The Wandel Hav Strike-Slip Mobile Belt – A Mesozoic plate boundary in North Greenland

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The historical 'de Geer Line' between Svalbard and Greenland is shown to have had a Mesozoic precursor now residing well within the continental Greenland plate, where it coincides with the Wandel Hav Strike-Slip Mobile Belt. Well-constrained phases in relative plate motion reflected in the mobile belt are discernible back to the mid Jurassic, with more obscure phases dating even further back. There is evidence that the Wandel Hav Strike-Slip Mobile Belt may have been formed already in Late Palaeozoic time during onset of Pangean break-up; evidence for strike-slip movements of this age is, however, largely circumstantial, due to severe overprinting during the later phases. Wrench tectonics along the 'fossil' plate boundary culminated around the Cretaceous – Palaeogene boundary in the major right-lateral, transpressional Kronprins Christian Land Orogeny. Thus, the Wandel Hav Strike-Slip Mobile Belt may constitute the geological/structural expression of the Mesozoic Laurentian – Eurasian plate boundary all the way up to initiation of actual seafloor spreading at chron 24 in Palaeogene time.

Key words: de Geer Line, North Greenland, plate boundary, strike-slip, wrench tectonic.

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The overall similarity in geological development of Svalbard, the Barents Shelf and the Wandel Sea Basin in North Greenland during Late Palaeozoic to Palaeogene time has long been recognized (e.g. Håkansson & Stemmerik 1984). The similarity is in good keeping with the common history shared by these two regions up to actual separation between Laurentia and Eurasia which, in the northern part of the North Atlantic region, commenced in the Palaeogene at about the Paleocene – Eocene transition. However, a major difference in timing of compressional events in Svalbard and in North Greenland has been found, severely obstructing coherent regional modeling (Håkansson & Pedersen 1982). In North Greenland compressional tectonics ceased no later than mid Paleocene time (Håkansson 1988, Lyck & Stemmerik 2000), well before the main Eocene compressional phases in Svalbard. To add to the complexity also the Eurekan Orogeny in the Sverdrup Basin of Arctic Canada further to the west experienced its main contraction during the later part of the Palaeogene.

Since 1976 several expeditions to the remote and quite hostile part of Greenland occupied by the Wandel Sea Basin have gradually improved our knowledge of the geological development, high-lighting the elements which are not immediately compatible with the much more intensely studied development of Svalbard and the Sverdrup Basin. The period of work condensed in this presentation took off while both authors participated in geological mapping expeditions into North Greenland launched in the later part of the 1970s under the leadership of Oscar (alias Niels Henriksen, as readers of this volume will now know). Our subsequent work in the area has drawn extensively on Oscar's logistical skills and general support.

Regional geological setting

The Wandel Sea Basin in North Greenland together with the Sverdrup Basin in Arctic Canada and the Svalbard platform record the Western Arctic history of interaction between Laurentia and Eurasia during Carboniferous to Palaeogene time (Fig 1). In this region the break-up between the two major plates commenced in the Carboniferous, but not until the Late

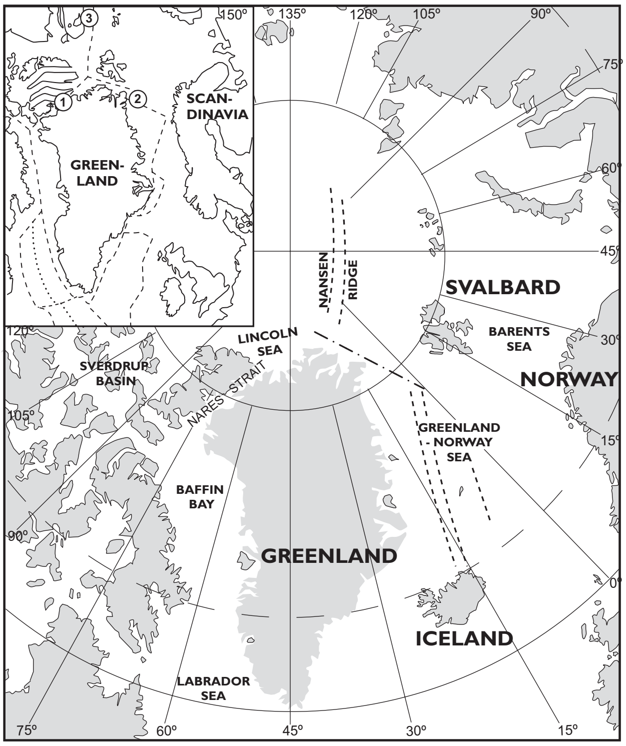


Fig. 1. Toponymic map of the Artic region. Inserted pre-drift ('late Mesozoic') map with 'Wegener Line' (1), 'de Geer Line' (2), and the fracture zone separating Eurasia and Laurentia/ the Lomonosov Ridge (3).

Cretaceous did actual sea-floor spreading set in. In the process several continental fragments became detached for shorter or longer periods of time, and towards the end of the period in the Late Cretaceous to Palaeogene, Greenland was temporarily moving independently from the main part of Laurentia. During the early part of this 'independent' stage (until chron 24), as well as an unknown time interval prior to this, the northeastern corner of Greenland constituted a severe kink to plate adjustments in the region. As a result this part of North Greenland was subjected to several episodes of deformation through at least the later half of the Mesozoic.

The three continental entities involved in these episodes of deformation were separated along a rather complex series of lineaments, which came together in a triple junction just north of Greenland before sea-floor spreading (Fig. 1). The lineaments are:

1) The system of fractures separating Laurentia and Greenland, which apparently follows the Nares Strait (the 'Wegener Line') and, further to the south, joins the Baffin Bay – Labrador Sea spreading ridges (Roest & Srivastava 1989; Chalmers et al. 1993, 1998).
2) The system of fractures separating Eurasia and Greenland (the 'de Geer Line') and, further to the south, the Knipovich and Mohn Ridges of the Greenland – Norway Sea (e.g. Talwani & Eldholm 1977).
3) The fracture zone separating Eurasia and Laurentia/Lomonosov Ridge, which eventually developed into the Nansen Ridge.

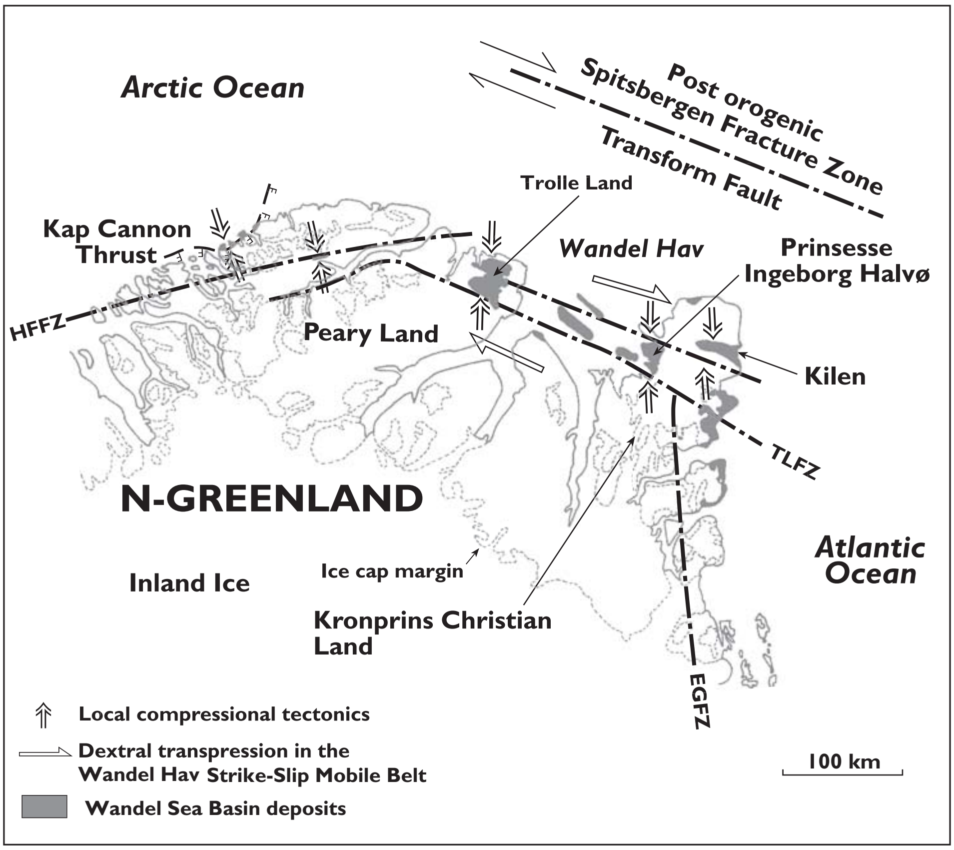
This paper is concerned with the 'de Geer Line'. It is our notion, that the northern part of this fracture system during the Mesozoic had a precursor now residing well within the Greenland part of the Laurentian continental plate; only subsequently did this plate boundary sidestep into its present position, in association with start of actual ocean floor formation at chron 24. This intracontinental Mesozoic plate boundary has its geological/structural expression in the Wandel Hav Strike-Slip Mobile Belt of Håkansson & Pedersen (1982).

Wandel Hav Strike-Slip Mobile Belt

The Wandel Hav Strike-Slip Mobile Belt is developed around the Trolle Land Fault System, a slightly south–eastwards diverging group of NW–SE oriented faults exposed in Trolle Land and Kronprins Christian Land, respectively (Fig. 2). The exposed segments of the fault system are assumed to be connected across the Wandel Sea and extending further towards the SE across the broad northeast Greenland shelf, possibly in direct relation to the Greenland Fracture Zone (cf. Fig 9 in Stemmerik et al. 2000). In the pre-drift position the Wandel Hav Strike-Slip Mobile Belt may have been directly related to structures on the southwestern margin of the Barents Sea platform. Towards NW the fault system gradually merges in a splay zone apexed close to the E-W oriented Harder Fjord Fault Zone.

The Trolle Land Fault System was formed in the Carboniferous, shortly after activity in the Ellesmerian North Greenland Fold belt had ceased, but phases of repetitive movement along most faults have caused severe overprint; only the later part of the dynamic-stratigraphic history of the fault system is therefore now discernible in any detail. Nevertheless, widespread fault control of Carboniferous and Permian deposition is well documented (e.g. Håkansson & Stemmerik 1989, Stemmerik et al. 1996). Three structural events are discernible in the later part of the Mesozoic, the transtensional Ingeborg and Kilen

Fig. 2. Main structural elements of the Kronprins Christian Land Orogeny in eastern North Greenland (HFFZ = Harder Fjord Fault Zone, TLFZ = Trolle Land Fault Zone, EGFZ = East Greenland Fault Zone)



Events, and the transpressional Kronprins Christian Land Orogeny (Pedersen 1988, Håkansson et al. 1993).

son 1983). The total age of basinal infills range from Turonian to the Maastrichtian – Danian boundary (Håkansson & Pedersen 1982, Håkansson 1988).

Ingeborg Event

The Ingeborg Event constitutes one of the major episodes of fault-controlled basin formation in the history of the Wandel Sea Basin. It predates deposition of Upper Jurassic – Lower Cretaceous successions in both eastern Peary Land and Kronprins Christian Land, and it most likely occurred towards the end of the Middle Jurassic. Vertical displacements in the order of 1 km have been inferred for this event, with a possible sinistral component (Pedersen & Håkansson in press).

Kilen Event

The Kilen Event includes the formation of at least six, fairly deep pull-apart basins right across eastern North Greenland in a right-lateral strike-slip regime. Deposition was rapid, and took place both continental and marine environments (Birkelund & Håkans-

Kronprins Christian Land Orogeny

During the right-lateral, transpressional Kronprins Christian Land Orogeny regional differences in deformation developed along the Wandel Hav Strike-Slip Mobile Belt. Variation in structural style is to a large extent reflecting the presence or absence of gypsum in the Carboniferous part of the succession, but the orientation of rejuvenated faults has also led to local deviations. In eastern Peary Land the right-lateral transpression was expressed mostly as simple strike-slip movements along near vertical faults. Compressional features are restricted to narrow block margins in all but one fault block in the otherwise rigid blocks of the Trolle Land Fault System. We believe that right-lateral displacement was transmitted further to the NW along part of the Harder Fjord Fault Zone, from the apex of the Trolle Land Fault System into the Lincoln Sea, in association with the western termination of the Kap Cannon Thrust (Fig. 2). In contrast, in Kronprins Christian Land, compressional

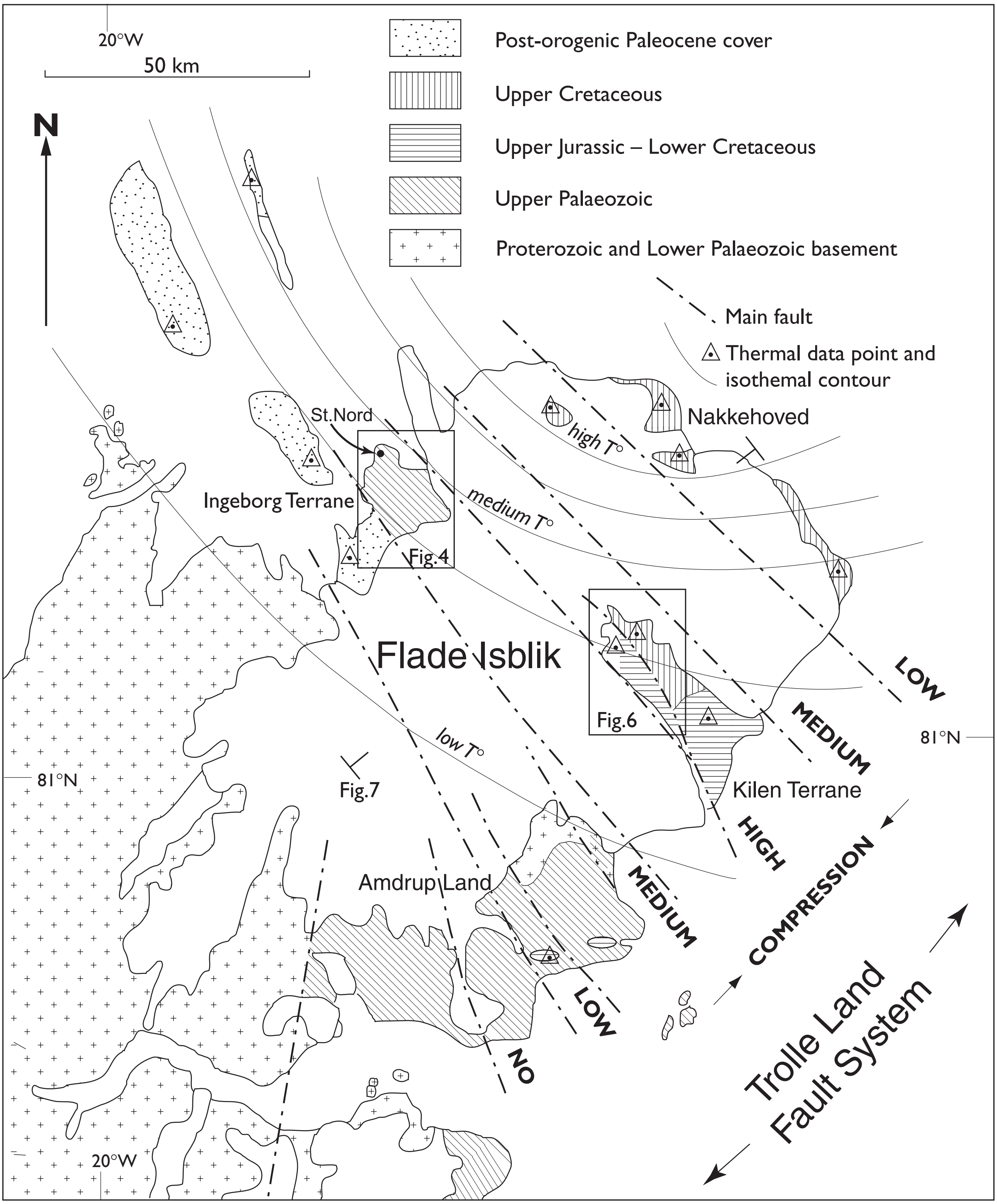


Fig. 3. Geological map of Kronprins Christian Land including the geotectonic elements related to the transform plate boundary in eastern North Greenland. Thermal maturity levels from Håkansson et al. (1994) and Stemmerik et al. (2000); degree of compression from Pedersen & Håkansson (in press).

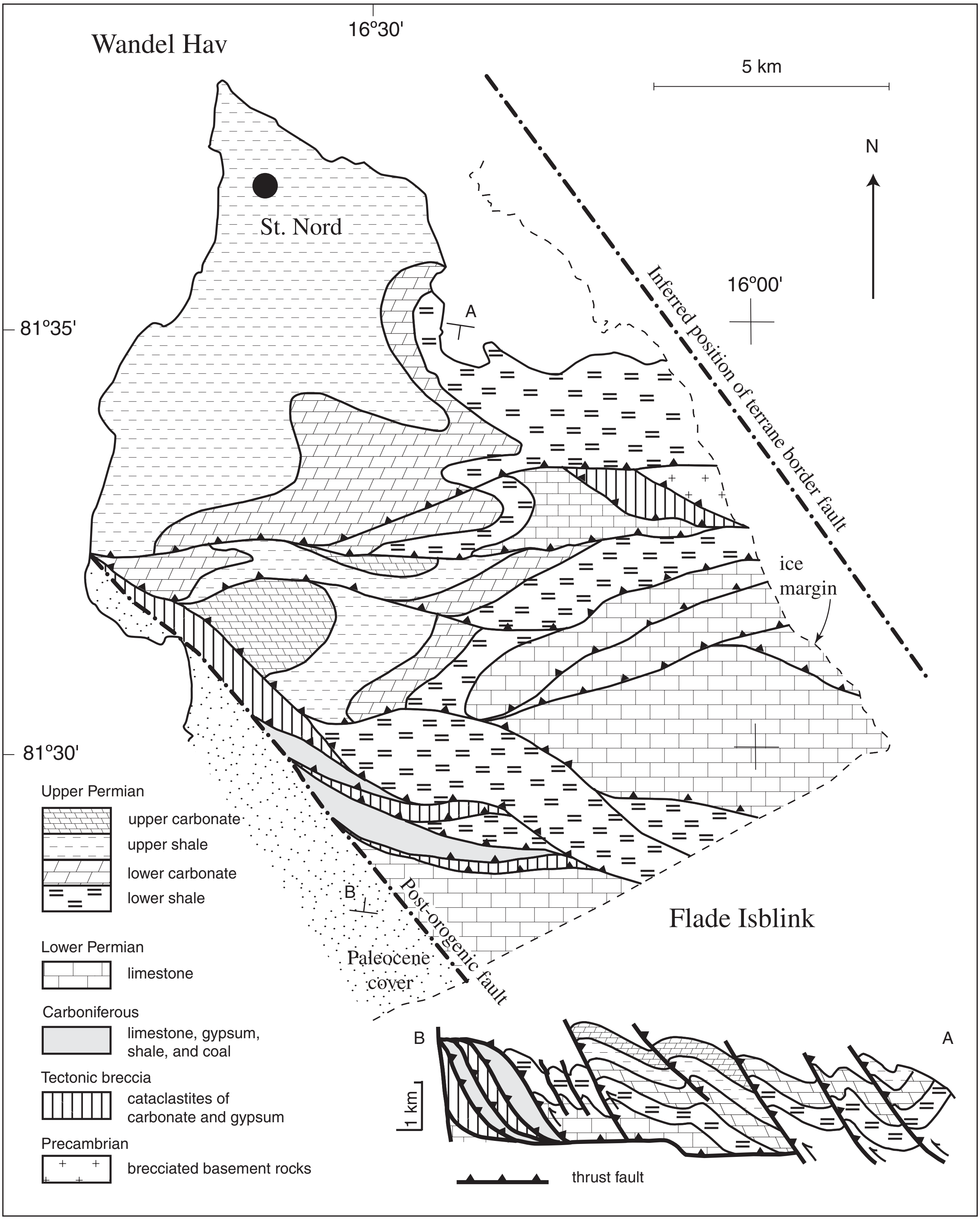


Fig. 4. Geological map of Prinsesse Ingeborg Halvø showing Upper Palaeozoic strata with dominant trust-and-fold/ramp-and-flat geometries characteristic of lower stockwerk deformation in the southeastern segment of the Kronprins Christian Land Orogeny. Apex zones with dense thrust imbricates are developed towards the terrane border faults, as illustrated in the schematic geological profile. (From Pedersen & Håkansson in press).

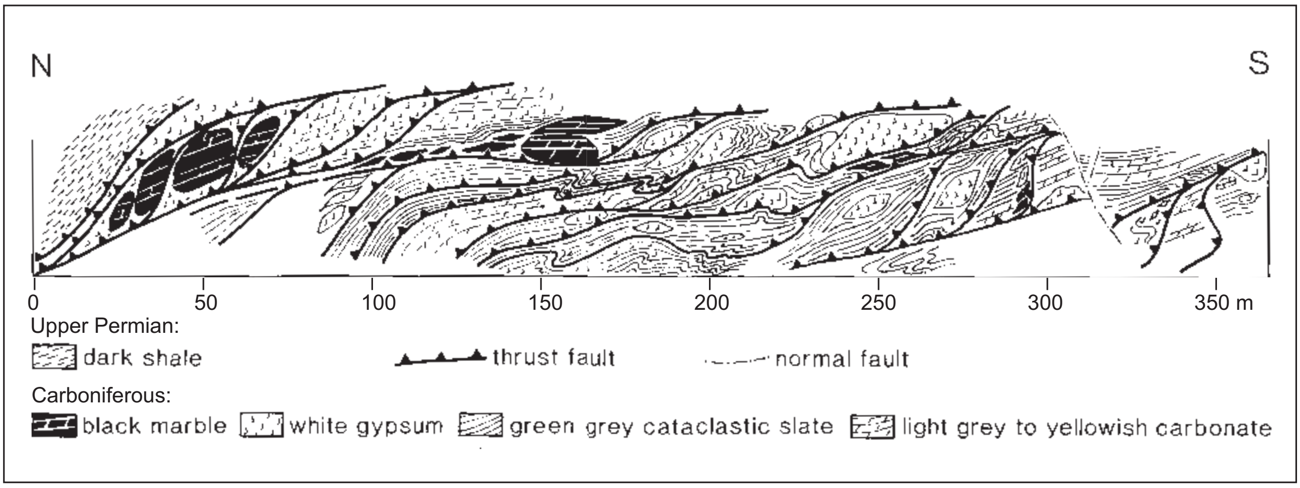


Fig. 5. Geological profile across the apex zone in the southern end of profile A-B in Prinsesse Ingeborg Halvø (cf. Fig. 4). Note the intense thrust faulting including anastomosing duplex structures and kataclastic megablocks (from Pedersen & Håkansson in press).

forces were transmitted along gypsiferous decollement zones between the faults of the Trolle land Fault System, causing regional deformation characterized by *en échelon* dome folds extending right across fault blocks. In this region deformation reached a climax in a fairly narrow, fault-parallel zone, which is dominated by thrust faulting and thrust fault folding in the lower stockwerk, while upper stockwerk deformation is dominated by dome folds with associated tear faulting (Pedersen & Håkansson in press).

Plate boundary

The structural style developed in Kronprins Christian Land allows some speculation concerning the driving force in the Wandel Hav Strike-Slip Mobile Belt. Two elements are particularly relevant to these considerations, 1) pronounced deformational symmetry, and 2) probable (albeit partly concealed) thermal maturation symmetry.

Transpressional deformation across the Trolle Land Fault System varies systematically across the Trolle Land Fault System (Fig. 3). From no deformation in the SW compression increased gradually, and rapidly, towards the NE, reaching a maximum in the Kilen and Ingeborg Terranes, only to diminish rapidly again further towards the NE in the Nakkehoved blocks. The sense of displacement in the intra-block deformation in the two most intensely deformed blocks points to the fault line separating the Kilen and Ingeborg Terranes as a most central feature. While transport along the E-W striking thrust planes in the Ingeborg Terrane was towards the south and southwest (Figs 4 & 5), transport along the similarly striking thrust planes in the Kilen Terrane was towards the north and northeast (Fig. 6). In a composite cross-section across the Trolle Land Fault System in Kronprins Christian Land it is therefore evident that the fault separating the Kilen and Ingeborg Terranes constitutes the main axis of a major right-lateral flower structure (Fig. 7) (Pedersen & Håkansson in press).

The present day thermal maturity pattern across Kronprins Christian Land is not immediately compatible with the structural symmetry described above, since maturity levels in surface strata have been found to increase from immature in the south to generally post-mature in the northern part (Fig. 3; Stemmerik et al. 2000, their fig. 9). However, in order to fully assess the thermal signature of the Kronprins Christian Land Orogeny a pronounced post-orogenic thermal overprint involving also the Upper Paleocene post-orogenic cover must be considered (Håkansson & Pedersen 1982). This short-lived post-Paleocene thermal event developed vitrinite reflectance (R_{max}) levels around 10 in near surface sediments of the focal area on the north coast of Kronprins Christian Land (curved iso-temperature contours on Fig. 3). Furthermore, the difference in stockwerk levels exposed in the Ingeborg and Kilen Terranes estimated to be around 3 to 5 km (Pedersen & Håkansson in press) should also be taken into account when assessing the apparent maturation asymmetry across the flower structure.

Thus, thermal levels along the axis of the Kronprins Christian Land Orogeny reached greenschist metamorphic grades in localized high-pressure zones in the lower stockwerk regime of the Ingeborg Terrane (Rasmussen & Håkansson 1996), while thermal altera-

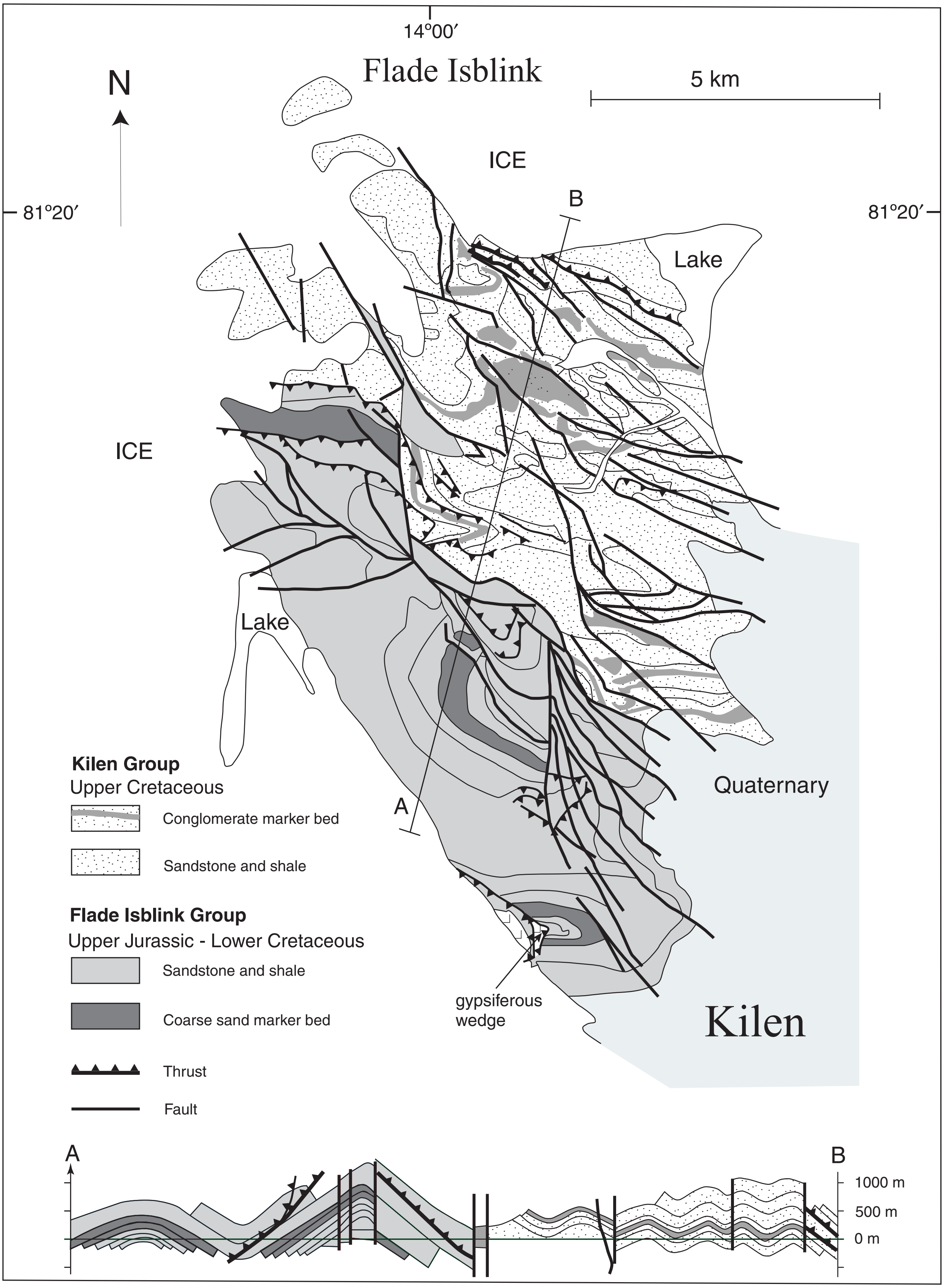


Fig. 6. Geological map of Kilen showing Upper Jurassic to Upper Cretaceous strata dominated by domal folding characteristic of higher stockwerk deformation in the southeastern segment of the Kronprins Christian Land Orogeny. Modified from Geological map of Kilen (Pedersen 1990, in Håkansson 1994).

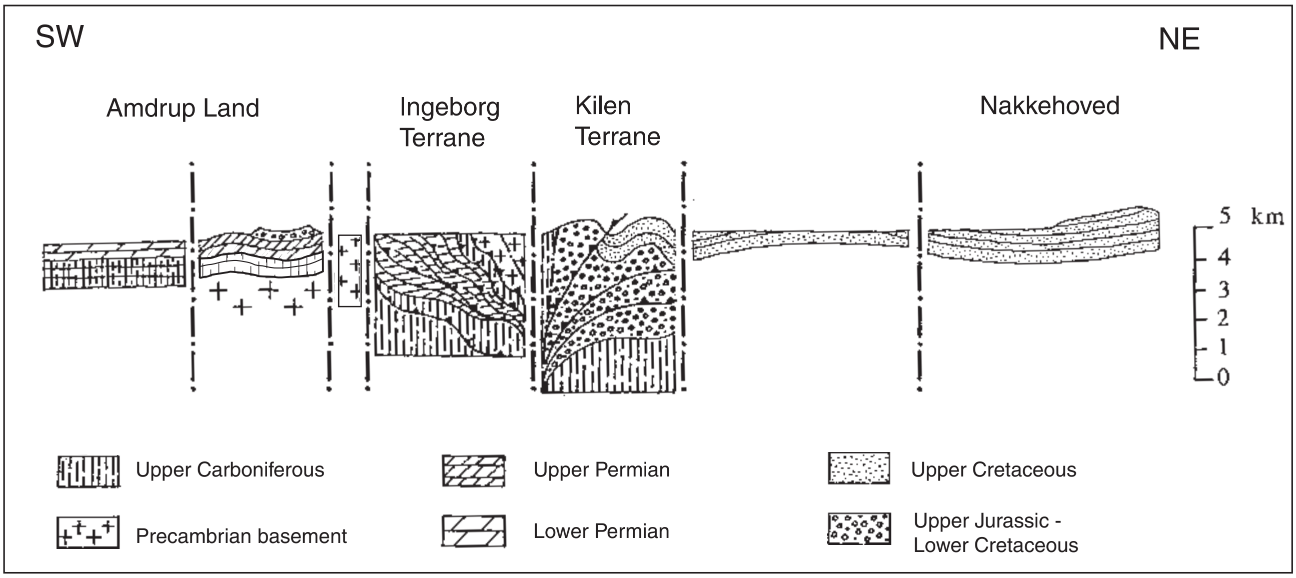


Fig. 7. NE-SW section across the Trolle Land Fault System in Kronprins Christian Land. Note deformational symmetry in the Kronprins Christian Land Orogeny across the Ingeborg-Kilen Terrane border fault. (After Pedersen & Håkansson in press).

tions in the Kilen Terrane, with vitrinite reflectance (R_m/ R_{max}) values between 0.58 and 2.24 (Håkansson et al. 1994), were much less severe. However, when the post-orogenic thermal overprint is subtracted, the original maturity pattern may, indeed, be fully compatible with the pronounced structural symmetry, with a high temperature axial zone along the Ingeborg–Kilen border fault.

Discussion

Extension between Eurasia and Laurentia in the Arctic realm commenced in Carboniferous time, and as such the boundary between the two continental plates was a broad zone of extensional faults. In the region between Greenland and Svalbard, the two plates were displaced via a NW-SE oriented transform fault zone characterized by transtensional regimes (the Late Palaeozoic Arctic Rift Zone of Gudlagsson et al. 1998). The entire fault zone was established and remained in an intra-continental setting until sea-floor spreading was initiated in both the northernmost North Atlantic and the Arctic Ocean at chron 24 time (at approximately the Paleocene – Eocene boundary). By this time activities in the Wandel Hav Strike-Slip Mobile Belt had ceased, most likely reflecting a shift of the plate boundary position in the transform fault zone towards the NE. Around chron 6 time deep-water connection between the Arctic and North Atlantic Oceans was established, so between chrons 24 and 6 the newly formed continental transform fault zone gradually shortened, to be replaced by continent-ocean transitions along the present day Svalbard - Greenland transform margin.

The intra-continental zone of stretching and crustal thinning may have lacked a definite plate boundary for extended periods of time. However, during periods of pronounced strike-slip dynamics, movements have conceivably been concentrated along a single major deep-seated wrench tectonic fracture zone, which then constituted the plate boundary. Thus the three distinct phases discernible in the Wandel Hav Strike-Slip Mobile Belt during the late Mesozoic, the mid- to late Jurassic and mid cretaceous Ingeborg and Kilen Events, and the latest Cretaceous Kronprins Christian Land Orogeny, record the youngest, and therefore most easily discernible episodes of wrench tectonics along the Laurentian–Eurasian plate boundary, with the border fault between the Kilen and Ingeborg Terranes functioning as the plate boundary (Fig. 8). Due to recurrent activity along the faults of the Trolle Land Fault System, including the plate boundary fault, previous episodes of strike-slip dominated regimes have been largely obscured. It is therefore not obvious whether the position of this particular plate boundary has remained stable until the final sidestepping into its present position, but potentially its late Mesozoic configuration may have been established already at the time of formation of the Trolle Land Fault System in the Late Palaeozoic.

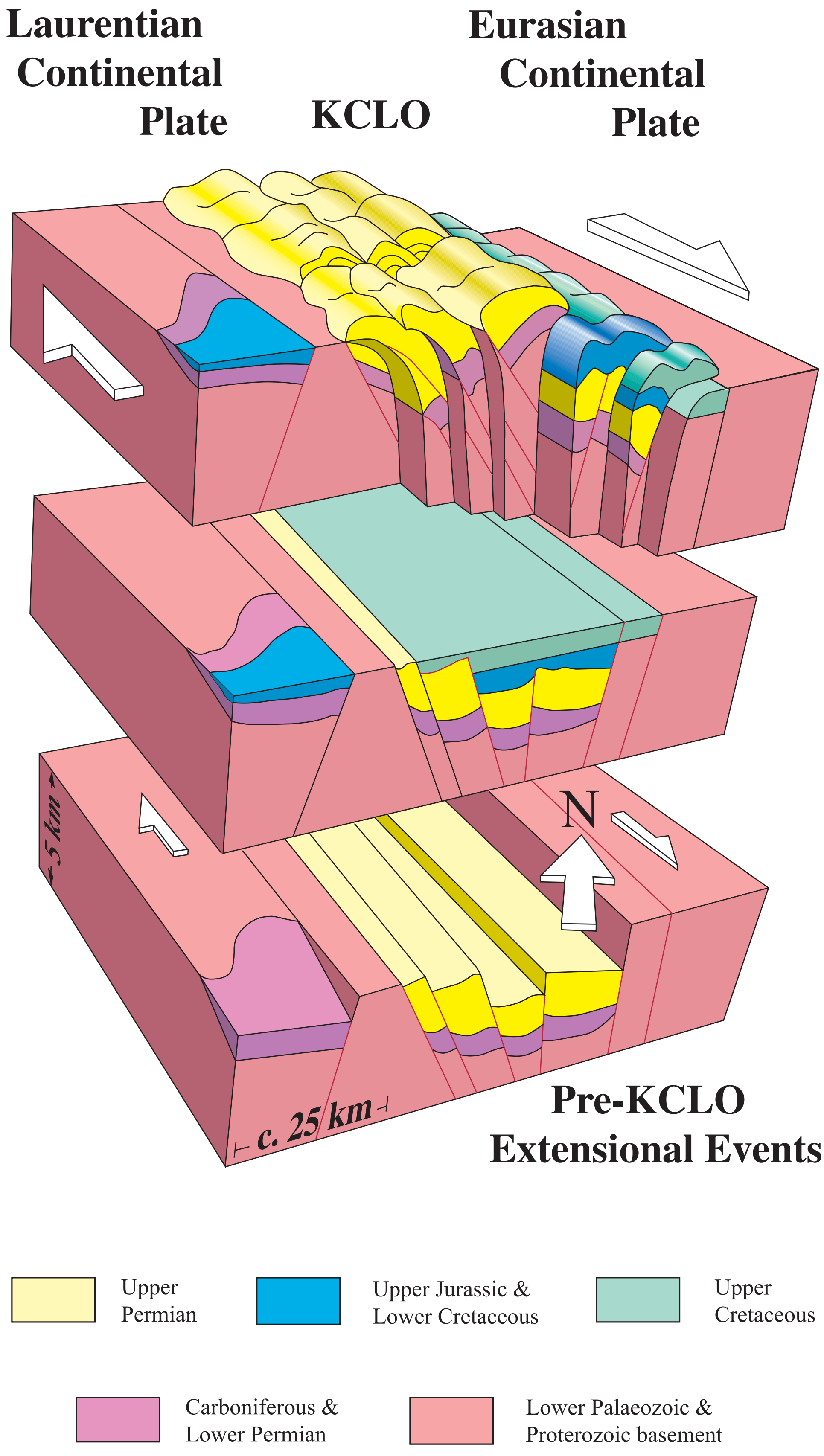


Fig. 8. Schematic block-diagrams illustrating the structural development of the Wandel Hav Strike-Slip Mobile Belt. First block (from below) represents a schematic average of both the mid- to late Jurassic Ingeborg Event and the mid Cretaceous Kilen Event; second block illustrates Late Cretaceous basin infilling immediately preceding transpression; top block illustrates the Kronprins Christian Land Orogeny (KCLO) in its final stage.

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