The Jan Mayen microcontinent: an update of its architecture, structural development and role during the transition from the Ægir Ridge to the mid-oceanic Kolbeinsey Ridge

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Abstract: We present a revised tectonostratigraphy of the Jan Mayen microcontinent (JMMC) and its southern extent, with the focus on its relationship to the Greenland–Iceland–Faroe Ridge area and the Faroe–Iceland Fracture Zone. The microcontinent's Cenozoic evolution consists of six main phases corresponding to regional stratigraphic unconformities. Emplacement of Early Eocene plateau basalts at pre-break-up time (56–55 Ma), preceded the continental break-up (55 Ma) and the formation of seawards-dipping reflectors (SDRs) along the eastern and SE flanks of the JMMC. Simultaneously with SDR formation, orthogonal seafloor spreading initiated along the Ægir Ridge (Norway Basin) during the Early Eocene (C24n2r, 53.36 Ma to C22n, 49.3 Ma). Changes in plate motions at C21n (47.33 Ma) led to oblique seafloor spreading offset by transform faults and uplift along the microcontinent's southern flank. At C13n (33.2 Ma), spreading rates along the Ægir Ridge started to decrease, first south and then in the north. This was probably complemented by intra-continental extension within the JMMC, as indicated by the opening of the Jan Mayen Basin – a series of small pull-apart basins along the microcontinent's NW flank. JMMC was completely isolated when the mid-oceanic Kolbeinsey Ridge became fully established and the Ægir Ridge was abandoned between C7 and C6b (24–21.56 Ma).

The Jan Mayen microcontinent (JMMC) is a structural entity encompassing the Jan Mayen Ridge and the surrounding area, including the Jan Mayen Basin, the Jan Mayen Basin South, the Jan Mayen Trough and the Southern Ridge Complex (SRC) (Fig. 1; Table 1). The JMMC is bordered to the north by the east and west segments of the Jan Mayen Fracture Zone and the volcanic complex of Jan Mayen Island (Svellingen & Pedersen 2003). To the south, it is bordered by the NE coastal shelf of Iceland, to the east by the Norway Basin and to the west by the Kolbeinsey Ridge. Early descriptions of the JMMC considered only the Jan Mayen Ridge (Vogt *et al.* 1970; Talwani *et al.* 1976*a*), a steep-flanked bathymetric horst structure with water depths varying between 200 and 2500 m that extends south from Jan Mayen Island. However, based on modern datasets, it is now accepted that the microcontinent is much larger than this and encompasses a number distinct, structurally controlled tectonic features that were formed by a succession of tectonic and volcanic events (e.g. Scott *et al.* 2005; Gaina *et al.* 2009; Peron-Pinvidic *et al.* 2012*a*, *b*; Gernigon *et al.* 2012). In total, the JMMC is 400–450 km long, and varies in width from 100 km in the north to 310 km in the south.

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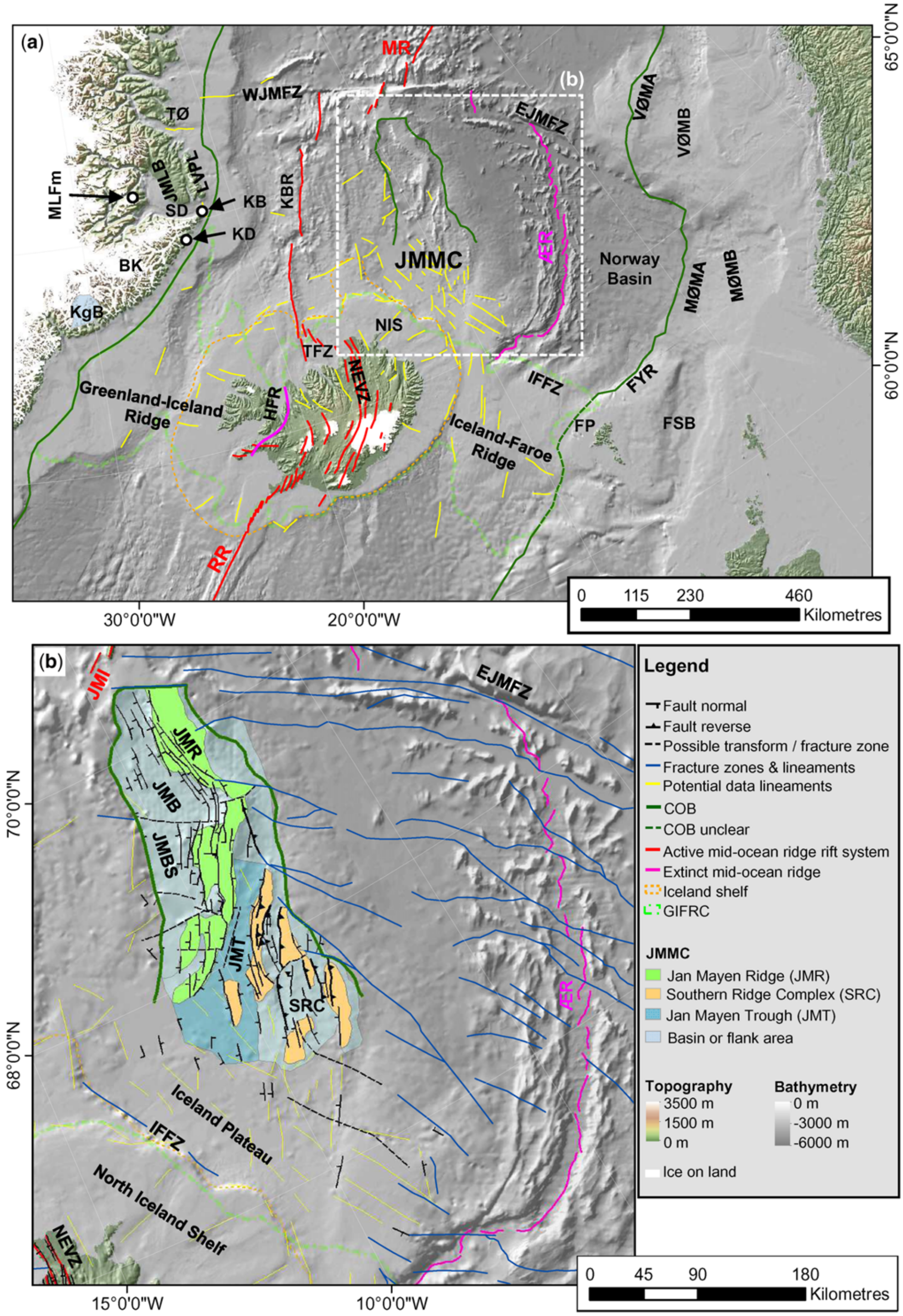


Fig. 1. Overview map (**a**) of the study area with the location of structural elements identified on potential field data. Structural elements map (**b**) for the JMMC study with mapped faults, fractures zones and lineaments based on this study and modified after Peron-Pinvidic *et al.* (2012*a*) and Gernigon *et al.* (2015) (for label keys, see Table 1). The background image is shaded bathymetry (IBCAO 3.0: Jakobsson *et al.* 2012; Amante & Eakins 2009).

Table 1. *Explanation of structural element abbreviations and label key, modified after Gunnarsson* et al. *(1989), Jóhannesson (2011), Hjartarson & Sæmundsson (2014), Hopper* et al. *(2014) and Magnúsdóttir* et al. *(2015)*

Abbreviation and label key					
General features:		**Central NE Atlantic:**			
COB	Continent–ocean boundary	JMMC	Jan Mayen microcontinent	IB	Iceland Basin
SDR	Seawards-dipping reflector	BR	Buðli Ridge		
Mid-oceanic ridges:		EFBN	Jan Mayen East Flank Basins North	GIFRC	Faroe–Iceland–Greenland Ridge Complex
ÆR	Ægir mid-oceanic ridge	EFBS	Jan Mayen East Flank Basins South	GIR	Greenland–Iceland Ridge
MR	Mohn's mid-oceanic ridge	HC/JMWIP	Hakarenna Channel/Jan Mayen West Igneous Province South	HFR	Húnaflóa Rift
KBR	Kolbeinsey mid-oceanic ridge	HR	Högni Ridge	ICE	Iceland onshore
RR	Reykjanes mid-oceanic ridge	JMT/HT	Jan Mayen Trough/Hléssund Trough	IFR	Iceland–Faroe Island Ridge
JMI	Jan Mayen Island System	JMB	Jan Mayen Basin	NEVZ	Northeast Volcanic Zone
Transfer systems and fracture zones:		JMRN	Jan Mayen Ridge North		
EJMFZ	East Jan Mayen Fracture Zone	LYR	Lyngvi Ridge	**Central Norway Margin:**	
IFFZ	Iceland–Faroe Fracture Zone	SFB/JMBS	Sörlahryggur Flank Basin/Jan Mayen Basin South	MØMA	Møre Marginal High
MIRFTS	Mid-Iceland Rift Transfer System	SHR	Sörlahryggur Ridge	MØMB	Møre Basin
SISZ	South Iceland Seismic Zone	WIPN	Jan Mayen West Igneous Province North	VØMA	Vøring Marginal High
TFZ	Tjörnes Fracture Zone			VØMB	Vøring Basin
WJMFZ	West Jan Mayen Fracture Zone	SRCCC	Jan Mayen microcontinent–Southern Ridge Complex (SRC) – continental crust		
Central East Greenland Margin:		FR	Fáfnir Ridge	**Faroe Islands Atlantic Margin:**	
BK	Blosseville Kyst	OR	Otur Ridge	FYR	Fugloy Ridge
JMLB	Jameson Land Basin			FP	Faroe Platform
KD	Kap Dalton outcrop site	SRCTC	Jan Mayen microcontinent–Southern Ridge Complex – transitional crust	FSB	Faroe–Shetland Basin
KB	Kap Brewster outcrop site	DR	Dreki Ridge		
KgB	Kangerlussuaq Basin	LR	Langabrún Ridge		
LVPL	Liverpool Land High	ORS	Otur Ridge southern spur		
ML Fm	Milne Land Formation outcrop site	TR	Treitel Ridge		
SD	Scoresby Sund				
TØ	Trail Ø	NIS	North Iceland Shelf		
		IP	Iceland Plateau		
		IPR	Iceland Plateau Rift		

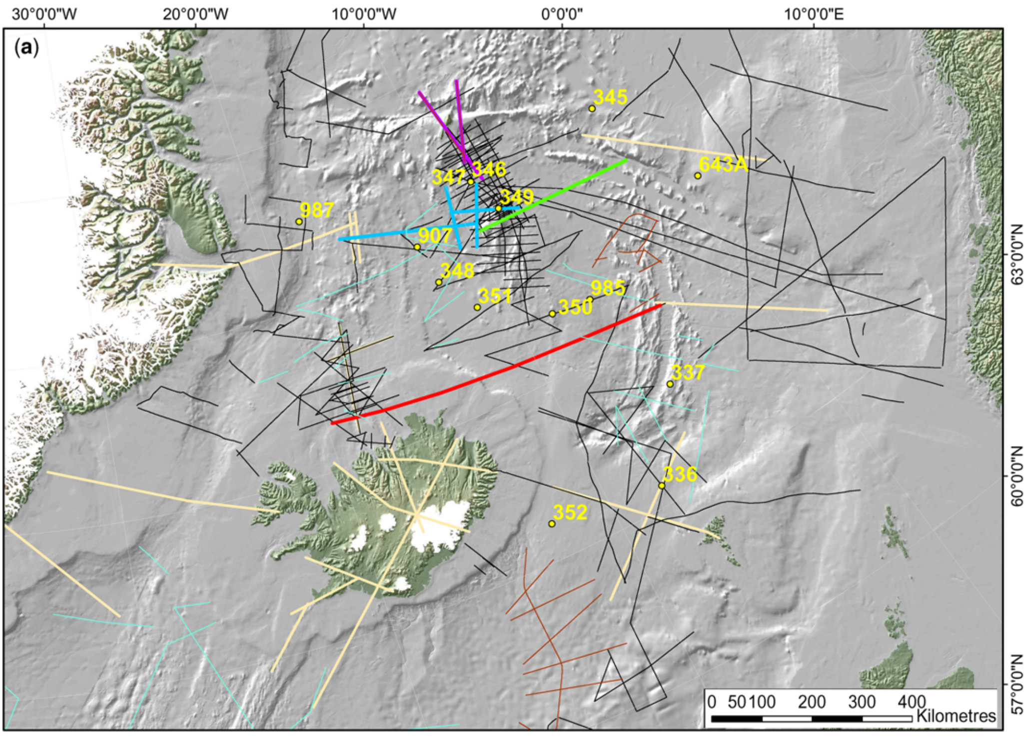


Fig. 2. Regional map showing shaded bathymetry (Amante & Eakins 2009; Jakobsson *et al.* 2012) and (**a**) refraction and reflection seismic lines and boreholes. Legend see Figure 2b.

The microcontinent is bounded on all sides by oceanic crust, although its southern limit remains poorly constrained. This is due, in part, to sparse data coverage south of 68° N (Fig. 2), but also to the occurrence of numerous intrusive and extrusive volcanic rocks that limit seismic imaging of the underlying features. Previous interpretations of the continent–ocean transition (COT) along the JMMC margins were mainly based on magnetic and/or gravity data (e.g. Vogt *et al.* 1970; Talwani & Eldholm 1977; Åkermoen 1989; Doré *et al.* 1999; Lundin & Doré 2002; Rey *et al.* 2003; Gaina *et al.* 2009; Gernigon *et al.* 2012) and seismic reflection data (Gunnarsson *et al.* 1989; Scott *et al.* 2005; Peron-Pinvidic *et al.* 2012*a*, *b*). Breivik *et al.* (2012) considered crustal velocity information from wide-angle data with potential field data to derive the location of the COT.

The purpose of this paper is to establish a detailed tectonic and stratigraphic framework for the JMMC based on a new regional database of geological and geophysical data. The analysis includes interpretation of new seismic reflection data, as well as recent geological findings, from on- and offshore central East Greenland (e.g. Larsen *et al.* 2013; Guarnieri 2015). This study has been facilitated by the interpretation of recently acquired commercial seismic reflection data that were made available for the project, together with older seismic reflection and refraction data collected offshore Iceland since the early 1970s (Fig. 2). Revised $^{39}Ar–^{40}Ar$ dates of East Greenland basalt samples (e.g. Tegner *et al.* 2008; Larsen *et al.* 2013), and an improved coverage of magnetic data and interpretations (CAMP-GM: Gaina *et al.* 2011; Gernigon *et al.* 2015), are also considered. Pre- and post-break-up sedimentary strata and igneous complexes, together with volcanostratigraphic seismic characterization, have been revisited, together with a reassessment of the seawards-dipping reflector sequences (SDRs), igneous complexes, sill and dyke intrusions, and hydrothermal vent complexes.

The JMMC margins are compared to the conjugate margins: the central East Greenland margin and the Møre margin off Norway (Blystad *et al.* 1995). The western JMMC margin is linked to central East Greenland, where the Palaeozoic–Mesozoic Jameson Land Basin is located (JMLB: Henriksen 2008) (Fig. 1). The segmentation and extent of the southern area of the JMMC and its link to the oblique opening of the Norway Basin are also considered. Finally, the question of how the igneous

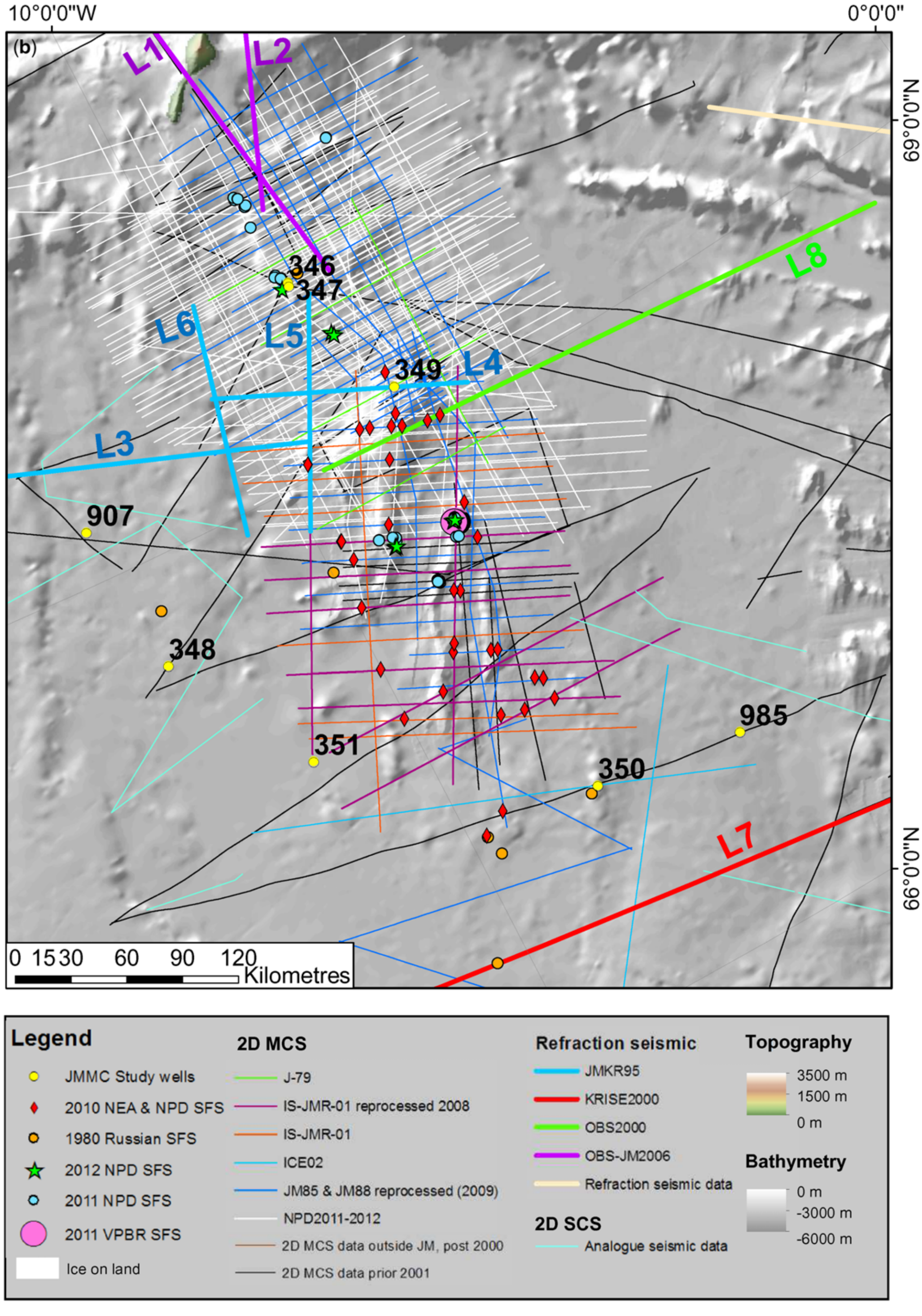
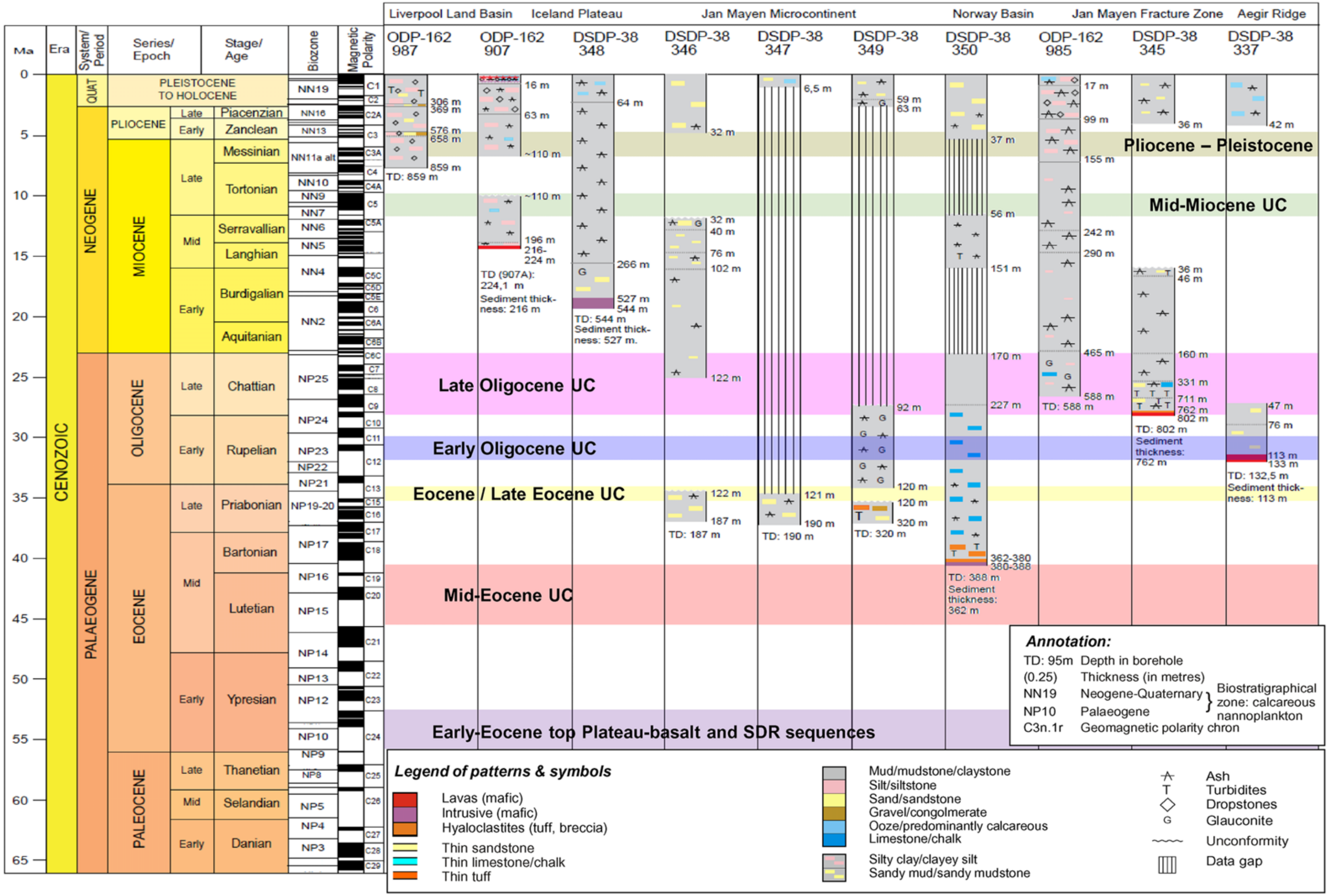


Fig. 2. (**b**) seabed sampling sites (NEA, National Energy Authority, Iceland; NPD, Norwegian Petroleum Directorate (2013); Spectrum ASA; TGS; SFS seafloor samples; VBPR, Volcanic Basin Petroleum Research AS).



Liverpool Land Basin
Iceland Plateau
Jan Mayen Microcontinent
Norway Basin
Jan Mayen Fracture Zone
Aegir Ridge
ODP-162 987
ODP-162 907
DSDP-38 348
DSDP-38 346
DSDP-38 347
DSDP-38 349
DSDP-38 350
ODP-162 985
DSDP-38 345
DSDP-38 337
Ma
Era
System/ Period
Series/ Epoch
Stage/ Age
Biozone
Magnetic Polarity
CENOZOIC
QUAT
NEOGENE
PALAEOGENE
PLEISTOCENE TO HOLOCENE
PLIOCENE
MIOCENE
OLIGOCENE
EOCENE
PALEOCENE
Piacenzian
Zanclean
Messinian
Tortonian
Serravallian
Langhian
Burdigalian
Aquitanian
Chattian
Rupelian
Priabonian
Bartonian
Lutetian
Ypresian
Thanetian
Selandian
Danian
Pliocene – Pleistocene
Mid-Miocene UC
Late Oligocene UC
Early Oligocene UC
Eocene / Late Eocene UC
Mid-Eocene UC
Early-Eocene top Plateau-basalt and SDR sequences
TD: 859 m
TD (907A): 224,1 m
Sediment thickness: 216 m
TD: 544 m
Sediment thickness: 527 m.
TD: 187 m
TD: 190 m
TD: 320 m
TD: 388 m
Sediment thickness: 362 m
TD: 588 m
TD: 802 m
Sediment thickness: 762 m
TD: 132,5 m
Sediment thickness: 113 m
Annotation:
TD: 95m Depth in borehole
(0.25) Thickness (in metres)
NN19 Neogene-Quaternary
NP10 Palaeogene
Biostratigraphical zone: calcareous nannoplankton
C3n.1r Geomagnetic polarity chron
Legend of patterns & symbols
Lavas (mafic)
Intrusive (mafic)
Hyaloclastites (tuff, breccia)
Thin sandstone
Thin limestone/chalk
Thin tuff
Mud/mudstone/claystone
Silt/siltstone
Sand/sandstone
Gravel/congolmerate
Ooze/predominantly calcareous
Limestone/chalk
Silty clay/clayey silt
Sandy mud/sandy mudstone
Ash
Turbidites
Dropstones
Glauconite
Unconformity
Data gap

events along the southern half of the JMMC are related to the Blosseville Kyst, the Iceland–Faroe Fracture Zone system that forms the NE limit of the Greenland–Iceland–Faroe Ridge Complex (GIFRC) (Árting 2014), and the Iceland Plateau (Fig. 1; Table 1) is addressed. The new interpretation has been used to model the detailed kinematics of the JMMC from pre-break-up time to the present day.

Geological setting of the central NE Atlantic

Several distinct rifting episodes and the subsequent break-up of the supercontinent Pangea led to the formation of a series of segmented rifted margins along the North Atlantic Ocean (Ziegler 1988). Extensional episodes are recognized from Devonian and Carboniferous times, initiated by the collapse of the Caledonian mountain belt (e.g. Andersen & Jamtveit 1990). Devonian onshore rift basins along East Greenland (Henriksen 2008) and SW Norway (Osmundsen & Andersen 1994, 2001; Osmundsen *et al*. 2002) are well documented, including their complex relationship to large-scale transtensional tectonics (Osmundsen & Andersen 2001). These basins are interpreted to extend in the central and northern part of the NE Atlantic during the Carboniferous, and were not affected by the Variscan Orogeny (Hopper *et al.* 2014), which occurred at the same time and influenced the NE and SE regions of the NE Atlantic, the North Sea and northern Europe (Pharaoh *et al.* 2010). During the Permian and Triassic periods, the entire NE Atlantic region was subjected to extension (e.g. Doré *et al.* 1999; Brekke 2000). At that time, a first rifting phase led to minor rotational block faulting and westwards tilted half-graben along East Greenland (Seidler 2000), forming terrestrial to shallow marine basins that discordantly covered the old Devonian–Carboniferous basin (Stemmerik 2000). The entire NE Atlantic system went through two major rifting phases during the Late Jurassic and a major Cretaceous rifting phase from the late Early Cretaceous (Aptian–Albian) to Late Cretaceous (Lundin & Doré 1997, 2011; Stoker *et al.* 2016), leading to significant crustal thinning in the central parts of the corridor and forming deep basins. The Cretaceous rifting phase may have included a hyperextension (Peron-Pinvidic *et al.* 2013), resulting in exhumation of deep crust and possibly mantle, as suggested by Osmundsen *et al.* (2002) or Osmundsen & Ebbing (2008).

During Late Paleocene and pre-break-up time, early volcanism associated with the North Atlantic igneous province occurred. Regionally extensive landwards flows consisting of subaerial and submarine lava flows onto adjacent elevated margins were emplaced during this time (Horni *et al.* 2016). Infilling of pre-existing basin areas formed escarpments and hyaloclastite deltas (Planke *et al.* 2000; Horni *et al.* 2016). Intense magmatism occurred at this time just SW of the JMMC, close to the Kangerlussuaq Basin and the southern extent of the Blosseville Kyst (e.g. Tegner *et al.* 2008; Brooks 2011). Magma-rich margins formed during the Early Eocene (56–55 Ma), in association with final rupture of the lithosphere and the onset of seafloor spreading of the NE Atlantic (e.g. Talwani & Eldholm 1977). The resulting North Atlantic continental margins contain SDR sequences observed on seismic reflection data (Hinz 1981). The break-up process was also accompanied by the emplacement of sill and dyke complexes into the margin flank areas. Oceanic crust was first formed in the Norway Basin at the end of chron C25 or the beginning of C24r (*c.* 55 Ma) forming the Ægir mid-oceanic ridge (e.g. Talwani & Eldholm 1977; Gaina *et al.* 2009).

The JMMC structure and stratigraphy observed between its eastern and western margins is profoundly segmented. A first-order boundary within the microcontinent is between the Jan Mayen Ridge and the SRC. Updated datasets suggest that the JMMC internal segmentation is probably related to the complex multistage seafloor spreading processes on both sides of the microcontinent.

Published plate tectonic reconstructions indicate a westwards migration of the plate boundary from the Norway Basin towards the Kolbeinsey mid-oceanic ridge (Nunns 1983*a*, *b*; Nunns *et al.* 1983; Lundin & Doré 2005; Doré *et al.* 2008; Gaina *et al.* 2009), suggesting a gradual separation of the microcontinent from East Greenland during the Early Miocene (Talwani & Eldholm 1977; Gunnarsson *et al.* 1989). Larsen *et al.* (2013) suggested that early rifting between the JMMC and East Greenland coast may have occurred from 49 to 44 Ma, with a direction semi-parallel to the Ægir mid-oceanic ridge system. This event generated increased igneous activity and structural deformation along the NE extent of the Blosseville Kyst (Fig. 1).

Fig. 3. The JMMC stratigraphic summary chart, partly based on DSDP and ODP boreholes (Talwani *et al.* 1976*a*, *b*; Manum & Schrader 1976; Manum *et al.* 1976*a*, *b*; Raschka *et al.* 1976; Nilsen *et al.* 1978; Thiede *et al.* 1995; Jansen *et al.* 1996; Channell *et al.* 1999*a*, *b*; Butt *et al.* 2001). This is used to tie the known shallow Cenozoic stratigraphy and unconformities to the seismic reflection data (see the type section in Fig. 4). The Pliocene–Pleistocene correlation marker is based on sedimentary core records (Talwani *et al.* 1976*a*, *b*).

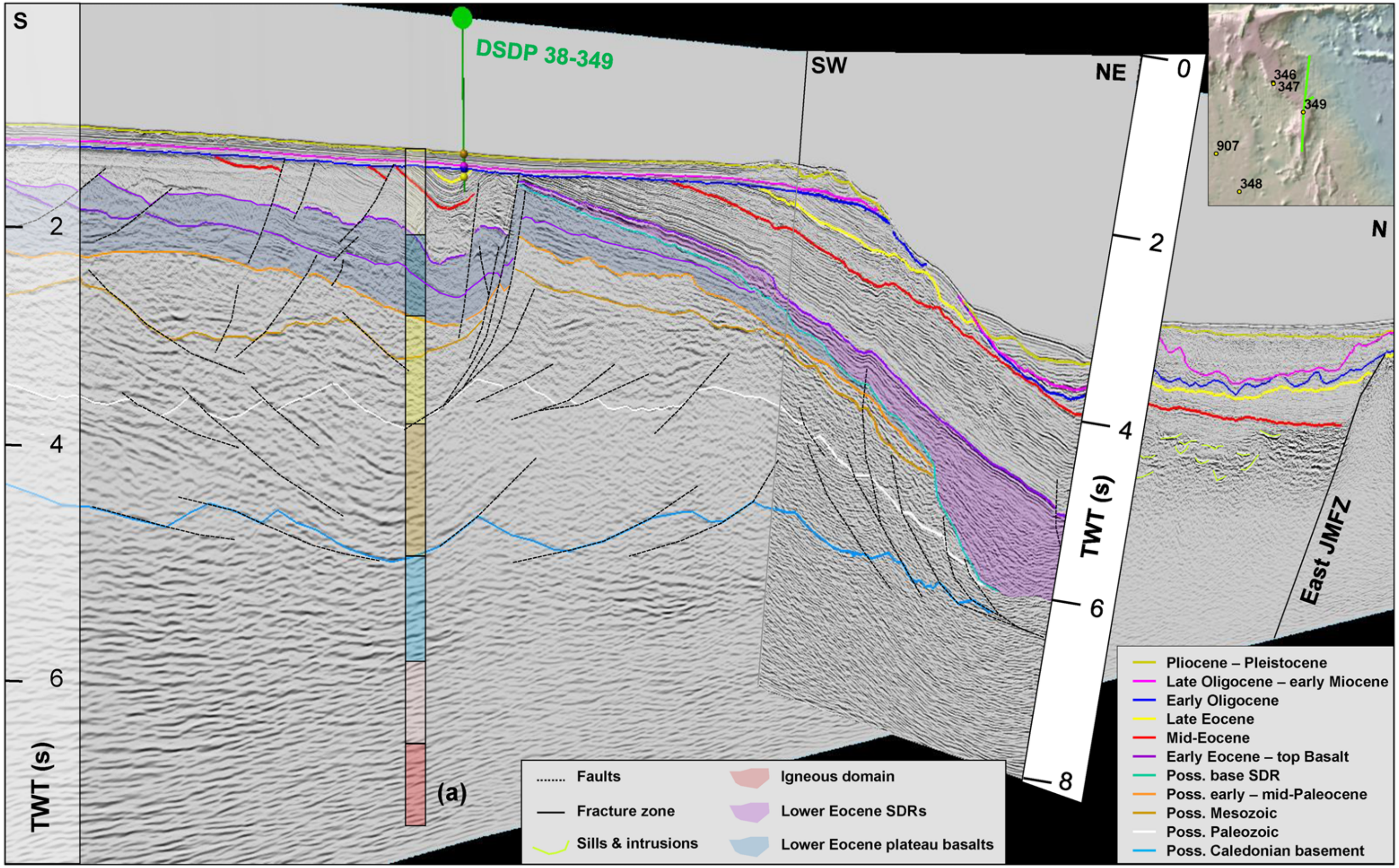


Fig. 4. Type section showing sedimentary basins below the Cenozoic succession and the seismic refraction velocity interval interpretation intersection (**a**) (Table 3). The SDR sequence (purple) is interpreted to overlie a thick basalt sequence (blue) that is likely to be equivalent to the plateau basalts exposed on East Greenland. The east–west line is courtesy of Spectrum ASA, and the north–south line is courtesy of NPD.

Data overview and methods

Geophysical datasets consist of magnetic and gravity anomaly compilations (Haase & Ebbing 2014; Nasuti & Olesen 2014) (Fig. 2), 2D multichannel seismic reflection data (2D MCS data) and seismic refraction data (Johansen *et al.* 1988; Olafsson & Gunnarsson 1989; Kodaira *et al.* 1998; Brandsdóttir *et al.* 2015). Eight shallow Ocean Drilling Program (ODP) and Deep Sea Drilling Program (DSDP) boreholes (legs 38, 151 and 162) (Eldholm & Windish 1974; Talwani & Udintsev 1976; Eldholm *et al.* 1987, 1989) provide some of the few samples from the JMMC (Figs 2–5). Results from seafloor sampling campaigns carried out in 1973 by Geodekyan *et al.* (1980), in 2010 by the National Energy Authority of Iceland (OS) and the Norwegian Petroleum Directorate (NPD), in 2012 by the NPD (Sandstå *et al.* 2012), and in 2012 by the Volcanic Basin Petroleum Research (VBPR) and TGS (Polteau *et al.* 2012) were also taken into account. Finally, recently revised ^{40}Ar–^{39}Ar dating of East Greenland coastal basalts and onshore unconformities within the igneous successions of the Blosseville Kyst area are considered (Larsen *et al.* 2013).

Seismic reflection data includes only a few 2D multichannel surveys from before 2001, of which the JM-85-88 results were reprocessed in 2009. More recent surveys include IS-JMR-01 (2001), ICE-02 (2002), WI-JMR-08 (2008), NPD-11 (2011) and NPD-12 (2012) (Fig. 2; Table 2). The reprocessed dataset was used for detailed volcanostratigraphic seismic characterization, which facilitated mapping and identification of structural elements, sedimentary sequences, SDR sequences, and sill and dyke complexes. Multibeam bathymetry data were used to map structural trends and features at the seafloor. This high-resolution bathymetry data in combination with seismic reflection data enabled us to differentiate strike-slip from normal fault systems and slump faulting along the steep escarpments of the microcontinent's ridges.

There are no deep drill holes on the JMMC. For this reason, the older history and stratigraphic correlations are inferred by comparison to better-known analogue areas along the conjugate margins, in particular the Jameson Land Basin (Surlyk *et al.* 1973; Surlyk & Noe-Nygaard 2001; Surlyk 1977, 1978, 1990, 1991, 2003; Henriksen 2008), and the mid-Norway Møre and Vøring margins (e.g. Brekke *et al.* 1999; Osmundsen *et al.* 2002; Faleide *et al.* 2010) (Fig. 1a; Table 1).

Correlation of stratigraphic information to seismic reflection data

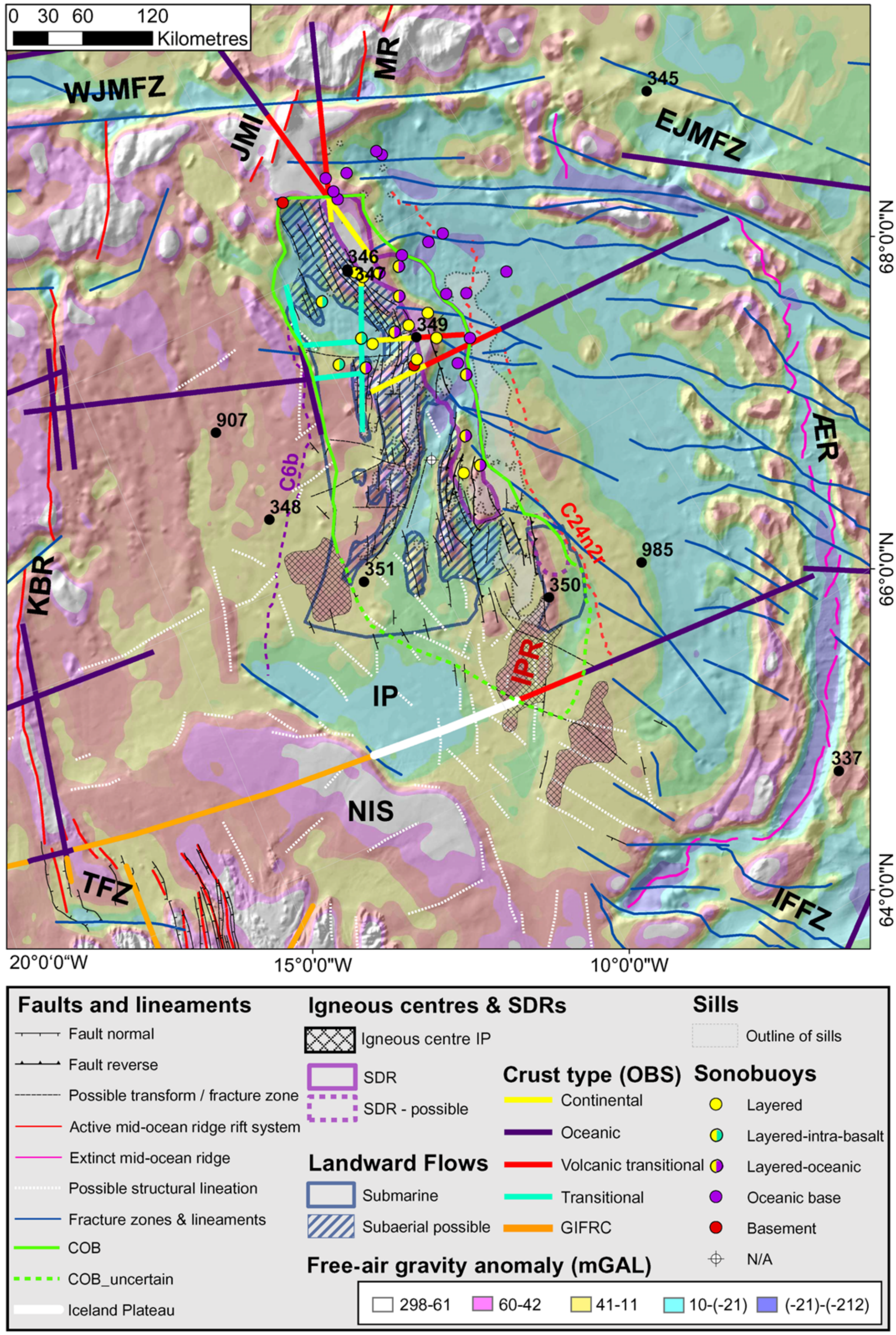
Information from DSDP Leg 38 (sites 346, 348, 349 and 350) and from seafloor samples retrieved by the NPD in 2011, 2012 and 2013 (Fig. 2b; Table 2) provide key constraints for tying it to the seismic reflection data along the central part of the JMMC (Fig. 3). This permits mapping of unconformities and post-basalt stratigraphy across the JMMC (Figs 4, 5 & 6). Some uncertainties in local stratigraphic correlations still exist, notably along the collapsed western flank of the JMMC and between the dislocated southern ridges. The sub-basalt sequences are only visible in the central area of the JMMC and around DSDP Leg 38 site 349. Seismic reflection data in vicinity of this drill site has been interpreted as possible Mesozoic and Palaeozoic strata based on comparisons to the Jameson Land Basin (Blischke *et al.* 2014*a*).

In addition to the well ties, onshore and offshore stratigraphic relationships along the western conjugate margin (Blosseville Kyst in East Greenland) provide information on the basalt stratigraphy that can be used for interpreting volcanic horizons on the seismic reflection dataset. This will be discussed in detail in the following section on 'Stratigraphic setting'.

Basement tie on reflection data using velocity interpretations

Significant uncertainty surrounds the full extent of the JMMC, primarily to the south but also to the east and west. Of particular focus here is the southern extent of the JMMC towards the Icelandic Shelf (Fig. 1). Talwani & Eldholm (1977) and Brandsdóttir *et al.* (2015) suggested that the JMMC terminates south of the SRC (Fig. 5). However, other studies propose severely stretched and fragmented continental crust and/or exhumed altered mantle for the southernmost part of the JMMC (Gaina *et al.* 2009; Breivik *et al.* 2012; Peron-Pinvidic *et al.* 2012*a*; Gernigon *et al.* 2015; Torsvik *et al.* 2015). Sparse data in combination with the inherent non-uniqueness of geophysical modelling and interpretation makes this particularly challenging. To better constrain this region, the 2D seismic reflection dataset was analysed in combination with the available seismic refraction data and crustal velocity models, as well as available well control along the ridges. This enabled an interpretation of the nature of acoustic basement and different crustal type domains (Figs 4 & 5).

Seismic refraction velocity model. Three ocean-bottom seismometer (OBS) experiments have been carried out for the larger JMMC area (Fig. 2; Table 2). The JMKR-95 survey included east–west- and SW–NE- orientated profiles (Kodaira *et al.* 1998), with profile JMKR95-L4 crossing the Jan Mayen Ridge just south of DSDP borehole


0 30 60 120
Kilometres
WJMFZ
JMI
MR
345
EJMFZ
68°0'0"N
346
347
349
907
C6b
348
351
C24n2r
985
350
66°0'0"N
KBR
IPR
IP
ÆR
337
NIS
TFZ
IFFZ
64°0'0"N
20°0'0"W
15°0'0"W
10°0'0"W
Faults and lineaments
Fault normal
Fault reverse
Possible transform / fracture zone
Active mid-ocean ridge rift system
Extinct mid-ocean ridge
Possible structural lineation
Fracture zones & lineaments
COB
COB_uncertain
Iceland Plateau
Igneous centres & SDRs
Igneous centre IP
SDR
SDR - possible
Landward Flows
Submarine
Subaerial possible
Crust type (OBS)
Continental
Oceanic
Volcanic transitional
Transitional
GIFRC
Sills
Outline of sills
Sonobuoys
Layered
Layered-intra-basalt
Layered-oceanic
Oceanic base
Basement
N/A
Free-air gravity anomaly (mGAL)
298-61
60-42
41-11
10-(21)
(-21)-(-212)

Leg 38 site 349. Line 8 of the OBS2000 survey lies 30 km south of that same borehole, crossing the SW end of the JMMC and the NW end of the EJMFZ (Mjelde *et al.* 2002, 2007; Breivik *et al.* 2012). The southern extent of the JMMC onto the Iceland Plateau was investigated as part of the KRISE survey in 2000 (Brandsdóttir *et al.* 2015) (L7 on Fig. 2b). A third survey in 2006 focused on the northern region of the JMMC, consisting of a NW–SE (L1) and a north–south profile (L2) across Jan Mayen Island (Kandilarov *et al.* 2012). Refraction data from all these surveys were used to constrain the southern extent of the JMMC.

Sonobuoys deployed during a 1985 seismic reflection survey provide velocity information for the upper layers of the microcontinent (Olafsson & Gunnarsson 1989). Based on these, we were able to better constrain the igneous crust of the JMMC, especially the area within the SDR sequences. Each sonobuoy location was assigned to a velocity-profile domain and incorporated into the volcanic facies map (Table 2; Fig. 5). Distinct velocity-profile domains are defined: layered, layered-intra-basalt, layered-oceanic, oceanic basement and basement of the microcontinent. The layered domain corresponds to velocity layers within the range 1.7–3.2 km s^{-1}, which are interpreted as post-break-up sediments; velocity layers between 3.9 and 5.5 km s^{-1} across the crest area of the JMMC, and distinct velocity interval breaks, are, however, most likely to correspond to pre-break-up sedimentary sections that correlate directly to seismic refraction data. The layered-intra-basalt domain corresponds to 270–470 m-thick basaltic layers (4–5 km s^{-1}) within the post-break-up sedimentary section (1.8–2.5 km s^{-1}) of the Jan Mayen Basin. A distinct velocity domain within the SDR area of the eastern flank is termed the layered-oceanic domain. The oceanic basement domain is characterized by thin low-velocity sediment layers ($<$2.5 km s^{-1}) on top of a high-velocity layer (4–5 km s^{-1}) that gradually and smoothly increases towards the base (5–6 km s^{-1}). These oceanic basement velocity domains were also compared to seismic refraction data interpretations (Breivik *et al.* 2012). One velocity profile at the crest of the JMMC is inferred to represent continental crust, as an abrupt velocity layer increase to 5.5 km s^{-1} was recorded below the thin post-break-up sediment cover (1.9–2.2 km s^{-1}).

Seismic velocities derived from wide-angle data were used as a basis for the depth and stratigraphic thickness estimations across the JMMC (Figs 4, 5, 6 & 7; Table 3). Relatively high-velocity values (4.4–5.6 km s^{-1}) have been assigned to the deeper layers above the acoustic basement where reflectivity is observed and interpreted as older pre-Cenozoic sedimentary sequences. This is similar to what is observed along the conjugate Norwegian Shelf, where the Mesozoic–Palaeozoic sections are usually interpreted to range between 4 and 5.5 km s^{-1} (Mjelde *et al.* 2008, 2009).

Stratigraphic setting

The following subsections summarize the interpretations of the Palaeozoic–Cenozoic succession over the JMMC. The total thickness of interpreted sediments is variable across the area and may reach up to 18 km along the eastern flank of the JMMC. The microcontinent contains several major unconformities and related structures that are linked to the complex tectonomagmatic processes on both sides.

A type section was constructed to provide a framework for mapping unconformity horizons and stratigraphic geometries along the JMMC (Figs 4 & 8). The section is based on bathymetric, borehole and seismic refraction data, combined with a dense grid of seismic reflection data. The section is orientated north–south along the strike of the Lyngvi Ridge, a central and stable block of the JMMC (Fig. 4, LYR in Fig. 8; Table 1).

The presence of Palaeogene volcanic rocks on the JMMC makes it difficult to interpret older strata below on seismic sections. Some local uncertainties in stratigraphic correlations still exist, notably along the microcontinent's collapsed western flank and between the dislocated southern ridges. Sub-basalt sequences are only visible within the central area of the microcontinent in the vicinity of DSDP Leg 38 site 349, where seismic reflection and refraction data have been compared to the Mesozoic and Palaeozoic strata of the Jameson Land Basin area of the East Greenland margin.

Fig. 5. Volcanic facies map based on the interpretation of seismic reflection and refraction data and information from wells, in addition to free-air gravity anomaly data (DTU2010: Andersen 2010). Refraction information includes velocity profile interpretations of wide-angle data and crustal-type interpretations (modified after Funck *et al.* 2014), as well as sonobuoy velocity profile interpretations (Olafsson & Gunnarsson 1989). Magnetic anomalies C6b and C24n2r are from Gernigon *et al.* (2015), showing the onset of oceanic seafloor spreading east and west of the JMMC. The extent of landwards flows labelled 'subaerial possible' refers to the pre-break-up plateau basalt extent over the area. The areas labelled 'submarine' areas are interpreted primarily by mapping the F-reflector (Gunnarsson *et al.* 1989) and are inferred as being related to the second break-up phase during Late Oligocene.

Table 2. *JMMC database and results that have been reviewed. Data and studies that have been used in this study are marked in column 'A'*

A	Year	Survey ID	Survey lead	Country	Platform name	Data repository	Data types
	1957		NAVO	USA			Aeromagnetic
X	1961–1971	V2304/V2703/V2803	L-DGO	USA	Vema/Conrad	NGDC	Bathymetry; magnetics; gravity; 2D multichannel reflection seismic (2D MCS)
X	1973	V3010	L-DEO	Norway	Vema/Conrad		Bathymetry; magnetics; gravity; 2D MCS
X	1974	DSDP Leg 38	DSDP		Glomar Challenger		Boreholes
	1975	CEPAN-75	CNEXO	France	Jean Charcot	Ifremer	Bathymetry; magnetics; gravity; 2D MCS
	1975	CEPAN-75	CNEXO	France	Jean Charcot	Ifremer	Bathymetry; magnetics; gravity; 2D MCS
	1975	CEPAN-75	CNEXO	France	Jean Charcot	Ifremer	Bathymetry; magnetics; gravity; 2D MCS
X	1975	BGR-75	BGR	Germany	Longva	BGR	2D MCS
X	1976	BGR-76	BGR	Germany	Explora	BGR	2D MCS
	1976	CGG-76	NPD/CGG	Norway			Aeromagnetic
	1977	IOS-77	UD/IOS	England	Shackleton	NGDC	2D MCS
X	1978	RC2114	L-DGO	USA	Robert Conrad	MGDS	Bathymetry; magnetics; gravity; 2D MCS2D MCS
X	1978	WGC-78		USA	Karen Bravo	Western-Geco	2D MCS
X	1979	J-79	NPD	Norway	GECO alpha	NPD	Bathymetry; magnetics; gravity; 2D MCS
X	1980		PAH/SGC	USSR	Akademic Kurchatov		Seafloor sampling
	1983	NGT83/RC2412	L-DGO/BGR	USA/Germany	Prospekta/Conrad		2D MCS, ESP, WA, CDP
	1983	RC2412	L-DEO	Norway	Robert D. Conrad		2D MCS and single-channel reflection seismic (2D SCS), gravimeter, magnetometer, sonar-echosounder
	1984	Arktis II/5	UHH	Germany	Polarstern		Refraction seismic
X	1985	JM-85	NPD/NEA	Norway	Malene Østervold	NPD	Bathymetry; magnetics; free air gravity; Bouguer gravity; magnetic; 2D MCS
X	1985	ODP Leg 104	ODP		JOIDES Resolution		Boreholes
X	1986	UiO-86	UiO	Norway	Håkon Mosby	NPD	2D MCS
X	1987	ESP	IFP	France			ESP; velocity; gravity
X	1988	JM-88	NPD/NEA	Norway	Håkon Mosby	NPD	Bathymetry; magnetics; gravity; 2D MCS; sonobuoy
X	2000	KRISE 2000	UiB	Norway	Håkon Mosby	UiB	2D MCS
X	2001	IS-JMR-01	InSeis	Norway	Polar Princess	CGGVeritas	2D MCS
X	2002	ICE-02	TGS-Nopec	Iceland	Zephyr 1	TGS-NOPEC	2D MCS; gravity
	2003	EW0307	L-DEO	USA	Maurice Ewing	MGDS	2D MCS; gravity; bathymetry cores
X	2005	JAS-05	NGU/NPD	Norway	Piper Navajo	NGU	Aeromagnetic
X	2006	OBS JM-06	UiB/Geomar	Norway/Germany	G. O. SARS	UiB	2D MCS; gravity, magnetics
X	2008	WI-JMR-08	Wavefield InSeis	Norway	Malene Østervold	Spectrum	2D MCS
X	2008	A8-2008	HAFRO/NEA	Iceland	Arni Fridriksson	HAFRO/NEA	Multibeam
X	2009	JM-85-88	Spectrum	Norway	Re-processing	Spectrum	2D MCS
X	2009	SAR-ICE-2009	NEA	Norway	ENVISAT satellite	Fugro NPA	Satellite Synthetic Aperture Radar (SAR)
X	2010	A11-2010	HAFRO/NEA/NPD	Iceland	Arni Fridriksson	HAFRO/NEA/ NPD/Fugro Geolab	Multibeam; seafloor sampling
	2010	B11-2008	HAFRO/NEA	Iceland	Arni Fridriksson	HAFRO/NEA	Bentic survey
X	2011	NPD-11	NPD/UiB	Norway	Harrier Explorer	NPD/PGS	2D MCS; seafloor sampling
X	2011	JMRS11	VPBR/TGS	Norway	TGS	VPBR/TGS	Seafloor sampling
X	2012	NPD-12	NPD/UiB	Norway	Nordic Explorer	NPD/PGS	2D MCS; seafloor sampling
X	2012	JAS-12	NGU/NPD/NEA	Norway	Piper Chieftain	NGU/NPD/NEA	Aeromagnetic

The Palaeozoic

Sub-basalt structures and inferred velocities along the JMMC (Fig. 4) are comparable to the Upper Palaeozoic–Lower Mesozoic rocks of the Jameson Land Basin and Traill Ø (Fig. 1a) areas onshore East Greenland, as well as of the Møre and Vøring basins offshore Norway (e.g. Surlyk *et al.* 1973; Surlyk & Noe-Nygaard 2001; Brekke *et al.* 1999; Osmundsen *et al.* 2002; Surlyk 2003; Henriksen 2008; Faleide *et al.* 2010). The inferred Palaeozoic section on the JMMC is thinner and more condensed in comparison to the East Greenland and Møre–mid-Norway areas. It can be inferred that the JMMC was at that time in a structurally higher position, corresponding to a shallow platform domain between the adjacent Jameson Land and Møre basins. Small sub-basin structures below the Cenozoic section are potentially linked to the region south of the Jameson Land Basin (Fig. 4). It remains uncertain whether older Palaeozoic, in particular Devonian and/or Carboniferous rocks similar to those that crop out along the NW edge of the Jameson Land Basin, underlie the northernmost part of the JMMC.

The Mesozoic

The interpreted Mesozoic–Paleocene interval of the JMMC has a velocity range of between 3.9 and 5.0 km s^{-1} (Table 3) (Kodaira *et al.* 1998; Kandilarov *et al.* 2012). These are similar to velocities interpreted for Mesozoic sequences in the Møre Basin, where pre-Cretaceous– Lower Cretaceous sections show a range of values between 3.85 and 5.35 km s^{-1} (Mjelde *et al.* 2008, 2009). Since subunits within the Mesozoic layers cannot be identified, an average value of 4.4 km s^{-1} is used for a time-depth conversion.

Although controversial, a seafloor sample has been interpreted to contain evidence of a Jurassic oil seep (Polteau *et al.* 2012) (NPD 2012) (Fig. 2b). Waxy bitumen samples from Cenozoic basalts on the Faroe Islands and the Isle of Skye in Scotland have also been associated with mature source rocks (Laier *et al.* 1997; Laier & Nytoft 2004).

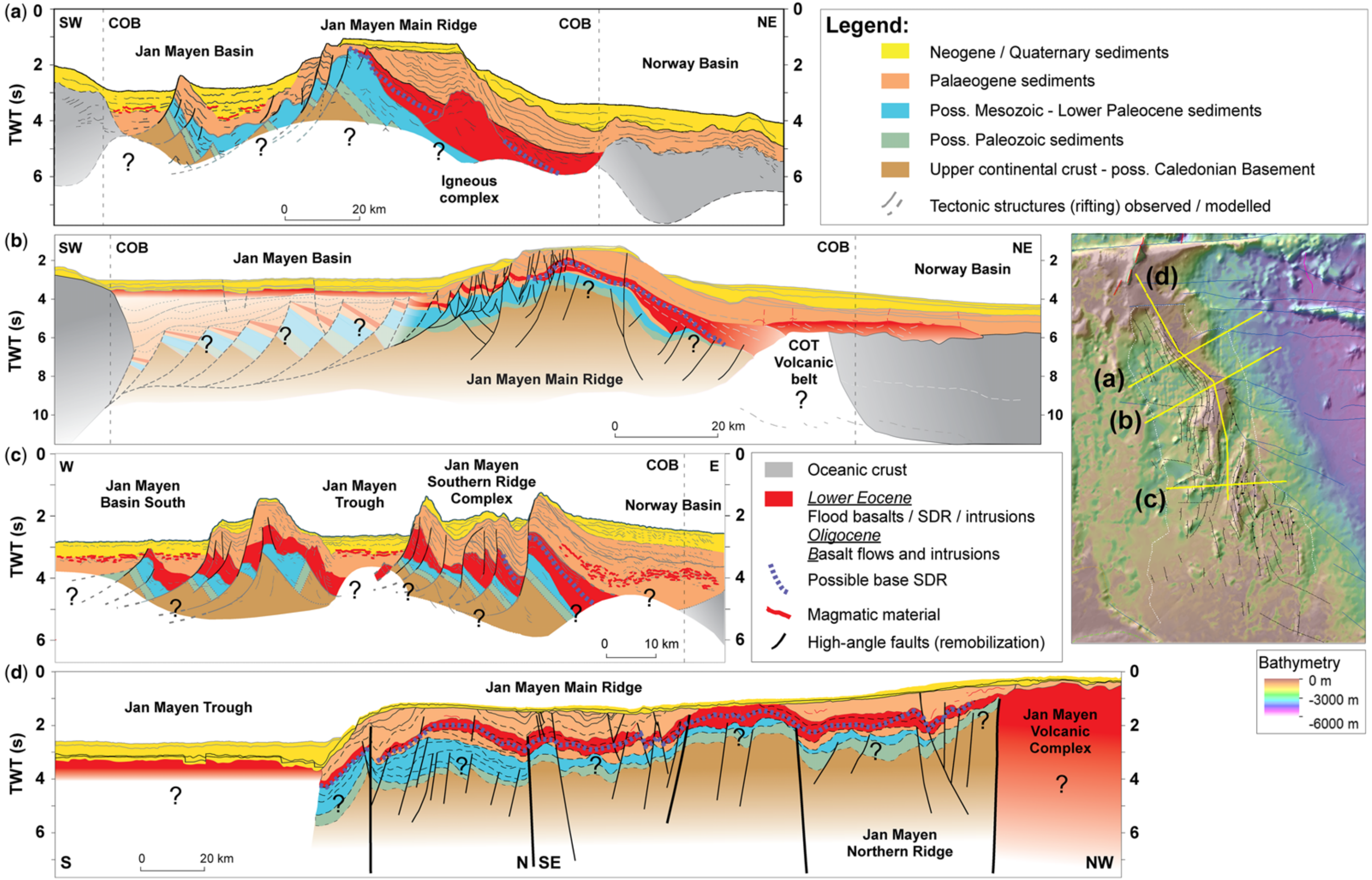
The Jameson Land Basin contains deltaic and lacustrine facies of Early Jurassic age that became increasingly influenced by marine processes during Mid–Late Jurassic, including deposits of a black organic-rich mudstone of the Hareelv Formation (Surlyk 2003), which is consistent with the regional setting of the NE Atlantic (Stoker *et al.* 2016). Thus, a trend towards a Mesozoic marine setting in the JMMC area can be inferred from regional structural observations. That would suggest a phase of southwards and eastwards crustal thinning during the Jurassic, which, in turn, may have resulted in a general subsidence of the region and the development of marine conditions (Peron-Pinvidic *et al.* 2012*b*).

The presence of a thin, Lower Cretaceous sedimentary succession across the JMMC seems probable according to results from a structural and stratigraphic comparison with the conjugate margins and the interpretation of the local seismic refraction data (Figs 4–6). During the Cretaceous, regional extension occurred throughout much of the NE Atlantic region (Stoker *et al.* 2016). Thick, deep-marine, sag-type basins formed during this process, including the Danmarkshavn and Thetis basins (Lundin & Doré 1997; Doré *et al.* 1999; Lundin & Doré 2011), the Traill Ø–Hold with Hope area of NE Greenland, and the Norwegian Vøring and Møre basins (Brekke 2000; Osmundsen *et al.* 2002; Faleide *et al.* 2010, 2010; Peron-Pinvidic *et al.* 2012*b*). However, all of the above-mentioned basins had their main extensional to hyperextensional phase during the Mesozoic, whereas the Jameson Land Basin had a main opening phase and faulting during the Palaeozoic (Henriksen 2008). Such hyperextension cannot be seen along central Eastern Greenland or the JMMC area, and possibly formed the western shelf margin of the Vøring basin.

The Cenozoic

Cenozoic sedimentary succession. The pre-break-up Cenozoic sedimentary succession was inferred by comparing onshore geological data from East Greenland to offshore areas of Scoresby Sund and Blosseville Kyst and the seismic reflection data of the JMMC. The post-break-up successions are derived from borehole data and seismic reflection data across the microcontinent, tied to the main unconformity horizons of the post-break-up succession (Figs 3, 4, 6 & 7). Mapping thickness intervals of the Cenozoic sequence along the ridge flanks and in-between the ridge segments enabled us to indicate areas of sediment deposition due to subsidence. Depositional settings for the Cenozoic strata are constrained by borehole data interpretations and onshore analogue comparisons.

Pre-break-up Cenozoic strata. In situ Paleocene dinoflagellate cyst assemblages were found in the uppermost pre-volcanic/pre-break-up sequences at the Blosseville Kyst area (Nøhr-Hansen & Piasecki 2002) (Figs 4, 6 & 7), which is the closest conjugate segment to the JMMC. This sequence corresponds to the upper marine sections of the Ryberg Formation in the Kangerlussuaq Basin (KgB on Fig. 1a) (Soper *et al.* 1976; Nøhr-Hansen *et al.* 2002), representing a regional marker that most likely also covered the JMMC area in the Paleocene. Dark mudstones of the Kap Brewster site (KB on Fig. 1a)


(a)
SW
COB
Jan Mayen Basin
Jan Mayen Main Ridge
COB
NE
Norway Basin
Igneous complex
TWT (s)
0
20 km
Legend:
Neogene / Quaternary sediments
Palaeogene sediments
Poss. Mesozoic - Lower Paleocene sediments
Poss. Paleozoic sediments
Upper continental crust - poss. Caledonian Basement
Tectonic structures (rifting) observed / modelled
(b)
SW
COB
Jan Mayen Basin
COB
NE
Norway Basin
COT Volcanic belt
Jan Mayen Main Ridge
(c)
W
Jan Mayen Basin South
Jan Mayen Trough
Jan Mayen Southern Ridge Complex
COB
E
Norway Basin
10 km
Oceanic crust
Lower Eocene
Flood basalts / SDR / intrusions
Oligocene
Basalt flows and intrusions
Possible base SDR
Magmatic material
High-angle faults (remobilization)
Bathymetry
0 m
-3000 m
-6000 m
(d)
Jan Mayen Main Ridge
Jan Mayen Trough
Jan Mayen Volcanic Complex
Jan Mayen Northern Ridge
S
N
SE
NW

contain reworked Cretaceous dinoflagellate cysts, indicating an age range between the late Danian to early Selandian (Nøhr-Hansen *et al.* 2002). Analogue areas for Lower Paleocene deposits include the Hold with Hope and Wollaston Foreland formations in Northeast Greenland (Larsen *et al.* 1999; Nøhr-Hansen 2003, 2012), and the Vøring and Møre basins offshore Norway (Brekke 2000; Faleide *et al.* 2010).

Post-break-up Cenozoic strata. The post-break-up Cenozoic sedimentary section is thickest along the microcontinent's eastern flank (Figs 5, 6 & 8), but has been eroded to a large extent across the highest sections of the ridges (e.g. the Lyngvi Ridge). Based on data from DSDP Leg 38 boreholes located on the northern Jan Mayen Ridge (Talwani *et al.* 1976*b*; Talwani & Eldholm 1977), the Cenozoic succession has been subdivided into a Lower Paleocene–Lower Oligocene unit, unconformably overlain by an Upper Oligocene–Quaternary unit (Figs 6 & 7).

The stratigraphic thickness of post-break-up sediments varies from 0 to 4200 m along the eastern flank of the JMMC (Fig. 8). The Cenozoic units consist predominantly of mudstone, whereas the Lower Paleocene–Lower Oligocene unit includes thin sand and muddy sand beds, which might have been deposited by turbidity currents on the JMMC shelf edge (Figs 3 & 7). The Upper Oligocene–Miocene units probably represent erosional sediments from the JMMC highs, redeposited into the surrounding lows. This can be seen around the highs of the SRC and its small sub-basins and in the borehole records (Talwani *et al.* 1976*b*; Talwani & Eldholm 1977). Above the Mid-Upper Miocene hiatus, Pliocene–Pleistocene deep-marine sediments are present across the microcontinent (Fig. 3). These youngest sediments are cut by deep-sea current features, causing localized erosion along the ridge segments, and were affected by gravitational slumping and faulting from the steep ridge flanks.

During the Pleistocene, several glacial events removed about 1 km of the Iceland Plateau basalts (Walker 1964) and much of the JMMC. The eroded sediments were likely to have been deposited into newly formed basins within the Iceland Plateau (Figs 5 & 9b), between the Iceland shelf and the SRC.

The Cenozoic igneous sequence

The Lower Palaeogene volcanic succession probably includes two major units: the pre-break-up plateau basalt sequence; and the break-up SDR sequence along the eastern flank of the JMMC (Planke *et al.* 2000) (Figs 4, 6 & 7). The southern and central part of the JMMC appear to be covered by Early Eocene plateau basalts, with a layered character of distinct lava-flow events interpreted as landwards flows (Planke *et al.* 2000). Apparent erosional effects at the top of these formations are probably filled with Lower Eocene sediments.

The pre-break-up igneous formations. The plateau basalt equivalent section on the JMMC is subdivided into two major units and appears to increase in thickness from north to south towards the SRC (Fig. 7c). A possible base of the plateau basalts was tied to the velocity model from refraction data (Kodaira *et al.* 1998). From this, an igneous stratigraphic thickness of approximately 1100 m is estimated across the crest of the JMMC. There are indications that the plateau basalt sequence continues to be downfaulted towards the south (Fig. 4), implying the formation of a topographical low south of the SRC (Figs 10 & 11a). This would possibly correlate with the very thick basalt sections in the Kangerlussuaq Basin, at the southernmost extent of the Blosseville Kyst, and the NW area of the Faroe Islands Platform (FP on Fig. 1a). In these regions, the main pre-break-up to break-up phase plateau basalts are well exposed onshore. The succession is estimated to be more than 6 km thick towards the southern extent of the Blosseville Kyst and the Kangerlussuaq area (Brooks 2011), but is progressively younger and dramatically thinner to the north in Scoresby Sund and Jameson Land Basin (Larsen *et al.* 1999, 2014). Based on age dating of exposed dykes that have similar ages to the plateau basalts (Larsen *et al.* 2014), it is inferred that the plateau basalts covered the Jameson Land Basin but were subsequently eroded away. The thickness of the eroded section is estimated at 2–3 km (Mathiesen *et al.* 2000).

The break-up igneous formations. During break-up (54–55 Ma), a magma-rich margin formed along the eastern flank of the JMMC with thick sequences of onlapping lava flows forming SDRs (Figs 4, 5 & 7).

Fig. 6. JMMC tectonostratigraphic type sections that are based on seismic reflection and refraction data interpretations, tied to shallow borehole data only. Possible Palaeozoic–Mesozoic formations of the JMMC are inferred from the structural and stratigraphic setting in comparison to the East Greenland analogue areas (Hamann *et al.* 2005). Seismic velocity models from refraction data are consistent with interpretation. Modified from Peron-Pinvidic *et al.* (2012*a*, *b*) and Blischke *et al.* (2014*b*. The volcanic margin is clear (see the sections in **a**–**c**) along the eastern flank of the microcontinent. The magmatic anomaly poor western margin that was formed during the second break-up (**d**) appears as a sharp boundary along the western margin of the microcontinent.

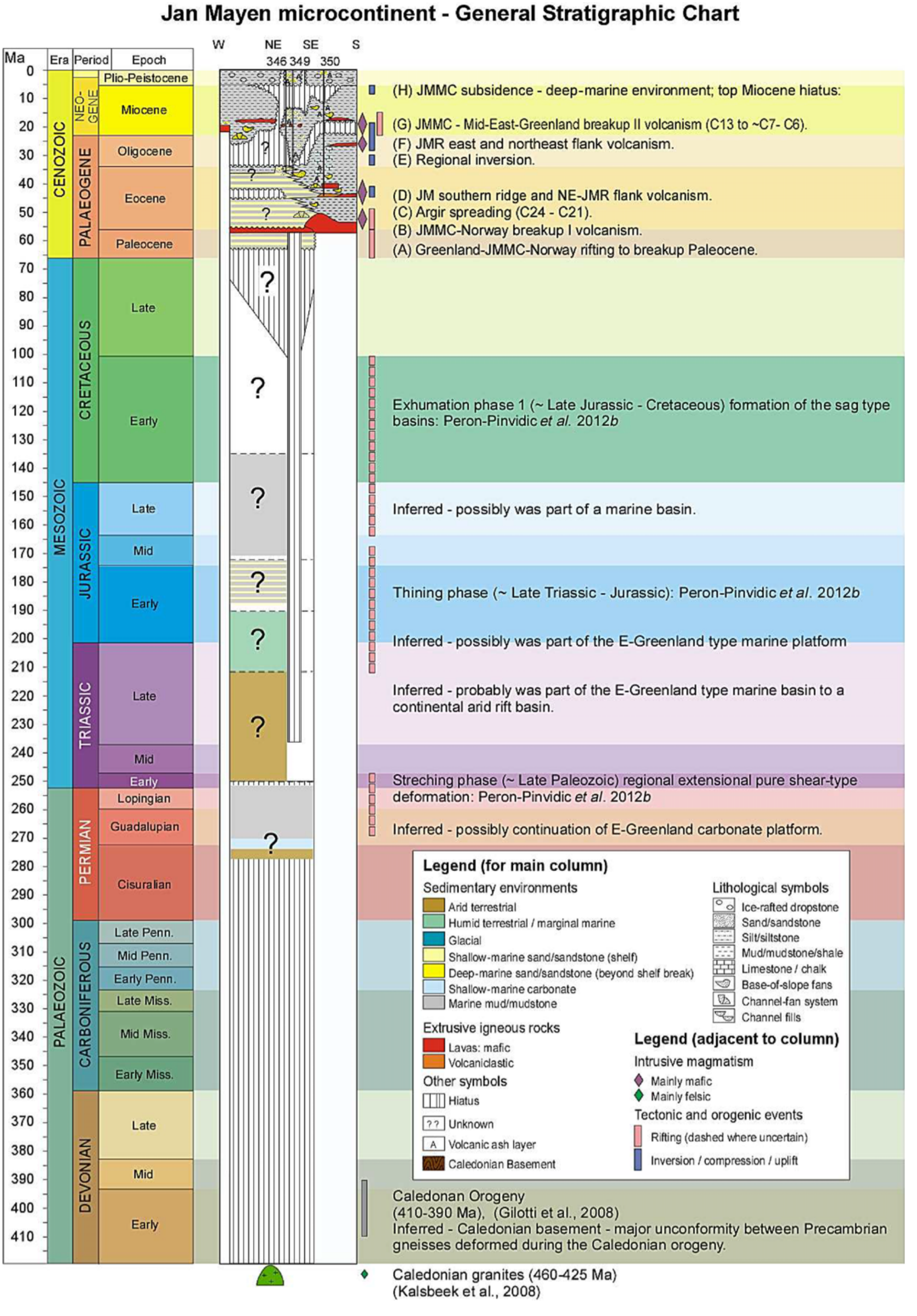


Fig. 7. Tectonostratigraphic chart of the JMMC region based on borehole data, seismic interpretation and analogue studies (Talwani & Eldholm 1977; Åkermoen 1989; Gunnarsson *et al.* 1989; Rey *et al.* 2003; Harðarsson *et al.* 2008;

These SDRs are considered to be subaerial lava flows onlapping higher terranes, stacking onto previous flows as rifting and seafloor spreading initiated along the margins (Hinz 1981; Mutter *et al.* 1982; Planke *et al.* 2000; Berndt *et al.* 2001). The SDRs along the eastern flank onlap westwards onto the crest of the main ridge and the SRC: they are up to 4–6 km thick at the NE end of the JMMC, thinning from north to south.

The Mid-Eocene–Neogene volcanostratigraphy

The Eocene sedimentary succession is intruded by many sills and dykes, especially along the eastern and SE flanks, coinciding with the Early–Middle Eocene time (49–44 Ma). During this period, igneous activity affected the entire southern extent of the microcontinent. The occurrence of a series of ridge jumps from east to west across the Iceland Plateau have been suggested by several authors (e.g. Gaina *et al.* 2009; Brandsdóttir *et al.* 2015) (Figs 5 & 9). The youngest substantial igneous event on the JMMC is expressed as a flat-lying, opaque reflection in seismic data, the so called 'F-Reflector' (Gunnarsson *et al.* 1989), which covers most of the northern Jan Mayen Basin, the western margin of the JMMC (Fig. 6b, c) and much of the Jan Mayen Trough (Figs 5 & 6d). This reflection is believed to correspond to regionally extensive composite sheets of flat-lying lava flows and intrusive rocks that covered the underlying structures in very shallow and unconsolidated wet sediment possibly during the Late Oligocene (28–22 Ma) (Gunnarsson *et al.* 1989). This corresponds to the time of plate boundary relocation from the Ægir mid-oceanic ridge to the Kolbeinsey mid-oceanic ridge (Gaina *et al.* 2009). No SDR type formations are observed along the JMMC western margin. Since the complete separation from the East Greenland margin, only the northern extent of the JMMC has been affected by volcanic activity, which is related to the present-day Jan Mayen Island volcanic system.

Kinematic reconstruction of the central NE Atlantic region

A series of detailed kinematic reconstructions for the JMMC tectonic blocks and surrounding areas is presented in Figures 10 and 11. Plate reconstruction parameters for the relative motion of the JMMC and conjugate margins were calculated using an interactive fitting method using GPlates (http://www.gplates.org: Boyden *et al.* 2011; see also Gaina *et al.* this volume, in review). Rotation parameters for Greenland relative to Eurasia are based on Gaina *et al.* (this volume, in review). The geographical extent of the individual JMMC tectonic blocks was guided by the interpretation of Peron-Pinvidic *et al.* (2012*a*) and Gernigon *et al.* (2015).

The model includes six stages: (1) the pre-break-up stage ending at 56–55 Ma; (2) the break-up stage at chron C24n2r (53.36 Ma) equivalent to chron C24B of Gunnarsson *et al.* (1989), associated with the formation of a wide volcanic margin; (3) an early intra-JMMC rifting phase around C22n (49.3 Ma); (4) a fully established intra-JMMC rift phase and the beginning of rift transfer from east to west around C21n (47.33 Ma); (5) westwards rift transfer and the initial western JMMC margin break-up phase around C13n (33.1 Ma); and (6) the complete isolation of JMMC by establishing the Kolbeinsey mid-oceanic ridge around C6b (21.56 Ma).

Structural elements included in plate tectonic reconstructions

We combined magnetic and gravity anomaly data interpretations with other structural, geological and geophysical data for defining several distinct structural elements that constitute independent

Fig. 7. (*Continued*) Gilotti *et al.* 2008; Kalsbeek *et al.* 2008; Gaina *et al.* 2009; Erlendsson 2010; Gernigon *et al.* 2012, 2015; Peron-Pinvidic *et al.* 2012*a*, *b*; Stoker *et al.* 2016). The chronostratigraphic scheme is based on Gradstein *et al.* 2012. The pre-break-up stratigraphic section is inferred from seismic data and analogue comparisons, primarily the Jameson Land Basin, East Greenland. (**a**) Greenland–JMMC–Norway rifting to break-up. (**b**) JMMC–Norway break-up I volcanism: emplacement of the plateau basalts, SDR, dyke complexes. (**c**) Aegir spreading (C24–C21): extension along the JMMC– mid-East Greenland rift. (**d**) JM southern ridge and NE–JMR flank volcanism. (**e**) Regional inversion causing an erosional hiatus across the main ridges, localized erosion into surrounding lows as marine fan–turbidite deposits, and minor reverse faulting. (**f**) JMR east and NE flank volcanism. (**g**) JMMC–mid-East Greenland break-up II volcanism (C13; *c.* C7–C6): the formation of composite sheets of flat-lying, shallow intrusions and lavas into shallow soft sediment (the F-reflector), and fault-connected dykes and sill intrusions simultaneously with the establishment of oceanic crust from the Kolbeinsey mid-oceanic ridge and formation of the Jan Mayen Basin. At this time, erosion along the Southern Ridge Complex occurred. (**h**) JMMC subsidence and establishment of a deep-marine environment. The Kolbeinsey mid-oceanic ridge continues to establish itself as the main spreading centre. Sedimentary sequences include ash layers. The top Miocene hiatus was possibly caused by regional uplift in conjunction with west to east migration of the main rift axis on Iceland.

Table 3. *Reflection seismic interval velocity estimates used for building a time-depth conversion model based on refraction data interpretations*

Seismic intervals	OBS model (Kodaira *et al.* 1998)		OBS model (Kandilarov *et al.* 2012)	Velocity data used for time-depth conversion	Estimated stratigraphic thickness across the JMMC	Estimated stratigraphic thickness OBS model Figure 4 intersection
	P-wave model layer	V_P (km s^{-1})		V_P (km s^{-1})	Thickness ranges (km)	TST estimate (km)
Seabed	Water depth		–	1.49	0–3.2	0.95
Plio-Pleistocene	Cenozoic sediments	2.0–3.5	1.7–2.2	1.8	0.1–1.1	0.06
Late Oligocene–Early-Miocene				2.0	0–1.05	0.09
Early Oligocene			2.2–3.2	2.3	0–2.05	0.29
Late Eocene						
Mid-Eocene				3.0	0–2.84	0.65
Basalts–Early Eocene	Basalt (SDR)	4.0–5.0	3.2–4.1	4.0	0–6	1.48
Early–Mid Paleocene	Possible Lower	3.9–4.7	3.9–5.0	4.4	0–4.5	2.25
Possible Mesozoic	Paleocene–Mesozoic					
Possible Palaeozoic	Possible Palaeozoic	5.0–5.3	5.0–5.5	5.2	0–4	3.82
Estimated stratigrahic and igneous section thickness above Caledonian basement:						8.64
Possible Caledonian Basement	Continental upper crust	5.5–6.7	5.5–6.5	5.6	0–15	2.79
Continental lower crust – sub-basalt	Continental lower crust	6.7–6.8	6.5–7.2	6.8	0–10	2.96
Estimated stratigrahic, igneous section, and crustal stratigraphic thickness:						14.4

Displayed are the possible stratigraphic thickness ranges across the highly variable mapped JMMC, and one specific stratigraphic thickness profile for the reflection seismic data intersection with the OBS model by Kodaira *et al.* (1998).

kinematic model blocks (isochrons and rotation model, see Gaina *et al.* this volume, in review). Interpreted fault and transfer systems are linked to stratigraphic thickness changes, mapped unconformities, age data control from borehole data and other geological information. Reconstructions include the present-day coastline for better reference (Figs 10 & 11).

We have compiled a number of structural lineaments in the JMMC area, which are based on published work, bathymetry, free-air gravity anomaly and derivatives, magnetic anomaly (Hopper *et al.* 2014), and seismic reflection data. These proposed structural lineaments (Fig. 1a) are based on features that can be inferred from at least two, and preferably three, different potential datasets.

We consider several observations that may give information on how the JMMC evolved during the multiphased break-up. Along the eastern margin, Palaeogene rocks dip steeply towards the Norway Basin (Fig. 6) and exhibit normal faulting associated with rapid subsidence within the northern and southern eastern-flank basin (EFBN and EFBS in Fig. 8; Table 1), in association with SDR emplacement and the early establishment of the Ægir mid-oceanic ridge system. The western margin, along the Jan Mayen Ridge North, the Sörlahryggur Flank Basin and the Sörlahryggur Ridge (JMRN, SFB, SHR in Fig. 8; Table 1), displays a more gentle west-facing listric normal fault system (Fig. 6), where rotated crustal blocks are downfaulted towards the Jan Mayen Basin (JMB in Fig. 8; Table 1) along major detachment faults. This indicates a distinct phase of extension and basin formation before the final break-up of the JMMC to the west. In addition, some minor reverse faulting occurred along the SE segments within the SRC, including the Fáfnir Ridge, the Otur Ridge, the Otur Ridge southern spur, the Langabrún Ridge and the Dreki Ridge (FR, OR, ORS, LR and DR in Figs 6 & 8; Table 1), as a result of regional inversion during the Late Eocene–Early Miocene.

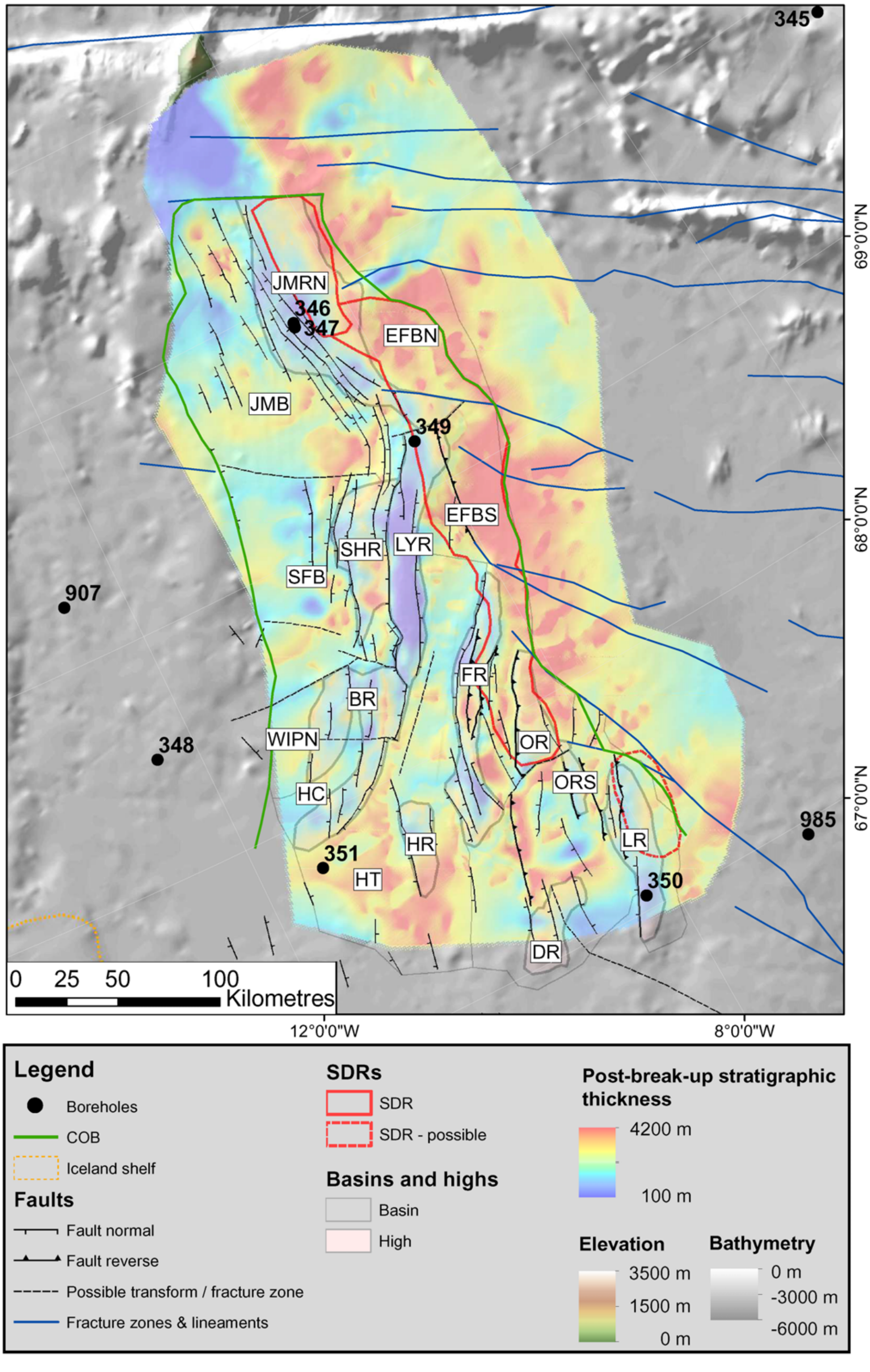
Stratigraphic unconformities represent major tectonostratigraphic markers. Several major and small-scale unconformities in the JMMC stratigraphy have been described (Figs 3, 4 & 7). Three unconformities are present within Eocene sections: (1) an Early Eocene main break-up unconformity at C24 (56–53 Ma); (2) a main Middle Eocene unconformity at C19–C20 (47–41 Ma) associated with the initiation of ridge transition from the Ægir mid-oceanic ridge to extension concentrated further west; and (3) an unconformity of the Late Eocene age at chron C15 (*c.* 35 Ma). Following these Eocene events, two major erosional events affected the microcontinent during the Oligocene. An unconformity that marks a major truncation surface at 33 Ma (C12–C11) can be observed across all ridge areas of the microcontinent and correlates to a change in the seafloor spreading direction along the Ægir mid-oceanic ridge axis before the cessation of the mid-oceanic ridge (Gernigon *et al.* 2015) (Fig. 11d). This transtensional phase resulted in small-scale reverse faulting across the SRC. A second unconformity marks a major hiatus in the Late Oligocene, which corresponds to the complete cessation of the Ægir mid-oceanic ridge. The microcontinent was isolated completely, as the Kolbeinsey mid-oceanic ridge became fully established along the western margin at chron C6b (22–21 Ma) (Fig. 11e).

Pre-break-up stage ending around 56–55 Ma

Major structural elements and subdivisions of the JMMC at pre-break-up time align fairly well with published regional trends and lineaments interpreted on the NE Atlantic continental margins (Hamann *et al.* 2005; Tsikalas *et al.* 2005, 2008; Vogt & Jung 2009; Gaina *et al.* 2009, 2013; Gernigon *et al.* 2012, 2015) (Fig. 10). Three main trends are observed (Fig. 10): (1) a north–south trend similar to the strike-slip fault systems of the Shetland Islands, which is also aligned with the Jameson Land Basin axis and the main boundary fault of the Liverpool Land High; (2) an east–west trend parallel to the strike-slip fault system proposed by Guarnieri (2015), forming the northern limit of the Faroe–Shetland region; and (3) a SE–NW trend that separates the JMMC from the Vøring margin to the north and the Faroe Islands region to the south. The latter two subdivisions also form the boundaries of several gaps in the reconstructions shown by Gaina *et al.* (this volume, in review).

At pre-break-up time, the JMMC was most probably a 40–100 km-wide crustal fragment, with stratigraphic and crustal geometries corresponding to the conjugate central East Greenland margin (Gaina *et al.* 2009; Gernigon *et al.* 2015) (Figs 1a, 10 & 11). The JMMC was bounded to the north by the proto-Jan Mayen Fracture Zone (proto-JMFZ in Fig. 10). The northern segment of the microcontinent near the proto-JMFZ that could be mapped shows stratigraphic and structural similarities with the Scoresby Sund and Blosseville Kyst areas.

The NNW–SSE-orientated axis of the Jameson Land Basin terminates abruptly at the Blosseville Kyst (Engkilde & Surlyk 2003), with no major east–west-striking fault structures marking its southern boundary in the Scoresby Sund area. This indicates that a deep basin may continue south underneath the Blosseville Kyst. The kinematic models here suggest that the central and southern JMMC were attached to that part of East Greenland prior to break-up, with the NNW–SSE-striking Liverpool Land high lining up with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JMRN
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0 25 50 100
Kilometres
69°0'0"N
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67°0'0"N
12°0'0"W
8°0'0"W
Legend
Boreholes
COB
Iceland shelf
Faults
Fault normal
Fault reverse
Possible transform / fracture zone
Fracture zones & lineaments
SDRs
SDR
SDR - possible
Basins and highs
Basin
High
Post-break-up stratigraphic thickness
4200 m
100 m
Elevation
3500 m
1500 m
0 m
Bathymetry
0 m
-3000 m
-6000 m

the northern Lyngvi Ridge, the central high of the JMMC (Fig. 8).

The southern boundary is less clear, but was probably influenced by the large-scale transform system proposed by Guarnieri (2015). This, in turn, was linked to the development of the Greenland–Iceland–Faroe Ridge Complex, a subdomain of the North Atlantic Igneous Province. The GIFRC forms a complex WNW–ESE-striking ridge structure that includes the Greenland–Iceland Ridge, the entire Iceland shelf and the Iceland–Faeroe Ridge.

The southernmost part of the microcontinent, where East Greenland links to the Faroe Platform and the Hatton Bank, remains far more uncertain owing to a lack of data constraints (Breivik *et al.* 2012; Brandsdóttir *et al.* 2015; Gernigon *et al.* 2015; Torsvik *et al.* 2015). Still, the stratigraphic mapping of the JMMC (event B in Fig. 7) suggests a potential link between the southern extent of the JMMC and the pre-break-up/break-up successions along the Blosseville Kyst of central East Greenland margin, the NW margin of the Faroe Platform and the northern edge of the Iceland Faroe Ridge (Figs 10 & 11a). The interpretation of seismic reflection data across the central part of the JMMC indicates two possible Early Eocene plateau basalt-equivalent sections that appear to increase in thickness from north to south (Fig. 4).

A gap in our pre-break-up reconstruction situated to the south of the JMMC is assumed to have been filled by either stretched continental crust (Torsvik *et al.* 2015) and/or pre-break-up formations of Palaeozoic–Early Paleocene age, similar to those known from onshore East Greenland and the Norwegian shelf margin (Brekke 2000).

Break-up stage around C24n2r (53.36 Ma)

The break-up stage (Fig. 11a and event (C) in Fig. 7) is marked by large-scale extrusive volcanism leading to the formation of the plateau basalts onshore East Greenland (Storey *et al.* 2007*a*, *b*). The plateau basalts mapped extend from East Greenland and across the Faroe Islands area. They have an estimated thickness of more than 6 km in East Greenland (Brooks 2011 and over 7 km at the Faroe Islands (Árting 2014).

The main structural elements of the JMMC are parallel to the overall trends of the basins and highs of the surrounding regions, except for the east Jan Mayen Fracture Zone, which appears to be linked to an initial rift centre just at the NW edge of the JMMC, as proposed by Gaina *et al.* (2009). This coincides with the formation of SDR sequences along the eastern margin, which reach a stratigraphic thickness of 4–6 km at the northeasternmost flank (Figs 4 & 5).

Early Eocene (53.36 Ma) volcanism marks the establishment of the Ægir mid-ocean ridge system at C24n2r (e.g. Gernigon *et al.* 2015), separating the mid-Norwegian Vøring and Møre basins from the Central East Greenland margin. Large igneous complexes were mapped on seismic reflection data along the eastern flank of the JMMC located close to fracture/fault zones (Figs 7a, b & 9). These complexes most probably formed after the initial emplacement of SDR sequences, cutting through that sequence and the initial oceanic crust, forming a 40–80 km-wide volcanic margin (Fig. 5) as Eocene sediments onlap and fill in those features.

Initial intra-JMMC rifting phase around C22n (49.3 Ma)

The initial intra-JMMC rifting phase at chron C22n (49.3 Ma; Fig. 11b) is marked by the southwards propagation of the Ægir mid-oceanic ridge and the establishment of a continuous spreading system in the Norway Basin. The EJMFZ extends from the Mohn's mid-oceanic ridge, which was established to the NE of the JMMC at C24 and separated the Vøring margin from the NE Greenland margin. A distinct rift segment can be seen along the SE margin of the JMMC, forming the eastern extent of the Iceland Plateau, here referred to as Iceland Plateau rift I (IPR-I: Fig. 11b, c). During the Lower Eocene, thick sediment wedges formed along the central eastern and NE flank of the microcontinent (Figs 7 & 8).

An uneven north to south change in spreading rate from intermediate to slow (Gernigon *et al.* 2015) led to oblique spreading within the Norway Basin, initiating a V-shaped mid-oceanic ridge structure and a counterclockwise rotation of the JMMC. This resulted in extension of the entire southern half of the microcontinent and the formation of small ridge segments. This extension widened the area across the southern half of the microcontinent from the original 100 km to approximately 150 km. This also explains the crustal

Fig. 8. Post-break-up stratigraphic thickness map includes estimates from the Lower Eocene (top SDR/flood basalts) to present day. The main ridges are heavily eroded and have only a very thin sediment cover. The low areas along the east flank show a very thick stratigraphic section. The thicker stratigraphic sections along the west flank of the ridge are related to the Jan Mayen Basin, as well as to several lows between the main structural highs. The stratigraphic thinning towards the Jan Mayen Island volcanic complex to the north and towards the south, and the area of borehole 350, where the Iceland Plateau Rift is proposed. For an explanation of abbreviations, see Table 1.

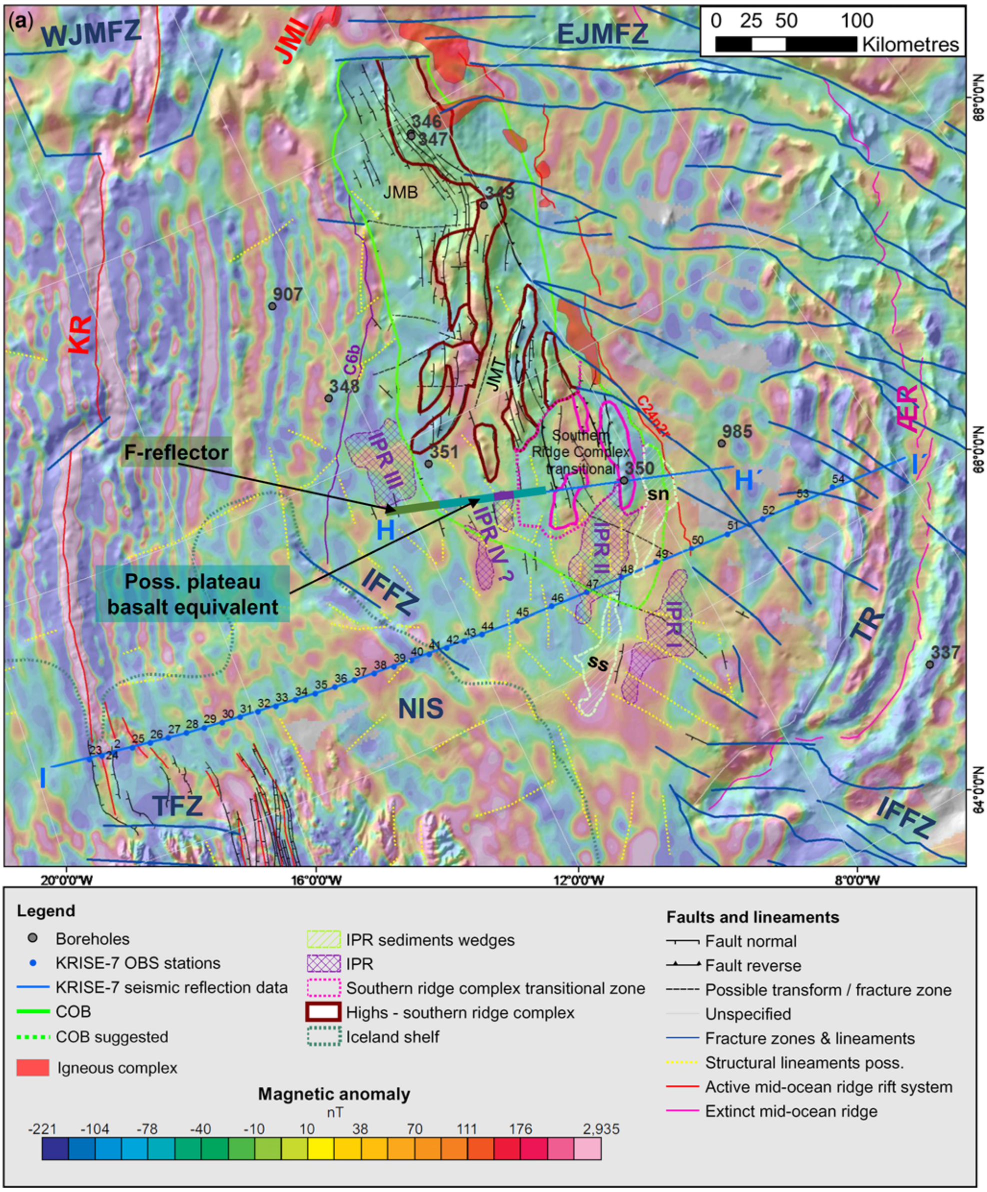

Fig. 9. Structure and volcanic elements map (**a**) of the JMMC and the Iceland Plateau. The proposed Iceland Plateau rifts I, II and III (IPR I, IPR II and IPR III) are interpreted on seismic reflection data. Gravity and magnetic anomalies are linked to segments of older microcontinent transitional crust 'Southern Ridge Complex transition', pre-break-up plateau basalts segments and youngest second break-up volcanics 'F-marker'. The Iceland Plateau rift II was described by Brandsdóttir *et al.* (2015) based on interpretation of seismic refraction data. The sediment wedges (sn and ss) correspond to observations on seismic reflection data (in b) and correlate to negative gravity anomalies west of the COB. Interpreted profiles.

thinning trend from north to south that has been observed on refraction data in the JMMC area (Kandilarov *et al.* 2012).

The Ægir mid-oceanic ridge system did not directly link up with the Reykjanes mid-oceanic ridge system to the south. Instead, the link to the Reykjanes mid-oceanic ridge was marked by a complex system of transforms and off-ridge volcanic systems that formed an Iceland-type oceanic crust within the proto-GIFRC (Árting 2014). In order to

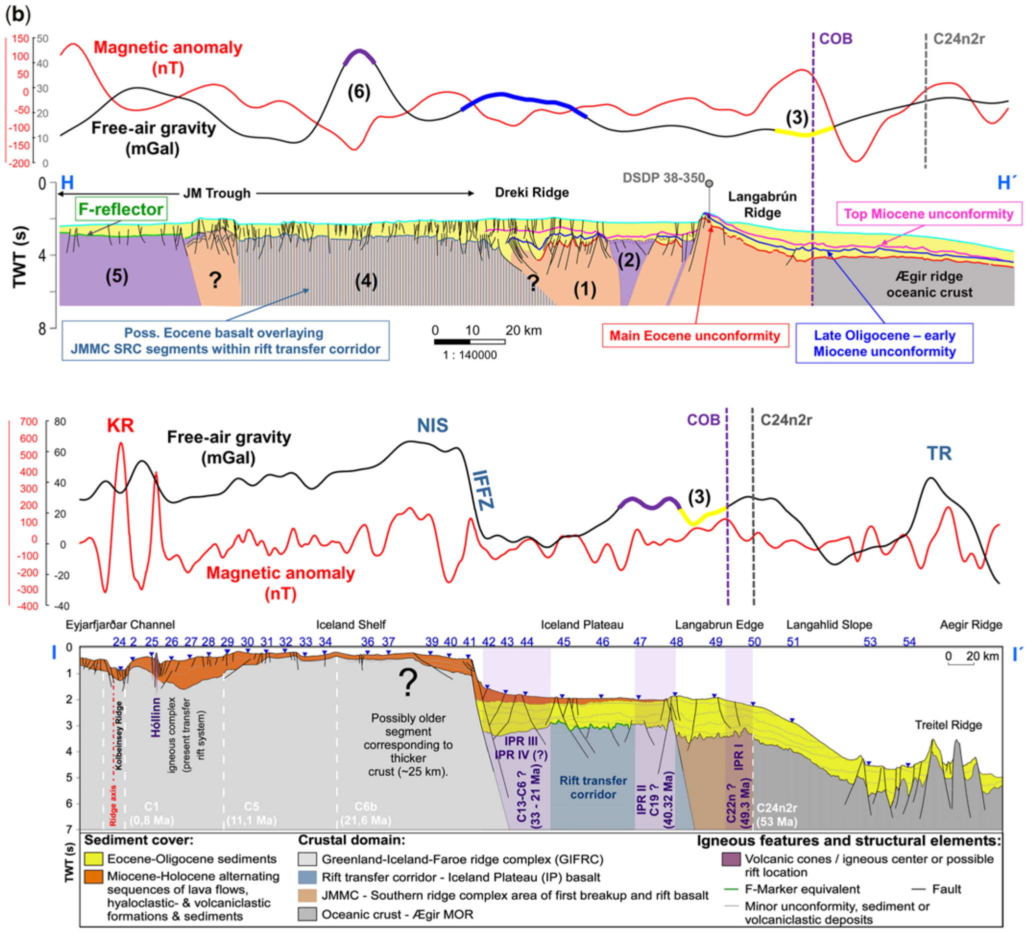

Fig. 9. (**b**) I–I′ from Brandsdóttir *et al.* (2015) and H–H′ across the SRC. The H–H’ profile based on TGS seismic reflection data crosses the southernmost area where the SRC is clearly observed and ties to DSDP site 350. Section H–H′ has several areas marked to explain the subdivision of the mapped structures: (1) The Dreki Ridge transfer system (possibly active from the Mid-Eocene to Oligocene with Miocene infill). (2) A graben structure that separated the Eocene ridges of the SRC. The strike of the graben is parallel to the Iceland Plateau rift II structure. (3) A sediment wedge that is thickest close to the COB. This is observed along the entire eastern edge of the JMMC and helps to define the COB location. (4) Areas where deep faulting appears absent and structures are distinctly different from elsewhere. A basalt cover is indicated, possibly equivalent to the plateau basalts. (5) A typical section where the F-reflector is observed and is connected to IPR III. (6) A positive gravity anomaly that might be related to another possible rift complex, but not confirmed on seismic reflection data. A clear signature on the magnetic anomaly data (Fig. 9a) south of intersection H–H′ is observed, however. Section I–I′ shows the Iceland Plateau rift between the Langabrun Edge and the Iceland Shelf. It includes a segment of thick crust between the C6 magnetic chron just west of the youngest rift system on NE Iceland (the Eyjarfjarðar Channel/Kolbeinsey mid-oceanic ridge).

maintain a spatial balance within the reconstruction, the areas of the Iceland Plateau and East Iceland must have been involved in this early stage of break-up, forming new basaltic crust and possibly SDR overlying older crust segments that remain as segments in-between off-mid-oceanic ridge volcanic segments (Erlendsson & Blischke 2013; Blischke *et al.* 2014*b*).

Fully established intra-JMMC rift phase and the beginning of rift migration around C21n: 47.33 Ma

The oblique seafloor spreading direction recorded by the Norway Basin oceanic crust caused large strike-slip/transfer fault systems that affected the eastern flank of the microcontinent (event D on

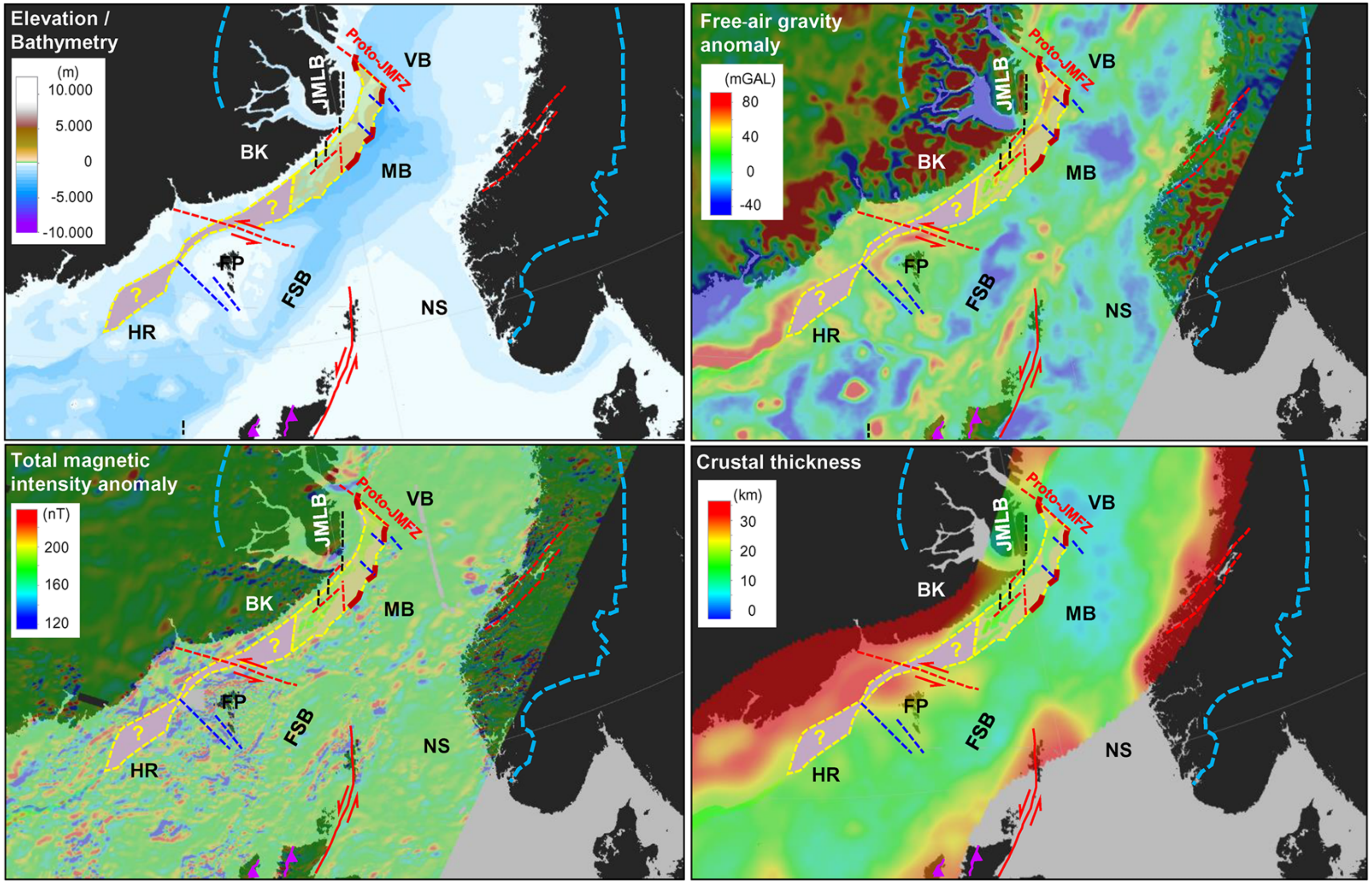

Fig. 10. *Continued*

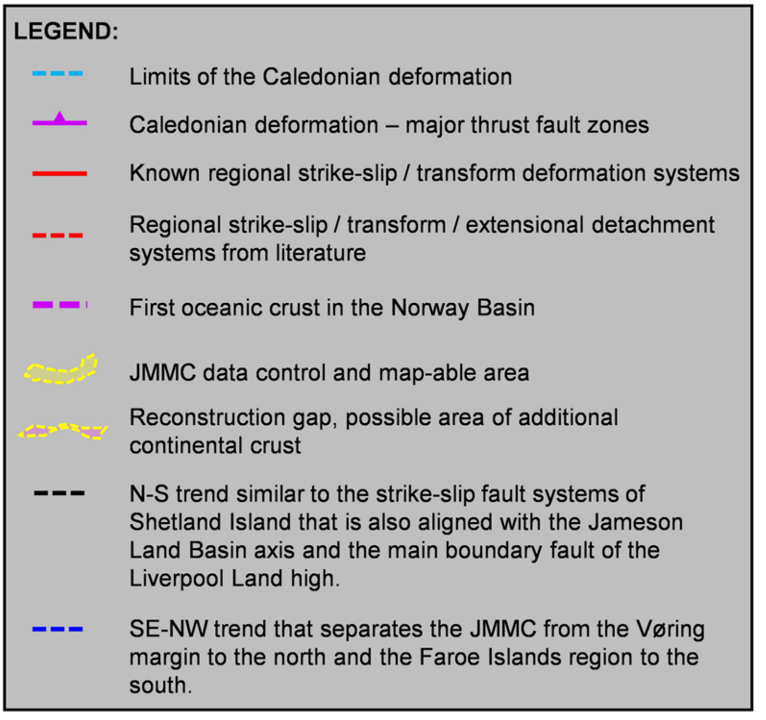

Fig. 10. Pre-break-up setting of the central NE Atlantic region, showing reconstructed present-day bathymetry, magnetic, gravity and crustal thickness data. Crustal thickness is based on the gravity inversion (Funck *et al.* 2014). The reconstruction is at pre-break-up stage ending at 56–55 Ma and is fixed to the European Plate. Features displayed are modified from data, and interpretations by Osmundsen & Andersen (2001), Torsvik *et al.* (2001), Foulger *et al.* (2005), Henriksen (2008), Gaina *et al.* (2009), Boyden *et al.* (2011), Peron-Pinvidic *et al.* (2012*a*, 2013), Gasser (2014), Hopper *et al.* (2014), Gernigon *et al.* (2015), Guarnieri (2015) and Torsvik *et al.* (2001, 2015). Regions marked are: BK, Blosseville Kyst; FP, Faroe Plateau; FSB, Faroe–Shetland Basin; HR, Hatton–Rockall margin and basin; JLB, Jameson Land Basin; MB, Møre Basin; NS, North Sea; VB, Vøring Basin.

Fig. 7) and subdivided the JMMC into the northern Jan Mayen Ridge and the SRC. The Ægir mid-oceanic ridge appears to terminate at the GIFRC (Fig. 11c).

A series of en echelon magnetic anomalies across the Iceland Plateau, referred to as the Iceland Plateau Rift System (Fig. 11c), is interpreted as marking the onset of a propagating rift system towards the Ægir mid-oceanic ridge (Figs 5 & 9), A NW–SE-striking fault system that links up to the Iceland–Faroe Fracture Zone and terminates the north–south fault trend of the SRC, marks the southern extent of the microcontinent. The NW–SE-striking fault system is in direct alignment with the volcanically active area of the Blosseville Kyst (F on Fig. 11c), where a major coast-parallel dyke swarm belonging to the Igtertivâ Formation magmatism is thought to have been caused by a regional extensional event at 49–44 Ma (Larsen *et al.* 2013). This event is also marked by a distinct unconformity, where the base consists of sediments that are dated to 49.09 ± 0.48 Ma and the top is formed by sediments intercalated with lava flows of the Bopladsdalen Formation, which are dated to 43.77 ± 1.08 Ma (Larsen *et al.* 2013). This Late–Middle Eocene time interval (49–44 Ma) coincides with an increase in observed sills and intrusions within the sediment stratigraphy (Fig. 8) of the JMMC area.

Westwards rift transfer and the initial western JMMC margin break-up phase around C13n: 33.1 Ma

By chron C13n (33.2 Ma), the Norway Basin seafloor spreading had changed from slow to ultraslow spreading (Gernigon *et al.* 2015), while, on

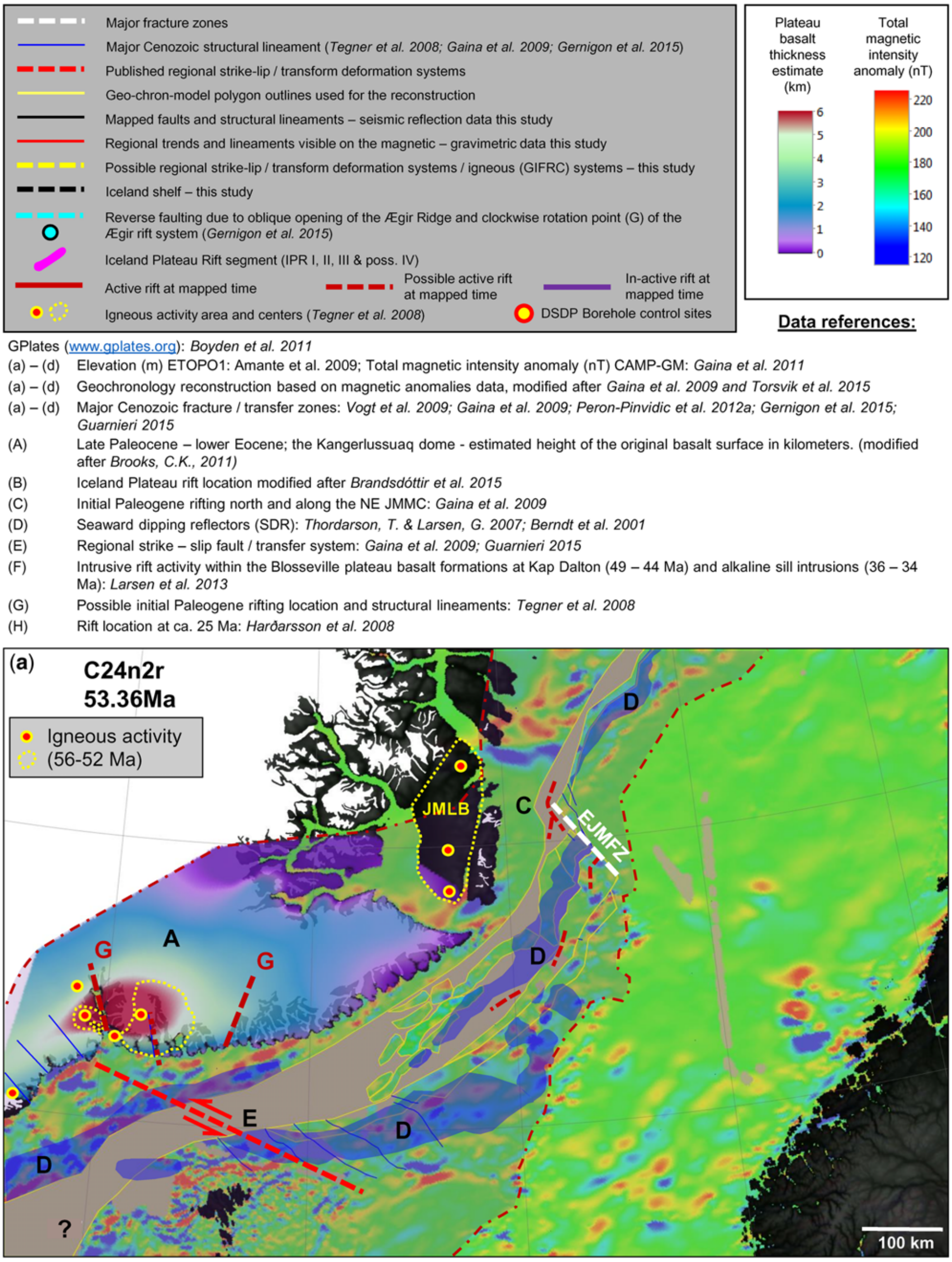

Fig. 11. Central NE Atlantic plate reconstructions relative to the European Plate: (**a**) break-up stage around chron C24n2r (53.36 Ma).

the western part of the JMMC, the proto-Kolbeinsey mid-oceanic ridge was forming. Two igneous complexes were identified on seismic reflection and gravity data, and are here referred to as the Iceland Plateau rift II and III systems (Figs 9 & 11d). Iceland Plateau rift II is located parallel to magnetic anomaly C19n (40.32 Ma) and forms the eastern shelf limit of Iceland (Brandsdóttir *et al.* 2015). Iceland Plateau rift III is observed on seismic reflection, gravity and magnetic anomaly data, and appears to have affected the nearby Hakarenna Channel (HC in Fig. 9). This area of the

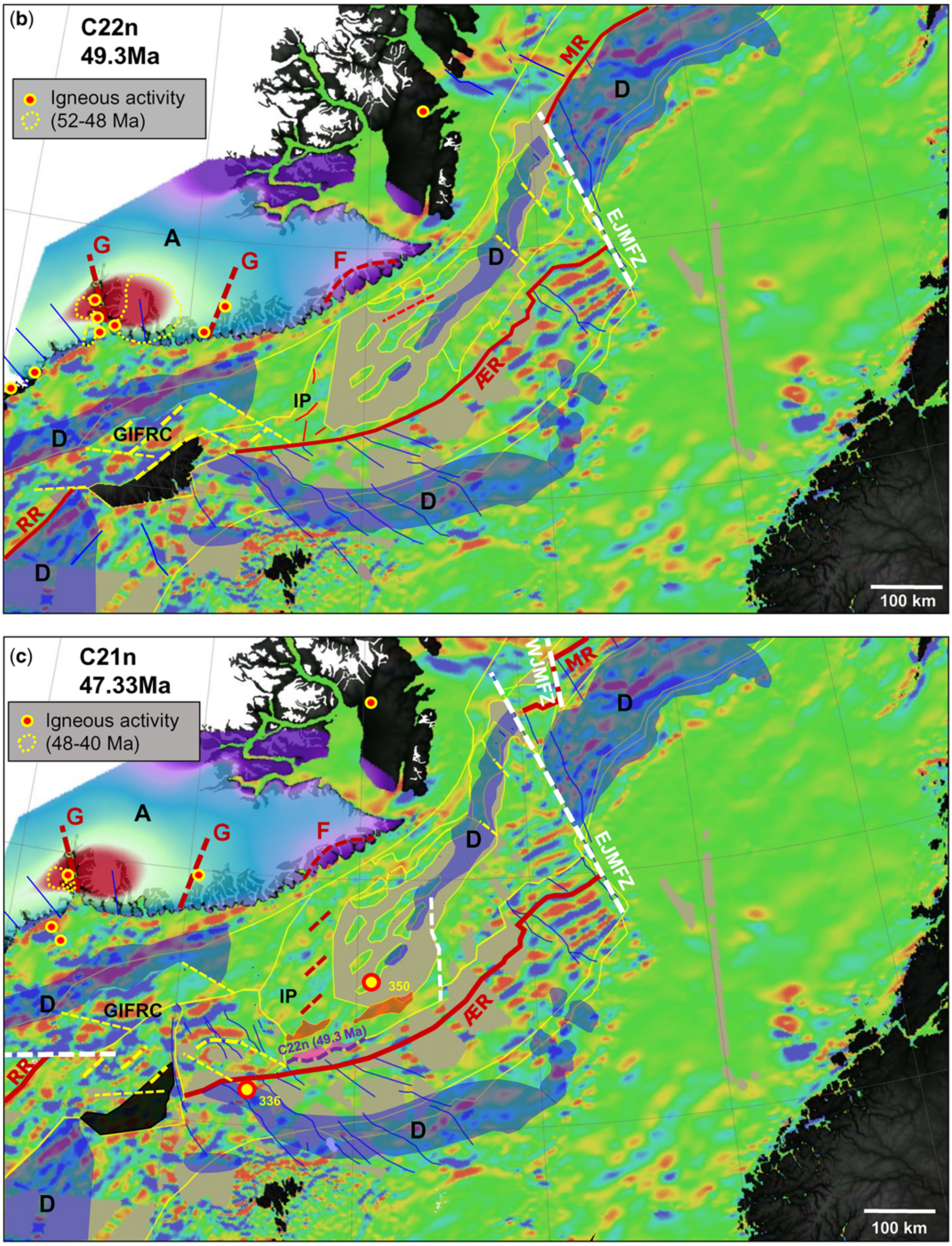

Fig. 11. (**b**) initial intra-JMMC rifting phase around chron C22n (49.3 Ma); (**c**) fully established seafloor spreading east of JMMC rift phase and beginning of intra-JMMC rift migration around chron C21n (47.33 Ma).

microcontinent was located parallel to the offshore Blosseville Kyst region at chron C13n, and lines up with observed offshore igneous centres (Árting 2014). This is interpreted as clear evidence that the rift transition had reached the SW corner of the JMMC by chron C13n.

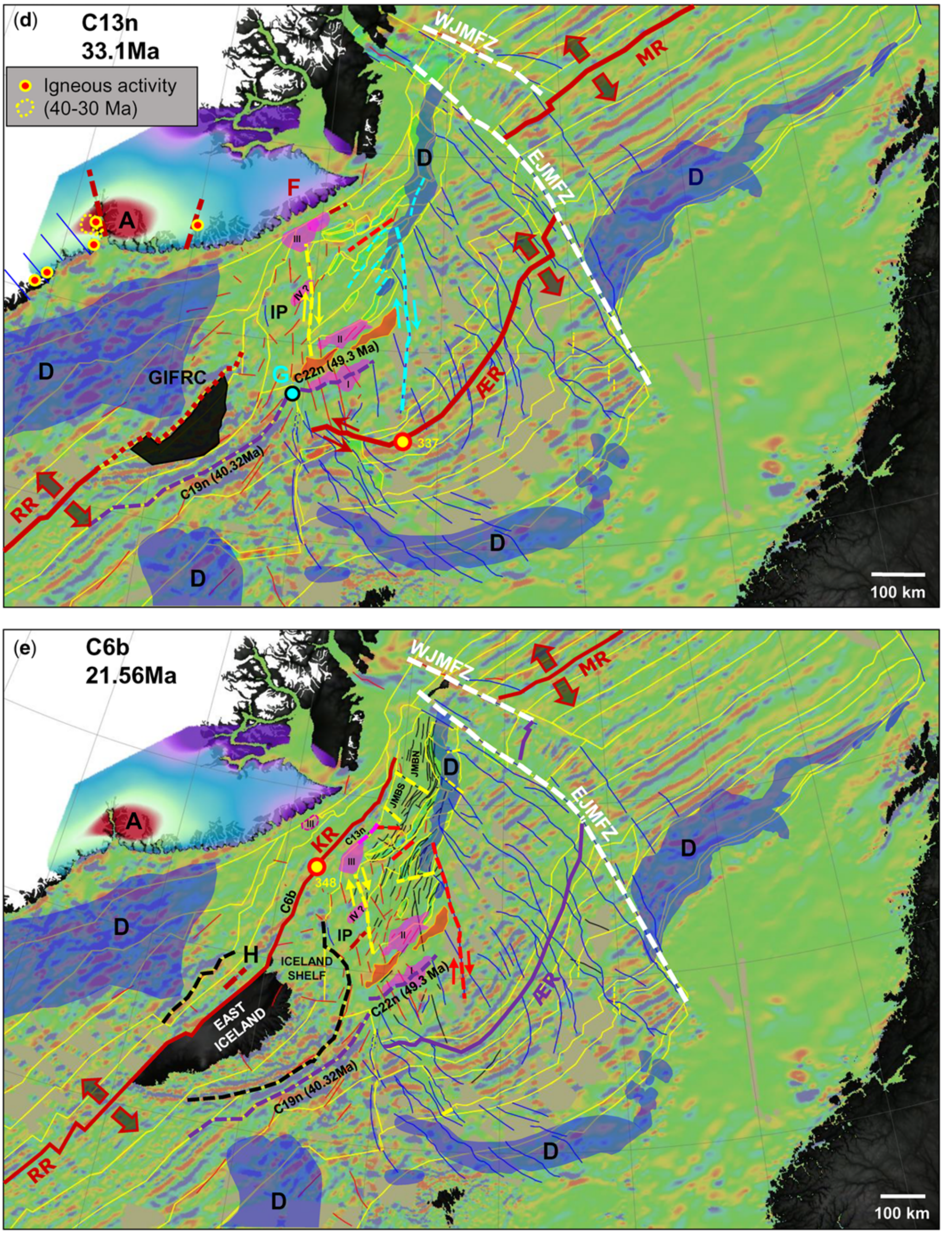

Fig. 11. (**d**) further westwards rift transfer and initial western JMMC margin break-up phase around chron C13n (33.1 Ma); and (**e**) complete isolation of the JMMC through the establishment of the Kolbeinsey mid-oceanic ridge around chron C6b (21.56 Ma). The kinematic reconstruction considers the JMMC as several independent tectonic blocks. Plate reconstruction parameters for the relative motion of the JMMC and conjugate margins were calculated using an interactive fitting method in GPlates (http://www.gplates.org: Boyden *et al.* 2011; see also Gaina *et al.* this volume, in review). The reconstructions include data interpretations for fault and transfer systems linked to stratigraphic thickness changes, mapped unconformities, age data from magnetic anomalies and borehole data. Present-day topography is included in the displays for a better reference to today's coastline.

During this phase, the Jan Mayen Basin and Jan Mayen Trough (HT in Fig. 8; Table 1) both developed as a consequence of Middle Eocene and Late Oligocene–Early Miocene extension prior to the establishment of the Kolbeinsey mid-oceanic ridge (Peron-Pinvidic *et al.* 2012*b*). The Jan Mayen Basin was initiated as a series of small pull-apart basins along the NW flank of the JMMC (Fig. 11d, e). These small basins spatially compensated for the rapid extension occurring during this second break-up phase (Fig. 6a, b). Rotation and compression along the SE JMMC, initiated in the previous phase, probably continued until the cessation of seafloor spreading in the Norway Basin. This resulted in inversion structures that are also observed in the stratigraphic record in the form of the Lower Oligocene unconformity across the microcontinent's ridges (Figs 3 & 6, event E in Fig. 7).

Extension of the SRC widened the area to about 310 km. The nature of the basement at depth still remains unconstrained, but can be interpreted in terms of highly stretched and probably very thin continental crust. This thin crust is covered by thick basalt formations emplaced since break-up. During rift transfer, the area was intersected by the Iceland Plateau rift systems that separated the stretched composite crust into segments, forming a transitional crust between continental crust and the oceanic crust of the Iceland Plateau. These basalt formations are probably Late Oligocene–Early Miocene and filled the topographical lows between the main structures along the Jan Mayen Ridge. They are indicated by the F-Marker on seismic reflection data (Figs 5 & 6).

Complete isolation of the JMMC by establishing the Kolbeinsey mid-oceanic ridge around C6b: 21.56 Ma

The final separation of the JMMC occurred around C6b at 21.56 Ma (e.g. Gernigon *et al.* 2015) (Fig. 11e), when the Kolbeinsey mid-oceanic ridge reached the JMFZ and the plate boundary in the Greenland Sea. This phase coincides with the initiation of Iceland as an insular province and the formation of the GIFRC by increased igneous activity (Harðarsson *et al.* 2008). The offshore area NW of Iceland, and the onshore and offshore areas of East Iceland, began to form the Icelandic Plateau basalts continuously throughout the Late Miocene (Walker 1964; Sæmundsson 1979; Thordarson & Larsen 2007).

Rift propagations have been shown to occur in a NW direction within the Iceland Plateau–GIFRC area up to the Late Miocene (7.2–5.3 Ma). At around 7 Ma, a northeastwards oceanic rift relocation occurred (Jóhannesson & Sæmundsson 2009) from the Húnaflóa rift centre (HFR on Fig. 1) in the NW of Iceland to the NE volcanic zone. As a consequence of substantially increased volcanic activity, new land formed and the GIFRC has been documented to have been located above or close to sea level (Denk *et al.* 2011). Well data from the highest ridges of the JMMC show a Mid–Late Miocene hiatus with marine sedimentation continuing only from the Pliocene onwards (Fig. 3).

During the Quaternary, the JMMC has only been affected by occasional volcanic activity of the Jan Mayen Island volcanic system, located at the northern edge of the JMMC, and gravitational erosion from the escarpment areas of the steep ridge flanks. In the Pleistocene, several glacial events removed about 1 km of the Iceland Plateau basalt (Walker 1964). The opposite occurred for the area between the Iceland Shelf and the SRC, indicating that the JMMC was subsiding during this last phase, presumably due to lithospheric cooling.

Discussion

The central focus of this contribution is the detailed development of the Jan Mayen microcontinent and its relationship to the surrounding areas to enable a better understanding of the full extent of the continental crust and its age and history. Central goals include:

(1) Establishing a detailed tectonic and stratigraphic framework for the JMMC:
   (a) the pre-break-up section and the JMMC relationship to the surrounding areas, in particular the East Greenland and Norway margins;
   (b) the stratigraphic and igneous record during first break-up;
   (c) the stratigraphic and igneous record during mid-oceanic ridge transfer.
(2) To develop a detailed kinematic model of the JMMC from pre-break-up time to the present day, in particular with respect to the second break-up phase and the formation of a microcontinent.
(3) To assess the Iceland–Faroe Fracture Zone (IFFZ) and the southern extent of the JMMC, in particular the connection to the Greenland–Iceland–Faroe Ridge Complex along the IFFZ, and the Iceland Plateau.

(1a) Stratigraphic records of the pre-break-up section

Where the JMMC type section intersects the seismic refraction profile line 4 of Kodaira *et al.* (1998) (Fig. 4), the pre-break-up sedimentary section, defined as the interval between the basalt and acoustic basement, is approximately 6 km thick. The velocity model indicates that this interval is characterized by velocities of 3.9–5.3 km s^{-1} (Kodaira *et al.* 1998). Palaeozoic–Mesozoic sequences in the Jameson Land Basin along East Greenland also show seismic velocities in the range between 3.5 and 5.5 km s^{-1} (Fechner & Jokat 1996), assuming similar velocities along the central eastern flank of the microcontinent, where the pre-break sections appear thickest and may reach up to 9 km thick.

Overall, the Lyngvi Ridge seismic profile is similar in structural character to the Jameson Land Basin, which is 3–5 s deep at its centre and contains up to 12–16 km of pre-break-up sedimentary sequences (Henriksen 2008) with multiple unconformities, complex faulting patterns and deep intrusive events (Blischke *et al.* 2014*b*).

(1b) Stratigraphic and igneous records during first break-up

The Early Eocene flood basalts, SDRs and igneous centres along the eastern flank of the JMMC are located within an interpreted volcanic-transitional crust consisting of stretched continental crust modified by significant volcanism. The earliest clear oceanic crust produced by the Ægir mid-oceanic ridge spreading centre is indicated by the onset of regular magnetic anomalies (chron C24n2r in Fig. 5) (Gernigon *et al.* 2015). The average thickness of oceanic crust in the Norway Basin is about 5.3 km ± 1 km (Breivik & Mjelde 2003), in contrast to the much thicker 6–10 km (Kandilarov *et al.* 2012) oceanic crust close to the Jan Mayen Island volcanic complex (JMI) and the west Jan Mayen Fracture Zone (WJMFZ in Fig. 5). The crustal thickness of the central area of the microcontinent (Fig. 6b) is 15–18 km based on refraction data (JMKR-95 in Figs 2 & 5), whereas the continental crust under the main Jan Mayen Ridge, close to wells 346 and 347, reaches up to 20 km (Kandilarov *et al.* 2012).

The break-up-related basaltic layers interpreted here along the JMMC are assumed to be correlative to the central East Greenland margin. Nøhr-Hansen (2003) and Larsen *et al.* (2013) reported that the landwards flows (Planke *et al.* 2000) of the plateau basalts overlie Lower Paleocene sediments at Kap Brewster and Kap Dalton (KB and KD on Fig. 1a), and mark an erosional horizon interpreted here as equivalent to the break-up conformity of the central JMMC (Figs 3 & 4).

Further to the west, the Milne Land Formation (56.36 ± 0.25 Ma) of the main plateau basalts discordantly overlies Precambrian gneiss (Storey *et al.* 2007*b*), marking the break-up unconformity for the north Blosseville Kyst and Scoresby Sund region. At break-up time (*c.* 55 Ma), this region was located approximately 400 km to the NE of the Faroe Island Plateau basalts.

The Faroe Islands, which have been covered by more than 7 km-thick landward basalt flows (Passey & Jolley 2009; Passey & Hitchen 2011; Árting 2014), is conjugate to the Kangerlussuaq Basin, located at the southernmost extent of the Blosseville Kyst. This plateau basalt succession has often been assumed to have had a similar stratigraphic thickness across the entire area further to the north, which would have included the proto-Jan Mayen microcontinent area. Seismic reflection data (Fig. 4; Table 3), however, indicate a thinner basaltic section of approximately 1.1–1.5 km over the central part of the JMMC. As noted earlier, the Jameson Land Basin may have been covered by thick flood basalts and 2–3 km of basalt may have been removed (Mathiesen *et al.* 2000). The same may have occurred here. By inference, the flood basalts associated with SDR formation probably covered the entire JMMC and may have been continuous with the flood basalts of the Blosseville Kyst area.

(1c) Stratigraphic and igneous records during mid-oceanic ridge transfer

Along the Blosseville Kyst area, the lower Igtertivâ Formation (C22: *c.* 49 Ma) coincides with the beginning of rift transfer away from the Ægir mid-oceanic ridge (F in Fig. 11b), which is followed by a hiatus between the lower (C22–C21: 49–47 Ma) and the upper Igtertivâ Formation (C20: *c.* 44 Ma) (Larsen *et al.* 2014). As only the Mid-Eocene (chron C20) unconformity (Fig. 3) is observed along the eastern flank of the microcontinent, it is assumed that the area was again above sea level from 49 to 44 Ma, eroding all pre-chron C22 deposits. The rift transfer processes may have contributed to some thermal uplift along the SW and southern flanks of the microcontinent, accompanied by emplacement of igneous complexes and sill intrusions primarily into the Lower Eocene strata along the NE and SE flanks of the JMMC. This is also seen in borehole data (DSDP 38-350: Fig. 3), and on seismic reflection and refraction data (Figs 4–6).

Along the southern flank of the microcontinent, increased magmatism most probably coincided with volcanism within the Greenland–Iceland–Faroe Ridge Complex region. The Eocene sediment succession shows many intrusive sills and dykes, especially along the eastern and SE flanks. These intrusions are primarily located within the Lower Eocene sediment sequences, possibly coinciding emplacement within the Mid-Eocene time interval (49–44 Ma). This time interval correlates well with the increased igneous activity observed along the East Greenland coast (Larsen *et al.* 2014) and may indicate a regional event, and, furthermore, may explain the major unconformity that has been observed along the JMMC in the Mid-Eocene (Figs 3, 4 & 7).

(2) The second break-up phase and the formation of a microcontinent

This second break-up phase between the western edge of the JMMC and the central East Greenland margin is most probably a magma-starved break-up due to the lack of SDR sequences and large-scale magmatic activity. A gradual rift propagation is observed beginning at chron C21 (Fig. 11c) accompanied by large-scale extension of the SRC, crustal thinning across the Iceland Plateau and a listric normal faulting along the western flank (Fig. 5). Extension rates were probably very small, consistent with a reduced magma supply. Lundin *et al.* (2014) suggested that this is likely in areas near the tip of a propagating rift and eventual normal oceanic-crust accretion.

The youngest regionally extensive igneous event indicated on seismic reflection data on the JMMC (Gunnarsson *et al.* 1989) is referred to as the ‘F-Reflector’, and covers an area of approximately 18 400 km^2 along the western and the SW to southern flanks of the Jan Mayen Ridge and within the Jan Mayen Trough (JMT in Fig. 5). This igneous formation is interpreted as shallow-marine landwards flows emplaced during chrons C13–C6b (33–21.56 Ma), possibly sourced from fissure-type volcanic complexes south and west of the microcontinent. Small lava deltas located on the SW extent of the JMMC on seismic reflection data indicate south–north to SW–NE flow directions.

During the second break-up event, the central East Greenland region was most probably the main sediment source, along with the Jan Mayen ridges and highs. The Jan Mayen Basin, including local low areas along the SW flank of the microcontinent, was filled with sediments sourced from the west as the microcontinent separated from the East Greenland margin (Fig. 8; Table 1). The southern area of the microcontinent towards the Iceland Plateau must have been elevated from the Mid-Oligocene, as the overall sediment stratigraphic thickness decreased from north to south and the Late Oligocene unconformity (Fig. 3) is observed on highs of the SRC (Fig. 6c).

After the Kolbeinsey mid-oceanic ridge had completely separated the microcontinent from East Greenland, the sediment supply was greatly reduced. Intra-Neogene unconformities within the oceanic sediments are observed away from the JMMC, and the occurrence of mounded onlapping sediment packages are observed on the flanks of the Jan Mayen Ridge. These attest to processes of erosion and deposition associated with deep-water bottom currents, which were common around the NE Atlantic region from the Mid-Miocene onwards (e.g. Bohrmann *et al.* 1990; Howe *et al.* 1994; Davies *et al.* 2001; Stoker *et al.* 2005). Borehole information (Talwani *et al.* 1976*b*; Talwani & Eldholm 1977) and interpretation of seismic reflection data show that these sediment sequences are very thin, deep marine, and form thick contourite deposits. Beginning in the Mid-Miocene, the sediment supply direction was from the North Iceland Shelf (NIS) area to the south. Sediment was supplied into the Ægir to Kolbeinsey rift transfer corridor of the Iceland Plateau (Fig. 5) and into the Hléssund Trough (HS in Fig. 8; Table 1), the southernmost extension of the Jan Mayen Trough.

(3) The Iceland–Faroe Fracture Zone and the southern extent of the JMMC

To understand the development of the southernmost part of the JMMC, the present-day development of the onshore areas of Iceland are considered, where complex transfer zones link the Reykjanes and Kolbeinsey mid-oceanic ridges to the main spreading axis (Sæmundsson 1974; Magnúsdóttir *et al.* 2015). These transfer systems result in en echelon orientated volcanic ridge segments, here referred to as flank systems (e.g. the Snæfellsnes and Öræfajökull volcanic zones: e.g. Hards *et al.* 1995; Prestvik *et al.* 2001; Einarsson 2008; Jakobsson *et al.* 2008). The present-day spreading axis is apparently migrating east via ridge jumps (Árting 2014). These observations serve as an analogue to understand how the left-lateral Greenland–Faroe Transfer System described by Guarnieri (2015) might have developed in time (Figs 10 & 11).

This transfer system between the Norway Basin and Kolbeinsey mid-oceanic ridge system that passes south of the JMMC and north of the Iceland–Faroe Ridge has been described previously (e.g. Vogt & Jung 2009; Gernigon *et al.* 2015). The interpretations of the wide-angle data along KRISE Line 7 (Brandsdóttir *et al.* 2015) (Figs 2 & 5), which extends from the Kolbeinsey mid-oceanic ridge to the Aegir mid-oceanic ridge, are important in this context. The western part of the profile crosses the Kolbeinsey mid-oceanic ridge and the NIS, which is part of the GIFRC. The crustal thickness ranges from 12 to 14 km near the Kolbeinsey Ridge, increasing gradually across the Iceland Shelf up to 25 km. Crustal thickness decreases abruptly down to around 8 km across the Iceland Plateau corridor and across the NIS shelf break, with a major fault escarpment dipping NE. Within the volcanic transitional area of the Iceland Plateau Rift (IPR), the crustal thickness again increases to 12 km. The oceanic crust towards the Aegir mid-oceanic ridge is relatively thin, at only 4–5 km thick. A domain characterized by velocity variations in lower-crustal structures across the Iceland Plateau is interpreted as an extinct spreading centre that is part of the Iceland Plateau Rift, which was active at the same time as the Aegir Ridge prior to the initiation of the Kolbeinsey Ridge. The spreading rate during that time decreased along the Aegir Ridge, as more and more of the extension was being taken up further west.

From the Iceland Plateau to the JMMC, a clear change in fault and lineament trends occurs based on the bathymetry and potential field datasets. These trends range from a north–south direction on the JMMC to a NW–SE trend on the Iceland Plateau. The latter trend is in alignment with the structural trend of the Iceland–Faroe Fracture Zone (IFFZ in Figs 1a & 5) and both trends correlate with magnetic anomalies. The junction of those two trends is suggested to mark the most likely southern boundary of the microcontinent as a structural entity. The boundary is probably a volcanic transitional-type crust that incorporates slivers of continental crust along with formed new volcanic crustal accretion. Gernigon *et al.* (2015) proposed a major SE–NW regional dextral strike-slip system from the Ægir mid-oceanic ridge to the centre of the microcontinent at the northern limit of the SRC. This system lies parallel to the Iceland Plateau corridor and the Iceland–Faroe Fracture Zone. In the Dreki Ridge area (Fig. 9a, b), where the segmentation of the SRC is clearly visible, a subdivision of the lineaments can be made. Here, distinct segments are likely to relate to pre-break-up segments of continental crust. Segments of possible Lower Eocene plateau basalts are intersected by possible oceanic crust. If the Iceland Plateau corridor represents a broad dextral SE–NW strike-slip fault zone, then the minimum horizontal stress lies approximately east–west, allowing faults to open and propagate in a north–south direction, which is parallel to the magnetic lineation in that area. These transtensional oblique rift systems were volcanically active and may be similar to the oblique rift segments observed today where the Reykjanes Ridge connects across Iceland to the Eastern Volcanic Zone (Clifton & Schlische 2003; Clifton & Kattenhorn 2005), and within the Northeastern Volcanic Zone (Khodayar 2014) on Iceland (NEVZ on Fig. 1a).

Conclusions

The objective of this study was to construct a detailed tectonostratigraphic history of the Jan Mayen microcontinent with a focus on the southernmost area. This was then integrated into kinematic reconstructions of the central NE Atlantic to better understand the Cenozoic development and the implications for the pre-Cenozoic development of regional rift basins, remnants of which probably underlie the JMMC. Complex structural patterns are observed along the microcontinent's margins, as well as the conjugate East Greenland and Norwegian margins on either side. The new model includes a description of how the southern JMMC structural elements were linked to tectonic features on the Iceland Plateau and Greenland–Iceland–Faroe Ridge Complex.

Mapping the pre- to post-break-up sedimentary strata and igneous complexes together with volcanostratigraphic seismic characterization has facilitated a reassessment and clearer definition of the igneous v. sedimentary domains of the JMMC area throughout its break-up history. The main results include:

- Interpretation of new and vintage geophysical data suggests that a significant pre-Palaeogene stratigraphic history is preserved. However, without deep borehole data, the age of possible sedimentary successions are speculative. Nevertheless, the conjugate Jameson Land and Møre basins are considered to be direct analogue areas for the JMMC. These basins are well constrained, and contain a sedimentary succession that includes Devonian continental sediments, Permo-Triassic continental and marine sequences, Jurassic and Cretaceous shallow- to deep-marine sequences, and Lower Paleocene alluvial to shallow-marine sediments.
- The break-up and post-break-up igneous sequences were separated into plateau basalts of probable Paleocene–Early Eocene age, seawards-dipping reflector sequences, igneous complexes, and sill and dyke intrusions along the flanks of the JMMC.
- A consistent kinematic model for the Cenozoic evolution of the JMMC and surrounding oceanic crust that consists of six main phases is proposed. The boundaries between these phases correlate to major unconformities and related structures. Important events include:
  (1) A pre-break-up stage ending at 56–55 Ma and the emplacement of Lower Eocene plateau basalts across the microcontinent and the Blosseville Kyst region, with an apparent thickening of the basalt sequences to the south, possibly continuing into the Faroe–Iceland–East Greenland corridor. The structures of the JMMC are consistently orientated with major structural lineaments of the surrounding regions prior to break-up. The main trends are aligned with the Jameson Land Basin and Liverpool Land high. The JMMC probably forms the southern extension of the Jameson Land Basin.

(2) A first break-up phase that began at 55 Ma (e.g. Gaina *et al.* 2009) and was associated with the formation of SDR along the east flank of the JMMC, followed by the initiation of seafloor spreading in the Norway Basin along the Ægir Ridge in the Early Eocene (chron C24n2r 53.36 Ma) (Gaina *et al.* 2009; Gernigon *et al.* 2015).
(3) An initial intra-JMMC rifting phase around chron C22n (49.3 Ma) and the establishment of a continuous spreading system in the Norway Basin and forming the eastern extent of the Iceland Plateau, here referred to as Iceland Plateau rift I (IPR-I: Fig. 11b, c). Initial extension of the entire southern half of the microcontinent occurred, widening it from originally 100 km to approximately 150 km. This eventually lead to early stage break-up in the Iceland Plateau area, forming new Lower Eocene volcanic formations (volcanic breccia, intrusions and SDR sequences) along the SE flank of the Southern Ridge Complex (SRC).
(4) The initiation of the southern JMMC rift transition at chron C21n (47.33 Ma) contemporaneous with oblique seafloor spreading east of the JMMC, causing the formation of transform systems and uplift along the southern flank of the JMMC. Volcanic activity occurred along the NE margin of the Blosseville Kyst (Larsen *et al.* 2014).
(5) A westwards rift transfer and initial break-up along the western JMMC around chron C13n–33.1 Ma. Oblique mid-oceanic ridge relocation via a SE–NW en echelon rift system occurred from the southern extent of the microcontinent during the Early Oligocene. Significant volcanism affected the SW area of the JMMC, referred to here as the Iceland Plateau rift III, which can be linked to the Blosseville Kyst margin. Oblique extension occurred along the NW flank of the JMMC, resulting in the opening of the Jan Mayen Basin and a series of small pull-apart basins and igneous intrusions with little to no evidence of SDR formation.
(6) A second break-up phase at chron C6b (21.56 Ma) with complete cessation of seafloor spreading in the Norway Basin (Gernigon *et al.* 2015) and the establishment of the Kolbeinsey mid-oceanic ridge as the main mid-ocean spreading centre.

- The extension of the southern half of the JMMC has been quantified from the original 40–100 km width up to a width of 310 km during the Early Eocene. The SRC is overprinted by volcanic extrusive complexes that consist primarily of Early Eocene basalt flows, which are interpreted as being similar to the plateau basalts exposed along the Blosseville Kyst of Greenland. These are onlapped by clear and well-developed SDRs associated with the final opening of the Norway Basin. Multiple phases of intrusive events appear to have affected the eastern flank of the microcontinent during the Eocene and the southern part of the JMMC during the Late Eocene–Early Oligocene.
- The Iceland–Faroe Fracture Zone across the Iceland Plateau has been mapped as an en echelon transfer system from the Ægir Ridge to the Kolbeinsey Ridge. Detailed mapping of the southern extent of the JMMC supports the Gaina *et al.* (2009) model in which mid-oceanic ridge propagation occurred directly south of the microcontinent, beginning in the latest Early Eocene (49.3 Ma) and continuing throughout the Eocene. This formed at least three rift-flank systems on the Iceland Plateau. These rifts flanks are referred to as Iceland Plateau rift IPR-I, IPR-II and IPR -III (Brandsdóttir *et al.* 2015).

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References

Åkermoen, T. 1989. *Jan Mayen-ryggen: et seismisk stratigrafisk og strukturelt studium* (The Jan Mayen Ridge: a seismic stratigraphic and structural study.). Cand. scient. thesis, University of Oslo.

Amante, C. & Eakins, B.W. 2009. *ETOPO1 1 Arc-Minute Global Relief Model: Procedures, Data Sources and Analysis*. NOAA Technical Memorandum NESDIS NGDC-24.

Andersen, O.B. 2010. The DTU10 gravity field and mean sea surface. Paper presented at the *Second International Symposium of the Gravity Field of the Earth (IGFS2)*, 20–22 September 2010, Fairbanks, Alaska, USA.

Andersen, T.B. & Jamtveit, B. 1990. Uplift of deep crust during orogenic extensional collapse: a model based on field studies in the Sogn–Sunnfjord area of Western Norway. *Tectonics*, **9**, 1097–1111.

Árting, U. 2014. Regional volcanism. *In*: Hopper, J.R., Funck, T., Stoker, M., Árting, U., Peron-Pinvidic, G., Doornenbal, H. & Gaina, C. (eds) *Tectonostratigraphic Atlas of the North-East Atlantic Region*. GEUS, Copenhagen, Denmark, 223–290.

Berndt, C., Mjelde, R., Planke, S., Shimamura, H. & Faleide, J.I. 2001. Controls on the tectono-magmatic evolution of a volcanic transform margin: the Vøring Transform Margin, NE Atlantic. *Marine Geophysical Researches*, **22**, 133–152.

Blischke, A., Erlendsson, Ö. & Árnadóttir, S. 2014*a*. *CRUSMID-3D – NORDMIN Status Report 2014 – Crustal Structure and Mineral Deposit Systems: 3D-modelling of Base Metal Mineralization in Jameson Land and Nickel Mineralization in Disko-Nuussuaq*. ÍSOR-2014/056. Closed Report for the Geological Survey of Denmark and Greenland and the National Energy Authority of Iceland, 184–194.

Blischke, A., Hjartarson, A., Erlendsson, Ö., Árnadóttir, S. & Peron-Pinvidic, G. 2014*b*. The Iceland margin, Jan Mayen microcontinent, and adjacent oceanic areas. *In*: Hopper, J.R., Funck, T., Stoker, M., Árting, U., Peron-Pinvidic, G., Doornenbal, H. & Gaina, C. (eds) *Tectonostratigraphic Atlas of the North-East Atlantic Region*. GEUS, Copenhagen, Denmark.

Blystad, P., Brekke, H., Færseth, R.B., Larsen, B.T., Skogseid, J. & Tørudbakken, B. 1995. *Structural Elements of the Norwegian Continental Shelf, Part II. The Norwegian Sea Region*. Norwegian Petroleum Directorate Bulletin, **8**.

Bohrmann, G., Henrich, R. & Thiede, J. 1990. Miocene to Quaternary paleoceanography in the Northern North Atlantic: variability in carbonate and biogenic opal accumulation. *In*: Bleil, U. & Thiede, J. (eds) *Geological History of the Polar Oceans: Arctic Versus Antarctic*. NATO Science Series C, **308**, 647–675.

Boyden, J.A., Müller, R.D. *et al.* 2011. Next-generation plate-tectonic reconstructions using Gplates. *In*: Keller, G. & Baru, C. (eds) *Geoinformatics: Cyberinfrastructure for the Solid Earth Sciences*. Cambridge University Press, Cambridge, 95–116.

Brandsdóttir, B., Hooft, E., Mjelde, R. & Murai, Y. 2015. Origin and evolution of the Kolbeinsey Ridge and Iceland Plateau, N-Atlantic. *Geochemistry, Geophysics, Geosystems*, **16**, 612–634.

Breivik, A. & Mjelde, R. 2003. *Modelling of Profile 8 Across the Jan Mayen Ridge*. Report of the Institute of Solid Earth Physics, University of Bergen, Bergen, Norway.

Breivik, A.J., Mjelde, R., Faleide, J.I. & Murai, Y. 2012. The eastern Jan Mayen microcontinent volcanic margin. *Geophysical Journal International*, **188**, 798–818.

Brekke, H. 2000. The tectonic evolution of the Norwegian Sea continental margin with emphasis on the Vøring and Møre basins. *In*: Nøttvedt, A. (ed.) *Dynamics of the Norwegian Margin*. Geological Society, London, Special Publications, **167**, 327–378, https://doi.org/10.1144/GSL.SP.2000.167.01.13

Brekke, H., Dahlgren, S., Nyland, B. & Magnus, C. 1999. The prospectivity of the Vøring and Møre basins on the Norwegian Sea continental margins. *In*: Fleet, A.J. & Boldy, S.A.R. (eds) *Petroleum Geology of Northwest Europe: Proceedings of the 5th Conference*. Geological Society, London, 261–274, https://doi.org/10.1144/0050261

Brooks, C.K. 2011. *The East Greenland Rifted Volcanic Margin*. Geological Survey of Den-mark and Greenland Bulletin, **24**.

Butt, F.A., Elverhoi, A., Forsberg, C.F. & Solheim, A. 2001. An evolution of the Scoresby Sund Fan, central East Greenland – evidence from ODP Site 987. *Norsk Geologisk Tidsskrift*, **81**, 3–15.

Channell, J.E.T., Amigo, A.E. *et al.* (eds). 1999*a*. Magnetic stratigraphy at Sites 907 and 985 in the Norwegian–Greenland Sea and a revision of the Site 907 composite section. *In*: Raymo, M.E., Jansen, E., Blum, P. & Herbert, T.D. (eds) *Proceedings of the Ocean Drilling Program, Scientific Results*, Volume **162**. Ocean Drilling Program, College Station, TX, 131–148.

Channell, J.E.T., Smelror, M., Jansen, E., Higgins, S.M., Lehman, B., Eidvin, T. & Solheim, A. 1999*b*. Age models for glacial fan deposits off East Greenland and Svalbard (sites 986 and 987). Paper presented at *Proceedings of the Ocean Drilling Program, Scientific Results*, College Station TX (Integrated Ocean Drilling Program Management International, Inc.), 162.

Clifton, A.E. & Kattenhorn, S.A. 2005. Structural architecture of a highly oblique divergent plate boundary segment. *Tectonophysics*, **419**, 27–40.

Clifton, A.E. & Schlische, R.W. 2003. Fracture populations on the Reykjanes Peninsula, Iceland: Comparison with experimental clay models of oblique rifting. *Journal of Geophysical Research*, **108**, 2074.

Davies, R., Cartwright, J., Pike, J. & Line, L. 2001. Early Oligocene initiation of North Atlantic Deep Water formation. *Nature*, **410**, 917–920, https://doi.org/10.1038/35073551

Denk, T., Grímsson, F. & Kvacek, Z. 2011. The Miocene floras of Iceland and their significance for Late Cainozoic North Atlantic biogeography. *Botanical Journal of the Linnean Society*, **149**, 369–417.

Doré, A.G., Lundin, E.R., Jensen, L.N., Birkeland, Ø., Eliassen, P.E. & Fichler, C. 1999. Principal tectonic events in the evolution of the northwest European Atlantic margin. *In*: Fleet, A.J. & Boldy, S.A.R. (eds) *Petroleum Geology of Northwest Europe: Proceedings of the 5th Conference*. Geological Society, London, 41–61, https://doi.org/10.1144/0050041

Doré, A.G., Lundin, E.R., Kusznir, N.J. & Pascal, C. 2008. Potential mechanisms for the genesis of

Cenozoic domal structures on the NE Atlantic margin: pros, cons and some new ideas. *In*: Johnson, H., Doré, T.G., Gatliff, R.W., Holdsworth, R.W., Lundin, E. & Ritchie, J.D. (eds) *The Nature and Origin of Compression in Passive Margins*. Geological Society, London, Special Publications, **306**, 1–26, https://doi.org/10.1144/SP306.1

Einarsson, P. 2008. Plate boundaries, rifts and transforms in Iceland. *Jökull*, **58**, 35–58.

Eldholm, O. & Windish, C.C. 1974. Sediment distribution in the Norwegian-Greenland Sea. *Geological Society of America Bulletin*, **85**, 1661–1676.

Eldholm, O., Thiede, J. *et al.* 1987. *Proceedings of the ODP Initial Reports*, Volume **104**. Ocean Drilling Program, College Station, TX.

Eldholm, O., Thiede, J. & Taylor, E. 1989. The Norwegian continental margin: tectonic, volcanic, and paleo-environmental framework. *In*: Eldholm, O., Thiede, J. *et al.* *Proceedings of the Ocean Drilling Program, Scientific Results*, Volume **104**. Ocean Drilling Program, College Station, TX, 5–26.

Engkilde, M. & Surlyk, F. 2003. Shallow marine syn-rift sedimentation: Middle Jurassic Pelion Formation, Jameson Land, East Greenland. *In*: Ineson, J.R. & Surlyk, F. (eds) *The Jurassic of Denmark and Greenland*. Geological Survey of Denmark and Greenland Bulletin, **1**, 813–863.

Erlendsson, Ö. 2010. *Seismic Investigation of the Jan Mayen Ridge – with a Close Study of Sill Intrusions*. Aarhus University, Aarhus, Denmark.

Erlendsson, Ö. & Blischke, A. 2013. *Haffréttarmál: hljóðendurvarps- og bylgjubrotsmælin-gar: skýrsla um stöðu mála á úrvinnslu og túlkun gagna* (Law of the sea: seismic reflection and refraction database and interpretation status report.). Report ÍSOR-2013/067. ÍSOR (Iceland GeoSurvey), Reykjavík, Iceland.

Faleide, J.I., Bjørlykke, K. & Gabrielsen, R.H. 2010. Geology of the Norwegian continental shelf. *In*: Bjørlykke, K. (ed.) *Petroleum Geoscience: From Sedimentary Environments to Rock Physics*. Springer, New York, 467–499.

Fechner, N. & Jokat, W. 1996. Seismic refraction investigation on the crustal structure of the western Jamson Land Basin, East Greenland. *Journal of Geophysical Research*, **101**, 15,867–15,881.

Foulger, G.R., Natland, J.H. & Anderson, D.L. 2005. A source for Icelandic magmas in re-melted Iapetus crust. *Journal of Volcanology and Geothermal Research*, **141**, 23–44.

Funck, T., Hopper, J.R. *et al.* 2014. Crustal structure. *In*: Hopper, J.R., Funck, T., Stoker, M., Árting, U., Peron-Pinvidic, G., Doornenbal, H. & Gaina, C. (eds) *Tectonostratigraphic Atlas of the North-East Atlantic Region*. Geological Survey of Denmark and Greenland (GEUS), Copenhagen, Denmark.

Gaina, C., Gernigon, L. & Ball, P. 2009. Palaeocene–Recent plate boundaries in the NE Atlantic and the formation of the Jan Mayen microcontinent. *Journal of the Geological Society, London*, **166**, 601–616, https://doi.org/10.1144/0016-76492008-112

Gaina, C., Werner, S.C., Saltus, R., Maus, S. & the CAMP-GM Group 2011. Circum-arctic mapping project: new magnetic and gravity anomaly maps of the arctic. *In*: Spencer, A.M., Embry, A.F., Gautier, D.L., Stoupakova, A. & Sørensen, K. (eds) *Arctic Petroleum Geology*. Geological Society, London, Memoirs, **35**, 39–48, https://doi.org/10.1144/M35.3

Gaina, C., Torsvik, T.H., Van Hinsbergen, D., Medvedev, S., Werner, S.C. & Labails, C. 2013. The African Plate: A history of oceanic crust accretion and subduction since the Jurassic. *Tectonophysics*, ISSN 0040-1951.604, s4–25. doi:10.1016/j.tecto.2013.05.037

Gaina, C., Nasuti, A., Kimbell, G.S. & Blischke, A. In review. Break-up and seafloor spreading domains in the NE Atlantic. *In*: Péron-Pinvidic, G., Hopper, J.R., Stoker, T., Gaina, C., Doornebal, H., Funck, T. & Árting, U. (eds) *The NE Atlantic Region: A Reappraisal of Crustal Structure, Tectonostratigraphy and Magmatic Evolution*. Geological Society of London, London, Special Publications, **447**.

Gasser, D. 2014. The Caledonides of Greenland, Svalbard and other Arctic areas: status of research and open questions. *In*: Corfu, F., Gasser, D. & Chew, D.M. (eds) *New Perspectives on the Caledonides of Scandinavia and Related Areas*. Geological Society of London, London, Special Publications, **390**, 93–129, https://doi.org/10.1144/SP390.17

Geodekyan, A.A., Verkhovskaya, Z.I., Sudyin, A.V. & Trotsiuk, V.Ya. 1980. Gases in seawater and bottom sediments. *In*: Udintsev, C.B. (ed.) *Iceland and Mid-Oceanic Ridge: Structure of the Ocean-Floor*. National Research Council, Reykjavik, Iceland, 19–36.

Gernigon, L., Gaina, C., Olesen, O., Ball, P., Peron-Pinvidic, G. & Yamasaki, T. 2012. The Norway Basin revisited: from continental breakup to spreading ridge extinction. *Marine and Petroleum Geology*, **35**, 1–19.

Gernigon, L., Blischke, A., Nasuti, A. & Sand, M. 2015. Conjugate volcanic rifted margins, seafloor spreading, and microcontinent: insights from new high-resolution aeromagnetic surveys in the Norway Basin. *Tectonics*, **34**, 907–933.

Gilotti, J.A., Jones, K.A. & Elvevold, S. 2008. Caledonian metamorphic patterns in Greenland. *In*: Higgins, A.K., Gilotti, J.A. & Smith, M.P. (eds) *The Greenland Caledonides: Evolution of the Northeast Margin of Laurentia*. Geological Society of America, Memoirs, **202**, 201–225.

Gradstein, F.M., Ogg, J.G., Schmitz, M.D. & Ogg, G.M. 2012. *The Geologic Time Scale 2012*. Elsevier, Amsterdam.

Guarnieri, P. 2015. Pre-breakup palaeo-stress state along the East Greenland margin. *Journal of the Geological Society, London*, **172**, 727–739, https://doi.org/10.1144/jgs2015-053

Gunnarsson, K., Sand, M. & Gudlaugsson, S.T. 1989. *Geology and Hydrocarbon Potential of the Jan Mayen Ridge*. Orkustofnun, Reykjavík Report OS-98014 & Norwegian Petroleum Directorate, Stavanger, OD-89-91.

Haase, C. & Ebbing, J. 2014. Gravity data. *In*: Hopper, J.R., Funck, T., Stoker, M.S., Árting, U., Peron-Pinvidic, G., Doornenbal, H. & Gaina, C. (eds) *Tectonostratigraphic Atlas of the North-East Atlantic Region*. Geological Survey of Denmark and Greenland (GEUS), Copenhagen, Denmark.

Hamann, N.E., Wittaker, R.C. & Stemmerik, L. 2005. Geological development of the Northeast Greenland shelf. *In*: Doré, A.G. & Vining, B.A. (eds) *Petroleum Geology: North-West Europe and Global Perspectives – Proceedings of the 6th Petroleum Geology Conference*. Geological Society, London, 887–902, https://doi.org/10.1144/0060887

Hards, V.L., Kempton, P.D. & Thompson, R.N. 1995. The heterogeneous Iceland plume: new insights from the alkaline basalts of the Snaefell volcanic centre. *Journal of the Geological Society, London*, **152**, 1003–1009, https://doi.org/10.1144/GSL.JGS.1995.152.01.21

Harðarsson, B., Fitton, J. & Hjartarson, Á. 2008. Tertiary volcanism in Iceland. *Jökull*, **58**, 161–178.

Henriksen, N. 2008. *Geological History of Greenland – Four Billion Years of Earth Evolution*. Geological Survey of Denmark and Greenland (GEUS), Copenhagen, Denmark.

Hinz, K. 1981. A hypothesis on terrestrial catastrophes wedges of very thick ocean-ward dip-ping layers beneath passive continental margins; their origin and palaeo-environmental significance. *Geologisches Jahrbuch*, **E2**, 3–28.

Hjartarson, A. & Sæmundsson, K. 2014. *Geological Map of Iceland – Bedrock Map, 1:600 000, Datum: ISN93*. Iceland GeoSurvey, Reykjavík.

Hopper, J.R., Funck, T., Stoker, M.S., Árting, U., Peron-Pinvidic, G., Doornenbal, H. & Gaina, C. (eds). 2014. *Tectonostratigraphic Atlas of the North-East Atlantic Region*. Geological Survey of Denmark and Greenland (GEUS), Copenhagen.

Horni, J., Hopper, J.R. *et al.* 2016. Regional distribution of volcanism within the North Atlantic Igneous Province. *In*: Péron-Pinvidic, G., Hopper, J., Stoker, M.S., Gaina, C., Doornenbal, H., Funck, T. & Árting, U. (eds) *The North-East Atlantic Region: A Reappraisal of Crustal Structure, Tectono-Stratigraphy and Magmatic Evolution*. Geological Society, London, Special Publications, **447**, xx–xx, https://doi.org/10.1144/SP447.?

Howe, J.A., Stoker, M.S. & Stow, D.A.V. 1994. Late Cenozoic sediment drift complex, northeast Rockall Trough, North Atlantic. *Palaeoceanography*, **9**, 989–999.

Jansen, E., Raymo, M.E. *et al.* 1996. *Proceedings of the Ocean Drilling Program. Initial Reports, Volume 162*. Ocean Drilling Program, College Station, TX.

Jakobsson, M., Mayer, L. *et al.* 2012. The International Bathymetric Chart of the Arctic Ocean (IBCAO) Version 3.0. *Geophysical Research Letters*, **39**, https://doi.org/10.1029/2012GL052219

Jakobsson, S.P., Jónasson, K. & Sigurdsson, I.A. 2008. The three igneous rock series of Iceland. *Jökull*, **58**, 117–138.

Jóhannesson, H. 2011. *Örnefnagjöf á landgrunninu og utan þess. III. Drekasvæðið, Rep. JHJ–2011–012*, 6 pp., National Energy Authority of Iceland, Reykjavík, Iceland.

Jóhannesson, H. & Sæmundsson, K. 2009. *Geological Map of Iceland. 1:600,000. Tectonics*. 1st edn. Icelandic Institute of Natural History, Reykjavik.

Johansen, B., Eldholm, O., Talwani, M., Stoffa, P.L. & Buhl, P. 1988. Expanding spread profile at the northern Jan Mayen Ridge. *Polar Research*, **6**, 95–104.

Kalsbeek, F., Higgins, A.K., Jepsen, H.F., Frei, R. & Nutman, A.P. 2008. Granites and granites in the East Greenland Caledonides. *In*: Higgins, A.K., Gilotti, J.A. & Smith, M.P. (eds) *The Greenland Caledonides: Evolution of the Northeast Margin of Laurentia*. Geological Society of America, Memoirs, **202**, 227–249.

Kandilarov, A., Mjelde, R. *et al.* 2012. The northern boundary of the Jan Mayen microcontinent, North Atlantic determined from ocean bottom seismic, multichannel seismic, and gravity data. *Marine Geophysical Research*, **33**, 55–76.

Khodayar, M. 2014. *Shift of Þeistareykir Fissure Swarm in Tjörnes Fracture Zone: Case of Pull-apart on Strike-slip?* Technical report, ISOR-2014/074, LV-2014-144, Iceland GeoSurvey for Landsvirkjun (National Energy Company of Iceland), Reykjavik, Iceland.

Kodaira, S., Mjelde, R., Gunnarsson, K., Shiobara, H. & Shimamura, H. 1998. Structure of the Jan Mayen microcontinent and implications for its evolution. *Geophysical Journal International*, **132**, 383–400.

Laier, T. & Nytoft, H.P. 2004. Waxy bitumen in basalts – Skye and Faroe Islands, North Atlantic. *Geochimica et Cosmochimica Acta*, **68**, (11), Supplement 234.

Laier, T., Nytoft, H.P., Jørgensen, O. & Isaksen, G.H. 1997. Hydrocarbon traces in the Tertiary basalts of the Faeroe Islands. *Marine and Petroleum Geology*, **14**, 257–266.

Larsen, L.M., Waagstein, R., Pedersen, A.K. & Storey, M. 1999. Trans-Atlantic correlation of the Palaeogene volcanic successions in the Faeroe Islands and East Greenland. *Journal of the Geophysical Society*, **156**, 1081–1095.

Larsen, L.M., Pedersen, A.K., Sørensen, E.V., Watt, W.S. & Duncan, R.A. 2013. Stratigraphy and age of the Eocene Igtertivâ Formation basalts, alkaline pebbles and sediments of the Kap Dalton Group in the graben at Kap Dalton. East Greenland. *Bulletin of the Geological Society of Denmark*, **61**, 1–18.

Larsen, L.M., Pedersen, A.K., Tegner, T. & Duncan, R.A. 2014. Eocene to Miocene igneous activity in NE Greenland: northward younging of magmatism along the East Greenland margin. *Journal of the Geological Society, London*, **171**, 539–553, https://doi.org/10.1144/jgs2013-118

Lundin, E.R. & Doré, A.G. 1997. A tectonic model for the Norwegian passive margin with implications for the NE Atlantic: early Cretaceous to break-up. *Journal of the Geological Society, London*, **154**, 545–550, https://doi.org/10.1144/gsjgs.154.3.0545

Lundin, E.R. & Doré, A.G. 2002. Mid-Cenozoic post-breakup deformation in the 'passive' margins bordering the Norwegian-Greenland Sea. *Marine and Petroleum Geology*, **19**, 79–93.

Lundin, E.R. & Doré, A.G. 2005. NE Atlantic breakup: a re-examination of the Iceland mantle plume model and the Atlantic–Arctic linkage. *In*: Doré, A.G. & Vining, B.A. (eds) *Petroleum Geology: North-West Europe and Global Perspectives – Proceedings of the 6th Petroleum Geology Conference*. Geological Society, London, 739–754, https://doi.org/10.1144/0060739

Lundin, E.R. & Doré, A.G. 2011. Hyperextension, serpentinization, and weakening: a new paradigm for rifted margin compressional deformation. *Geology*, **39**, 347–350.

Lundin, E.R., Redfield, T.F. & Peron-Pindivic, G. 2014. Rifted continental margins: geometric influence on crustal architecture and melting. *In*: Pindell, J., Horn, B. *et al.* (eds) *33rd Annual GCSSEPM Foundation Bob F. Perkins Conference. Sedimentary Basins: Origin, Depositional Histories, and Petroleum Systems*. Gulf Coast Section SEPM, Houston, TX, 18–53.

Magnúsdóttir, S., Brandsdóttir, B., Driscoll, N. & Detrick, R. 2015. Postglacial tectonic activity within the Skjálfandadjúp Basin, Tjörnes Fracture Zone, offshore Northern Iceland, based on high resolution seismic stratigraphy. *Marine Geology*, **367**, 159–170. https://doi.org/10.1016/j.margeo.2015.06.004

Manum, S.B. & Schrader, H.J. 1976. Sites 346, 347, and 349. *In*: Talwani, M. & Udintsev, G. (eds) *Initial Reports of the Deep Sea Drilling Project*, Volume **38**. United States Government Printing Office, Washington, DC, 521–594.

Manum, S.B., Raschka, H. & Eckhardt, F.J. 1976*a*. Site 350. *In*: Talwani, M. & Udintsev, G. (eds) *Initial Reports of the Deep Sea Drilling Project*, Volume **38**. United States Government Printing Office, Washington, DC.

Manum, S.B., Raschka, H., Eckhardt, F.J., Schrader, H., Talwani, M. & Udintsev, G. 1976*b*. Site 337 initial reports of the Deep Sea Drilling Project. *In*: Talwani, M., Udintsev, G. *et al.* (eds) *Initial Reports of the Deep Sea Drilling Project*, Volume **38**. United States Government Printing Office, Washington, DC, 117–150,

Mathiesen, A., Bidstrup, T. & Christinsen, F.G. 2000. Denudation and uplift history of the Jameson Land Basin, East Greenland-constrained from maturity and apatite fission track data. *Global and Planetary Change*, **24**, 275–301.

Mjelde, R., Aurvåg, R., Kodaira, S., Shimamura, H., Gunnarsson, K., Nakanishi, A. & Shiobara, H. 2002. Vp/Vs-ratios from the central Kolbeinsey Ridge to the Jan Mayen Basin, North Atlantic; implications for lithology, porosity and present-day stress field. *Marine Geophysical Researches*, **23**, 123–145.

Mjelde, R., Eckhoff, I. *et al.* 2007. Gravity and S-wave modelling across the Jan Mayen Ridge, North Atlantic; implications for crustal lithology. *Marine Geophysical Researches*, **28**, 27–41.

Mjelde, R., Breivik, A.J., Raum, T., Mittelstaedt, E., Ito, G. & Faleide, J.I. 2008. Magmatic and tectonic evolution of the North Atlantic. *Journal of the Geological Society, London*, **165**, 31–42, https://doi.org/10.1144/0016-76492007-018

Mjelde, R., Raum, T., Kandilarov, A., Murai, Y. & Takanami, T. 2009. Crustal structure and evolution of the outer Møre Margin, NE Atlantic. *Tectonophysics*, **468**, 224–243.

Mutter, J.C., Talwani, M. & Stoffa, P.L. 1982. Origin of seaward-dipping reflectors in oceanic crust off the Norwegian margin by 'subaerial sea-floor spreading'. *Geology*, **10**, 3–12.

Nasuti, A. & Olesen, O. 2014. Magnetic data. *In*: Hopper, J.R., Funck, T., Stoker, M.S., Árting, U., Peron-Pinvidic, G., Doornenbal, H. & Gaina, C. (eds) *Tectonostratigraphic Atlas of the North-East Atlantic Region*. Geological Survey of Denmark and Greenland (GEUS), Copenhagen, Denmark, 41–51.

Nilsen, T.H., Kerr, D.R., Talwani, M. & Udintsev, G. 1978. Turbidites, redbeds, sedimentary structures, and trace fossils observed in DSDP Leg 38 cores and the sedimentary history of the Norwegian–Greenland Sea. *In*: *Initial Reports of the Deep Sea Drilling Project. Supplement to Volume 38*. United States Government Printing Office, Washington, DC, 259–288.

Nøhr-Hansen, H. 2003. Dinoflagellate cyst stratigraphy of the Palaeogene strata from the wells Hellefisk-1, Ikermiut-1, Kangâmiut-1, Nukik-1, Nukik-2 and Qulleq-1, offshore West Green-land. *Marine and Petroleum Geology*, **20**, 987–1016.

Nøhr-Hansen, H. 2012. Palynostratigraphy of the Cretaceous-Lower Palaeogene sedimentary succession in the Kangerlussuaq Basin, southern East Greenland. *Review of Palaeobotany and Palynology*, **178**, 59–90.

Nøhr-Hansen, H. & Piasecki, S. 2002. Paleocene subbasaltic sediments on Savoia Halvø, East Greenland. *Geology of Greenland Survey Bulletin*, **191**, 111–116.

Norwegian Petroleum Directorate 2012. *Submarine Fieldwork on the Jan Mayen Ridge: Integrated Seismic and ROV-Sampling*. Norwegian Petroleum Directorate, Stavanger, Norway, http://www.npd.no/en/Publications/Presentations/Submarine-fieldwork-on-the-Jan-Mayen-Ridge/

Norwegian Petroleum Directorate 2013. *The Petroleum Resources on the Norwegian Continental Shelf*. Norwegian Petroleum Directorate, Stavanger, Norway, http://www.npd.no/en/Publications/Resource-Reports/2013/

Nunns, A. 1983*a*. The structure and evolution of the Jan Mayen Ridge and surroundings regions. *In*: Watkins, J.S. & Drake, C.L. (eds) *Studies in Continental Margin Geology*. American Association of Petroleum Geologists, Memoirs, **34**, 193–208.

Nunns, A.G. 1983*b*. Plate tectonic evolution of the Greenland-Scotland Ridge and surrounding regions. *In*: Bott, M.H.P., Saxov, S., Talwani, M. & Thiede, J. (eds) *Structure and Development of the Greenland–Scotland Ridge*. Plenum, New York, 11–30.

Nunns, A.G., Talwani, M. *et al.* 1983. Magnetic anomalies over Iceland and surrounding seas. *In*: Bott, M.H.P., Saxov, S., Talwani, M. & Thiede, J. (eds) *Structure and Development of the Greenland-Scotland Ridge*. Plenum, New York, 661–678.

Olafsson, I. & Gunnarsson, K. 1989. *The Jan Mayen Ridge: Velocity Structure from Analysis of Sonobuoy Data*. OS-89030/JHD-04. Orkustofnun, Reykjavík.

Osmundsen, P.T. & Andersen, T.B. 1994. Caledonian compressional and late-orogenic extensional deformation in the Staveneset area, Sunnfjord, Western Norway. *Journal of Structural Geology*, **16**, 1385–1401.

Osmundsen, P.T. & Andersen, T.B. 2001. The middle Devonian basins of western Norway: sedimentary response to large-scale transtensional tectonics. *Tectonophysics*, **332**, 51–68, https://doi.org/10.1016/s0040-1951(00)00249-3

Osmundsen, P.T. & Ebbing, J. 2008. Styles of extension offshore mid-Norway and implications for mechanisms of crustal thinning at passive margins. *Tectonics*, **27**, TC6016.

Osmundsen, P.T., Sommaruga, A., Skilbrei, J.R. & Olesen, O. 2002. Deep structure of the Mid Norway rifted margin. *Norwegian Journal of Geology*, **82**, 205–224.

Passey, S. & Hitchen, K. 2011. Cenozoic (igneous). *In*: Ritchie, J.D., Ziska, H., Johnson, H. & Evans, D. (eds) *Geology of the Faroe-Shetland Basin and Adjacent Areas*. British Geological Survey and Jarðfeingi Research Report RR/11/01 British Geological Survey, Keyworth, Nottingham, 209–228.

Passey, S.R. & Jolley, D.W. 2009. A revised lithostratigraphic nomenclature for the Palaeogene Faroe Islands basalt Group, NE Atlantic Ocean. *Earth and Environmental Science, Transactions of the Royal Society of Edinburgh*, **99**, 127–158.

Peron-Pinvidic, G., Gernigon, L., Gaina, C. & Ball, P. 2012*a*. Insights from the Jan Mayen system in the Norwegian-Greenland Sea – I: mapping of a microcontinent. *Geophysical Journal International*, **191**, 385–412.

Peron-Pinvidic, G., Gernigon, L., Gaina, C. & Ball, P. 2012*b*. Insights from the Jan Mayen system in the Norwegian-Greenland Sea – II: architecture of a microcontinent. *Geophysical Journal International*, **191**, 413–435.

Peron-Pinvidic, G., Manatschal, G. & Osmundsen, P.T. 2013. Structural comparison of archetypal Atlantic rifted margins: a review of observations and concepts. *Marine and Petroleum Geology*, **43**, 21–47.

Pharaoh, T.C., Dusar, M. *et al.* 2010. Tectonic evolution. *In*: Doornenbal, J.C. & Stevenson, A.G. (eds) *Petroleum Geological Atlas of the Southern Permian Basin Area*. European Association of Geoscientists & Engineers, Houten, The Netherlands, 25–57.

Planke, S., Symonds, P.A., Alvestad, E. & Skogseid, J. 2000. Seismic volcanostratigraphy of large-volume basaltic extrusive complexes on rifted margins. *Journal of Geophysical Research*, **105**, 19335–19351.

Polteau, S., Mazzini, A., Trulsvik, M. & Planke, S. 2012. *JMRS11 – Jan Mayen Ridge Sampling Survey 2011*. VBPR-TGS, Commercial Report, February 2012.

Prestvik, T., Goldberg, S., Karlsson, H. & Grönvold, K. 2001. Anomalous strontium and lead isotope signatures in the off-rift Öræfajökull central volcano in southeast Iceland: evidence for enriched endmember(s) of the Iceland mantle plume? *Earth and Planetary Science Letters*, **190**, 211–220.

Raschka, H., Eckhardt, F.J. & Manum, S.B. 1976. Site 348. *In*: Talwani, M. & Udintsev, G. (eds) *Initial Reports of the Deep Sea Drilling Project*, Volume **38**. United States Government Printing Office, Washington, DC, 595–654.

Rey, S.S., Eldholm, O. & Planke, S. 2003. Formation of the Jan Mayen Microcontinent, the Norwegian Sea. *Eos, Transactions of the American Geophysical Union*, **84**, Abstract T31D-0872.

Sandstå, N.R., Pedersen, R.B., Williams, R.D., Bering, D., Magnus, C., Sand, M. & Brekke, H. 2012. *Submarine fieldwork on the Jan Mayen Ridge; integrated seismic and ROV-sampling*. Norwegian Petroleum Directorate, Stavanger, Norway, http://www.npd.no/

Sæmundsson, K. 1974. Evolution of the Axial Rifting Zone in Northern Iceland and the Tjörnes Fracture Zone. *Geological Society of America Bulletin*, **85**, 495–504.

Sæmundsson, K. 1979. Outline of the geology of Iceland. *Jökull*, **29**, 7–28.

Scott, R.A., Ramsey, L.A., Jones, S.M., Sinclair, S. & Pickles, C.S. 2005. Development of the Jan Mayen microcontinent by linked propagation and retreat of spreading ridges. *In*: Wandås, B.T.G., Nystuen, J.P., Eide, E. & Gradstein, F. (eds) *Onshore–Offshore Relationships on the North Atlantic Margin*. Norwegian Petroleum Society, Oslo, 69–82.

Seidler, L. 2000. Incised submarine canyons governing new evidence of Early Triassic rifting in East Greenland. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **161**, 267–293.

Soper, N.J., Higgins, A.C., Downie, C., Matthews, D.W. & Brown, P.E. 1976. Late Cretaceous-early Tertiary stratigraphy of the Kangerdlugssuaq area, east Greenland, and the age of opening of the north-east Atlantic. *Journal of the Geological Society, London*, **132**, 85–104, https://doi.org/10.1144/gsjgs.132.1.0085

Stemmerik, L. 2000. Late Palaeozoic evolution of the North Atlantic margin of Pangea. Palaeo-geography Palaeo-climatology. *Palaeoecology*, **161**, 95–126.

Stoker, M.S., Praeg, D. *et al.* 2005. Neogene evolution of the Atlantic continental margin of NW Europe (Lofoten Islands to SE Ireland): anything but passive. *In*: Doré, A.G. & Vining, B.A. (eds) *Petroleum Geology: North-West Europe and Global Perspectives – Proceedings of the 6th Petroleum Geology Conference*. Geological Society, London, **6**, 1057–1076, https://doi.org/10.1144/0061057

Stoker, M.S., Stewart, M. *et al.* 2016. An overview of the Upper Paleozoic–Mesozoic stratigraphy of the NE Atlantic region. *In*: Péron-Pinvidic, G., Hopper, J., Stoker, M.S., Gaina, C., Doornenbal, H., Funck, T. & Árting, U. (eds) *The North-East Atlantic Region: A Reappraisal of Crustal Structure, Tectono-Stratigraphy and Magmatic Evolution*. Geological Society, London, Special Publications, **447**, first published online August 11, 2016, https://doi.org/10.1144/SP447.2

Storey, M., Duncan, R.A. & Swisher, C.C., III. 2007*a*. Paleocene-Eocene thermal maximum and opening of the Northeast Atlantic. *Science*, **316**, 587–589.

Storey, M., Duncan, R.A. & Tegner, C. 2007*b*. Timing and duration of volcanism in the North Atlantic Igneous Province: implications for geodynamics and links to the Iceland hotspot. *Chemical Geology*, **241**, 264–281.

Surlyk, F. 1977. *Stratigraphy, Tectonics and Palaeogeography of the Jurassic Sediments of the Areas North of Kong Oscars Fjord, East Greenland*. Bulletin Grønlands Geologiske Undersøgelse, **123**.

Surlyk, F. 1978. *Submarine Fan Sedimentation Along Fault Scarps On Tilted Fault Blocks*

(Jurassic–Cretaceous Boundary, East Greenland). Bulletin Grønlands Geologiske Undersøgelse, **128**.

Surlyk, F. 1990. Timing, style and sedimentary evolution of Late Paleozoic–Mesozoic extensional basins of East Greenland. *In*: Hardman, R.F.P. & Brooks, J. (eds) *Tectonic Events Responsible for Britain's Oil and Gas Reserves*. Geological Society, London, Special Publications, **55**, 107–125, https://doi.org/10.1144/GSL.SP.1990.055.01.05

Surlyk, F. 1991. Tectonostratigraphy of North Greenland. *In*: Peel, J.S. & Sønderholm, M. (eds) *Sedimentary Basins of North Greenland*. Bulletin Grønlands Geologiske Undersøgelse, **160**, 25–47.

Surlyk, F. 2003. The Jurassic of East Greenland: a sedimentary record of thermal subsidence, onset and culmination of rifting. *In*: Ineson, J.R. & Surlyk, F. (eds) *The Jurassic of Denmark and Greenland*. Geological Survey of Denmark and Greenland Bulletin, **1**, 659–722.

Surlyk, F. & Noe-Nygaard, N. 2001. Cretaceous faulting and associated coarse-grained marine gravity flow sedimentation, Traill Ø, East Greenland. *In*: Martinsen, O.J. & Dreyer, T. (eds) *Sedimentary Environments Offshore Norway – Paleozoic to Recent*. Norwegian Petroleum Society, Special Publications, **10**, 293–319.

Surlyk, F., Callomon, J.H., Bromley, R.G. & Birkelund, T. 1973. *Stratigraphy of the Lower Jurassic–Lower Cretaceous Sediments of Jameson Land and Scoresby Land, East Greenland*. Bulletin Grønlands Geologiske Undersøgelse, **105**.

Svellingen, W. & Pedersen, R. 2003. Jan Mayen: a result of ridge-transform-micro-continent interaction. *Geophysical Research Abstracts*, **5**, 12993.

Talwani, M. & Eldholm, O. 1977. Evolution of the Norwegian-Greenland Sea. *Geological Society of America Bulletin*, **88**, 969–999.

Talwani, M. & Udintsev, G. (eds). 1976. *Initial Reports of the Deep Sea Drilling Project*, Volume **38**. United States Government Printing Office, Washington, DC.

Talwani, M., Udintsev, G. & Shirshov, P.R. 1976*a*. Tectonic synthesis. *In*: Talwani, M. & Udintsev, G. (eds) *Initial Reports of the Deep Sea Drilling Project*, Volume **38**. United States Government Printing Office, Washington, DC, 1213–1242.

Talwani, M., Udintsev, G. & White, S.M. 1976*b*. Introduction and explanatory notes, Leg 38, Deep Sea Drilling Project. *In*: Talwani, M. & Udintsev, G. (eds) *Initial Reports of the Deep Sea Drilling Project*, Volume **38**. United States Government Printing Office, Washington, DC, 3–19.

Tegner, C., Brooks, C.K., Duncan, R.A., Heister, L.E. & Bernstein, S. 2008. ^{40}Ar–^{39}Ar ages of intrusions in East Greenland: rift-to-drift transition over the Iceland hotspot. *Lithos*, **101**, 480–500.

Thiede, J., Firth, J.V. *et al.* 1995. Site 907. *In*: Myhre, A.M., Thiede, J. *et al.* (eds) *Proceedings of the Ocean Drilling Program, Initial Reports*, Volume **151**. Ocean Drilling Program, College Station, TX, 57–111.

Thordarson, T. & Larsen, G. 2007. Volcanism in Iceland in historical time: volcano types, eruption styles and eruptive history. *Journal of Geodynamics*, **43**, 118–152.

Torsvik, T.H., Mosar, J. & Eide, E.A. 2001. Cretaceous-Tertiary geodynamics: a North Atlantic exercise. *Geophysical Journal International*, **146**, 850–866.

Torsvik, T.H., Amundsen, H.E.F. *et al.* 2015. Continental crust beneath southeast Iceland. *Proceedings of the National Academy of Sciences of the United States of America*, **112**, 1818–1827.

Tsikalas, F., Eldholm, O. & Faleide, J.I. 2005. Crustal structure of the Lofoten-Vesterålen continental margin, off Norway. *Tectonophysics*, **404**, 151–174.

Tsikalas, F., Faleide, J.I. & Kusznir, N.J. 2008. Along-strike variations in rifted margin crustal architecture and lithosphere thinning between northern Vøring and Lofoten margin segments off mid-Norway. *In*: Rosenbaum, G., Weinberg, R.F. & Regenauer-Lieb, K. (eds) *Geodynamics of Lithospheric Extension. Tectonophysics*. **458**, 68–81.

Vogt, P.R. & Jung, W.Y. 2009. Treitel ridge: a unique inside corner hogback on the west flank of extinct Aegir spreading ridge, Norway basin. *Marine Geology*, **267**, 86–100.

Vogt, P.R., Anderson, C.N., Bracey, D.R. & Schneider, E.M. 1970. North Atlantic Magnetic Smooth Zones. *Journal of Geophysical Research*, **75**, 3955–3968.

Walker, G.P.I. 1964. Geological investigations in eastern Iceland. *Bulletin of Volcanology*, **27**, 351–363.

Ziegler, P.A. 1988. *Evolution of the Arctic-North Atlantic and the Western Tethys*. American Association of Petroleum Geologists, Memoirs, **43**.