majka *et al.*, 2012; Manecki *et al.*, 1998) and a major erosional unconformity between Tonian–lower Cryogenian and upper Cryogenian–Ediacaran rocks (Bjørnerud, 1990; Bjørnerud *et al.*, 1991; Wala *et al.*, 2021), was completely overprinted by Caledonian deformation in the Middle Ordovician–Silurian (462 ± 11 Ma and 424 ± 6 Ma; Faehnrich *et al.*, 2020). Nevertheless, smaller nearby shear zones, which are less prone to reactivation and overprinting and strike parallel to the Vimsodden–Kosibapasset Shear Zone, may have preserved records of Timanian movement (Faehnrich *et al.*, 2020, their sample 16-73A), thus potentially illustrating the reactivation history of Timanian thrusts in the Norwegian Arctic. Note that the large-scale (hundreds of kilometers) strike-slip movements initially suggested by early studies of the Vimsodden–Kosibapasset Shear Zone were invalidated by the geometry of Timanian thrusts in Storfjorden (Koehl *et al.*, 2022a) and by the probable continuation of Timanian thrusts in the Fram Strait (Koehl, 2020; Koehl, 2024), northern Greenland (Estrada *et al.*, 2018a; Rosa *et al.*, 2016), and Arctic Canada (Estrada *et al.*, 2018b).

Other erosional unconformities exist onshore Svalbard between upper Neoproterozoic (Ediacaran) and lower Paleozoic rock successions. The northernmost is the unconformity observed between the Ediacaran Dracoisen Formation and the lower Paleozoic Kapp Sparre Formation in western Nordaustlandet (Stouge *et al.*, 2011). Koehl *et al.* (2022a, their supplement S2b) identified the presence of a major Timanian thrust in adjacent portion of the northern Barents Sea, the Steiløya–Krylen fault zone. It is probable that this major fault was reactivated during Caledonian contraction in the early Paleozoic, thus explaining the occurrence of the unconformity in western Nordaustlandet.

Some interpreted late Neoproterozoic Timanian thrusts are overlain by wedges of lower Paleozoic rocks thickening towards the faults (e.g., Figure 3a and c and Figure 4b). These geometries potentially suggest syn-tectonic sedimentation along normal faults in the early Paleozoic. Some of these potential normal faults are associated with upwards-convex reflections geometrically similar to rollover anticlines (e.g., southernmost thrust system in Figure 3c). However, most of the wedges of lower Paleozoic rocks can be explained by Caledonian reverse reactivation of nearby Timanian thrusts during mid-Paleozoic Caledonian contraction (e.g., Figure 3a and Figure 4b) with an interpretation as foreland/piggy-back basins. This is particularly well illustrated in Figure 4a and c.

Since most WNW–ESE-striking Timanian thrusts were not suitably oriented to accommodate E–W-oriented Caledonian contraction, many were not reactivated during the Caledonian Orogeny.

In addition, convex-upwards bedding reflections are found both within Proterozoic and lower Paleozoic (metamorphosed) basement rocks, some of which are onlapped by lower Paleozoic sedimentary rocks (Figure 3c). This would imply continuous normal faulting during the late Neoproterozoic–early Paleozoic. This contrasts markedly with the occurrence of major thrust-cored basement highs in the area (e.g., northern thrust system in Figure 3c), contractional indicators within all basement-seated thrust systems in the study area (e.g., asymmetric folds, contractional duplexes, antiformal thrust stacks, and minor thrusts; Figure 3a–c and Koehl *et al.*, 2022a their Figure 4a–e), and reverse offsets of the lower Paleozoic rock succession in nearby areas (Figure 3c and Figure 4c) together with onshore evidence for two major contractional events during this period (Timanian and Caledonian orogenies; Braathen *et al.*, 1999; Majka *et al.*, 2008; Mazur *et al.*, 2009).

Furthermore, some of the apparent traces of normal faulting occur within major Proterozoic basement highs, which were therefore deeply eroded in the early Paleozoic. Since Timanian mylonitic thrust systems represent major rheological discontinuities, it is highly probable that they contributed to shaping the relief carved by erosion in the early Paleozoic and created some depression, which were later passively filled with lower Paleozoic sediments.

Use of trilobite assemblages to infer disconnection of Baltica and Svalbard in the Cambrian–Ordovician

The marked differences in trilobite assemblages in southwestern Spitsbergen and Laurentia (presence of Olenellus svalbardensis Kielan; Birkenmajer, 1978; Birkenmajer & Orlowski, 1977; Fritz, 1972; Kielan, 1960; Poulsen, 1974), and in Baltica (dominance of Holmia, Schmidtiellus, and Kjerulfia genera of the Holmiidea family; Ahlberg, 1980; Ahlberg *et al.*, 1986) led previous workers to suggest a proximity of the southwestern terrane of Spitsbergen with Laurentia and a separation by large distances with Baltica (*e.g.*, Torsvik & Cocks, 2016). The lower Cambrian trilobites in Svalbard were found in shallow sea sediments (dolomite) of the Blåstertoppen Formation (Birkenmajer, 1978).

In addition, bathyurid and megistaspinid trilobites found exclusively on Laurentia–northeastern Spitsbergen and Baltica respectively were used to suggest that these continents were disconnected in the Early Ordovician. Both groups are thought to have evolved mostly in shallow seas and to reflect shallow marine environments (Fortey & Cocks, 2003).

Seismic data in the northern Barents Sea and Svalbard clearly show that elongated, WNW–ESE-trending highs following reactivated–overprinted Timanian thrust systems existed in the early Paleozoic (Figure 3a and c, and Figure 4b–c). Extremely thin to absent lower Paleozoic successions over these highs suggest that they were emerged above sea level for most of the early Paleozoic, *i.e.*, an environment not habitable by trilobites. These emerged WNW–ESE-trending highs formed in the late Neoproterozoic (–earliest Paleozoic?) and represented discrete topographical barriers between the southern (Baltica) and northern (Svalbard) portions of the continent. These barriers are thought to have prevented exchanges and mixing between trilobite communities of Baltica and Svalbard and to have acted as barriers between shelf faunas (Figure 5a). This is further illustrated by the hiatus between uppermost Neoproterozoic and Early–Middle Ordovician sedimentary rocks onshore Bjørnøya (Smith, 2000), which suggests that this island was largely emerged throughout the Cambrian and exposed to continental erosion, and by shallow marine fossil assemblages within Lower–Middle Ordovician rocks on the island indicating persisting shallow marine environment during the Ordovician. The presence of elongated highs in the Barents Sea is also supported by erosion or non-deposition of early–middle Cambrian deposits along NW–SE-trending highs in the Timanides of northwestern Russia (Bogolepova & Gee, 2004).

Furthermore, the large number of WNW–ESE-striking Timanian thrusts in the Barents Sea suggest that, even if a few, N–S-trending, shallow marine connections (*e.g.*, N–S-trending troughs) existed between the footwall and hanging wall of individual WNW–ESE-striking Timanian thrusts, dispersal of marine shelf faunas between Baltica and Svalbard–Laurentia would have been difficult due to the large number of topographical barriers (*i.e.*, Timanian thrusts) between Baltica and Svalbard (Figure 5a). Note that such barriers did not impede exchanges between northern Norway and northwestern Russia as suggested by comparable continental to shallow marine faunal assemblages in the Ediacaran–Cambrian (*e.g.*, Desiatkin *et al.*, 2021; Högström *et al.*, 2013; Jensen *et al.*, 2018; Kolesnikov, 2019; Kolesnikov & Desiatkin, 2022). Additional obstacles to faunal mixing between Svalbard and Baltica may have been related to (1) climatic and environmental barriers due to the latitude difference between Svalbard, which was located at relatively low latitude comparable to Laurentia and Siberia (both of which also display bathyurid trilobite assemblage), and Baltica, which was located at mid to high southerly latitudes (*e.g.*, Cocks & Torsvik, 2002; Cocks & Torsvik, 2021; Fortey & Cocks, 2003; Figure 1), and (2) to the onset of Caledonian folding and thrusting in the Early Ordovician in Baltica (Eide & Lardeaux, 2002; Roberts *et al.*, 2002) and in Svalbard (Dallmeyer *et al.*, 1990; Horsfield, 1972), hence further compartmentalizing the Barents Sea and preventing faunal exchanges between Baltica and Svalbard (Figure 5b). Caledonian deformation both formed new N–S- to NNE–SSW-striking thrusts (e.g., Braathen *et al.*, 1999; Ohta, 1979; Ohta *et al.*, 1986; Witt-Nilsson *et al.*, 1998) and reactivated WNW–ESE-striking Timanian thrusts with minor dominantly sinistral strike-slip to reverse movements (e.g., Koehl *et al.*, 2022a; Koehl *et al.*, 2023; Mazur *et al.*, 2009), reworking some of them into NNE–SSW-striking folds and thrusts (Koehl *et al.*, 2022a; Koehl *et al.*, 2023; Koehl & Stokmo, 2024). It is worth noting that transgressive events

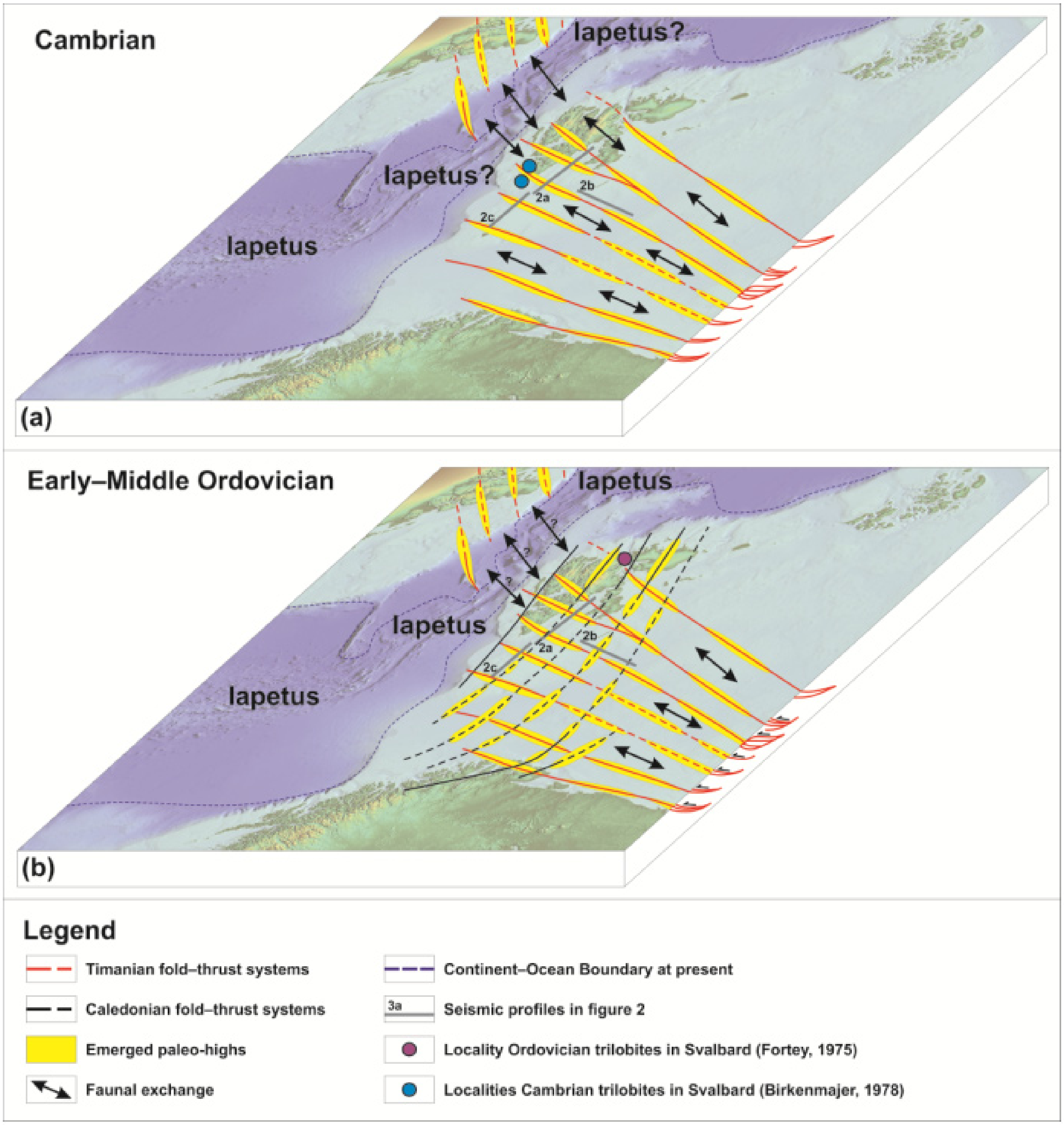

Figure 5. Conceptual model showing how emerged paleo-highs in the Barents Sea and Svalbard following (**a**) preexisting Timanian thrusts in the Cambrian and (**b**) both inherited (and reactivated) Timanian and newly formed Caledonian thrusts in the Ordovician controlled biological exchanges/mixing between Svalbard and Baltica in the early Paleozoic. Despite the opening of Iapetus, biological mixing between Greenland and Svalbard may have been possible until the Early Ordovician when top-east/southeast Caledonian thrusting and folding initiated, which was possibly compensated by transgression due to the closing of Iapetus (Fortey, 1984). Present Continent–Ocean Boundary is from Dumais *et al.* (2020).

related to the closing of Iapetus may have partly compensated Caledonian folding and thrusting in the Ordovician in the north, therefore probably further allowing continuous exchange between Svalbard and Greenland (Fortey, 1984).

A critical example of the described climatic and environmental barrier is illustrated by the distribution of Early Ordovician trilobite in Gondwana (Smethurst *et al.*, 1998; Figure 1). Northern Africa and Avalonia were located near the South Pole and show Calymenacean–Dalmanitacean assemblages, whereas other parts of Gondwana located at lower latitudes (e.g., South America, Arabia, India, and Australia) show Dikelokephalinid assemblages (Figure 1).

Fossil assemblages are still very useful in inferring connections between continents, *e.g.*, juxtaposition of South America and western Africa in the late Paleozoic–Mesozoic (Cisneros *et al.*, 2015; Colosi, 1925; de Beaufort, 1925; Eckhardt, 1922; Modesto, 2006; Trewick, 2017; von Ubisch, 1921; von Ubisch, 1928) or a connection of northern Norway with northwestern Russia in the Ediacaran–Cambrian (Desiatkin *et al.*, 2021; Högström *et al.*, 2013; Jensen *et al.*, 2018; Kolesnikov, 2019; Kolesnikov & Desiatkin, 2022), but the present study shows that the use of paleontological markers to infer disconnection between continents should be considered with care. In the present case, the Svalbard Archipelago was accreted to Baltica and to Laurentia in the latest Neoproterozoic during the Timanian Orogeny (Koehl, 2020; Koehl *et al.*, 2022a). Svalbard remained attached to Baltica throughout the Paleozoic–early Cenozoic. In the early Paleozoic, Svalbard was separated from Laurentia by the Iapetus Ocean and later collided with Laurentia as suggested by blueschist and eclogite facies metamorphism of Caledonian age in western Spitsbergen (Dallmeyer *et al.*, 1990; Horsfield, 1972; Kosminska *et al.*, 2014; Ohta *et al.*, 1995). However, the maximum distance between Svalbard and Laurentia at that time remains speculative. The Iapetus Ocean between Svalbard and Laurentia may have reached a width of several thousands of kilometers just like between Laurentia and Baltica (*e.g.*, Domeier, 2016; Torsvik & Trench, 1991) or may have been significantly narrower. The fossil records on both continents simply suggest that exchanges of shelf faunas were possible between Svalbard and Laurentia in the early Cambrian–earliest Ordovician and, thus, that these two continents were possibly located close to each other and/or that they remained at a similar latitude (e.g., Figure 1 and Figure 5a–b). Blueschist–eclogite facies metamorphism in western Spitsbergen indicates that oceanic crust was subducted between Svalbard and Laurentia in the early Paleozoic, *i.e.*, that the suture of the Iapetus Ocean is most likely located in western Spitsbergen and that Svalbard and Baltica remained attached to each other throughout the Paleozoic, which is further supported by the identification of Timanian thrusts in the Loppa High and the southwestern Barents Sea (Koehl *et al.*, 2023).

It is worth noting that other biotic assemblages such as acritarchs and chitinozoans do not yield the same results as trilobites when considering a disconnection between Baltica and Laurentia in the Cambrian–Ordovician (Servais *et al.*, 2005; Slater *et al.*, 2017). Fortey and Mellish (1992) previously used biased arguments (e.g., unrevised dataset of acritarch species) to discredit the use of these groups (Servais *et al.*, 2023). However, acritarchs and chitinozoans are now known to be just as valuable paleogeographic indicators as trilobites and show similar assemblages on both Baltica and Laurentia, thus suggesting a proximity of the two paleocontinents (Servais *et al.*, 2005; Servais *et al.*, 2023; Slater *et al.*, 2017), *i.e.*, contrasting with the results from trilobite faunas.

The trilobite fossil record of Laurentia, Baltica, and Svalbard is also not without ambiguities. For instance, Poulsen (1974) and Palmer and Peel (1979) showed that specimens of the Holmia genera, which are representative of the Baltican trilobite province (Ahlberg *et al.*, 1986), are also found in northeastern Greenland (*i.e.*, Laurentia), therefore suggesting a link between Baltica and Laurentia in the early Cambrian rather than a separation by large distances.

Another potential bias is the lack of consideration of paleothermoclines, which appear to have controlled the distribution of trilobites in northern Greenland in the middle Cambrian (Babcock, 1994). There, deep-water polymeroid trilobites show affinities to shallow, cool-water assemblages in paleocontinents located at high paleolatitude at that time, i.e., Baltica (Babcock, 1994). The resemblance of northern Greenland deep-water fauna with Baltican fauna was initially used to ascribe an allochthonous character to middle Cambrian rocks in northern Greenland (i.e., exotic terrane). However, cool-water species were proven to be ubiquitous regardless of depth and latitude. In addtion, mixing of the Baltican and Laurentian trilobite assemblages occurred through gravity flow in northern Greenland, therefore invalidating the possibility of large tectonic transport of the rocks containing the Baltican assemblages in the middle Cambrian (Babcock, 1994). These rocks were simply deposited at discrete levels in the water column (i.e., different temperature conditions and depositional environment). Babcock (1994)'s study not only suggests a strong influence of temperature (paleothermocline) on the distribution of fauna, but also an affinity of Laurentia and Baltica in the middle Cambrian, thus further questioning the use of trilobite assemblages to infer tectonic plate separation.

Implications for plate reconstructions worldwide

The present study suggests that paleontological evidence, alone, is not a robust enough argument to infer long-distance separation of two continents or terranes. Consequently, many plate tectonics reconstructions, including recent ones, using the paleontological record as a discriminating factor should be reexamined. For example, Popov and Cocks (2017) using the faunal recruitment principle of Fortey and Cocks (2003) proposed a separation of all the Kazakh terranes by at least 1000 km from one another, and a similar separation (of the Kazakh terranes) with Siberia and Baltica in the early Paleozoic based on faunal assemblages, thus suggesting that the Kazakh terranes formed an archipelago several thousands of kilometers wide. Such enormous size is unrealistic as shown by the space problem it generates on plate reconstructions with other major continents located at similar latitude such as Baltica and Laurentia (Domeier, 2018). It is therefore paramount to distinguish stand-alone discriminating factors and factors to be used in combination with others, and to establish clear guidelines as to what factors or combination of factors do warrant major continent/terrane separation.

The Earth's sedimentary record represents only local and partial records of past faunal assemblages during specific time periods because of the non-deposition of sediments and their erosion in emerged areas for example. Let us image a distant future in which the fossil record of polar bears in Norway, Sweden and Finland was non-existent, due to for example non-preservation of polar bear remains in emerged areas of Norway and/or erosion of most if not all of the sedimentary record of the past few million years. This is reasonable because Norway does not show any onshore sedimentary record of the Cretaceous–early Cenozoic period for example (*i.e.*, more than 100 Myr), whereas both Greenland and Svalbard show Cretaceous and early Cenozoic sedimentary strata (*e.g.*, Dallmann, 2015; Stemmerik *et al.*, 1998; Svennevig, 2018). Let us also imagine that the sedimentary record from present-day and onwards in both Greenland, Norway, and Svalbard was preserved and captured the current distribution of polar bears in Arctic areas (*i.e.*, in Greenland and Svalbard; Dupouy-Camet *et al.*, 2017). Following the faunal recruitment principle proposed by Fortey and Cocks (2003), paleontologists examining the fossil record of the present-day period and onwards in Greenland, Svalbard, and Norway millions of years from now could infer that the former two were likely part of the same tectonic plate and were disconnected from (not on the same plate as) the latter based on the presence of polar bear remains both in Greenland and Svalbard but not in Norway (see current distribution of polar bears in Dupouy-Camet *et al.*, 2017). This is erroneous because Svalbard belongs to the same tectonic plate as Baltica (Eurasian Plate), whereas Greenland belongs to the North American Plate. The faunal recruitment principle of Fortey and Cocks (2003) simply does not take into account environmental factors such as paleoclimatic belts, paleothermoclines, and major tectonic structures, which may play a significant role in the distribution of species and resulting fossil record.

Conclusions

In the early Paleozoic, inherited Timanian thrust systems defined WNW–ESE-trending paleo-highs exposed to continental erosion in the northern Barents Sea. These highs acted as dispersal barriers for shallow marine faunas (*e.g.*, Cambrian–Ordovician trilobites) that have been commonly used to infer continent–terrane separation in plate tectonics reconstructions. While the trilobite record suggests that Svalbard and Baltica were disconnected in the Cambrian–Ordovician, the presence of continuous, crustal-scale Timanian thrust systems throughout the Barents Sea and the Svalbard Archipelago indicates that Svalbard was accreted to Baltica in the latest Neoproterozoic and that these two continents remained attached to each other throughout the Paleozoic. The present study therefore suggests that paleontological records alone are not robust enough proxies to infer continent and/or terrane disconnection since other factors (*e.g.*, major thrust systems, latitude differences, paleoclimatic belts, and paleothermocline) may play a significant role in preventing exchange and mixing between biological assemblages of aggregated continental plates during extended periods of time.

Data availability

Source data

The Two-Way Time (TWT) seismic reflection data used in the present study is under license by the DISKOS (Norwegian National Data Repository for Petroleum Data) database of the Norwegian Petroleum Directorate. The data may be accessed for research purposes and access can be requested by contacting the Norwegian Petroleum Directorate at https://www.npd.no/fakta/om-oss/kontakt-oss/.

Underlying data

DataversNO: Replication data for: Implications of Timanian thrusts systems in the Barents Sea and Svalbard on using palontological constraints for plate tectonics reconstructions. doi.org/10.18710/BWZHL8 (Koehl, 2023).

This project contains the following underlying data:

- 00_ReadMe.txt. (detailed instructions to reuse the dataset and dataset relationship to existing contributions and datasets)
- Figure 1–Figure 5 (high resolution versions of the figures included in the present manuscript in jpg format. All copyright permissions granted).

Acknowledgements

The Norwegian Petroleum Directorate is thanked for granting access and allowing publication of seismic data in the Barents Sea and Svalbard.

References

Aarseth I, Mjelde R, Breivik AJ, *et al.*: **Crustal structure and evolution of the Arctic Caledonides: results from controlled-source seismology.** *Tectonophysics.* 2017; **718**: 9–24.
Publisher Full Text

Abrajevitch A, van der Voo R: **Incompatible ediacaran paleomagnetic directions suggest an equatorial geomagnetic dipole hypothesis.** *Earth Planet Sci Lett.* 2010; **293**(1–2): 164–170.
Publisher Full Text

Ahlberg P: **Early Cambrian trilobites from northern Scandinavia.** *Norsk Geologisk Tidsskrift.* 1980; **60**: 153–159.
Reference Source

Ahlberg P, Bergström J, Johansson J: **Lower Cambrian olenellid trilobites from the Baltic Faunal Province.** *GFF.* 1986; **108**(1): 39–56.
Publisher Full Text

Anell IM, Braathen A, Olaussen S: **Regional constraints of the Sørkapp Basin: a carboniferous relic or a cretaceous depression.** *Mar Petrol Geol.* 2014; **54**: 123–138.
Publisher Full Text

Babcock LE: **Biogeography and biofacies patterns of Middle Cambrian polymeroid trilobites from North Greenland: palaeogeographic and palaeo-oceanographic implications.** *Bull Grønlands geol Unders.* 1994; **169**: 129–147.
Publisher Full Text

Barrère C, Ebbing J, Gernigon L: **3-D density and magnetic crustal characterization of the southwestern Barents Shelf: implications for the offshore prolongation of the Norwegian Caledonides.** *Geophys J Int.* 2011; **184**(3): 1147–1166.
Publisher Full Text

Bergström SM: **Biogeography, evolutionary relationships, and biostratigraphic significance of Ordovician platform conodonts.** *Foss Strat.* 1983; **15**: 35–58.
Publisher Full Text

Birkenmajer K: **Cambrian succession in South Spitsbergen.** *Studia Geologica Polonica.* 1978; **59**: 7–46.
Reference Source

Birkenmajer K, Orlowski S: **Olenellid fauna from the base of Lower Cambrian sequence in south Spitsbergen.** *Norsk Polarinstitutt Årbok.* 1977; **1976**: 167–186.
Reference Source

Bjørnerud M: **An upper proterozoic unconformity in northern Wedel Jarlsberg Land, southwest Spitsbergen: Lithostratigraphy and tectonic implications.** *Polar Res.* 1990; **8**: 127–139.
Reference Source

Bjørnerud M, Decker PL, Craddock C: **Reconsidering Caledonian deformation in southwest Spitsbergen.** *Tectonics.* 1991; **10**(1): 171–190.
Publisher Full Text

Bogolepova OK, Gee DG: **Early palaeozoic unconformity across the timanides, nW Russia**. In: *The Neoproterozoic Timanide Orogen of eastern Baltica*. edited by: Gee, D. G. and Pease, V., *Geol Soc London, Mem*. 2004; **30**: 145–157.
Publisher Full Text

Braathen A, Maher HD Jr, Haabet TE, *et al.*: **Caledonian thrusting on Bjørnøya: implications for Palaeozoic and Mesozoic tectonism of the western Barents Shelf.** *Nor Teol Tidsskr.* 1999; **79**(1): 57–68.
Publisher Full Text

Breivik AJ, Mjelde R, Grogan P, *et al.*: **A possible Caledonide arm through the Barents Sea imaged by OBS data.** *Tectonophysics.* 2002; **355**(1–4): 67–97.
Publisher Full Text

Breivik A, Mjelde R, Grogan P, *et al.*: **Crustal structure and transform margin development south of Svalbard based on Ocean Bottom Seismometer data.** *Tectonophysics.* 2003; **369**(1–2): 37–70.
Publisher Full Text

Breivik AJ, Mjelde R, Grogan P, *et al.*: **Caledonide development offshore-onshore Svalbard based on ocean bottom seismometer, conventional seismic, and potential field data.** *Tectonophys.* 2005; **401**(1–2): 79–117.
Publisher Full Text

Bro EG, Shvarts VH: **Processing results from drill hole Raddedalen-1, Edge Island, Spitzbergen Archipelago**. All-Russian Research Institute for Geology and Mineral Resources of the World Ocean, St. Petersburg, Pangaea, Report 5750. 1983.
Publisher Full Text

Butler RF: **Paleomagnetism: magnetic domains to geologic terrains**. Blackwell Scientific Publications, Oxford, UK, 1992; 1–319.
Reference Source

Cisneros JC, Abdala F, Jashashvili T, *et al.*: ***Tiarajudens eccentricus* and *Anomocephalus africanus*, two bizarre anomodonts (Synapsida, Therapsida) with dental occlusion from the Permian of Gondwana.** *R Soc Open Sci.* 2015; **2**(7): 150090.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

Clark SA, Faleide JI, Hauser J, *et al.*: **Stochastic velocity inversion of seismic reflection/refraction traveltime data for rift structure of the southwest Barents Sea.** *Tectonophysics.* 2013; **593**: 135–150.
Publisher Full Text

Cocks LRM, Torsvik TH: **Earth geography from 500 to 400 million years ago: a faunal and palaeomagnetic review.** *J Geol Soc.* London, 2002; **159**(6): 631–644.
Publisher Full Text

Cocks LRM, Torsvik TH: **Ordovician palaeogeography and climate change.** *Gondwana Res.* 2021; **100**: 53–72.
Publisher Full Text

Colosi G: **La teoria de la traslazione dei continenti e le dottrine biogeografiche.** *L'Universo.* 1925; **6**(3).

Cowie JW: **The cambrian of spitsbergen and Scotland**. In: *Cambrian of the British Isles, Norden and Spitsbergen*. edited by: Holland, C.H, John Wiley & Sons, London, UK, 1974.
Reference Source

Cowman PF, Bellwood DR: **Vicariance across major marine biogeographic barriers: temporal concordance and the relative intensity of hard versus soft barriers.** *Proc Biol Sci.* 2013; **280**(1768): 20131541.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

Dallmann WK: **Geoscience atlas of Svalbard**. Norwegian Polar Institute, Tromsø, Norway, Report Series. 2015; **148**: 292.
Reference Source

Dallmeyer RD, Peucat JJ, Hirajima T, *et al.*: **Tectonothermal chronology within a blueschist-eclogite complex, west-central Spitsbergen, Svalbard: Evidence from ^{40}Ar/^{39}Ar and Rb-Sr mineral ages.** *Lithos.* 1990; **24**(4): 291–304.
Publisher Full Text

De Beaufort LF: **De beteekenis van de theorie van Wegener voor de zoögeografie, Handelingen van het XXe Nederlandsch Natuur- en Geneeskundig Congress, April 14-16, 1925**. Groningen, Netherlands, 1925.

Desiatkin VD, Kolesnikov AV, Rimsky AA, *et al.*: **Palaeopascichnids from the Upper Vendian Chernyi Kamen Formation of the Middle Urals (Perm Region).** *Dokl Earth Sci.* 2021; **499**(2): 643–647.
Publisher Full Text

Domeier M: **A plate tectonic scenario for the Iapetus and Rheic oceans.** *Gondwana Res.* 2016; **36**(4): 275–295.
Publisher Full Text

Domeier M: **Early Paleozoic tectonics of Asia: towards a full-plate model.** *Geosci Front.* 2018; **9**(3): 789–862.
Publisher Full Text

Dumais MA, Gernigon L, Olesen O, *et al.*: **New interpretation of the spreading evolution of the Knipovich Ridge derived from aeromagnetic data.** *Geophys J Int.* 2020; **224**(2): 1422–1428.
Publisher Full Text

Dupouy-Camet J, Bourée P, Yera H: ***Trichinella* and polar bears: a limited risk for humans.** *J Helminthol.* 2017; **91**(4): 440–446.
PubMed Abstract | **Publisher Full Text**

Eckhardt WR: **Die Beziehungen der afrikanischen Tierwelt zur südasiatischen.** *Naturwissenschaftliche Wochenschrift.* 1922; **51**.

Eide EA, Lardeaux JM: **A relict blueschist in meta-ophiolite from the central Norwegian Caledonides-discovery and consequences.** *Lithos.* 2002; **60**(1–2): 1–19.
Publisher Full Text

Estrada S, Mende K, Gerdes A, *et al.*: **Proterozoic to Cretaceous evolution of the western and central Pearya Terrane (Canadian High Arctic).** *J Geodyn.* 2018b; **120**: 45–76.
Publisher Full Text

Estrada S, Tessensohn F, Sonntag BL: **A Timanian Island-arc fragment in North Greenland: the Midtkap igneous suite.** *J Geodyn.* 2018a; **118**: 140–153.
Publisher Full Text

Faehnrich K, Majka J, Schneider D, *et al.*: **Geochronological constraints on Caledonian strike–slip displacement in Svalbard, with implications for the evolution of the Arctic.** *Terra Nova.* 2020; **32**(4): 290–299.
Publisher Full Text

Fortey RA: **Cambrian-Ordovician Rocks Adjacent to Hinlopenstretet, North Ny Friesland, Spitsbergen.** *GSA Bulletin.* 1975; **84**(7): 2227–2242.

Fortey RA: **Global earlier Ordovician transgressions and regressions and their biological implications.** In: Aspects of the Ordovician System, edited by: Bruton, D.L., Palaeontological Contributions from the University of Oslo, Universitetsforslaget, Oslo, Norway, 1984; **295**: 37–50.
Reference Source

Fortey RA, Bruton DL: **Cambrian-Ordovician Rocks Adjacent to Hinlopenstretet, North Ny Friesland, Spitsbergen.** *GSA Bulletin.* 1973; **84**(7): 2227–2242.
Publisher Full Text

Fortey RA, Bruton DL: **Lower Ordovician trilobites of the Kirtonryggen Formation, Spitsbergen.** *Fossils and Strata.* 2013; **59**(59): 120.
Reference Source

Fortey RA, Cocks LRM: **Palaeontological evidence bearing on global Ordovician-Silurian continental reconstructions.** *Earth-Sci Rev.* 2003; **61**(3–4): 245–307.
Publisher Full Text

Fortey RA, Mellish CJT: **Are some fossils better than others for inferring palaeogeography?: The early Ordovician of the North Atlantic region as an example.** *Terra Nova.* 1992; **4**(2): 210–216.
Publisher Full Text

Fritz WH: **Lower Cambrian trilobites from the sekwi formation type section, Mackenzie Mountains, north-western Canada.** *Geological Survey of Canada Bulletin.* 1972; **212**: 1–89.

Gee DG, Fossen H, Henriksen N, *et al.*: **From the early Paleozoic platforms of Baltica and Laurentia to the Caledonide Orogen of Scandinavia and Greenland.** *Episodes.* 2008; **31**(1): 44–51.
Publisher Full Text

Gee DG, Teben'kov AM: **Svalbard: a fragment of the Laurentian margin.** In: *The Neoproterozoic Timanide Orogen of eastern Baltica*. edited by: Gee,D. G. and Pease, V., Geol. Soc. London, Mem., 2004; **30**(1): 191–206.
Publisher Full Text

Gernigon L, Nasuti A, Roberts D, *et al.*: **Crustal and basin evolution of the southwestern Barents Sea: from Caledonian orogeny to continental breakup.** *Tectonics.* 2014; **33**(4): 347–373.
Publisher Full Text

Gudlaugsson ST, Faleide JI, Johansen SE, *et al.*: **Late Palaeozoic structural development of the South-western Barents Sea.** *Mar Petrol Geol.* 1998; **15**(1): 73–102.
Publisher Full Text

Hansen J, Holmer LE: **Taxonomy and biostratigraphy of Ordovician brachiopods from northeastern Ny Friesland, Spitsbergen.** *Zootaxa.* 2011; **3076**(1): 1–122.
Publisher Full Text

Harland WB: **Contribution of Spitsbergen to understanding of tectonic evolution of North Atlantic region.** *Am Assoc Pet Geol Memoir.* 1969; **12**: 817–851.
Publisher Full Text

Harland WB, Cutbill LJ, Friend PF, *et al.*: **The Billefjorden Fault Zone, Spitsbergen - the long history of a major tectonic lineament.** *Norsk Polarinst Skr.* 1974; **161**: 1–72.
Reference Source

Harland WB, Hambrey MJ, Waddams P: **Vendian geology of Svalbard.** *Norsk Polarinst Skri.* 1993; **193**: 1–150.
Reference Source

Harland WB, Kelly SRA: **Eastern Svalbard platform.** In: *Geology of Svalbard*. edited by: Harland W. B., Geol. Soc. London, Mem., 1997; **17**: 521.
Publisher Full Text

Harland WB, Scott RA, Auckland KA, *et al.*: **The Ny Friesland Orogen, Spitsbergen.** *Geol Mag.* 1992; **129**(6): 679–708.
Publisher Full Text

Högström A, Jensen S, Palacios T, *et al.*: **New information on the Ediacaran-Cambrian transition in the Vestertana Group, Finnmark, northern Norway, from trace fossils and organic-walled microfossils.** *Norw J Geol.* 2013; **93**: 95–106.
Reference Source

Horsfield WT: **Glaucophane schists of caledonian age from Spitsbergen.** *Geol Mag.* 1972; **109**(1): 29–36.
Publisher Full Text

Jakobsson M, Mayer L, Coackley B, *et al.*: **The International Bathymetric Chart of the Arctic Ocean (IBCAO) Version 3.0.** *Geophys Res Lett.* 2012; **39**(12): L12609.
Publisher Full Text

Jensen S, Högström AES, Høyberget M, *et al.*: **New occurrences of *Palaeopascichnus* from the Stáhpogieddi formation, Arctic Norway, and their bearing on the age of the Varanger Ice Age.** 2018; **55**(11).
Publisher Full Text

Kielan Z: **On two Olenellid trilobites from Hornsund, Vestspitsbergen.** *Studia Geologica Polonica.* 1960; **4**: 83–92.

Klitzke P, Franke D, Ehrhardt A, *et al.*: **The Paleozoic evolution of the Olga Basin region, northern Barents Sea: a link to the Timanian Orogeny.** *Geochem Geophys Geosyst.* 2019: **20**(2): 614–629.
Publisher Full Text

Knudsen C, Gee DG, Sherlock SC, *et al.*: **Caledonian metamorphism of metasediments from Franz Josef Land.** *GFF.* 2019; **141**(4): 295–307.
Publisher Full Text

Koehl JBP: **Impact of Timanian thrusts on the Phanerozoic tectonic history of Svalbard, Keynote lecture.** *EGU General Assembly.* May 3rd-8th 2020, Vienna, Austria, 2020.
Publisher Full Text

Koehl JBP: **Early Cenozoic Eurekan strain partitioning and decoupling in central Spitsbergen, Svalbard.** *Solid Earth.* 2021; **12**(5): 1025–1049.
Publisher Full Text

Koehl JBP: **Replication data for: implications of Timanian thrusts systems in the Barents Sea and Svalbard on using palontological constraints for plate tectonics reconstructions.** *DataverseNO.* V1, 2023.
http://www.doi.org/10.18710/BWZHL8

Koehl JBP: **The myth of the De Geer Zone [version 1; peer review: 1 approved with reservations].** *Open Res Eur.* 2024 awaiting peer review.
Publisher Full Text

Koehl JBP, Allaart L: **The Billefjorden Fault Zone north of Spitsbergen: a major terrane boundary?** *Polar Res.* 2021; **40**: 7668.
Publisher Full Text

Koehl JBP, Magee C, Anell IM: **Impact of Timanian thrust systems on the late Neoproterozoic-Phanerozoic tectonic history of the Barents Sea and Svalbard.** *Solid Earth.* 2022a; **13**: 85–115.
Reference Source

Koehl JBP, Marshall JEA, Lopes GM: **The timing of the Svalbardian Orogeny in Svalbard: a review.** *Solid Earth.* 2022b; **13**(8): 1353–1370.
Publisher Full Text

Koehl JBP, Polonio I, Rojo L: **Timanian fold-and-thrust belt and Caledonian overprint in the Selis Ridge imaged by new 3D seismic attributes and spectral decomposition.** *Tektonika.* 2023; **1**(1): 76–100.
Publisher Full Text

Koehl JBP, Stokmo EMB: **Caledonian reactivation and reworking of Timanian thrust systems and implications for latest mesoproterozoic to mid-Paleozoic tectonics and magmatism in northern Baltica [version 1; peer review: 1 not approved].** *Open Res Eur.* 2024; **4**: 30.
Publisher Full Text

Kolesnikov AV: **Stratigraphic correlation potential of the Ediacaran palaeopascichnids.** *Estudios Geológicos.* 2019; **75**(2): e102.
Publisher Full Text

Kolesnikov A, Desiatkin V: **Taxonomy and palaeoenvironmental distribution of palaeopascichnids.** *Geol Mag.* 2022; **159**(7): 1175–1191.
Publisher Full Text

Kośmińska K, Majka J, Mazur S, *et al.*: **Blueschist facies metamorphism in Nordenskiöld Land of west-central Svalbard.** *Terra Nova.* 2014; **26**(5): 377–386.
Publisher Full Text

Kröger B, Finnegan S, Franeck F, *et al.*: **The Ordovician Succession adjacent to Hinlopenstredet, Ny Friesland, Spitsbergen.** *Am Mus Novit.* 2017; **3882**: 1–28.
Publisher Full Text

Krysinski L, Grad M, Mjelde R, *et al.*: **Seismic and density structure of the lithosphere–asthenosphere system along transect Knipovich Ridge–Spitsbergen–Barents Sea - geological and petrophysical implications.** *Pol Polar Res.* 2013; **34**(2): 111–138.
Reference Source

Labrousse L, Elvevold S, Lepvrier C, *et al.*: **Structural analysis of high-pressure metamorphic rocks of Svalbard: reconstructing the early stages of the Caledonian orogeny.** *Tectonics.* 2008; **27**(5): 22.
Publisher Full Text

Lemoine P: **Madagaskar.** In: *Handbuch der regionale Geologie VII 4, 6.* edited by: Winter, C., Heidelberg, Germany, 1911.
Reference Source

Majka J, Larionov AN, Gee DG, *et al.*: **Neoproterozoic pegmatite from Skoddefjellet, Wedel Jarlsberg Land, Spitsbergen: additional evidence for c. 640 Ma tectonothermal event in the Caledonides of Svalbard.** *Polish Polar Res.* 2012; **33**(1): 1–17.
Reference Source

Majka J, Mazur S, Manecki M, *et al.*: **Late Neoproterozoic amphibolite-facies metamorphism of a pre-Caledonian basement block in southwest Wedel Jarlsberg Land, Spitsbergen: new evidence from U-Th-Pb dating of monazite.** *Geol Mag.* 2008; **145**(6): 822–830.
Publisher Full Text

Major H, Winsnes TO: **Cambrian and Ordovician fossils from Sørkapp Land, Spitsbergen.** *Norsk Polarinstitutt Skrifter.* 1955; **106**: 63.
Reference Source

Manecki M, Holm DK, Czerny J, *et al.*: **Thermochronological evidence for late Proterozoic (Vendian) cooling in southwest Wedel Jarlsberg Land, Spitsbergen.** *Geol Mag.* 1998; **135**(1): 163–69.
Publisher Full Text

Mazur S, Czerny J, Majka J, *et al.*: **A strike-slip terrane boundary in Wedel Jarlsberg Land, Svalbard, and its bearing on correlations of SW Spitsbergen with the Pearya terrane and Timanide belt.** *J Geol Soc London.* 2009; **166**: 529–544.
Publisher Full Text

Mitchum RM, Vail PR, Sangree JB: **Seismic Stratigraphy and Global Changes of Sea Level, Part 6: Stratigraphic Interpretation of Seismic Reflection Patterns in Depositional Sequences**. In: Seismic Stratigraphy — Applications to Hydrocarbon Exploration, edited by: Payton, C. E., AAPG Memoirs, 1977; **26**: 117–133.
Reference Source

Modesto SP: **The cranial skeleton of the Early Permian aquatic reptile *Mesosaurus tenuidens*: implications for relationships and palaeobiology.** *Zool J Linn Soc-Lond.* 2006; **146**(3): 345–368.
Publisher Full Text

Ohta Y: **Blue schists from Motalafjella, Western Spitsbergen.** *Norsk Polarinst.* 1979; **167**: 171–218.
Reference Source

Ohta Y, Hirajima T, Hiroi Y: **Caledonian high-pressure metamorphism in central western Spitsbergen.** *GSA Mem.* 1986; **164**: 205–216.
Publisher Full Text

Ohta Y, Krasil'scikov AA, Lepvrier C, *et al.*: **Northern continuation of Caledonian high-pressure metamorphic rocks in central-western Spitsbergen.** *Polar Res.* 1995; **14**(3): 303–315.
Publisher Full Text

Palmer AR, Peel JS: **New Cambrian faunas from Peary Land, eastern North Greenland.** *Rapp Grønlands geol Unders.* 1979; **91**: 29–36.
Publisher Full Text

Popov LE, Cocks LRM: **Late Ordovician palaeogeography and the positions of the Kazakh terranes through analysis of their brachiopod faunas.** *Acta Geol Pol.* 2017; **67**(3): 323–380.
Reference Source

Poulsen V: **Olenellacean trilobites from eastern North Greenland.** *Bull Geol Soc Denmark.* 1974; **23**: 79–101.
Reference Source

Roberts D, Walker N, Slagstad T, *et al.*: **U-Pb zircon ages from the Bymarka

ophiolite, near Trondheim, Central Norwegian Caledonides, and regional implications. *Norw J Geol.* 2002; **82**: 19–30.
Reference Source

Rosa D, Majka J, Thrane K, *et al.*: **Evidence for Timanian-age basement rocks in North Greenland as documented through U-Pb zircon dating of igneous xenoliths from the Midtkap volcanic centers.** *Precambrian Res.* 2016; **275**: 394–405.
Publisher Full Text

Servais T, Blieck A, Caridroit M, *et al.*: **The importance of plankton and nekton distributions in Ordovician palaeogeographical reconstructions.** *B Soc Geol Fr.* 2005; **176**(6): 531–543.
Publisher Full Text

Servais T, Harper DAT, Kröger B, *et al.*: **Changing palaeobiogeography during the Ordovician Period.** In: *A Global Synthesis of the Ordovician System.* Harper, D. A. T., Lefebvre, B., Percival, I. G. and Servais, T., Geological Society, London, Special Publications, 2023; **532**.
Publisher Full Text

Shulgin A, Faleide JI, Mjelde R, *et al.*: **Crustal domains in the Western Barents Sea.** *Geophys J Int.* 2020; **221**(3): 2155–2169.
Publisher Full Text

Slater BJ, Harvey THP, Guilbaud R, *et al.*: **A cryptic record of burgess shale-type diversity from the early Cambrian of Baltica.** *Palaeontology.* 2017; **60**(1): 117–140.
Publisher Full Text

Smethurst MA, Khramov AN, Pisarevsky S: **Palaeomagnetism of the lower ordovician orthoceras limestone, St. Petersburg, and a revised drift history for Baltica in the early Palaeozoic.** *Geophys J Int.* 1998; **133**(1): 44–56.
Publisher Full Text

Smith MP: **Cambro-Ordovician stratigraphy of Bjørnøya and North Greenland: constraints on tectonic models for the Arctic Caledonides and the tertiary opening of the Greenland Sea.** *J Geol Soc London.* 2000; **157**: 459–470.
Publisher Full Text

Smith MP, Rasmussen JA: **Cambrian-Silurian development of the Laurentian margin of the Iapetus Ocean in Greenland and related areas**. In: *The Greenland Caledonides: Evolution of the Northeast Margin of Laurentia.* Higgins, A. K., Gilotti, J. A. and Smith, M. P., Geological Society of America Memoir, 2008; **202**: 137–167.
Publisher Full Text

Smith MP, Rasmussen JA, Robertson S, *et al.*: **Lower Palaeozoic stratigraphy of the East Greenland Caledonides.** *GEUS Bulletin.* 2004; **6**: 5–28.
Publisher Full Text

Stemmerik L, Dalhoff F, Larsen BD, *et al.*: **Wandel Sea Basin, eastern North Greenland.** *Geology of Greenland Survey Bulletin.* 1998; **180**: 55–62.
Publisher Full Text

Stouge S, Christiansen JL, Holmer LE: **Lower Palaeozoic stratigraphy of Murchisonfjorden and Sparreneset, Nordaustlandet, Svalbard.** *Geografiska Annaler, Series A.* 2011; **93**(4): 209–226.
Publisher Full Text

Svennevig K: **Update of the seamless 1:500 000 scale geological map of Greenland based on recent field work in the Wandel Sea Basin, eastern North Greenland.** *Geol Surv Den Greenl.* 2018; **41**: 39–42.
Publisher Full Text

Torsvik TH, Cocks LRM: **Norway in space and time: a Centennial cavalcade.** *Norw J Geol.* 2005; **85**(1): 73–86.
Reference Source

Torsvik TH, Cocks LRM: **Cambrian.** In: *Earth History and Palaeogeography.* Cambridge University Press, Cambridge, UK, 2016; 85–100.
Publisher Full Text

Torsvik TH, Rehnström E: **Cambrian palaeomagnetic data from Baltica: implications for true polar wander and Cambrian palaeogeography.** *J Geol Soc*. 2001; **158**(2): 321–329.
Publisher Full Text

Torsvik TH, Trench A: **The Ordovician history of the Iapetus Ocean in Britain: new palaeomagnetic constraints.** *J Geol Soc London.* 1991; **148**(3): 423–425.
Publisher Full Text

Trewick S: **Plate tectonics in biogeography.** In: *The International Encyclopedia of Geography.* edited by: Richarson, D., Castree, N., Goodchild, M. F., Kabayashi, A., Liu, W. and Marston, R. A., John Wiley & Sons, Chichester, 2017.
Publisher Full Text

Von Ubisch L: **Wegeners Kontinentalverschiebungstheorie und die Tiergeographie.** Verhandlungen der Physikalisch-Medizinischen Gesellschaft zu Würzburg, Würzburg, Germany, 1921.
Reference Source

Von Ubisch L: **Tiergeographie und Kontinentalverschiebung.** *Z.Ver-erbungslehre.* 1928; **47**: 159–179.
Publisher Full Text

Wala VT, Ziemniak G, Majka J, *et al.*: **Neoproterozoic stratigraphy of the Southwestern Basement Province, Svalbard (Norway): Constraints on the Proterozoic-Paleozoic evolution of the North Atlantic-Arctic Caledonides.** *Precambrian Res.* 2021; **358**: 106138.
Publisher Full Text

Wegener A: **Die Entstehung der Kontinente und Ozeane.** Friedr. Vieweg & Sohn A.-G, Braunschweig, Germany, 1929.

Witt-Nilsson P, Gee DG, Hellman FJ: **Tectonostratigraphy of the caledonian atomfjella antiform of northern Ny Friesland, Svalbard.** *Norsk Geol Tidsskr.* 1998; **78**: 67–80.
Reference Source

Wright DF, Stigall AL: **Geologic drivers of late ordovician faunal change in laurentia: investigating links between tectonics, speciation, and biotic invasions.** *PLoS One.* 2013; **8**(7): e68353.
PubMed Abstract | **Publisher Full Text** | **Free Full Text**

Open Peer Review

Current Peer Review Status: ✓ ✓ ✓

Version 2

Reviewer Report 30 July 2024

https://doi.org/10.21956/openreseurope.19579.r42115

© **2024 Izquierdo-Llavall E.** This is an open access peer review report distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

✓ **Esther Izquierdo-Llavall**
Instituto Geológico y Minero de España, Zaragoza, Spain

I agree with the changes made by the author.

Competing Interests: No competing interests were disclosed.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Reviewer Report 26 July 2024

https://doi.org/10.21956/openreseurope.19579.r42114

© **2024 Milia A.** This is an open access peer review report distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

✓ **Alfonsa Milia**
National Research Council of Italy, Rome, Italy

The author has satisfied the requests. I ask to change the status of the manuscript to "approved"
best wishes,
Alfonsa Milia

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: interpretation of seismic reflection profiles, stratigraphy and tectonics

I confirm that I have read this submission and believe that I have an appropriate level of

expertise to confirm that it is of an acceptable scientific standard.

Version 1

Reviewer Report 04 June 2024

https://doi.org/10.21956/openreseurope.18006.r40215

© 2024 Kounov A. This is an open access peer review report distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

✓ **Alexandre Kounov**
Basel University, Basel, Switzerland

This paper is presenting several seismic reflections profiles on the basis of which it was suggested the existence of a WMW-ESE trending thrust belt acting as a barrier for the shallow marine fauna between Svalbard Archipelago and Baltica from the Cambrian to the Ordovician. Such a scenario comes to refute the previously suggested idea of the existence of a large Iapetus ocean between these two crustal fragments.
I think that the paper is generally well written and the presented data support well the suggested major conclusions. However, I have some remarks concerning the early Paleozoic tectonic evolution of the study area. It is not getting clear if the author suggests some active tectonics during the early Paleozoic responsible for the formation of the highs barrier or the relief is totally inherited from the Neoproterozoic Timanian thrusting.
Details of my remarks and suggestions could be found in an annotated PDF file.:

Is the work clearly and accurately presented and does it cite the current literature?
Yes

Is the study design appropriate and does the work have academic merit?
Yes

Are sufficient details of methods and analysis provided to allow replication by others?
Yes

If applicable, is the statistical analysis and its interpretation appropriate?
Yes

Are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions drawn adequately supported by the results?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Structural geology, Tectonics

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Author Response 24 Jun 2024

Jean-Baptiste Koehl

Dear Dr. Kounov, thank you very much for your input on the manuscript, it is highly appreciated. Here is our reply to your comments. We hope the changes we implemented improve the shortcomings of the manuscript highlighted by your comments and suggestions. Please do not hesitate to contact us shall this not be the case for some comments. **Comments by the reviewer**
Comment 1: Plate tectonic reconstruction concept did not exist so far back in time.
Response: Agreed.
Changes: Replaced “plate tectonic reconstruction” by “trying to understand plate tectonics”.

Comment 2: To much of “similar” words in this sentence.
Response: Agreed.
Changes: Replaced “similar” by “comparable”.

Comment 3: Tell us a bit more about these terranes.
Response: Agreed.
Changes: Added “The Svalbard Archipelago (excluding Bjørnøya) is commonly believed to be divided into three terranes consisting of Proterozoic–early Paleozoic metamorphic rocks, which recorded different tectonothermal events (e.g., Harland, 1969; Harland *et al.*, 1992; Harland *et al.*, 1993).” and added Harland (1969) and Harland et al. (1993) to the reference list.

Comment 4: Why within the Spitsbergen? Could you show on figure 1b where it could be? In figure 4 the Iapetus ocean is given between the Greenland and the archipelago.
Response: Agreed.
Changes: Added the location of high-pressure Caledonian rocks in western Spitsbergen and added reference to Figure 1b.

Comment 5: The post-Timanian thrusts rather cut through the whole Lower Paleozoic sediments and I do not see evidence of syn-tectonic sedimentation. I would say from what I see in the sections that the major Timanian thrusting continues in the early Paleozoic where the sedimentation was syn-tectonic with the formation of piggy-back basins. I see one big event of thrusting which is waning somewhere within the early Paleozoic. Unfortunately we do not have
Response: Disagreed. Thrusting mostly occurred in the late Neoproterozoic as documented by the minor propagation of Timanian thrusts into lower Paleozoic metasedimentary rocks (e.g., Figure 3b–c). Thus, only minor reactivation of Timanian thrusts occurred during the

Caledonian Orogeny in the early–mid Paleozoic.
Changes: Replaced “top-SSW and top-NNE thrusting” by “minor top-SSW and top-NNE reactivation of Timanian thrust systems” and added “, evidence of which are found throughout the Barents Sea and northern Norway (Koehl *et al.*, 2023; Koehl and Stokmo, 2024” at the end of the paragraph.

Comment 6: Here you confirm the early Paleozoic tectonics which is syn-sedimentational. This must be different from the Caledonian mid Paleozoic event.
Response: Disagreed. See response to comment 5.
Changes: See response to comment 5. Added “formed in the late Neoproterozoic (–earliest Paleozoic?) and” in the third sentence of the paragraph.

Comment 7: Here you have the age of the major thrusting which led to the relief formation and erosion. An alternative scenario will be to have slow subsidence during this time span which is leading to the filing of a formed during the Neoproterozoic relief. By the early-middle Ordovician the whole relief was drowned and sediments started to be deposited everywhere. Would you believe in such scenario?
Response: Disagreed. The hiatus suggests exposure above sea level, which could be through either thrusting, or eustatic sea-level fall, or a combination of both during the latest Neoproterozoic because lower Paleozoic (meta) sedimentary rocks cap the Proterozoic basement highs (Figure 2 and Figure 3). Regional subsidence is possible to explain the flooding of the Proterozoic basement highs, but so is eustatic sea-level rise. Since this is not the focus of the present manuscript and does not impact the main conclusions, it is best to leave it out.
Changes: See response to comments 5 and 6.

Comment 8: It seems to me too long and containing a lot of irrelevant information. I will suggest to shorten it to the most important message from the study area only.
Response: Disagreed. These are far-reaching implications of the present works, which could be applied to many other studies.
Changes: None.

Comment 9: I am a bit puzzled. I am afraid I did not understand your idea. On page 7 in the Discussion you are talking about Early Paleozoic thrusting, basement uplift and deposition. From this I have understood that the highs were formed during this early Paleozoic tectonic event and therefore they are not inherited from the Timanian orogeny as you are stating here. Please make it clear in the whole text.
Response: Agreed. The thrust systems are Timanian and formed in the late Neoproterozoic. The early Paleozoic signal (reverse offset of early Paleozoic metasedimentary rocks; Figure 3b–c) represents a minor reactivation of the Timanian thrusts during Caledonian contraction. This was further specified in the text. See also response to comments 5 and 6.
Changes: See response to comments 5 and 6.

Competing Interests: No competing interests were disclosed.

Reviewer Report 28 May 2024

https://doi.org/10.21956/openreseurope.18006.r38100

© 2024 Izquierdo-Llavall E. This is an open access peer review report distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

? **Esther Izquierdo-Llavall**
Instituto Geológico y Minero de España, Zaragoza, Spain

This manuscript presents the interpretation of three seismic reflection profiles located in the eastern offshore of Svalbard. These profiles are in double time and two of them are N-S-striking whereas the third one is E-W striking; they do not intersect to each other. The interpreted seismic units and seismic facies are well-tied although none of the available exploration wells are located along seismic traces (from wells shown in figure 1). From the interpretation of seismic lines, authors propose a structural map of Timanian thrusts extending along the Russian and Norwegian Barents Sea. The map and the accompanying explanation highlights that these thrusts are along-strike continuous, with no major structural interruptions, which suggests there is no an ancient (post-thrusting) suture zone disrupting them (representing the suture of the Iapetus Ocean). At this point, previous paleontological data suggesting a ~5000 km separation between the Baltica and Svalbard (ancient Iapetus Ocean) during early Paleozoic times are discussed and the paleontological criteria used is questioned.

The manuscript is well written and presented ideas are easy to follow. I personally found very interesting the way in which the author uses structural data to constrain plate tectonics models. The abstract and plain language summary are concise and clear. But the reader misses some relevant information at some points of the text/figures. Here there is a list of the main points that could be improved:

1. The presented seismic lines are located close to the eastern coast of Svalbard but the structural correlation of Timanian thrusts extends over hundreds/thousands of kilometers further to the East of this seismic information. It remains unclear how this structural correlation (which is key in the paleontological and tectonic plates model discussed) is done. If it is based on additional seismic/gravity/magnetic data from previous studies (as mentioned in the Introduction), it will be worth to show a map of magnetic/gravity anomalies and their trend or a map with the location of previously interpreted seismic profiles. Authors argue on the continuity of the thrust system, but readers would need to know how continuous (or discontinuous) the dataset used for inferring thrust geometries is.
2. A 5000 kilometers distance between Baltica and Laurentia in the Ordovician is suggested by paleontological and paleomagnetic data (said in the Introduction), but only paleontological data are questioned in the discussion. To complete this last part of the manuscript, it could be interesting to include some comments on the reliability of paleomagnetic constraints. Are available paleomagnetic data useful to infer the location of the Iapetus Ocean? Can they constraint the terrane paleolatitudes discussed in the manuscript?
3. Use of wells. Wells are not located over seismic traces but at a certain distance from them. Authors reference previous works to say that well tying was done, but it is probably useful

   for the reader to visualize (although projected) where these wells are on seismic profiles. Also, the reader misses some words on the depth of the wells. Are they reaching the pre-Cambrian and it is therefore a well-based knowledge of the seismic facies related to these basement units?
4. Interpretation of seismic profiles. Some of the thrusts affecting the Precambrian basement show a normal fault kinematics when the top Proterozoic horizon is examined. Besides, these apparently normal faults are consistent with thickness changes in overlying lower Paleozoic units (that thicken towards fault planes). This occurs in the southern part of figure 2c and central part of 2a. How are these thickness variations explained? It seems they indicate an extensional reactivation of basement faults during the lower Paleozoic which would have to be reconciled with the contractional reactivation described in relation to the basement high in figure 2c. Additionally, a word on the faults affecting upper Paleozoic units is missing.
5. Figure 1: The horizontal scale and the reference on the structural mapping of Timanian thrusts are lacking. A label indicating the location of the island of Bjørnøya, which is mentioned in the text, can be included.
6. Figures 2-3. Indicate in the figure caption that inlets in figure 2 are shown in figure 3. Resolution of the seismic profiles (2 and 3) is low and makes difficult the evaluation of the quality of the seismic interpretation done. Even if the high-resolution profiles are published as underlying data, the author may try to play a bit with palette colors, brightness... to try to better capture the main features that are interpreted in the seismic profiles shown in the manuscript.
7. Figure 4. From the text, the reader gets that WNW-ESE-striking Timanian thrusts were contractionally reactivated as WNW-ESE Caledonian thrusts. But figure 4 shows two perpendicular trends for Timanian-Caledonian structures?

I hope all these comments and suggestions will help the author to refine the present version of the manuscript.

Is the work clearly and accurately presented and does it cite the current literature?

Yes

Is the study design appropriate and does the work have academic merit?

Yes

Are sufficient details of methods and analysis provided to allow replication by others?

Yes

If applicable, is the statistical analysis and its interpretation appropriate?

Not applicable

Are all the source data underlying the results available to ensure full reproducibility?

Partly

Are the conclusions drawn adequately supported by the results?

Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Structural geology and tectonics, paleomagnetism

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 24 Jun 2024

Jean-Baptiste Koehl

Furthermore, some of the apparent traces of normal faulting occur within major Proterozoic basement highs, which were therefore deeply eroded in the early Paleozoic. Since Timanian mylonitic thrust systems represent major rheological discontinuities, it is highly probable that they contributed to shaping the relief carved by erosion in the early Paleozoic and created some depression, which were later passively filled with lower Paleozoic sediments."

Comment 5: Figure 1: The horizontal scale and the reference on the structural mapping of Timanian thrusts are lacking. A label indicating the location of the island of Bjørnøya, which is mentioned in the text, can be included.
Response: Agreed. However, the location of the island of Bjørnøya is already displayed in Figure 1b.
Changes: Added "Timanian thrusts are from Koehl et al. (2022a), Koehl et al. (2023), Koehl (2024), and Koehl and Stokmo (2024)." in the caption of Figure 1 and a scale to Figure 1a and b.

Comment 6: Figures 2-3. Indicate in the figure caption that inlets in figure 2 are shown in figure 3. Resolution of the seismic profiles (2 and 3) is low and makes difficult the evaluation of the quality of the seismic interpretation done. Even if the high-resolution profiles are published as underlying data, the author may try to play a bit with palette colors, brightness… to try to better capture the main features that are interpreted in the seismic profiles shown in the manuscript.
Response: Agreed. The author of the present manuscript has tried to manipulate the color palette and brightness to the figure's advantage, without much success. The high-resolution versions of the figures are crucial to visualize the discussed features and are published on DataverseNO (Open Access data repository), as commonly done for studies of regional seismic reflection profiles by the author of the present manuscript (e.g., Koehl et al., 2022a; Koehl et al., 2023; Koehl, 2024; Koehl and Stokmo, 2024).
Changes: Added "The white rectangles indicate the location of Figure 3a–d." in the caption of Figure 2, and "The location of (a–d) is shown as white rectangles in Figure 2a–c." in the caption of Figure 3.

Comment 7: Figure 4. From the text, the reader gets that WNW-ESE-striking Timanian thrusts were contractionally reactivated as WNW-ESE Caledonian thrusts. But figure 4 shows two perpendicular trends for Timanian-Caledonian structures?
Response: This is correct. Some WNW–ESE-striking Timanian thrusts were reactivated during the Caledonian Orogeny and new N–S-striking thrusts formed during the Caledonian

Orogeny and/or major Timanian thrusts were partly reworked into N–S- to NNE–SSW-striking fold-and-thrust systems (e.g., Koehl et al., 2022a; Koehl et al., 2023).
Changes: Added "(and reactivated)" in the caption of Figure 4 and "Caledonian deformation both formed new N–S- to NNE–SSW-striking thrusts (e.g., Ohta, 1979; Ohta *et al.*, 1986; Witt-Nilsson *et al.*, 1998; Braathen *et al.*, 1999) and reactivated WNW–ESE-striking Timanian thrusts with minor dominantly sinistral strike-slip to reverse movements (e.g., Mazur *et al.*, 2009; Koehl *et al.*, 2022a; Koehl *et al.*, 2023), reworking some of them into NNE–SSW-striking folds and thrusts (Koehl *et al.*, 2022a; Koehl *et al.*, 2023; Koehl & Stokmo, 2024)." to the discussion. Also added Ohta (1979), Ohta et al. (1986), and Witt-Nilsson et al. (1998) to the literature list.

Competing Interests: No competing interests were disclosed.

Reviewer Report 14 April 2024

https://doi.org/10.21956/openreseurope.18006.r38105

© **2024 Milia A.** This is an open access peer review report distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Alfonsa Milia
National Research Council of Italy, Rome, Italy

The paper discusses how the presence of a thrust belt in the Barents Sea and Svalbard may have been a barrier for the spread of trilobites between different regions. The implications of this are fundamental for the palaeogeographic reconstruction of the area where, in contrast, the presence of an ocean as a barrier for the spread of trilobites had been assumed. The subject is interesting, and the "Smoking gun" is the documentation of emerged areas at that time. It is important to point out that: a) The story concerns the recognition of a thrust belt located in the area where the Iapetus ocean was hypothesized, during the pre-Paleozoic-Paleozoic period, in the Barents Sea-Svalbard. The hypothesis of an ocean in that area was based on the distribution of trilobites in the area and in particular on the differences in the Trilobite assemblage between Laurentia-Svalbard and Baltica. To understand the new proposed geological history, it is important to reconstruct the physiography of the area and of the emerged zones that may have functioned as a barrier for the distribution of the Trilobites. The broader outcome is the reevaluation of the role of paleontology in reconstructing the paleogeography of an area. b) The challenge is to individuate the erosional truncation, gaps in the succession that suggest the formation of the barriers at that time. c) The work is based on the interpretation of seismic reflection profiles.
I suggest to eliminate: 1) the term "Sequence stratigraphy", as this term is linked to the identification of systems tracts to be correlated with climatic fluctuations, and replace it with the term "Seismic stratigraphy"; 2) The term "Toplap" that is classically referred to the strata termination of the upper part of the progradational units; in this contest is more appropriate the use of "angular unconformity" or "erosional truncation".

Abstract:
Methods: I suggest to change in “The interpretation of seismic reflection profiles from the DISKOS database, calibrated with the boreholes drilled in the adjacent emerged areas, was used to reconstruct the geology of the area and in particular the buried thrust belt" The term "NEW INTERPRETATION" does not seem appropriate since the interpretation proposed by the author seems to be the same or very similar to the one published by the same author in 2022 (e.g. Koehl *et al.*, 2022[1]). However, a more detailed interpretation can be made in Figure 3, where some details of the seismic profiles can be seen (see the attached modified linked figure here, with an explanation of the annotations in the paragraph below):
Regarding figure 3, the author should check the reference in the text relating to figure 3C and 3D which are perhaps reversed. Regarding the interpretation of the profiles, although the chain areas present complex structures that are difficult to interpret on seismic profiles, following the parallel sections of the reflectors, the angular discordances and the stratal terminations it is possible to propose more detailed interpretations).

Conclusion: I suggest to change in “The individuation of emerged areas in correspondence of the thrust belt suggest that …. The results indicate that paleontological constraints….” This is because the subject of the paper is the analysis of the thrust belt using the interpretation of seismic profiles.

Keywords: insert “seismic reflection profiles” (the paper is based on the interpretation of seismic reflection profiles)

The **Introduction** should focus on the palaeogeography of the area and the presence of an ocean in the palaeogeographical maps. Successively you can explain on what basis it was made, and introduce the discovery of the thrust belt, first assumed from the OBS data and then reconstructed using seismic profiles etc. Beginning with "Paleontological contraints have been ..." suggests the idea that this is paleontological work.

Geological setting: I suggest to add a figure with a paleogeography. I think this is fundamental for this work.
The last sentence of the Geologic Setting “The present study focuses…” should be deleted.

Methods: Please add a figure with a stratigraphic column of the area or a well stratigraphy. What does “new knowledge in the seismic facies and structural character.” mean?

Results: I suggest reorganizing this paragraph by first describing the seismic units by identifying the 4 main units (e.g. A, B,C,D). Then, based on the geometric features and correlation with the stratigraphies of boreholes and outcrops, a geological attribution can be given (e.g. Age, lithology etc. Pre-Cambrian, Cambrian-Silurian, Devonian- Permian, Mesozoic).
I recommend talking about thickness in seconds. However, if it is necessary to report in kilometers it would be helpful to indicate the speeds used for the transformation from seconds to kilometres.

Discussion: Please change in “CALEDONIAN REACTIVATION OF TIMANIAN THRUST AND EVIDENCE OF PHYSIOGRAPHIC BARRIERS”
Please change “Local toplap geometries…….” in “Angular unconformities …………………suggest that………. where **deformed** and eroded prior to the Devonian”.

The lack of an angular unconformity and a thin succession do not document a continental erosion! However, these characteristics in correspondence of a structural high due, for example, to the nappes superposition suggest the formation of a submarine or continental physiographic barrier.

Figure 1: Order caption: toponyms (NY, W), wells (P1, R1), fault zones/anticlines (AA, RA, BeFZ, BFZ, etc.).

References

1. Koehl J, Marshall J, Lopes G: The timing of the Svalbardian Orogeny in Svalbard: a review. *Solid Earth*. 2022; **13** (8): 1353-1370 Publisher Full Text

Is the work clearly and accurately presented and does it cite the current literature?

No

Is the study design appropriate and does the work have academic merit?

Yes

Are sufficient details of methods and analysis provided to allow replication by others?

Yes

If applicable, is the statistical analysis and its interpretation appropriate?

Yes

Are all the source data underlying the results available to ensure full reproducibility?

Yes

Are the conclusions drawn adequately supported by the results?

Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: interpretation of seismic reflection profiles, stratigraphy and tectonics

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.