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Mesozoic and Cenozoic tectonics of the Møre Trøndelag Fault Complex, central Norway: constraints from new apatite fission track data

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Abstract

The Møre Trøndelag Fault Complex (MTFC) of central Norway is a long-lived structural zone whose tectonic history included dextral strike slip, sinistral strike slip, and vertical offset. Determination of an offset history for the MTFC is complicated by the lack of well preserved stratigraphic markers. However, low temperature apatite fission track (AFT) thermochronology offers important new clues by allowing the determination of exhumation histories for individual fault blocks presently exposed within the MTFC area. Previously published AFT data from crystalline basement in and near the MTFC suggest the region has a complicated pattern of exhumation. We present new AFT data from a NW–SE transect perpendicular to the principal structural grain of the MTFC. FT analyses of 15 apatite samples yielded apparent ages between 90 and 300 Ma, with mean FT length ranging from 11.8 to 13.5 μm. Thermal models based upon the age and track length data show the MTFC is comprised by multiple structural blocks with individual exhumation histories that are discrete at the 2σ confidence level. Thermal modeling of the AFT data indicates exhumation progressed from west to east, and that the final juxtaposition and exhumation of the innermost blocks took place during Cretaceous or Tertiary (possibly Neogene) time. We suggest that least some of the fracture lineaments of central Norway were re-activated during Mesozoic extension and the opening of the Norwegian sea, and may have remained active into the Cenozoic.

1. Introduction

The prominently expressed fracture lineaments of western Norway, first reported by Kjerulf (1879) and Hobbs (1911), have been shown to be widespread elements of Norwegian bedrock geology (e.g. Gabrielsen and Ramberg, 1979). In the Møre-Trøndelag region, a large-scale tectonic zone was defined by satellite image analysis of these same fracture patterns (Gabrielsen and Ramberg, 1979). Known today as the Møre Trøndelag Fault Complex (MTFC), the zone is widely agreed to have played an important role in the development of the Norwegian margin (e.g. Gabrielsen et al., 1999; Braathen, 1999).

The MTFC is the northernmost of several important regional structures identified in southern Norway. A simplified geological map of southern Norway (Fig. 1) shows autochthonous and parautochthonous Baltic shield basement covered by Lower Paleozoic platform deposits and three Caledonian allochthons (e.g. Bryhni and Sturt, 1985): Baltic cover (Upper Allochthon), Baltic basement and cover (Middle Allochthon), and rocks of ophiolitic and island arc affinity (Lower Allochthon). Two major structural zones, the MTFC and the Hardangerfjord Shear Zone (HSZ), run southwest across the map and continue offshore. The Nordfjord Sogn Detachment Zone (NSD) wraps on- and offshore in a convoluted manner between the MTFC and the HSZ (Norton, 1986). These geo-historic zones of weakness constitute obvious candidates for structural reactivation. In this paper we explore the Mesozoic and

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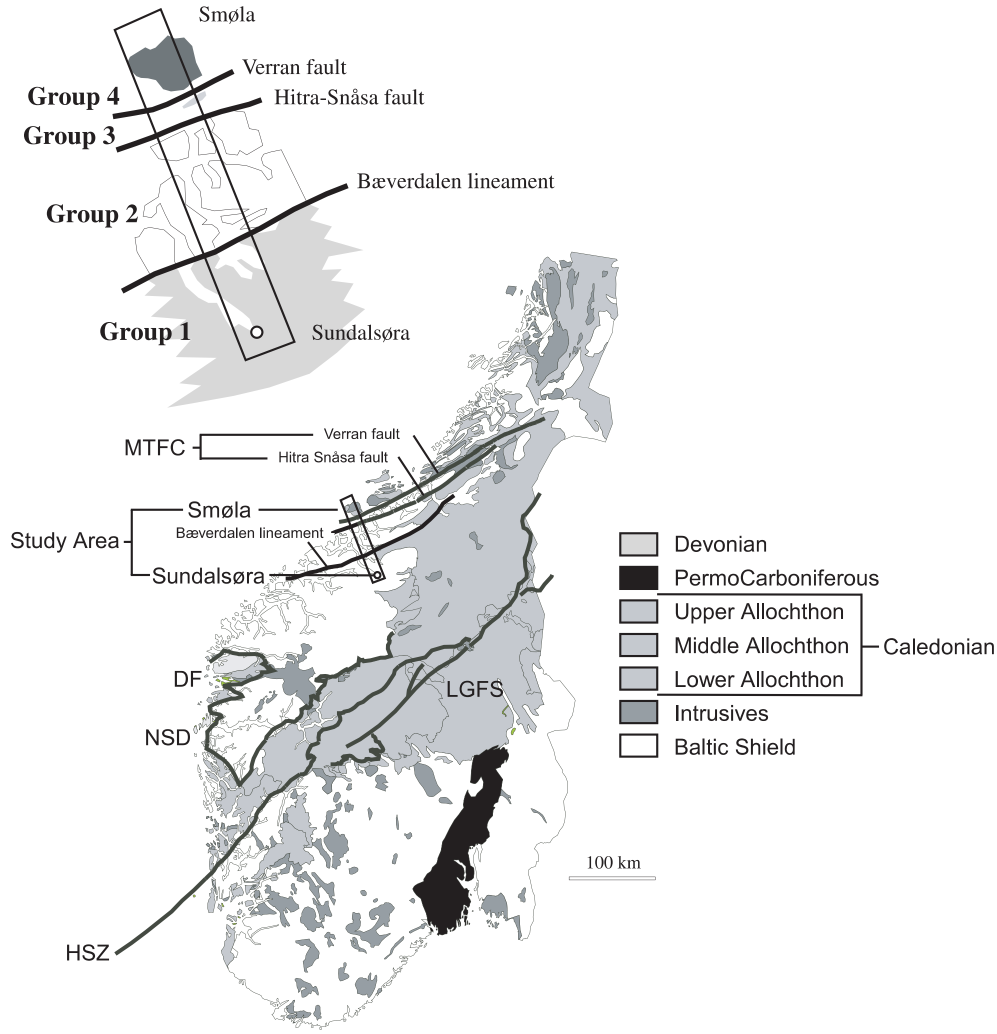

Fig. 1. Location map of Norway after Andersen et al. (1999) and Seranne (1992) showing the generalized geology of southern Norway. Principal structures with a possible Mesozoic/Cenozoic history of movement include the Møre Trøndelag Fault Complex (MTFC), Nordfjord Sogn Detachment (NSD), Dalsfjord Fault (DF), Lærdal-Gjende Fault System (LGFS) and the Hardangerfjord Shear Zone (HSZ). The study area is shown in boxed outline.

Cenozoic record of the MTFC using new apatite fission track (AFT) data collected from a sea level transect oriented perpendicular to its structural grain.

2. Post-caledonian faulting

Although the dearth of onshore post-Paleozoic sedimentary rocks led previous workers to propose significant Tertiary exhumation of Scandinavia (e.g. Holtedahl, 1953; Torske, 1972), limitations imposed by the tools of the day precluded recognition of corresponding post-Permian onshore faulting. Although few examples of preserved post-Palaeozoic deposits are known from the Norwegian mainland, it was clearly evident to early geologists that Mesozoic rocks were once deposited along the brim of the western Baltoscandic shield (e.g. Vogt, 1905). For example, late Jurassic—early Cretaceous sediments are preserved in a N–S trending downthrown fault block on Andøya in the north Norway county of Nordland (Vogt, 1905; Dalland, 1975, 1979, 1981; Bjorøy and Vigran, 1979). There, Devonian-early Carboniferous weathering and subsequent late Palaeozoic burial was followed by late Triassic uplift and multiple events of mid Jurassic-Hauterivian-Barremian-Aptian age extension and faulting (Dalland, 1979). In the strait of Vikastraumen southwest of Bergen, southern Norway, coal-bearing sandstones and conglomerates of early late Jurassic (middle Oxfordian) age have recently been discovered (Fossen et al., 1997). These rocks were trapped along a fault plane, and reflection seismic profiling suggests that a sequence of similar rocks up to 60 m thick exists below the seafloor. Additionally, other sedimentary rocks of possible Jurassic age have been encountered further south along the west coast of Norway (Karmsundet Basin, southeast of

Karmøy; Bøe et al., 1992) and sedimentary rocks of Mesozoic age are believed to exist beneath a Quaternary cover at Lista at the southernmost tip of Norway (Lista basin; Holtedahl, 1988). The presence of these sedimentary basins at a relatively high structural level suggests significant rock column uplift has occurred since the time of their deposition.

Onshore, modern geophysical, petrologic and geochronological studies have uncovered convincing evidence of Mesozoic faulting. Locally, extension began shortly after the peak of Caledonian compression (e.g. Andersen and Jamtveit, 1990; Fossen, 1992) and became continental in scale during the Mesozoic. Episodes of late Paleozoic, Mesozoic and possibly early Cenozoic reactivation have been suggested for the Verran fault of the MTFC (Torsvik et al., 1989; Grønlie and Roberts, 1989; Grønlie et al., 1994), the Dalsfjord Fault (Torsvik et al., 1992), and the Lærdal-Gjende Fault System (LGFS; Milnes and Koestler, 1985; Andersen et al., 1999). Offshore, geophysical and borehole studies have shown graben development and faulting continued until the late Cretaceous or early Tertiary (e.g. Doré et al., 1999).

The MTFC is principally comprised by the Hitra-Snåsa and Verran faults. It is a potentially long-lived tectonic system, possibly with Precambrian roots (Aanstad et al., 1981, Grønlie and Roberts, 1989; Seranne, 1992). Its importance during Caledonian times seems indisputable, and Torsvik et al. (1989) inferred it to be part of a possible Caledonian suture. First defined onshore (Gabrielsen and Ramberg, 1979), the MTFC is today recognized to extend far offshore.

Previous workers have proposed an extensive, and sometimes contradictory, Paleozoic and early Mesozoic history for the MTFC (e.g. Roberts, 1983; Buckovics et al., 1984; Bøe and Bjerklie, 1989; Grønlie and Roberts, 1989; Torsvik et al., 1989; Seranne, 1992; Gabrielsen et al., 1999). Several studies have specifically addressed the timing of faulting along structures comprising the MTFC. Grønlie and Roberts (1989) interpreted dextral strike slip duplexes between the Verran and Hitra Snåsa faults to be of Mesozoic age. Supporting their conclusion, fault related Mesozoic paleomagnetic overprints have been resolved in several locations along the MTFC (Torsvik et al., 1989; Grønlie and Torsvik, 1989). Grønlie et al. (1994) reported a late Jurassic cooling event along the Verran fault of the MTFC, recorded by apatite, zircon, and sphene fission track data.

The HSZ forms a tectonic zone subparallel to both the MTFC and the trend of the faults bounding the Permo-Carboniferous volcanics of the Oslo Rift (Fig. 1). Seismic reflection data show that the HSZ is a major structural discontinuity projecting offshore as far as the Horda Platform (e.g. Hurich and Kristoffersen, 1988). A stratigraphically controlled seismic section interpreted by Ditcha (1998) shows widespread Permo-Triassic, Jurassic, and some Cretaceous to Tertiary displacement across faults splaying from the offshore continuation of the HSZ (see also Hurich and Kristoffersen, 1988). Onshore, the HSZ was responsible for excision of tectonostratigraphy and exhumation of Fennoscandian basement, and may form a continuous structure with the LGFS (Andersen et al., 1999). Paleomagnetic data show some of the brittle, down to the west normal faults of the LGFS may have been active circa mid-late Permian and late Jurassic (Andersen et al., 1999).

The Nordfjord Sogn Detachment (NSD; Fig. 1) forms the boundary between Precambrian crystalline basement and tectonostratigraphically overlying Caledonian and Devonian units. Using paleomagnetism, Torsvik et al. (1992) concluded the low-angle Dalsfjord Fault (part of the Nordfjord Sogn detachment; Fig. 1) underwent Permian and Upper Jurassic or Lower Cretaceous reactivation. Using the ^{40}Ar/^{39}Ar technique Eide et al. (1999) resolved Permo-Triassic and Late Jurassic Early Cretaceous resetting ages for the same rocks, supporting the conclusions of paleomagnetic fault-dating studies in southern and central Norway.

These data indicate strongly that significant onshore faulting occurred during the Mesozoic (and possibly the Cenozoic) throughout southern Norway. Recent apatite fission track data support this conclusion: Rohrman et al. (1995) presented sea level AFT ages of $\approx$110 Ma near the innermost heads of several fjords in southwestern western Norway. Using thermal modeling based on the kinematics of apatite annealing, Rohrman et al. (1995) suggested an exhumation event of significant magnitude occurred in western Norway between 40 and 20 Ma. The unequivocal record of Mesozoic extension in the North- and Norwegian Seas and the growing evidence of Mesozoic faulting onshore suggest to us that at least some of the fracture lineaments formed or were reactivated as Mesozoic/Cenozoic tectonic structures.

3. Thermochronometry

In the absence of stratigraphic markers, low temperature geochronology such as AFT or uranium thorium helium (UTH) can provide critical structural information. Although the technique has limitations, AFT data nonetheless comprise a powerful tool with which to identify different structural blocks and compare their histories of cooling and exhumation. Gallagher et al. (1998) provided a thorough review of the fission track method and its application to geological problems. Referring the reader to their article for details, we note two considerations that are important to our use of AFT data.

(1) Because the rate of annealing of fission tracks in apatite is a function of both time and temperature, an AFT age does *not* represent the passage of the sample below a single critical isotherm. For example, when extrapolated

to geological time scales the laboratory experiments of Laslett et al. (1987) suggested annealing occurs between 60 and 110 °C with a 10 °C uncertainty. Therefore, relating a fission track age to a closure temperature is only plausible when it can be demonstrated that no significant annealing has occurred post-closure time (Gallagher et al., 1998). Most of the ages quoted in our study show length histograms and modeled ages indicating that cooling from 110 °C to below 60 °C was slow rather than rapid. Thus, we do not consider a fixed closure temperature to be valid for our AFT ages, and rely upon forward thermal modeling to relate time and temperature.

(2) Many workers have demonstrated the sensitivity of AFT ages to changes in elevation, particularly where rapid exhumation enabled the preservation of a fossil Partial Annealing Zone (PAZ; e.g. Fitzgerald and Gleadow, 1988). Rapidly cooled samples of statistically different ages from common elevations could be expected to unambiguously resolve structural offset. Slow cooling within a PAZ, exposure to a lateral thermal gradient, differential sedimentary cover, or various combinations, could cause widely separated rocks of similar elevation within a homogeneous structural block to record very different AFT ages. However, rocks with different thermal histories that have been structurally juxtaposed will record different AFT ages if sampled at the same level.

By stacking four vertical profiles and shifting their base elevations by as much as 2000 m Rohrman et al. (1995) interpreted the Hunnedalen sample suite of Andriessen (1990) to be an exhumed Jurassic PAZ. There, within a zone of ~300 vertical meters, the AFT ages span ~160 Ma to ~240 Ma. If their interpretation is correct, AFT ages of common elevations from a Jurassic PAZ in western Norway might be expected to range widely, perhaps by as much as ~80 Ma. A similar experiment stacking sections of vertical AFT profiles and correcting the vertical position from different structural blocks within a tectonic unit was performed in the Snowy Mountains in Australia (Kohn et al., 1999). Their results demonstrated the existence of an exhumed PAZ and enabled the identification of present day vertical displacements within a structural unit. We have emulated these studies, but by sampling exclusively at sea level we have endeavored to eliminate the elevation function as a variable when interpreting our AFT data. Because the present fjord topography post-dates our youngest AFT ages by millions of years, we disregard perturbed geothermal gradients due to deeply incised topography as a contributor to differential AFT ages.

4. Data

We collected 16 samples along a transect located between Sundalsøra and Smøla, perpendicular to the principle structural grain of the MTFC. The transect cross-cuts two known structures and one topographically expressed lineament: the Verran and Hitra Snåsa faults of the MTFC, and the Bæverdalen lineament (Fig. 1). The Bæverdaen lineament runs south from Orkanger and Trondheimsfjord and, unlike the Verran and Hitra Snåsa strands, has been the subject of very little work.

All samples were taken within 100 m of sea level and away from fault zones that might have thermally affected fission track length and age data. Possible structures were identified by LandSAT imagery, and sample locations were controlled with 1:50,000 scale topographic maps, and GPS/GIS technology. Laboratory work was completed at the Vrije University in Amsterdam, The Netherlands (see Table 1 caption for analytical details).

Fig. 2 shows the relationship between distance from coast and the measured apatite fission track ages and track lengths. The AFT data clearly show the Verran, Hitra Snåsa, and Bæverdalen lineament to bound four crustal blocks of statistically discrete age and track length populations. Clearly, the exhumation to present-day surface temperatures of each structural block must have occurred some time after the recorded AFT age.

In the following discussion we refer to the four populations as Group 1 through Group 4 (Fig. 2).

5. Models

With the uncertainty in apatite fission track "closure" temperature described above, inverse modeling of apatite fission track age and length data has become important technique to help interpret their PAZ cooling histories (e.g. Laslett et al., 1987; Ketcham et al., 1999). However, as with the better-known example of potential field data, computer generated thermal cooling paths provide only non-unique solutions. In this study, emphasis is placed on using inverse models to compare general cooling trends within the AFT age/length-defined geographic regions rather than to calculate and interpret detailed cooling paths of individual samples.

Track lengths and AFT ages were modeled using MonteTrax and AFTAsolve software. We ran models using both Laslett Durango and Ketcham Multikinetc annealing equations (Laslett et al., 1987; Ketcham et al., 1999). The results from both annealing models were similar, and for discussion we show only those from MonteTrax. All models excepting sample S10 and S11 were "open", with minimal constraints placed upon the possible cooling paths sought by the computer program. Models for all samples other than S10 and S11 show good to excellent correlation with the observed age/length data. Samples S1 and S2, from the easternmost end of the transect, show Neogene cooling. Because in both samples the initiation of the cooling event is

Table 1
Table showing analytical data for AFT samples presented in this study. The samples were prepared for external detector AFT analysis using standard procedures well described in many publications (e.g. Gallagher et al., 1998). Etch times were between 20 and 30 seconds. The apatite fission track ages were determined by Redfield using a zeta of 367.93 +/- 17.60 determined from Fish Canyon, Durango, and Mt. Dromedary age standards using standard glass CN5. Length measurements were made using a digitizing pad and the microscope drawing tube as described in many publications. All errors are reported at the 2 sigma confidence level. Non-quantitative assessment of etch-pit widths suggests most samples were composed of chemically similar apatite

Name	Elev (m)	UTM E	UTM N	Grains	Ns	Ni	Pooled Age (Ma)	2 sigma Error (Ma)	Chi2	P(X)	Length (μl)	2 sigma Error (μl)	Length Std. dev.	No. of Tracks
S1	10	477610	6952090	20	202	355	93.14	18.75	12.15	87.9	11.85	0.52	2.18	71
S2	10	474040	6971910	20	1278	1866	111.94	13.58	28.63	7.2	12.69	0.36	1.82	102
S4	5	477619	6988271	20	449	460	158.95	26.14	15.02	72.1	13.11	0.30	1.50	101
S5	10	466740	6994980	20	1188	1172	164.99	21.01	30.05	5.1	13.47	0.26	1.38	101
S6	20	470950	7001220	20	1155	1286	146.40	18.53	28.09	8.2	13.07	0.36	1.86	101
S7	5	471640	7004270	20	1922	1895	165.09	19.28	27.91	8.5	12.89	0.28	1.42	103
S8	5	470200	7014120	20	1010	1007	163.27	21.52	29.46	5.9	12.88	0.34	1.17	100
S9	5	463950	7013130	20	305	303	163.86	30.98	14.05	78.1	13.21	0.30	1.49	99
S10	5	456280	7018330	20	1317	796	267.17	35.35	21.58	30.6	12.79	0.30	1.56	101
S11	10	455000	7019500	21	2648	1423	299.72	35.16	21.96	34.3	12.84	0.36	152.00	74
S12	5	454180	7022730	21	1424	1061	217.56	27.54	17.01	65.2	13.00	0.28	1.43	103
S13	20	457610	7032350	18	1777	1396	206.52	24.92	27.4	5.3	13.44	0.36	1.10	35
S14	5	451480	7037050	20	2148	1673	208.28	24.37	17.76	53.9	13.40	0.26	1.37	100
S15	5	448710	7042540	13	2382	1678	229.89	26.71	15.21	23.0	12.74	0.20	1.43	200
S16	5	453680	7020360	20	656	378	279.95	45.25	21.35	31.8	12.80	0.30	1.57	100
Glass CN5			Zeta	367.9										
rho d 896194			Zeta Std. dev. 17.6											
Nd 13891														

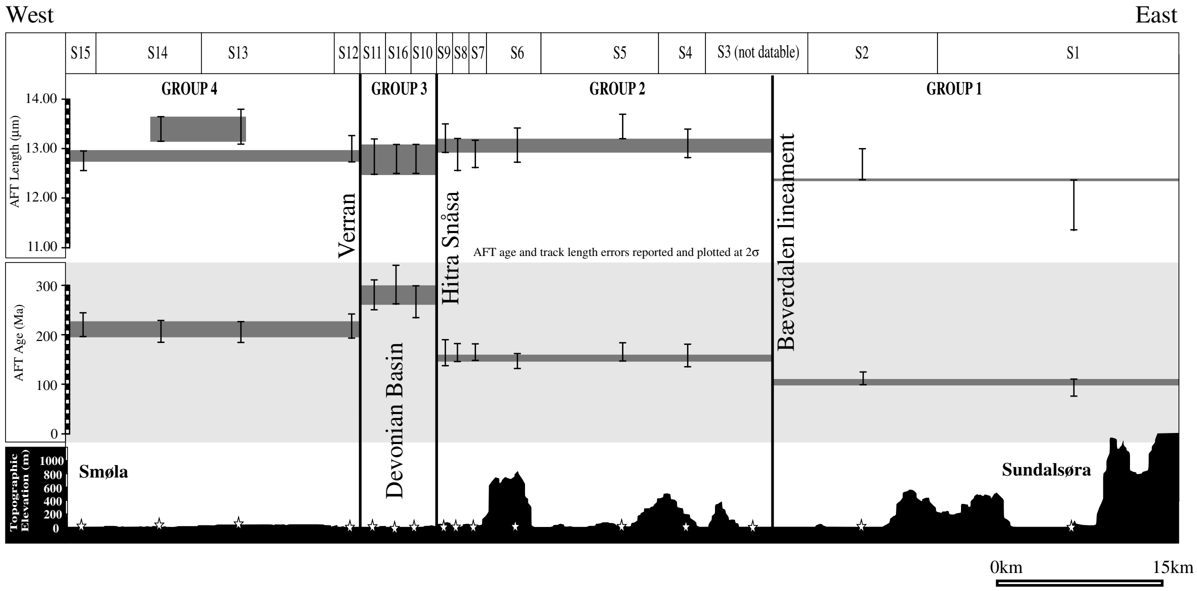

Fig. 2. Apatite fission track age and track length data plotted over a topographic cross section along the profile between Sundalsøra and Smøla, Norway. Note that Sample S16 is not sequentially located. All error bars are shown at the 2σ confidence level. Statistically discrete age and track length populations lie between the three principal structures cross-cutting the transect. Each age represents a time period when the rocks were within Partial Annealing Zone (PAZ) temperatures (≈60–120 °C). Exhumation to present-day surface temperatures of each structural block must have occurred some time after the recorded AFT age. For example, Group 1 samples must have been exhumed after ≈100 Ma.

within PAZ temperatures, and because an experimental model using short initial track lengths of 15.75 also resolved the event, we consider it to be real rather than the well-known "Global Neogene Cooling" AFT model artifact.

The oldest AFT ages come from the island Edøy, between the Verran and Hitra Snåsa strands of the MTFC. Samples S10 and S11 were collected from a greenschist facies outcrop of Devonian system conglomerate within the MTFC. Their apatites are known to have had a complicated thermal history, having been crystallized, cooled, exhumed, eroded, buried, and re-exhumed. The third age from Edøy, S16, comes from a meta-volcanic rock, whose apatites were erupted, rapidly cooled, buried, and exhumed. While S16 models well, S10 and S16 are problematic. Both display a range of etch-pit widths that suggest a wide range in apatite chemical composition, possibly indicating a greater resistance to annealing than were they dominated by flourine rich apatites. However, the greenschist facies grade of S10 and S11 suggest that even the most annealing-resistant apatite grains should have had all fission tracks completely annealed during post-Devonian metamorphism. Consequently, models for S10 and S11 seem less robust: we limit our interpretation to the observation that the AFT apparent age of the Edøy rocks indicates they were exhumed from PAZ depths in the late Paleozoic or early Mesozoic.

Fig. 4 presents a comparison of the different Laslett-type models shown in Fig. 3. We assume partial annealing occurred between 110 and 60 °C. The time that each sample entered and exited PAZ conditions were calculated from the model output data and are shown by stars. The mean entry or exit time for each sample group are shown by heavy black lines. Although the degree of uncertainty is too high to resolve statistically discrete PAZ exit times, a trend of increasing PAZ-exit ages is observed from east to west. A statistically discrete change of PAZ-entry time can be resolved across the Hitra Snåsa strand of the MTFC. Fig. 4 suggests Group 1 samples were exhumed ~32 Ma, Group 2 samples ~72 Ma, Group 3 samples ~105 Ma, and Group 4 samples between ~116 and ~155 Ma.

6. Discussion

Although it is not possible to unequivocally assign an absolute closure temperature to the AFT data, it is clear the ages were "set" somewhere between ~60 and ~110 °C (e.g. Gallagher et al., 1998). Assuming a paleogeothermal gradient of 25 °C/km and a mean Paleo-Average Annual Surface Temperature (PAAST!) of 10 °C the AFT ages reflect cooling within a zone some 2–4 km deep. In turn, this suggests a minimum of 2 km overburden was removed from each block since the time of cooling. The ~100 million year cooling difference between the inner and outer blocks suggests they were subjected to very different exhumation pathways. Inverse models also strongly suggest sharp differences in thermal histories are present over very short horizontal distances.

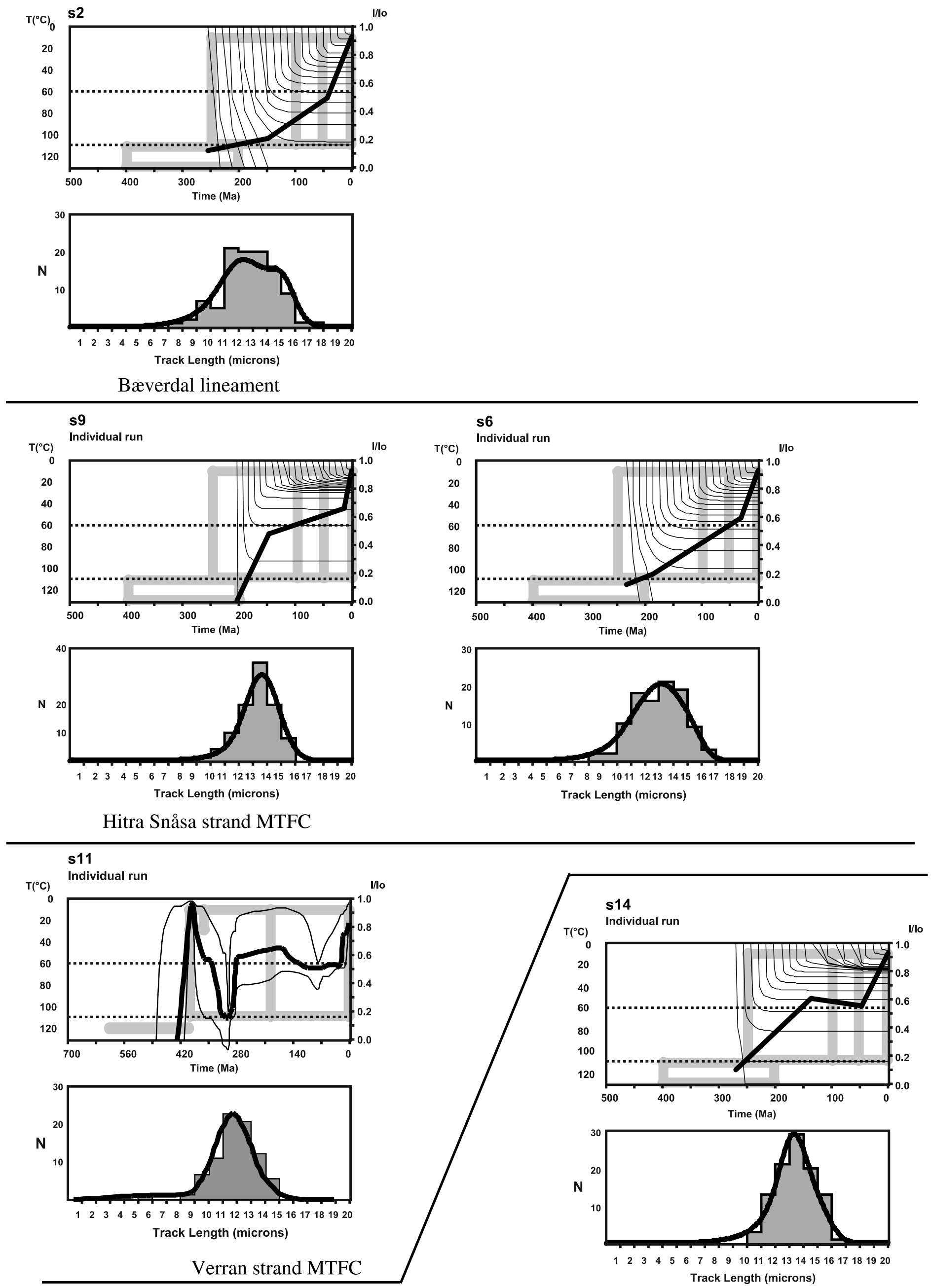

Fig. 3. Results from forward modelling using the Laslett et al. (1987) annealing model for five selected samples. Sample S11 (shown) was modeled using AftaSOLVE by Ketcham et al. (1999); all other samples were modeled with the MonteTrax software (Gallagher, 1995). Output has been divided into geographic groups. GROUP 1: Models for both S1 and S2 show ''upwardly concave'' time temperature paths, indicating an increase in rate of exhumation towards the end of cooling (S2 shown). Both samples entered the apatite PAZ ≈200 Ma and experienced accelerated cooling in the middle Tertiary ≈25–45 Ma. GROUP 2. All models for samples within this group suggest cooling to apatite PAZ temperatures occurred ≈200 Ma. In most cases, cooling below the apatite PAZ occurred by the middle Tertiary. In addition to their statistically significantly older AFT ages, most samples from Group 2 are distinguished from samples in Group 1 by ''downwardly concave'' cooling curves suggesting cooling slowed during exhumation of the PAZ (e.g. S9, shown). Sample S6 (shown) is anomalous. GROUP 3: The oldest AFT ages of the entire transect distinguish Group 3 from Groups 1, 2, and 4. Samples S10 (not shown) and S11 (shown) is from a small sliver of Devonian age conglomerate tectonically juxtaposed within the Møre Trøndelag Fault Complex. Sample S16 (not shown) is from a metavolcanic sliver also tectonically juxtaposed within the MTFC. In all cases, models suggest the samples entered the apatite PAZ in the middle Paleozoic. The model for S11 shows a relatively poor fit to the observed track length histogram, perhaps reflecting complex annealing behavior due to wider compositional variation. Total annealing (e.g. metamorphism to greenschist facies) might have occurred ≈300 Ma. GROUP 4: All samples from Group 4 are located on the outboard island of Smøla. Model cooling histories within Group 4 vary greatly. For example, models for samples S13 and S14 suggest cooling to apatite PAZ temperatures occurred ≈250–200 Ma, but that sample S13 was exhumed much more rapidly than S14. The modeled thermal history for for sample S12 suggests the apatite PAZ was approached in the late Paleozoic, and S15 might have experienced re-heating.

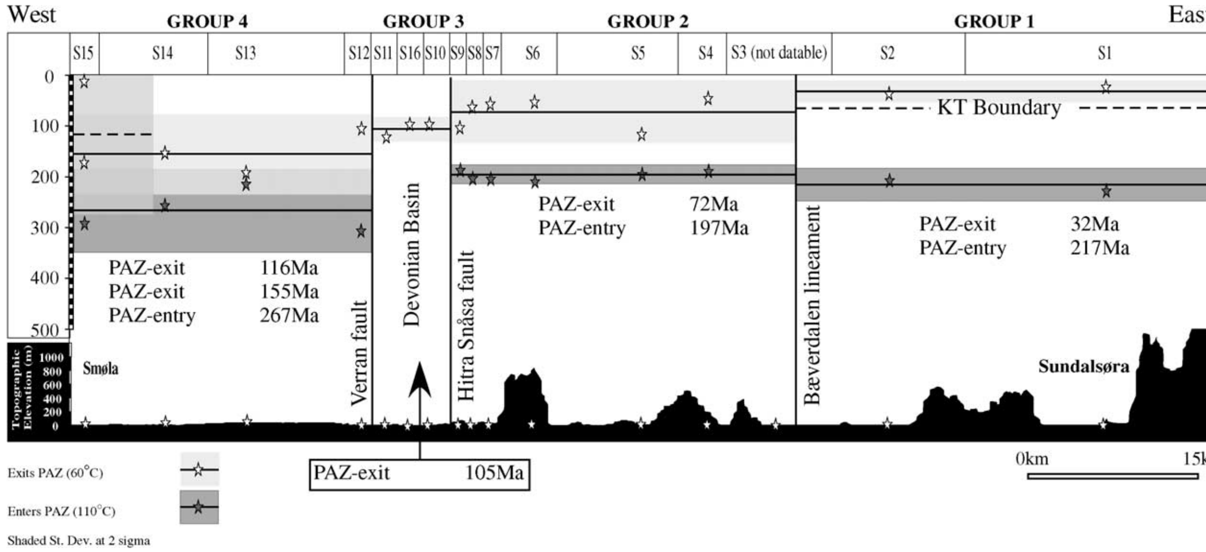

Fig. 4. Figure showing the relationships between groups of Laslett type thermal models presented in Fig. 3. Partial annealing is assumed to have occurred between 110 and 60 °C. PAZ-entry and PAZ-exit times were calculated from the Laslett-type thermal models of Fig. 3. The entry time of each sample into the PAZ is represented by a shaded star, and its time of exit from the PAZ is shown by a white star. The arithmetic mean of PAZ-entry and PAZ-exit for each group is shown by heavy black lines. (Group 4 is shown with the model-determined ≈15 Ma reheating of S15 included (dashed line) and excluded (solid line) from the calculation of the mean). The 2σ standard deviation of the population is given by shading.

Fig. 5 shows the four age groups in regional context with AFT data published by Grønlie et al. (1994) and Rohrman et al. (1995). Considerable variation in AFT ages over very short distances are noted. Such differences in thermal history might be due to burial by (and subsequent erosion of) sedimentary cover of variable thickness, as has been suggested for other parts of Scandinavia (e.g. Cederbom et al., 2000; Cederbom, 2001; Hendriks and Andriessen, 2000). Minor deposits of Jurassic age sedimentary rocks west of Kristiansund (Bøe and Bjerklie, 1989) hint at a Mesozoic MTFC characterized by small transtensional sedimentary basins, and provide a strong argument that since-removed sedimentary cover could be considered one cause of the observed AFT age distribution. However, the increasing evidence for onshore Mesozoic and possibly Cenozoic faulting described above requires structural juxtaposition in response to Tertiary extension be considered as well. The large juxtapositions in age and track-length distributions observed across very short distances along our Sundalsøra to Smøla transect cause us to favor an interpretation invoking a high degree of structural juxtaposition rather than burial.

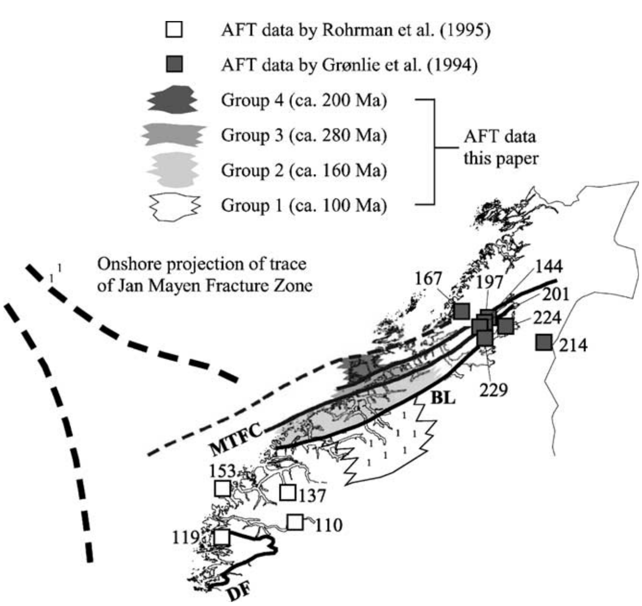

Fig. 5. AFT data from previous workers shown in comparison with the AFT age and length zones defined in this study and with respect to major onshore and offshore structures and structural zones. An on-strike projection of the oceanic Jan Meyen Fracture Zone intersects with western Norway just south of the study area.

Given the limitations of the fission track method, it is not possible to present meaningful calculations of absolute offset across the MTFC. However, the PAZ time-of-exit trend shown in Fig. 4 suggests that AFT exhumation of the MTFC rocks near Smøla was completed ~150 Ma whilst inboard, near Sundalsøra, AFT exhumation continued until ~25 to ~45 Ma. These data are supported by time temperature path modeling of AFT data from southern Norway by Rohrman et al. (1995), who suggested exhumation occurred in two phases: Mesozoic, and Neogene (~30 Ma). Their modeled time temperature paths provide regional support to the possibility that the structures bounding Group 1 and Group 2 ages (e.g. the Bæverdalen lineament) were active during Tertiary times.

7. Conclusions

New apatite fission track data from the Møre Trøndelag Fault Complex region have been presented along a transect from Sundalsøra to the island of Smøla. The data help resolve the Tertiary history of western Norway by supporting the following conclusions:

(1) The Møre Trøndelag Fault Complex in the Sundalsøra-Smøla region is comprised by (at least) four fault bounded geotectonic blocks which have significantly different cooling histories.
(2) Although the data do not preclude large components of strike slip offset across the MTFC as proposed by other workers, we interpret the AFT data also to require a large net component of down to the west relative motion between the inner and outer blocks. The AFT data strongly suggest that net dip slip components have been significant throughout extended periods over our transect across the MTFC.
(3) The apatite PAZ times of entry and exit of blocks bounded by the MTFC and other lineaments were significantly different, and vertical throw across the different branches of the MTFC occurred neither simultaneously nor equally. Although difficult to quantify, the timing of exhumation from the AFT window follows a clear trend, occurring first in the west (Smøla) and later to the east (Sundalsøra).
(4) Thermal age/length models from the $\approx$100 Ma AFT ages from sea level sites within the innermost block suggest the fault systems bounding the blocks were active during the Cretaceous and Tertiary. In turn, this raises the possibility that many faults and yet-to-be-discovered faults hiding in the fracture lineaments of the Møre-Trøndelag region were tectonically active during the Cenozoic, and that now-eroded sedimentary basins existed throughout the late (post-Devonian) Paleozoic and Mesozoic within the realm of the MTFC.

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