A new fragment of the early earth crust: the Aasivik terrane of West Greenland

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Abstract

The Aasivik terrane is a ~1500 km² complex of gneisses dominated by ~3600 Ma components, which has been discovered in the Archaean craton of West Greenland, ~20–50 km south of the Paleoproterozoic Nagssugtoqidian orogen. The Aasivik terrain comprises granulite facies tonalitic to granitic gneisses with bands of mafic granulite, which include disrupted mafic dykes. Four gneiss samples of the Aasivik terrain have given imprecise SHRIMP U–Pb zircon ages of 3550–3780 Ma with strong loss of radiogenic lead and new growth of zircon probably associated with a granulite facies metamorphic event(s) at ~2800–2700 Ma. To the Southeast, the Aasivik terrane is in tectonic contact with a late Archaean complex of granitic and metapelitic gneisses with apparently randomly distributed mafic and ultramafic units, here named the Ukaleq gneiss complex. Two granitic samples from the Ukaleq gneiss complex have U–Pb zircon ages of 2817 ± 9 and 2820 ± 10 Ma and t_{zircon \text{Nd}} values of 2.3–5.4. Given their composition and positive \epsilon_{Nd} values, they probably represent melts of only slightly older juvenile crust. A reconnaissance SHRIMP U–Pb study of a sample of metasedimentary rock from the Ukaleq gneiss complex found ~2750–2900 Ma zircons of probable detrital origin and that two or more generations of 2700–2500 Ma metamorphic zircons are present. This gneiss complex is provisionally interpreted as a late Archaean accretionary wedge. A sample of banded granulite facies gneiss from a complex of banded gneisses south of the Aasivik terrain here named the Tasersiaq gneiss complex has yielded two zircon populations of 3212 ± 11 and 3127 ± 12 Ma. Contacts between the three gneiss complexes are mylonites which are locally cut by late-post-kinematic granite veins with SHRIMP U–Pb zircon ages of ~2700 Ma. The isotopic character and the relationships between the lithologies from the different gneiss complexes suggest the assembly of unrelated rocks along shear zones between 2800 and 2700 Ma. The collage of Archaean gneiss complexes were intruded by A-type granites, here named the Umiatsiaasat granites, at ~2700 Ma, later than the tectonic intercalation of the gneiss complexes. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Aasivik terrane; SHRIMP U–Pb; Ukaleq gneiss complex; Umiatsiaasat granites

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1. Introduction

Rock complexes with ages in excess of 3600 Ma have been identified in all the continents (Black et al., 1971, 1986; McGregor, 1973; Moorbath et al., 1972, 1973; Baadsgaard, 1973; Bowring et al., 1989; Bridgwater and Schiøtte, 1991; Myers, 1988; Nutman et al., 1991; Kinny and Nutman, 1996; Krylov et al., 1989; Song et al., 1996; Compston and Krumener, 1988). However, the ancient components of the continents are in general found as small enclaves, which are commonly migmatised by younger felsic components. The largest continuous > 3600 Ma complex is the West Greenland Itsaq Gneiss Complex, which underlies ~ 3000 km². Friend et al. (1988) and Nutman et al. (1996) showed that the > 3500 Ma rocks were confined to the so-called Akulleq terrane, which is bounded to the Northwest by the Akia terrain and to the Southeast by the Tasiusarsuaq terrain (Friend et al., 1988; Nutman et al., 1996). The Akulleq terrain is dominated by tonalite–trondhjemite–granodiorite (TTG) gneisses metamorphosed at amphibolite facies during the early Archaean. The Early Archaean rocks of the Godthåbsfjord area thus represent allochthonous mid-crustal segments from an early Archaean continent. Further insight into the thickness structure and composition of this early Archaean continental mass can be gained by finding further segments of > 3600 Ma rocks within the West Greenland Archaean block.

The three terrains of the Godthåb region are separated by Archaean mylonites and have shared the same geologic history since ~ 2700 Ma, which can be regarded as the age of final accretion of that cratonic block. Currently, the northern limit of the Akia terrain is uncertain. Further northwards, Archaean rocks are penetratively deformed in the southern part of the Paleooproterozoic Nagssugtoqidian orogen (Hammer et al., 1997 and references therein) (Fig. 1).

The region bordering the inland ice ~ 50 km south of the Nagssugtoqidian front and ~ 100 km north of the northern most exposure of the Akulleq terrain can be divided into a number of domains, based on Landsat image texture, stream sediment geochemistry (Steenfelt, 1994), occurrence and deformation state of Paleooproterozoic mafic dykes (Escher et al., 1970) and occurrence of Mesozoic kimberlite and carbonatite intrusions (Larsen et al., 1983). A large domain shown as the Aasivik terrane in Fig. 2, shows contrasts in all
these characters relative to the surrounding domains, and it is separated from bordering domains by pronounced topographic lineaments. We suggest that this domain is a tectonic terrane dominated by early Archaean rocks.

Through most of this millennium the area has been favoured by Eskimo caribou hunters, and traces of their summer camps are frequently encountered. We have therefore chosen the name Aasivik (= summer camp) for the terrane.

2. Geology

We have identified five crustal components in the studied area (Figs. 2 and 3) (1) The Aasivik terrane, (2) the Ukaleq gneiss complex, (3) The Tasersiaq gneiss complex, (4) The Umiatsiasat granite plutons and (5) Mafic dykes tentatively correlated with the Kangamiut dykes in the adjoining areas, but here referred to as “metadolerite dykes”.

2.1. Aasivik terrain

The Aasivik terrain is dominated by garnet bearing two pyroxene granulite facies orthogneisses. The gneisses have a layered appearance defined by 1–50 m thick, planar felsic macro units with slightly varying colour index, intercalated with boudinaged mafic units ranging from a few centimetres to 50 m thick. At one locality, the gneisses are crosscut by fractures each rimmed by up to 2 m in wide haloes of amphibolite facies retrogression. In these zones, hornblende and biotite outline a mm–cm scale banding, which re-
veal very complicated fold patterns internally in the macro units. The retrogression was not accompanied by any deformation other than fracturing. We therefore assume that the large gneiss units were generally strongly deformed relative to their protolith, but that the granulite facies metamorphic recrystallisation obscured complex structures formed before or during metamorphism. This has implications for geochemical sampling, since even apparently homogeneous granulite facies gneiss samples may represent a mixture of several chemical and chronostratigraphic end members.

The structures outlined by the alternation of mafic and felsic macro units is much simpler, and define large open folds with km-scale amplitude. This may suggest that the mafic bodies represent dykes intruded into an already strongly deformed gneiss complex.

2.2. Ukaleq gneiss complex

The Ukaleq gneiss complex forms a package of granulite facies rocks dominated by garnet–biotite–feldspar–quartz ± sillimanite rocks spanning greywacke–pelite composition, interrupted by 0.5–1 m thick layers of garnet bearing leucogranite, and rare thin diorite sheets. The felsic rocks contain abundant pods of hornblende–augite–hypersthene–plagioclase–quartz metabasites and olivine–tremolite–diopside–spinel ultramafic rocks. Due to deformation and extensive anatexis of the felsic rocks, the complex has the appearance of a mélangé, and no sedimentary structures have been observed. Based on its composition, we interpret this gneiss complex as mainly supracrustal in origin, and dominated by metasediments.

2.3. Tasersiaq gneiss complex

The Tasersiaq gneisses are dominated by banded granulite facies orthogneisses and are separated from the Aasivik gneiss complex and the Ukaleq gneiss complex by E–W and NW–SE trending topographic lineaments. The gneisses have been retrogressed along the E–W lineaments that separate them from the Aasivik gneiss complex. Tasersiaq gneisses are found within 100 m from a Umiatsiaasat granite dome, but it has not been demonstrated that the granite intruded the Tasersiaq gneisses. The Tasersiaq gneisses are intruded by the metadolerite dykes.

2.4. Umiatsiaasat granites

The supracrustal rocks of the Ukaleq gneiss complex were intruded by granite plutons exposed in large topographic domes typically 3–5 km long and 1–2 km across. The axes of the domes trend 140°, which is also the strike of foliations and lithologic layering in banded basement gneisses found in the cusps between domes. In most cases, the granites are hosted by gneisses which can be identified as belonging to the Ukaleq gneiss complex, but in a number of outcrops the banded gneiss host cannot be assigned to any particular defined unit. One granite dome extends across the lineament that separates the Aasivik and Ukaleq gneisses, which suggests that the granites were emplaced later than the assembly of the gneiss complexes.

2.5. Lineaments and Archaean mylonites

Marked topographic lineaments dissect the entire region in a nearly orthogonal pattern (Fig. 2). These lineaments coincide with the boundaries between the Aasivik gneiss complex, the Ukaleq gneiss complex and the Tasersiaq gneiss complex. Where examined, these lineaments also coincide with zones of high strain, including mylonites. The mylonites have synkinematic growth of garnet suggesting that they were formed at granulite facies. The mylonites are generally annealed, and quartz and feldspar grains show no strain, but recrystallisation at lower metamorphic grade is uncommon in the studied examples. In a number of cases, the mylonites have experienced partial melting at various stages in the deformation process. One prominent set of mylonites with foliations of 140°/30°NE and a sinistral sense of displacement, and a less prominent set with foliation of 80°/70°SE and steeply plunging lineation have been observed. However, systematic structural studies of the high strain zones have not yet
been carried out. The high strain zones are hosts of a diffuse network of red granitic veins. In some places, these veins consist of mylonite or fine grained annealed mylonite. In other places, the veins are distinctly magmatic and consist of isotropic garnet bearing myrmekitic granite. Gneisses in the vicinity of the veins are affected by metasomatic infiltration, seen as a red colouration of the gneisses, which only partially overprint the compositional banding. We interpret the red granitic rocks as syn- to post-kinematic relative to the high strain zones. They could have been formed by flux melting within these zones as a response to fluid introduction during deformation, or be preferentially intruded into these zones from an external source.

2.6. Metadolerite dykes

The gneiss complexes were intruded by rare E–W trending metadolerite dykes. Such dykes have not been observed in the post-tectonic granites. However, the dykes show no signs of displacement along lineaments within the Aasivik gneiss complex. We interpret the dykes as emplaced later than the juxtaposition of the two complexes, but preferentially intruded into the gneissic rocks for structural and rheological reasons. The dolerite dykes show no signs of penetrative deformation, and the igneous mineral assemblage is widely preserved, although amphibolite facies metadoleritic domains are common. In places, the metamorphic hornblende–plagioclase assemblage is replaced by garnet and clinopyroxene along fractures. We interpret the two metamorphic assemblages as formed during one event of static metamorphism in which amphibolite facies metamorphism was followed by dehydration, possibly in response to decompression. Based on their field occurrence and petrography we correlate these mafic dykes with the E–W component of the Paleoproterozoic Kangamiut dyke swarm (Ramberg, 1949).

3. Geochemistry

At present, geochemical characterisation of the Aasivik gneisses is only at a reconnaissance stage. Major element compositions of apparently homogeneous lithologies from the Aasivik and Ukaaleq gneiss complexes and the Umiatsiaasat granites are given in Table 1. Sample 430476 is a trondhjemitic granite, while samples 430441, 430451 and 940000 are granites. These granites are slightly peraluminous and alkaline, and project along the

<table>
<thead>
<tr>
<th>Sample #</th>
<th>430441</th>
<th>430451</th>
<th>430476</th>
<th>430498</th>
<th>940000</th>
<th>940012</th>
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<tr>
<td>SiO₂</td>
<td>72.71</td>
<td>74.12</td>
<td>67.59</td>
<td>65.67</td>
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<td>0.3</td>
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<td>Al₂O₃</td>
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<td>18.37</td>
<td>14.55</td>
<td>13.87</td>
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<tr>
<td>Fe₂O₃</td>
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<td>0.35</td>
<td>0.79</td>
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<tr>
<td>FeO</td>
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<td>0.73</td>
<td>3.83</td>
<td>0.73</td>
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<tr>
<td>MnO</td>
<td>0.22</td>
<td>0.02</td>
<td>0.02</td>
<td>0.07</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>MgO</td>
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<td>0.33</td>
<td>0.56</td>
<td>1.25</td>
<td>0.47</td>
<td>0.29</td>
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<td>CaO</td>
<td>2.25</td>
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<td>3.27</td>
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<td>1.17</td>
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<td>Na₂O</td>
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<td>6.34</td>
<td>3.21</td>
<td>3.95</td>
<td>2.87</td>
</tr>
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<td>K₂O</td>
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<td>1.66</td>
<td>4.48</td>
<td>4.33</td>
<td>5.37</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>0.05</td>
<td>0.04</td>
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<td>0.23</td>
<td>0.06</td>
<td>0.07</td>
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<tr>
<td>Volat</td>
<td>0.27</td>
<td>0.29</td>
<td>0.2</td>
<td>0.44</td>
<td>0.44</td>
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</tr>
</tbody>
</table>

* 430441 = felsic gneiss cut by red veins, 430451 = charnockite, 430476 = trondhjemitic gneiss, 430498 = ~2730 Ma post-kinematic rapakivi granite, 940000 = red myrmekitic granite, 940012 = ~2700 Ma post-kinematic granite.
1–2 kbar water saturated cotectic in the haplogranite system. Petrographically they are sub-
solvus granites and the excess Al is expressed as
garnet in the mode. The granites are thus formed
at high pressure. Compositionally they resemble
the ≈ 2800 Ma Ikattoq gneisses of the Akulleq
terrain in Godthåbsfjord (McGregor et al., 1991).

4. Zircon geochronology

4.1. Analytical technique and data assessment

U–Th–Pb isotopic ratios and concentrations of
zircons were determined using SHRIMP I and
were calibrated to the Australian National Uni-
versity standard zircon SL13 (572 Ma; $^{206}\text{Pb}$/
$^{238}\text{U} = 0.0928$). Descriptions of analytical
procedure and data assessment were given by
Compston et al. (1984), Nutman (1994) and
dilution and SHRIMP analyses of zircons from
several well-preserved Proterozoic and Archaean
samples (Roddick and van Breemen, 1994; Ire-
land, 1995) demonstrate that SHRIMP $^{207}\text{Pb}$/
$^{206}\text{Pb}$ ratios are accurate.

As further cross-check on the accuracy of
$^{207}\text{Pb}/^{206}\text{Pb}$ ratios obtained with SHRIMP, zir-
cons from the Paleoproterozoic norite QGNG
were analyzed interspersed with some of the un-
knowns. From isotope dilution thermal ionisation
analysis, different QGNG zircon fractions have
$^{207}\text{Pb}/^{206}\text{Pb}$ ages of 1850 ± 2 Ma (C.M. Fanning,
personal communication, 1995), and ~1850 Ma
to as low as ~1810 Ma (T. Skjöld, personal
communication, 1996). QGNG analyses run with
samples presented here yielded a $^{207}\text{Pb}/^{206}\text{Pb}$
weighted mean age of 1863 ± 18 Ma.

SHRIMP zircon geochronology results on nine
samples are reported here. For some of them,
many zircon analyses were undertaken, whereas
for others fewer were done. The results are suffi-
cient to demonstrate that there is an important
early Archaean component to the crust in the
area, and has determined the age of late Archaean
rocks and some metamorphic zircon growth with
precisions of ~10 Ma (2σ).

4.2. Aasivik gneiss complex

4.2.1. 94-0338 and 94-0000

94-0338 and 94-0000 are migmatitic gneisses.
94-0338 and 94-0000 yielded similar mixed zircon
populations. Brown prismatic grains are domi-
nant, up to 200 µm long, commonly with pro-
nounced µm-scale euhedral zoning and locally
metamict. In a few cases, the centres of these
gains consist of clearer, non-zoned zircon. These
gains show deep embayments on prismatic faces
and rounding of pyramidal terminations. Less
commonly, there are overgrowths of clear zircon
on their terminations. Also present are a few
small, clear to brown oval to multifaceted grains.
The heavy mineral separates also contained mon-
azites, which were not analyzed.

In 94-0338, three analyses of an oval grain gave
close to concordant ages, with a $^{207}\text{Pb}/^{206}\text{Pb}$ mean
age of 2712 ± 12 Ma (Fig. 4a). The dominant
poorly preserved prismatic grains of 94-0338 have
moderate to high U content (up to 750 ppm) and
yielded mostly discordant ages with $^{207}\text{Pb}/^{206}\text{Pb}$
ages between ~3200 and 3600 Ma. Several grains
have $^{207}\text{Pb}/^{206}\text{Pb}$ ages of ~3600 Ma, one of
which is concordant, within error. These grains
are interpreted to be early Archaean in age, and
to have suffered variable loss of radiogenic Pb in
a zircon-growth event at ~2700 Ma, also more
recently. Three analyses with the oldest $^{207}\text{Pb}$/
$^{206}\text{Pb}$ ages yield a mean age of 3596 ± 9 Ma.
However, given the disturbed nature of the zir-
cons, this is interpreted by us as a minimum age,
but probably close to the true value.

In 94-0000, metamorphic overgrowths and a
brown oval grain yielded close to concordant ages
with $^{207}\text{Pb}/^{206}\text{Pb}$ ages between 2628 ± 70 and
2711 ± 44 Ma (2σ), with a mean value of
2688 ± 12 Ma, indistinguishable at the 95%
confidence level from the 2712 ± 12 Ma age de-
termined on a metamorphic grain in 94-0338.
Analyses of the dominant brown prismatic grains
yielded an array of older ages, of which two with
the oldest $^{207}\text{Pb}/^{206}\text{Pb}$ ages of > 3500 Ma are
close to concordant (Fig. 4b). This indicates an
important early Archaean component in this
sample.
4.2.2. 430441

430441 is a banded gneiss migmatised by a fine network of red coloured granitic veins just north of the E–W trending lineament separating the Aasivik and the Ukaleq gneiss terrains. It yielded mostly pale yellow to clear prismatic grains up to 300 µm long with aspects ratios of 2–5 and have well-developed µ-scale euhedral zoning. Pyramidal terminations are slightly rounded, and one has a metamorphic overgrowth, too small to be analyzed with the 40-µm spot used in the analytical session. The grains are interpreted as a magmatic population, slightly modified during metamorphism. Amongst the ~50 mounted hand-picked grains one was devoid of euhedral zoning, but with a possible rind of new zircon, a few microns thick. Analyses of two of the dominant well-zoned prismatic grains showed high U contents (>1000 ppm), close to concordant ages, with a $^{207}\text{Pb}/^{206}\text{Pb}$ mean age of 2817 ± 10 Ma, which is interpreted as the timing of magmatic crystallisation of the granite neosome (Fig. 4b). Two analyses of the non-zoned zircon gave a low U content (<100 ppm), close to concordant ages, with a $^{207}\text{Pb}/^{206}\text{Pb}$ mean age of 3784 ± 18 Ma. This probably indicates an early Archaean age of the banded gneiss protolith.

4.2.3. 430476 and 430475

The zircons in 430476 and 430475 are similar to the main population in 94-0338, but are slightly larger on average, and less strongly coloured. Six analyses of 430476 grains yielded a discordant array on a concordia diagram, like the 94-0338 zircons (Fig. 4c). In this case, no analyses yielded concordant ages and the oldest $^{207}\text{Pb}/^{206}\text{Pb}$ age was 3559 ± 48 (2σ). Five analyses of grains from 430475 yielded discordant points (Fig. 4d), with the least discordant result having the oldest $^{207}\text{Pb}/^{206}\text{Pb}$ age of 3602 ± 8 Ma (2σ). As for samples 94-0000 and 94-0338 the (moderate to high U) protolith zircons suffered Pb-loss in a late Archaean, generating the observed discordant array of data. These results are not sufficient to define accurate and precise ages, but they do indicate the zircons are probably a strongly disturbed 3600 Ma population.
4.3. Ukaleq gneiss complex

4.3.1. 94-0006

The supracrustal rock 94-0006 is a garnet–biotite–feldspar–quartz gneiss interpreted as a semipelitic metasediment. It gave a low yield of zircons. Dominant are equant to oval grains, < 100 μm across, strongly zoned and brown in colour. Some of these grains form twins. Also present are prismatic and rounded anhedral grains up to 150 μm long. These are brown to yellow and also generally strongly zoned. The terminations of these grains are rounded. The equant, oval and twinned grains have on average higher U contents and lower Th:U than the rounded prismatic grains. A reconnaissance study of sixteen grains was undertaken on this sample. All analyses yielded close to concordant ages (Fig. 6) with \(^{207}\text{Pb} / ^{206}\text{Pb}\) ages from 2530 ± 46–2905 ± 20 Ma (2σ). The oval, equant and twinned grains yielded \(^{207}\text{Pb} / ^{206}\text{Pb}\) ages of up to 2726 ± 24 Ma and if metamorphic in origin probably grew or were recrystallised in several high-grade events. The rounded prismatic grains yielded the oldest ages (1-1, 8-1, 10-1, 11-1 in Table 2). If they are detrital in origin, their ages indicate that the sediment must have been deposited in the late Archaean.

4.3.3. 430455

430455 is a thin diorite sheet which form an early component in the gneisses hosting the Umiatsiaasat granites. It yielded a population of clean colourless to pale yellow prismatic grains, up to 200 μm long, with some faint euhedral zoning. Neither inherited cores nor metamorphic overgrowths were observed. The grains show only slight rounding from metamorphic corrosion. Five grains were analyzed, which had low U content (59–154 ppm) and close to concordant ages (Fig. 5d). All analyses yielded a \(^{207}\text{Pb} / ^{206}\text{Pb}\)-weighted mean age of 2701 ± 16 Ma, interpreted as the magmatic age of the sample.

4.4. Tasersiaq gneiss complex

A granulite facies gneiss 430428 from the Tasersiaq gneiss complex yielded prismatic and more rarely equant colourless to very pale yellow zircons, up to 250 μm long and mostly with low aspect ratios of 1–3. They are non-zoned or show weak μm-scale euhedral zoning, more prominent towards, the exterior of the grains. Inclusions of apatite and opaques are common. Pyramidal terminations are slightly rounded, and some prismatic faces are slightly embayed. There are no obvious overgrowths of metamorphic zircon. Twelve grains were analyzed. They have low U contents (73–250 ppm), yielded concordant or close to concordant ages (Fig. 5a) with a range in \(^{207}\text{Pb} / ^{206}\text{Pb}\) ages from 3226 ± 36 Ma–2971 ± 41 (2σ). Four analyses (4-1, 8-1, 9-1 and 11-1) yielded a \(^{207}\text{Pb} / ^{206}\text{Pb}\)-weighted mean age of 3212 ± 11 Ma. Five analyses (1-1, 2-1, 6-1, 7-1, 12-1) yielded a distinctly younger age of 3127 ± 12 Ma, and the remaining three somewhat younger ages. There are no obvious morphological differences between grains of different age, but on average, the oldest ones have the lowest U
Table 2
SHRIMP U–Pb zircon analyses

<table>
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<tr>
<th>Spot</th>
<th>U (ppm)</th>
<th>Th/U</th>
<th>f206%</th>
<th>206Pb/238U ratio</th>
<th>207Pb/206Pb ratio</th>
<th>207Pb/206Pb (age)</th>
<th>% (disc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>94-0338</td>
<td>4-0338</td>
<td>0.01</td>
<td>0.11</td>
<td>0.3025 ± 42</td>
<td>3571 ± 20</td>
<td>0</td>
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<tr>
<td>1-2</td>
<td>707</td>
<td>0.18</td>
<td>0.04</td>
<td>0.633 ± 44</td>
<td>0.2723 ± 09</td>
<td>3319 ± 50</td>
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</tr>
<tr>
<td>3-1</td>
<td>394</td>
<td>0.19</td>
<td>0.03</td>
<td>0.652 ± 13</td>
<td>0.2926 ± 07</td>
<td>3433 ± 04</td>
<td>6</td>
</tr>
<tr>
<td>4-1</td>
<td>144</td>
<td>0.46</td>
<td>0.11</td>
<td>0.695 ± 17</td>
<td>0.3220 ± 14</td>
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<tr>
<td>4-2</td>
<td>548</td>
<td>0.16</td>
<td>0.04</td>
<td>0.620 ± 18</td>
<td>0.2822 ± 13</td>
<td>3375 ± 07</td>
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<tr>
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<td>667</td>
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<td>0.03</td>
<td>0.556 ± 08</td>
<td>0.2439 ± 05</td>
<td>3145 ± 03</td>
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<td>6-1</td>
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<td>0.01</td>
<td>0.474 ± 21</td>
<td>0.1854 ± 29</td>
<td>2702 ± 25</td>
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<td>0.01</td>
<td>0.636 ± 11</td>
<td>0.3000 ± 08</td>
<td>3470 ± 04</td>
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<tr>
<td>8-1</td>
<td>638</td>
<td>0.14</td>
<td>0.06</td>
<td>0.608 ± 09</td>
<td>0.2636 ± 13</td>
<td>3269 ± 08</td>
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<tr>
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<td>164</td>
<td>0.81</td>
<td>0.07</td>
<td>0.603 ± 21</td>
<td>0.3158 ± 22</td>
<td>3550 ± 11</td>
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<tr>
<td>10-1</td>
<td>568</td>
<td>0.17</td>
<td>&lt;0.01</td>
<td>0.559 ± 10</td>
<td>0.2430 ± 16</td>
<td>3140 ± 11</td>
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<tr>
<td>11-1</td>
<td>366</td>
<td>0.31</td>
<td>0.09</td>
<td>0.621 ± 18</td>
<td>0.3073 ± 68</td>
<td>3507 ± 34</td>
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<tr>
<td>12-1</td>
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<td>0.23</td>
<td>0.01</td>
<td>0.668 ± 15</td>
<td>0.3049 ± 27</td>
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<td>0.06</td>
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<td>0.3122 ± 39</td>
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<td>0.626 ± 11</td>
<td>0.2747 ± 21</td>
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<td>15-1</td>
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<td>0.666 ± 15</td>
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<td>16-1</td>
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<td>0.62</td>
<td>0.03</td>
<td>0.629 ± 13</td>
<td>0.2831 ± 14</td>
<td>3380 ± 08</td>
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</tbody>
</table>

| 94-0000 | 4-0000 | 0.01 | 0.11 | 0.3025 ± 42 | 3571 ± 20 | 0 |
| 1-2 | 218 | 1.33 | 0.39 | 0.52 ± 13 | 0.2027 ± 36 | 2848 ± 29 | 0 |
| 3-1 | 227 | 1.89 | 0.20 | 0.695 ± 12 | 0.164 ± 18 | 3552 ± 16 | 5 |
| 4-1 | 680 | 0.68 | 1.00 | 0.628 ± 12 | 0.2785 ± 09 | 3354 ± 05 | 6 |
| 5-1 | 522 | 0.61 | 0.27 | 0.598 ± 10 | 0.2745 ± 10 | 3332 ± 06 | 8 |
| 6-1 | 253 | 0.22 | 0.01 | 0.514 ± 11 | 0.1773 ± 38 | 2628 ± 35 | 2 |
| 7-1 | 128 | 0.55 | <0.01 | 0.516 ± 11 | 0.1838 ± 08 | 2687 ± 07 | 0 |
| 8-1 | 161 | 0.41 | 0.05 | 0.505 ± 11 | 0.1831 ± 14 | 2681 ± 13 | 2 |
| 9-1 | 315 | 0.28 | 0.01 | 0.515 ± 13 | 0.1791 ± 17 | 2644 ± 16 | 1 |
| 10-1 | 388 | 0.41 | <0.01 | 0.504 ± 24 | 0.1864 ± 25 | 2711 ± 22 | 3 |
| 11-1 | 822 | 0.338 | 0.05 | 0.548 ± 11 | 0.2400 ± 07 | 3120 ± 05 | 10 |

| 430475 | 4-0475 | 0.01 | 0.11 | 0.3025 ± 42 | 3571 ± 20 | 0 |
| 1-1 | 581 | 0.26 | 0.17 | 0.531 ± 14 | 0.2916 ± 24 | 3426 ± 13 | 20 |
| 2-1 | 289 | 0.25 | 0.06 | 0.616 ± 18 | 0.3055 ± 07 | 3498 ± 04 | 12 |
| 3-1 | 210 | 0.61 | 0.12 | 0.717 ± 18 | 0.3207 ± 08 | 3602 ± 04 | 3 |
| 4-1 | 183 | 0.59 | 0.06 | 0.648 ± 17 | 0.3011 ± 24 | 3476 ± 12 | 7 |
| 5-1 | 200 | 0.31 | 0.11 | 0.633 ± 15 | 0.2746 ± 12 | 3333 ± 07 | 5 |

| 430476 | 4-0476 | 0.01 | 0.11 | 0.3025 ± 42 | 3571 ± 20 | 0 |
| 1-1 | 48 | 0.06 | 0.79 | 0.594 ± 57 | 0.2712 ± 13 | 3313 ± 79 | 9 |
| 3-1 | 88 | 0.29 | 0.15 | 0.655 ± 21 | 0.3177 ± 49 | 3559 ± 24 | 9 |
| 4-1 | 644 | 0.17 | 0.01 | 0.678 ± 16 | 0.3086 ± 09 | 3514 ± 05 | 5 |
| 5-1 | 189 | 0.42 | 0.12 | 0.699 ± 18 | 0.3170 ± 20 | 3555 ± 10 | 4 |
| 6-1 | 60 | 0.07 | 0.26 | 0.667 ± 24 | 0.2604 ± 66 | 3249 ± 40 | 1 |
| 7-1 | 204 | 0.11 | 0.18 | 0.550 ± 14 | 0.2251 ± 13 | 3018 ± 09 | 6 |

| 430428 | 4-0428 | 0.01 | 0.11 | 0.3025 ± 42 | 3571 ± 20 | 0 |
| 1-1 | 73 | 0.76 | 0.24 | 0.619 ± 36 | 0.2418 ± 54 | 3132 ± 36 | 1 |
| 2-1 | 147 | 0.63 | 0.18 | 0.606 ± 15 | 0.2417 ± 15 | 3131 ± 10 | 2 |
| 3-1 | 109 | 0.54 | 0.38 | 0.573 ± 17 | 0.2187 ± 29 | 2971 ± 21 | 2 |
content. The rock is interpreted as having two age components of $3212 \pm 11$ Ma and $3127 \pm 12$ Ma, followed by subsequent disturbance. From the zircon data alone, it is uncertain whether the ages represent different phases in a composite sample or whether the protolith is $3127 \pm 12$ Ma, but carries $3212 \pm 11$ Ma inherited material.
5. Discussion

U–Pb age determination has been carried out on zircons extracted from a number of units. Samples 430428, 430475 and 430476 are regional banded gneisses, 94-0006 is a paragneiss, 94-0338 and 430441 are red-coloured metasomatized gneisses, 430451 is an isotropic charnockite, probably a diatexite, 94-0000 is a red myrmekitic granite and 430455 is an undeformed diorite dyke intruded into the supracrustal package. As can be seen from Table 2 and Figs. 3–6, the regional gneisses give disturbed ages in the range ~3600–3780 Ma for the samples within the Aasivik terrain as outlined in Fig. 1. Sample 430428 south of the bounding lineament contains ~3100 and ~3200 Ma components. These ages have not been represented in the zircon populations in other samples from the region. The ages found in this sample are within the range of ages of gneisses from the Akia terrane to the south (Friend et al., 1988; Nutman et al., 1996) and it is tentatively suggested that the Tasersiaq gneiss complex forms a part of the Akia terrane.

The supracrustal sample from the Ukaleq gneiss complex contains 2750–2900 Ma zircons of probable detrital origin, which gives the maximum age of deposition. This along with a positive $\varepsilon_{\text{Nd}}$ of the anatectic granites ($t_{\text{zircon}, \varepsilon_{\text{Nd}}} = 2.3–5.4$; Løfqvist, unpublished data) formed within the metasediments suggests that the sources of the sediments were dominated by juvenile or only slightly older material at 2800–2700 Ma. The chaotic intercalation of metapelitic rocks, mafic granulites and peridotites together with the occurrence wedged between a late Archaean and an early Archaean gneiss complex suggests that the Ukaleq gneiss complex form part of a late Archaean accretionary wedge.

The red granites and the charnockitic diatexite found in the lineaments separating the different gneiss complexes are all dominated by 2700–2800 Ma zircons. We suggest that this age range is bracketing the time of deformation in the zones, and thus the time of tectonic juxtaposition of the gneiss complexes.

Fig. 5. U–Pb concordia diagrams for SHRIMP analysis of zircons from a) Felsic gneiss from the Tasersiaq terrain. b) 430428 Red coloured banded gneiss bordering the Aasivik terrain. c) 430451 Diatexite near contact of Umiatsiaasat granite dome. d) 430455 Diorite sheet in gneisses along contact of Umiatsiaasat granite dome.
The nature of the contact between this gneiss complex and the Aasivik terrane has not been investigated in this study, but a pronounced topographic lineament coincides with contrasts in stream sediment geochemistry (Steenfelt, 1994), topographic grain, occurrence of kimberlite intrusions (Larsen et al., 1983). This lineament separates a region where no early Archaean zircons have been identified in the gneisses (Kalsbeek and Nutman, 1996) to the north from the early Archaean gneisses to the south, and is here taken as the terrane boundary.

We suggest that the gneiss complexes were assembled at \( \approx 2700 \) Ma and formed a stable craton during Nagssugtoqidian orogeny which caused penetrative deformation and metamorphism of all rock units only 20–50 km to the north.

Kimberlite intrusions which are common in the adjoining terrains have not been identified within the Aasivik terrane, which in turn is partly defined by the apparent absence of kimberlite intrusions. By applying the well-proven method of circular reasoning, we can deduce that the terrane constraint on the distribution of kimberlite intrusions indicates that the Aasivik terrane has deep lithospheric roots. The occurrence of diamond in a kimberlite south of the Aasivik terrane (Nunaoil A/S press release, 1996) indicate that the kimberlite originated at \( > 150 \) km depth. This is accord with the barometric estimates by Larsen and Rønsbo, 1993) for kimberlites along the inferred western and northern boundaries of the Aasivik terrane. If this interpretation is correct the early Archaean terrane is the exposed lower crustal level of a continent which had already existed for one billion years at the time of terrane assembly at 2700 Ma, and not merely a tectonic panel such as a fault block or nappe. This interpretation is in accord with Abbott (1996), who suggested that only accreted material with deep lithospheric roots could have been stabilised as parts of the continental crust during the Archaean. In this respect, the Aasivik terrane differs from the Akulleq terrane of the Godthåbsfjord region, which represent tectonic slices of an old gneiss complex intercalated with younger gneiss units. The Akulleq terrane is dominated by mid-crustal
amphibolite facies rocks, while the Aasivik terrane is at high-pressure granulite facies. The possibility that the Aasivik terrane represents the roots of the allochthonous Akulleq terrane should be investigated further by detailed geochemistry and chronometry.

6. Conclusions

The region south of the Nagssugtoqidian front in West Greenland comprises three Archaean gneiss complexes, which were assembled at 2800–2700 Ma. The early Archaean Aasivik terrane gives U–Pb zircon ages of 3500–3600 Ma for the formation of gneiss protoliths, but probably comprise gneisses formed back to ~3800 Ma, judging from the occurrence of zircons with an age of 3780 Ma. This gneiss terrain is dominated by granitic gneisses with a complicated deformation history, intruded by large mafic dykes of unknown age, and now represented by pods and layers of mafic granulite. No large supracrustal units have been identified in the early Archaean gneiss complex at present. The Aasivik terrane probably underlies ~1500 km². This terrane is in contact to the Southwest with the Tasersiaq mid-Archaean gneiss complex, which we provisionally interpret as the northern extension of the Akia terrane (eg. Nutman et al., 1996) of the Nuuk region. One sample of banded gneiss from this gneiss complex has given ages of 3127 ± 12 Ma and 3212 ± 11 for the formation of gneiss protoliths. The late Archaean Ukaleq gneiss complex to the Southeast is dominated by supracrustal rocks with similarities to modern accretionary complexes and intruded by post-kinematic A-type granite plutons, which probably also stitch the tectonic boundaries between the early Archaean and the mid-Archaean and late Archaean terranes.

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References

Bowring, S.A., Williams, I.S., Compston, W., 1989. 3.96 Ga gneisses from the Slave Province, Northwest Territories, Canada. Geology 17, 971–975.


