U–Pb ages on single detrital zircon grains from the Tasmiyele Group: implications for the evolution of the Olekma Block (Aldan Shield, Siberia)

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Abstract

The Aldan Shield of Siberia is one of the largest exposures of the Siberian Craton and has been divided into different units according to their geological characteristics. In the central part of the shield, the main divisions are the Olekma and West Aldan Blocks. The former contains supracrustal rocks and typical greenstone belts. We report U–Pb isotopic analyses on 51 single detrital zircon grains from 5 samples of quartzite collected at different stratigraphical levels from clastic metasediments of the Tasmiyele Group situated in the Olekma Block. The youngest sub-concordant grain (2963 ± 5 Ma) provides an older limit to the deposition. Combined with other information on the geological evolution of this part of the Aldan Shield, the results show that sediments were deposited between 2500 and ~ 2960 Ma, and that detritus was derived from the neighbouring basement of the Olekma Block. The age spectrum presented by detrital zircons implies the creation of large amounts of differentiated material during the period 2900–3000 Ma which represents an important crustal event for this part of the Aldan Shield. Moreover, it appears from these results and previous works that the Tasmiyele Group and the Tungurcha Group, initially grouped together to form the Tungurcha Greenstone Belt, are two distinct and unrelated units. The Tasmiyele Group, whose affiliation with greenstone belts is uncertain, was deposited at the same time or after the formation of the Olondo Greenstone Belt.

1. Introduction

Despite covering up to 80% of the Earth surface, sediments have not been intensively studied using conventional geochemical techniques. This is mainly due to mixing between components of various origin and also to the complexity of the processes occurring during diagenesis and/or alteration. However, clastic sedimentary rocks and their detrital minerals, can carry important information on the composition, tectonic setting and evolution of the source(s) region(s) from which they come from (e.g. Maas and McCulloch, 1991). Furthermore, they may represent the only remnants of source rocks which have since disappeared (Froude et al., 1983; Compston and Pidgeon, 1986). In sedimentary environments, detrital zircons constitute a mixture of grains from source rocks whose origin, age and evolution may be totally
different. Therefore, even two grains which appear identical in shape and colour, cannot be considered to have been derived from the same source rock. Age determinations of single zircon grains are therefore essential to identify different age populations and this paper presents U–Pb ages on 51 detrital zircon grains from the Tasmiyele Group (Olekma Block, Aldan Shield). The study aims to resolve the age spectrum presented by the zircon populations and to obtain information on the provenance of the detritus and on the age of deposition of the Tasmiyele Group. Furthermore, the age patterns reflect the evolution of the source regions and allow a direct comparison between the Tasmiyele Group and other supracrustal units of the Olekma Block. Another purpose of this study was to search for evidence of very old (Early Archaean) zircon grains. With the discovery of 3.4 Ga old Archaean rocks within the Omolon massif (Bibikova, 1984), it was hoped to find, in the Olekma Block, the most ancient core of the Aldan Shield.

2. Geological setting

The Tasmiyele Group outcrops on the Olekma Block (Fig. 1) in the middle part of the Archaean Aldan Shield. The Aldan Shield, which constitutes the largest exposure of the Siberian Craton, has been traditionally subdivided into various geological units according to structural and metamorphic characteristics (Dook et al., 1989). In the middle part of the shield, the main divisions are constituted by the Olekma granite-greenstone terrain and the West Aldan granulite–gneiss Block (Fig. 1). These two blocks are separated by the Amga fault which appears to represent a ductile shear zone, related to thrusting of the West Aldan Block westward over the edge of the Olekma Block (Smelov, 1989; Smelov and Beryozkin, 1993). The age of this event has been clearly shown to be Proterozoic (1.9–2.0 Ga) (Nutman et al., 1992). The West Aldan Block consists mainly of granitoids and tonalitic to granodioritic gneisses. Supracrustal belts (metavolcanic and metasedimentary rocks) are also preserved. All these rocks have undergone amphibolite-facies metamorphism. Eastwards, the grade of metamorphism and deformation increases and relict eclogites are found in the easternmost part of the Olekma Block (Smelov, 1989), assigned to be of Mesoproterozoic age (Nutman et al., 1992). Published geochronological results (Jahn et al., 1991; Nutman et al., 1992; Glebovitsky and Drugova, 1993; Neymark et al., 1993; Velikoslavinsky et al., 1993), emphasize that the basement of the Olekma Block is mainly constituted of 2.9–3.0 Ga old rocks. So far, the oldest rocks identified are 3.25 Ga old orthogneisses (Nutman et al., 1992), although Neymark et al. (1993) proposed for the 2.98 Ga Amnunnakta granitoid massif a Nd model age of 3700 Ma, that reflects the occurrence of much older sialic material. Greenstones belts outcropping on the Olekma Block have not been dated yet, except for the Olando Greenstone Belt. Ages from volcanics of this typical greenstone belt are indistinguishable from ages of the basement rocks (~ 3.0 Ga) (Baadsgaard et al., 1990). The Tungurcha Greenstone Belt, more than 170 km long and 25–30 km wide, is constituted by the Tungurcha Group (lower part) and the Tasmiyele Group (upper part). The Tungurcha Group outcrops as isolated tectonic fragments which may have constituted a single sequence (Bogomolova and Smelov, 1989). The slabs differ from each other in their constituent rocks which comprise volcanics, mafic plutonic rocks, schists, carbonates and clastic sediments. A minimum age for the deposition and subsequent thrusting of the Tungurcha Group is given by a tonalitic gneiss (3016 ± 8 Ma) intruding gneisses and ultramafic
rocks of the group on the west side of the Olekma river (Nutman et al., 1992). The metasediments of the Tasmyle Group outcrop in a north-south graben-like structure whose boundaries are defined by tectonic contacts (Fig. 1c). On its western flank a blastomylonite zone is developed in rocks of both the adjacent gneissic basement and the graben. The eastern boundary is a two-mica granite massif clearly cross-cutting the sedimentary sequence. Sills of metadiabases occur in the lower part of the series. Sediments and diabases have been deformed and metamorphosed under metamorphic conditions that do not exceed the middle amphibolite facies. The mineral assemblages in the diabases indicate that the rocks have equilibrated under metamorphic conditions of about 500–530°C and 1–2.5 kbar (Bogomolova and Smelov, 1989). The sedimentary sequence is composed of mica-quartz schists, quartzites and micaceous quartzites. Primary sedimentary textures and beddings are well preserved and six bedded units (units 1 to 6 in Fig. 1c) can be distinguished which consist of basal coarse-grained sediments which progressively fine upward (Bogomolova and Smelov, 1989). The total thickness of the group does not exceed 1000 m. Though no geochronological data are available, the Tasmyle

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**Fig. 1.** Composite map. (a) The geographical location of the Archaean Aldan Shield in the former Soviet Union. (b) A geological map of a portion of the central part of the Aldan Shield, showing the location of the various units and blocks mentioned in the text: Ol = Olondo Greenstone Belt; Tn = Tungurcha Greenstone Belt; Ts = Tasmyle Group. Geology is from Dook et al. (1989), as clarified by B.M. Jahn. The rectangle labelled c encloses the sampling site. (c) A more detailed map of the sampling area showing sample location. Geology is from Bogomolova and Smelov (1989).
Group has been considered as representing the upper part of the Tungurucha Greenstone Belt and its deposition has been proposed to occur before 2.5 Ga (Bogomolova and Smelov, 1989).

3. Samples

Five samples of quartzites and micaceous quartzites (Si-10, Si-11, Si-12, Si-13 and Si-14) have been collected during the IGCP field trip in 1989. Sampling has been done at different stratigraphical levels of the sedimentary pile in order to determine an age spectrum for the whole series, from base (sample Si-10) to top (sample Si-14), on the basis of primary sedimentary features. The samples will also allow detection of rocks of different ages in the source areas of the Tasmyle Group. The samples typically consist of angular fragments of quartz showing undulose extinction, microcline, plagioclase with myrmekite structure, tourmaline, garnet and opaques. The matrix (groundmass) is composed of chlorite, quartz, biotite and muscovite. Zircon is an accessory mineral. The occurrence of feldspar, together with the angular shape of quartz, implies relatively short sedimentary transport. The samples yielded abundant zircon grains which are relatively homogeneous with respect to external morphology but show a wide range in size. Most samples are dominated by light pink to colourless translucent crystals, the morphology of which can be divided into two broad categories. (1) A major component of the total population is constituted by prismatic euhedral crystals with undamaged or almost undamaged faces and corners. These grains clearly show no signs of metamorphic or erosion-related rounding. (2) A minor component is represented by rounded zircons showing signs of abrasion of external surfaces. Some grains present only slight rounding of the corners whereas others are well rounded suggesting a rather long transport and/or that they may have passed through more than one cycle of erosion and deposition.

The preponderance of well-preserved crystal forms is attributed to short sedimentary transport of the grains and to a provenance from a source area close to the basin as previously pointed out by the angular shape of quartz and the occurrence of feldspar. However, the occurrence of rounded grains also indicates that some grains have probably been transported over a longer distance than the main population. No metamorphic multifaceted grains, commonly found in high-grade metamorphic rocks have been observed and there is no evidence that the zircons are other than detrital in origin.

4. Analytical technique

Zircons were separated from 3 to 5 kg of rock using standard heavy liquids. Grains used for U–Pb analyses were hand picked under a binocular microscope according to colour and morphology and air abraded during a few hours following the technique of Krogh (1982). Grains were then carefully washed with highly purified reagents (4 N HNO₃, tridistilled water and 2 N HNO₃) and weighted on a Cahn electronic micro-balance. Zircons were dissolved in 48 h at 195°C in a Teflon microbomb with 5 μl of tridistilled 48% HF. After dissolution, the solution was evaporated to dryness and the microbomb was then filled with tridistilled 6 N HCl and heated for a few hours. Following Lancelot et al. (1976) and Bruguier et al. (1994), an aliquot was then spiked with a ^208 Pb–^235 U tracer. The unspiked part was used for measurement of the Pb isotopic composition. Both solutions, evaporated with 0.25 N H₃PO₄ (2 μl), were loaded with 1 mg/ml silicagel (6 μl) onto a single Re filament without previous chemical separation of the elements. Isotopic measurements were carried out on a VG Sector mass spectrometer using a Daly detector. As Pb and U were loaded together on the same filament, Pb was first measured before running U. While heating the samples, signals on masses 201, 203 and 205 were commonly observed, corresponding to Ti⁺ and BaPO₄⁺⁺ (compounds of ¹³⁷Ba, ¹³⁸Ba,¹⁶O, ¹⁷O and ¹⁸O) interferences. Pb isotopic ratios were therefore only measured at high temperatures (1400–1500°C) after complete vaporization of Ti and Ba compounds. Total Pb blanks over the period of the analyses range from 16 to 25 pg. The calculation of common Pb was made by subtracting blanks and then assuming the remaining common Pb has been incorporated to the crystal and has a composition determined from the model of Stacey and Kramers (1975). A correc-
tion of $0.24 \pm 0.05\%$ a.m.u. for mass fractionation was applied. Corrected isotopic ratios were calculated according to Bruguier and De La Boisse (1990), and regression lines and intercepts according to Ludwig (1987). Analytical uncertainties are listed as $2\sigma$ and uncertainties in ages as $95\%$ confidence levels. Decay constants are those recommended by the IUGS Subcommission on Geochronology (Steiger and Jäger, 1977).

5. Results

5.1. Quartzite Si-10

Thirteen crystals selected among the various grain types present in this sample have been analysed. U contents range from 76 to 434 ppm (Table 1) and there is no simple relationship between U concentration and degree of discordance. However, grains 6 and 7, among the richest in U (280 and 434 ppm, respectively), are the most discordant and grain 8, with a low U concentration (76 ppm) is the least discordant. Reported on the concordia diagram (Fig. 2), experimental points do not form a linear array indicating that the zircons analyzed do not form a single, homogeneous population. This is commonly observed for detrital zircons which originated from various source rocks (Davis et al., 1990; Krogh and Keppie, 1990; Ross et al., 1992). Considering the discordance of experimental points, the apparent

\[ ^{207}\text{Pb}/^{206}\text{Pb} \]

age determined for each grain provides reliable minimum ages for the source rocks from which the zircons are derived. Of the thirteen grains analyzed, none provide \(^{207}\text{Pb}/^{206}\text{Pb}\) ages ranging from 2900 to 2990 Ma. Four grains (3, 4, 8 and 13, in black in Fig. 2) have slightly older \(^{207}\text{Pb}/^{206}\text{Pb}\) ages ranging from 3040 to 3090 Ma and, as we will see below, exceeding those of the other grains analyzed in this study.

5.2. Quartzite Si-11

Seven grains have been analysed on this sample. U contents range from 169 to 725 ppm (Table 1). Surprisingly, for a set of detrital zircons, and unlike the previous sample, experimental points can be fitted to a chord (Fig. 3) intersecting the concordia curve at $2997 \pm 28$ Ma and $242 \pm 98$ Ma (MSWD = 37). The scattering of experimental points, expressed by the high value of the MSWD, is essentially due to grain 20. Removing this data point from the regression, for example on the assumption that this grain underwent zero-age Pb losses, leads to values of $2997 \pm 4$ Ma for the upper intercept and $280 \pm 13$ Ma for the lower intercept (MSWD = 0.9). As these grains are detrital in origin, and because two grains, even when identical in shape and colour criteria, cannot be assumed to be cogenetic, we prefer not to delete any of the results and favour the $2997 \pm 28$ Ma value. The observed alignment could then correspond to U–Pb discordancy patterns for zircon grains of identical or nearly identical ages having suffered a similar evolution (Schäfer and Allègre, 1982). Therefore, this could be regarded as the age of rocks of the source area feeding the Tasmylee Group which is consistent with previously published radiometric data from basement rocks of the Olekma Block (e.g. Nutman et al., 1992). The lower intercept is significantly different from zero and suggests disturbance of the U–Pb systems in the past but this does not correlate with any known geological event. Moreover, the apparent \(^{207}\text{Pb}/^{206}\text{Pb}\) ages for all grains but one (grain 17, the most discordant and the richest in U) span a narrow range of time (from 2900 to 2980 Ma), which encompasses the range of variations observed for sample Si-10. This small range in age, together with the good alignment of experimen-
<table>
<thead>
<tr>
<th>Sample</th>
<th>Weight (mg)</th>
<th>U (ppm)</th>
<th>Pb (ppm)</th>
<th>206/238U</th>
<th>207/235U</th>
<th>208/238U</th>
<th>Apparent Age (Ma)</th>
<th>Disc. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Zr, C, Eu, L</td>
<td>0.005</td>
<td>178</td>
<td>97</td>
<td>524</td>
<td>0.1208</td>
<td>0.4664 ± 20</td>
<td>14.062 ± 062</td>
<td>0.2187 ± 4</td>
</tr>
<tr>
<td>2 Zr, P, Eu, S</td>
<td>0.005</td>
<td>194</td>
<td>122</td>
<td>533</td>
<td>0.2099</td>
<td>0.5009 ± 23</td>
<td>14.528 ± 064</td>
<td>0.2104 ± 3</td>
</tr>
<tr>
<td>3 Zr, C, Rd, L</td>
<td>0.005</td>
<td>237</td>
<td>113</td>
<td>1351</td>
<td>0.1136</td>
<td>0.5222 ± 21</td>
<td>16.874 ± 067</td>
<td>0.2343 ± 2</td>
</tr>
<tr>
<td>4 Zr, P, Eu, L</td>
<td>0.006</td>
<td>318</td>
<td>192</td>
<td>1386</td>
<td>0.1136</td>
<td>0.5222 ± 21</td>
<td>16.874 ± 067</td>
<td>0.2343 ± 2</td>
</tr>
<tr>
<td>5 Zr, C, Eu, L</td>
<td>0.007</td>
<td>127</td>
<td>61</td>
<td>1273</td>
<td>0.1072</td>
<td>0.4158 ± 27</td>
<td>12.560 ± 095</td>
<td>0.2191 ± 8</td>
</tr>
<tr>
<td>6 Zr, P, Rd, L</td>
<td>0.008</td>
<td>280</td>
<td>108</td>
<td>2402</td>
<td>0.1136</td>
<td>0.5222 ± 21</td>
<td>16.874 ± 067</td>
<td>0.2343 ± 2</td>
</tr>
<tr>
<td>7 Zr, P, Eu, L</td>
<td>0.009</td>
<td>434</td>
<td>169</td>
<td>3359</td>
<td>0.1165</td>
<td>0.3362 ± 18</td>
<td>13.102 ± 053</td>
<td>0.2291 ± 3</td>
</tr>
<tr>
<td>8 Zr, C, Rd, S</td>
<td>0.010</td>
<td>76</td>
<td>48</td>
<td>1029</td>
<td>0.1187</td>
<td>0.5321 ± 30</td>
<td>16.869 ± 098</td>
<td>0.2299 ± 3</td>
</tr>
<tr>
<td>9 Zr, P, Rd, L</td>
<td>0.013</td>
<td>114</td>
<td>71</td>
<td>1382</td>
<td>0.2314</td>
<td>0.4912 ± 32</td>
<td>14.983 ± 106</td>
<td>0.2212 ± 5</td>
</tr>
<tr>
<td>10 Zr, C, Rd, L</td>
<td>0.013</td>
<td>185</td>
<td>105</td>
<td>2831</td>
<td>0.1291</td>
<td>0.3362 ± 18</td>
<td>13.102 ± 053</td>
<td>0.2291 ± 3</td>
</tr>
<tr>
<td>11 Zr, P, Eu, L</td>
<td>0.013</td>
<td>166</td>
<td>85</td>
<td>607</td>
<td>0.0918</td>
<td>0.4502 ± 29</td>
<td>13.178 ± 089</td>
<td>0.2123 ± 4</td>
</tr>
<tr>
<td>12 Zr, C, Eu, L</td>
<td>0.015</td>
<td>193</td>
<td>107</td>
<td>2186</td>
<td>0.0983</td>
<td>0.4785 ± 29</td>
<td>15.095 ± 095</td>
<td>0.2288 ± 4</td>
</tr>
<tr>
<td>13 Zr, C, Eu, L</td>
<td>0.005</td>
<td>435</td>
<td>163</td>
<td>1372</td>
<td>0.0480</td>
<td>0.3401 ± 14</td>
<td>09.923 ± 042</td>
<td>0.2116 ± 2</td>
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<tr>
<td>14 Zr, C, Eu, L</td>
<td>0.005</td>
<td>169</td>
<td>93</td>
<td>408</td>
<td>0.1000</td>
<td>0.4714 ± 24</td>
<td>14.234 ± 071</td>
<td>0.2190 ± 5</td>
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<tr>
<td>15 Zr, C, Eu, L</td>
<td>0.005</td>
<td>575</td>
<td>191</td>
<td>903</td>
<td>0.0360</td>
<td>0.3047 ± 23</td>
<td>08.804 ± 066</td>
<td>0.2096 ± 2</td>
</tr>
<tr>
<td>16 Zr, C, Eu, L</td>
<td>0.006</td>
<td>725</td>
<td>170</td>
<td>1612</td>
<td>0.0700</td>
<td>0.2073 ± 21</td>
<td>05.635 ± 057</td>
<td>0.1972 ± 2</td>
</tr>
<tr>
<td>17 Zr, P, Eu, L</td>
<td>0.006</td>
<td>200</td>
<td>112</td>
<td>1826</td>
<td>0.0620</td>
<td>0.4974 ± 22</td>
<td>15.067 ± 065</td>
<td>0.2197 ± 3</td>
</tr>
<tr>
<td>18 Zr, C, Rd, S</td>
<td>0.003</td>
<td>331</td>
<td>196</td>
<td>1780</td>
<td>0.1220</td>
<td>0.5055 ± 27</td>
<td>15.335 ± 079</td>
<td>0.2200 ± 3</td>
</tr>
<tr>
<td>19 Zr, P, Rd, L</td>
<td>0.005</td>
<td>314</td>
<td>113</td>
<td>2307</td>
<td>0.1070</td>
<td>0.3144 ± 29</td>
<td>15.095 ± 095</td>
<td>0.2288 ± 4</td>
</tr>
</tbody>
</table>

Table 1
U–Pb isotopic data for single zircon grains from the Tasmiyele Group of the Olekma Block (Aldan Shield, Siberia)
Table 1 (continued)

<table>
<thead>
<tr>
<th>Sample</th>
<th>Weight (mg)</th>
<th>U (ppm)</th>
<th>Pb</th>
<th>206Pb/238U</th>
<th>207Pb/235U</th>
<th>208Pb/232U</th>
<th>Apparent age (Ma)</th>
<th>Disc. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si-14</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>45 Zr, P, Eu, L</td>
<td>0.006</td>
<td>140</td>
<td>80</td>
<td>653</td>
<td>0.1504</td>
<td>0.4832 ± 21</td>
<td>14.724 ± 060</td>
<td>0.2210 ± 4</td>
</tr>
<tr>
<td>46 Zr, P, Eu, L</td>
<td>0.007</td>
<td>190</td>
<td>112</td>
<td>1184</td>
<td>0.1339</td>
<td>0.5068 ± 45</td>
<td>15.322 ± 144</td>
<td>0.2192 ± 3</td>
</tr>
<tr>
<td>47 Zr, P, Eu, S</td>
<td>0.007</td>
<td>170</td>
<td>89</td>
<td>734</td>
<td>0.1081</td>
<td>0.4606 ± 26</td>
<td>13.729 ± 077</td>
<td>0.2161 ± 4</td>
</tr>
<tr>
<td>48 Zr, C, Rd, L</td>
<td>0.008</td>
<td>91</td>
<td>49</td>
<td>407</td>
<td>0.0995</td>
<td>0.4777 ± 26</td>
<td>14.042 ± 068</td>
<td>0.2132 ± 5</td>
</tr>
<tr>
<td>49 Zr, C, Eu, L</td>
<td>0.009</td>
<td>205</td>
<td>119</td>
<td>2219</td>
<td>0.1019</td>
<td>0.5089 ± 46</td>
<td>15.481 ± 137</td>
<td>0.2206 ± 3</td>
</tr>
<tr>
<td>50 Zr, C, Rd, S</td>
<td>0.009</td>
<td>226</td>
<td>145</td>
<td>1435</td>
<td>0.1172</td>
<td>0.5556 ± 42</td>
<td>16.865 ± 130</td>
<td>0.2202 ± 6</td>
</tr>
<tr>
<td>51 Zr, P, Eu, L</td>
<td>0.011</td>
<td>152</td>
<td>97</td>
<td>1563</td>
<td>0.0880</td>
<td>0.5666 ± 63</td>
<td>17.003 ± 194</td>
<td>0.2176 ± 7</td>
</tr>
</tbody>
</table>

P = pink to purple; C = colourless; Eu = euhedral; Rd = rounded; L = elongated; S = squat; r = radiogenic lead corrected from blank, fractionation and initial Pb (after Stacey and Kramers, 1975). The right-hand column is percentage discordance assuming recent lead losses.

tal points, strongly suggests that the source region is homogeneous chronologically and likely consists essentially of ~3000 Ma old rocks or that the grains were derived from only one type of source rock. Due to the observed variety of morphological types (shape and degree of rounding) we favour the hypothesis of a uniform source area.

5.3. Quartzite Si-12

Sixteen grains have been analysed for this sample, collected near the middle of the sedimentary pile. U contents range from 48 to 570 ppm, excepted for grain 33 which presents a higher U concentration (1205 ppm). Reported on the concordia diagram (Fig. 4), experimental points show variable degrees of discordance. The least discordant grains (circle on Fig. 4) can be fitted to a discordia line (MSWD = 10.6), intersecting concordia at 2996 ± 27 Ma and 281 ± 344 Ma for the upper and lower intercept, respectively. The upper intercept is identical to that determined for sample Si-11, and, in a same way, could be interpreted as reflecting an average age for rocks of the source area. The lower intercept, within error margins, is not significantly different from zero. Of the sixteen grains analysed, thirteen plot on or close to a line (dashed line in Fig. 4) connecting the origin and the 2996 Ma intercept. The two most discordant analyses (grain 25 and 26) lie on this line and testify to a rather simple history of the U–Pb systems of the grains, controlled by recent Pb losses. This also indicates that the crystals have not suffered significant ancient Pb losses. Three grains, however (22, 32 and 33), are markedly displaced to the left of this line and lie on a chord that has a non-zero lower

![Fig. 3. Concordia diagram showing U–Pb results on single zircon grains from the quartzite sample Si-11.](image)

![Fig. 4. Concordia diagram showing U–Pb results on single zircon grains from the quartzite sample Si-12. Regression of the least discordant grains (circles) provides an average age of 2996 ± 27 Ma (heavy line). The dashed line traces a chord between the origin and 2996 Ma.](image)
intercept. These grains are among the richest in uranium (309–1205 ppm) and they may have experienced a more complex Pb loss history compared to the main population. They may also have derived from parent rocks significantly younger than the bulk grains but older than 2881 Ma (207 Pb/206 Pb age of grain 33). Moreover, the observed trend again suggests that the source area is uniform chronologically. The sixteen grains yield apparent 207 Pb/206 Pb ages ranging from 2881 to 2999 Ma.

5.4. Quartzite Si-13

Six zircon grains have been analysed in this sample. They belong essentially to the euhedral grain type (see Table 1). U contents range from 188 to 377 ppm. Reported on the concordia diagram (Fig. 5), the six grains do not define a simple alignment but scatter along a line (MSWD = 35) whose intersections with the concordia curve are 3006 ± 72 Ma and 429 ± 661 Ma for the upper and lower intercept, respectively. The upper intercept value is identical to the average age obtained for samples Si-11 and Si-12 and the lower intersection is not significantly different from zero. The 207 Pb/206 Pb apparent ages for the six grains analyzed range from 2911 to 2994 Ma.

5.5. Quartzite Si-14

This sample has been collected close to the top of the sedimentary pile. The nine crystals analysed have U concentrations ranging from 90 to 320 ppm. A Pb loss chord calculated from these analyses provides an upper intercept of 3014 ± 59 Ma, the lower intercept (559 ± 532 Ma) being close to zero within error margins (MSWD = 39). Analysis 51 (Fig. 5) is only 2% discordant and the 207 Pb/206 Pb age of this grain (2963 ± 5 Ma), assuming inheritance is not a factor in the interpretation, represents a good estimate of the age of crystallization of the rock from which it originated. This age places a maximum age constraint on the deposition of the Tasmiyele Group. Analysis 50 is only 4% discordant and yields a 207 Pb/206 Pb age of 2982 ± 3 Ma. The 207 Pb/206 Pb ages determined for the nine grains analysed range from 2910 to 2988 Ma.

6. Discussion

This study on the metasediments of the Tasmiyele group has been made on samples collected at different levels of the sedimentary pile in order to obtain chronological information on the whole series. Zircons have been selected from different morphological types allowing access to a great variety of grains and thus to the age spectrum of rocks from the source areas. This age spectrum reflects the evolution of the eroded crustal segments and makes it possible to determine the origin of the sediments. Moreover, the results enable the age of deposition of the sediments to be constrained and allow a direct comparison with other supracrustal rocks from the Olekma Block.

6.1. Age spectrum

Average 207 Pb/206 Pb ages for the bulk of the zircons extracted are consistent along the sedimentary pile and range from 2996 to 3014 Ma. The distribution of data from quartzites Si-10, Si-11, Si-13 and Si-14 allows us to infer that the dominant time for Pb loss from the zircons was post 500 Ma. Zircons from quartzite Si-12 clearly show evidence of strong episode of Pb loss in recent times. Moreover, the similarity in 207 Pb/206 Pb ages for almost all the grains (see Table 1) indicates a simple Pb loss history. These observations suggest that for most grains a great proportion of the radiogenic lead loss
occurred recently, in which case the $^{207}\text{Pb}/^{206}\text{Pb}$ apparent ages could be regarded as a reasonably good approximation to the age of crystallization. The $^{207}\text{Pb}/^{206}\text{Pb}$ age distribution of detrital zircons from the Tasmiyele Group is remarkably homogeneous and contrasts with the age spectrum commonly observed for sedimentary formations (Froude et al., 1983; Compston and Pidgeon, 1986; Krogh and Keppie, 1990; Rainbird et al., 1992; Ross et al., 1992). This distribution has important implications for the tectonic and magmatic evolution of the source areas. Indeed, the $^{207}\text{Pb}/^{206}\text{Pb}$ apparent ages of the 51 grains analysed are restricted to a range of 2800–3100 Ma. The lower limit is due to grains 17 and 33 which present $^{207}\text{Pb}/^{206}\text{Pb}$ ages of 2803 Ma and 2881 Ma, respectively, and high U contents (725 and 1205 ppm). Moreover, these analyses are among the most discordant and it is likely that they may have been prone to loose significant proportions of radiogenic lead under relatively mild conditions or by diffusion from radiation-damaged domains. This phenomenon may have occurred sometime in the past in addition to the recent lead losses. We therefore consider that for these grains, the $^{207}\text{Pb}/^{206}\text{Pb}$ age is probably not a reasonably good approximation to the age of crystallisation. With the exception of these two experimental points, the age spectrum spans only 200 Ma and ages range from 2900 to 3100 Ma. It is also noteworthy that the age distribution is similar in the four samples Si-11, Si-12, Si-13 and Si-14, and, to some degree, in sample Si-10. The latter, collected at the bottom of the sedimentary pile, exhibits a slightly different age distribution with four zircon grains showing apparent ages older than 3040 Ma. However, because of the degree of discordance shown by experimental points, it is not possible to decide unequivocally whether these four grains derived from source material emplaced during a distinct, older event (i.e. > 3100 Ma) or originated from rocks belonging to one, single protracted event broadly occurring between 2900 and 3100 Ma. A $^{207}\text{Pb}/^{206}\text{Pb}$ age frequency distribution is shown in Fig. 6. Excluding grains 17 and 33, which exhibit younger apparent ages, as well as grains 3, 4, 8 and 13 whose $^{207}\text{Pb}/^{206}\text{Pb}$ ages range from 3040 to 3090 Ma, the remaining 45 grains exhibit a normal-like distribution with a geometric mean of 2961 Ma. In this distribution, 2/3 of the analyses are within 1σ uncertainties and more than 95% within 2σ uncertainties (±56 Ma). As pointed out before, because these grains present a simple evolution, controlled by recent lead losses, the apparent $^{207}\text{Pb}/^{206}\text{Pb}$ age of the grains should not be really different from the true age of the rock from which they derived. Then, assuming that the zircons analysed reflect the evolution of the eroded source areas, the age spectrum indicates that a large proportion of these areas consists of rocks formed during the period (2961 ± 56 Ma). Because zircon grains are relatively scarce in mafic lithologies, it is very likely that most of the grains derived from acidic to intermediate rocks. The period identified above is then likely to represent a time of accretion of important volumes of crustal material in the source area. Moreover, these results do not show the imprint of the Proterozoic (1900–2000 Ma) granulite-facies metamorphism that affects the West Aldan Block and the eastern part of the Olekma Block (Nutman et al., 1992). This is supported by a simple evolution of the U–Pb systems of the detrital zircons from the Tasmiyele Group which provide no evidence of ancient isotopic disturbances. This observation is in agreement with the conclusions of Nutman et al. (1992) showing that the
effects of this event are restricted to the easternmost part of the Olekma Block. These results also agree with the proposition that the Aldan Shield is made up of undisturbed Archaean crustal segments that have evolved separately and that were welded together during Proterozoic time.

6.2. Sediment sources

Bibikova (1984) proposed that the isotopic characteristics of Archaean zircon grains (U contents and $^{208}\text{Pb}/^{206}\text{Pb}$ ratio) could be correlated with the nature of the rock from which they derived. Indeed, the $^{208}\text{Pb}/^{206}\text{Pb}$ ratio is linearly correlated with the $^{232}\text{Th}/^{238}\text{U}$ ratio and reflects the Th/U ratio of the rock, providing no differential movement of Th and U or of uranogenic and thorogenic Pb had occurred. In such a diagram (Fig. 7) most data-points fall in the field of granodioritic and tonalitic gneisses of magmatic origin. A few analyses, however, are located in the field of volcanic rocks. This distribution suggests that zircons from the Tasmieye Group originated mainly from gneissic rocks. The lack of metamorphic grains (high $^{208}\text{Pb}/^{206}\text{Pb}$ ratio and low U content) is also in agreement with the fact that no typical, multifaceted, metamorphic grains have been detected during examination of the zircon concentrate. As seen above, the age distribution for detrital zircons of the Tasmieye Group indicates an origin of the sediments from a source area mainly consti-
tuted by 2900–3000 Ma old rocks. The age spectrum and the inferred characteristics of the analyzed grains are consistent with an origin of the clastic metasediments from the neighbouring basement of both the Olekma and West Aldan Block. However, the great proportion of rocks with ages ranging from 2900 to 3100 Ma on the Olekma Block (Bibikova, 1989; Baadsgaard et al., 1990; Nutman et al., 1992; Glebovitsky and Drugova, 1993; Neymark et al., 1993; Velikostavinsky et al., 1993) and the well-preserved shapes of most grains suggest that the source rocks for the metasediments may be located in the adjacent crystalline basement of the Olekma Block. Whether the West Aldan Block constitutes a plausible source depends on its position relative to the Olekma Block at the time of deposition. However, several authors (Nutman et al., 1992; Smelov and Beryozkin, 1993) have proposed that these two blocks underwent a separate Archaean evolution and were juxtaposed only during Proterozoic time (1900–2000 Ma). Therefore, an origin of the sediments from the Olekma Block alone, without noticeable contribution of materials from the West Aldan Block, is more likely. The four older grains detected in sample Si-10, assuming that they are truly older than the main population, may have originated from ~3.2 Ga old rocks recognized on the Olekma Block (Putchel et al., 1989b; Nutman et al., 1992) which have suffered strong lead losses during the ~3000 Ma event. At least, the likelihood that some of the zircon grains analyzed derived from volcanic materials and their similarity in age with grains derived from plutonic rocks is consistent with the proposition that some greenstone belts and the bulk of the basement on the Olekma Block developed at the same time, as suggested by previous studies (Baadsgaard et al., 1990; Nutman et al., 1992).

6.3. Constraints on the age of deposition

Analyses of detrital zircons from sedimentary rocks make it possible to constrain the age of deposition of a sedimentary pile. Indeed, the youngest detrital zircon in a sediment provides an older limit to the deposition (Armstrong et al., 1990; Davis et al., 1990; Robb et al., 1989; Krogh and Keppie, 1990). The accuracy of this constraint is dependant

![Fig. 7. $^{208}\text{Pb}/^{206}\text{Pb}$ versus U (ppm) diagram showing data points of single zircon grains from the Tasmieye Group quartzite samples. Fields shown after Bibikova (1984).]
on a number of factors among which are the fact that the youngest zircon present in the rock has been effectively analyzed, the time interval between the last magmatic or metamorphic event occurring in the source areas and the deposition, the velocity of the uplift in these areas and the time spent before erosion and transport of the sediments in the basin with the possibility for detrital zircons to pass through more than one cycle of erosion and deposition. All these factors can combine together to precisely constrain the deposition age. In this study, only few concordant to sub-concordant points (less than 5% discordance) have been obtained and thus, the constraint on the age deposition is weak. Nevertheless, grain 45 from sample Si-14 is only 2% discordant and presents a $^{207}\text{Pb} / ^{206}\text{Pb}$ age of 2963 ± 5 Ma which constitutes a maximum age for the deposition of the Tasmiyele Group. Moreover, Bogomolova and Smelov (1989) have indicated a 2500 Ma age for diabases intruding the metasediments. This age constitutes a minimum value for deposition of the sediments and is in good agreement with a 2420 Ma minimum U–Pb zircon age obtained from the two-mica granite intruding the east flank of the Tasmiyele Group (Bruguier, 1993). These values combined suggest that deposition of the Tasmiyele Group took place during Archaean time, between 2500 and 2960 Ma. Previous geochronological data from the Olekma Block indicate three main magmatic periods at 2.70–2.75 Ga (Nutman et al., 1992), 2.9–3.0 Ga (Bibikova, 1989; Putchel et al., 1989a; Baadsgaard et al., 1990) and before 3.2 Ga (Putchel et al., 1989b; Nutman et al., 1992). The two last magmatic periods (2.9–3.0 Ga and > 3.2 Ga) obviously took place before deposition of the sediments, but the lack of zircon grains with minimum ages younger than 2800 Ma suggests that the Tasmiyele Group was already deposited before the third 2.70–2.75 Ga magmatic period.

6.4. Correlation with different units of the Olekma Block

The Tasmiyele Group outcrops in the western part of the Tungurucha Greenstone Belt and, due to its geographical location and the scarcity of volcanic material, has been previously associated with the Tungurucha Group and interpreted as representing the upper part of the Tungurucha Greenstone Belt (Bogomolova and Smelov, 1989). However, noticeable differences have already been pointed out by these authors. The Tungurucha Group, which represents the lower part of the Tungurucha Greenstone Belt, consists of numerous tectonic units. Metasediments of this group have been deposited and subsequently carried onto the basement of the Olekma Block before 3016 ± 8 Ma as indicated by the age of a tonalitic gneiss intruding the sediments (Nutman et al., 1992). The Tasmiyele Group, on the contrary, outcrops in a graben-like structure and it is not certain whether this sedimentary complex is really part of a greenstone belt (Bogomolova and Smelov, 1989). From this study, U–Pb single zircon grain results indicate that most of the analyzed crystals yield $^{207}\text{Pb} / ^{206}\text{Pb}$ ages ranging from 2900 to 3000 Ma and grain 51 provides a maximum age of ~ 2960 Ma for the deposition of the sediments. This clearly shows that deposition of the Tasmiyele Group took place at least 50 Ma after that of the Tungurucha Group. These two formations are therefore likely to be two distinct units. This study also allows a direct comparison with the Olondo Greenstone Belt from which geochronological results have been published. According to these results, the formation of this typical greenstone belt occurred between 2966 ± 16 Ma (Putchel et al., 1989a) and 3006 ± 11 Ma (Baadsgaard et al., 1990). Therefore, sedimentary units of the Tasmiyele Group were deposited at the same time or after those of the Olondo Greenstone Belt.

7. Conclusions

Conclusions from this study on single detrital zircon grains from five samples of the Tasmiyele Group are as follows:

(1) The age of deposition of the Tasmiyele Group is bracketed by the age of the youngest concordant to sub-concordant grain analysed (2963 ± 5 Ma, this study) and that of intrusive material (~ 2500 Ma, Bogomolova and Smelov, 1989). Geochronological
data from the Olekma Block also suggest that deposition probably occurred before 2.70–2.75 Ga.

(2) The age spectrum is coherent with a local origin for the sediments. No 'exotic' origin is required to explain the age spectrum presented by the zircon populations. It is proposed that most of the detrital zircons found in the metasediments originated from gneissic source rocks which form the bulk of the Olekma Block. Some grains possibly derived from volcanic material from adjacent greenstone belts.

(3) This part of the Aldan Shield has experienced an important crustal event ~ 3.0 Ga ago. This period is now well identified in many Archaean cratons (Sino–Korean, Kaapvaal and Yilgarn cratons; see for example Zhang et al., 1984; Kröner et al., 1989; Pidgeon and Wilde, 1990) and is believed to represent a worldwide event of crust formation (Jahn et al., 1991). Since then, this Archaean segment has not undergone major geological perturbations. The ~ 2.0 Ga high-grade event, found in the west Aldan Block, is not recorded by our data indicating that its effects do not extend to this part of the Olekma Block, as pointed out by previous authors (Nutman et al., 1992).

(4) This study also failed in the search for ancient (Early Archaean) material in the Aldan Shield. The oldest grains identified present $^{207}\text{Pb}/^{206}\text{Pb}$ ages ranging from 3040 to 3090 Ma and may be attributed to ~ 3.2 Ga old source material having suffered strong lead losses during the ~ 3.0 Ga event. As target materials for a search for ancient witnesses, quartzites from the Tasmiyele Group have not the required qualities. Indeed, their local derivation reduces the likelihood that the source areas may contain very old zircons. A more mature sediment, sampling wider areas of Archaean surfaces would have been more promising. Moreover, the importance of the ~ 3.0 Ga event in the Olekma Block also suggests that older zircons may have been destroyed.

(5) The Tasmiyele Group and the Tungurcha Group, initially grouped together to form the Tungurcha Greenstone Belt, are more probably two distinct units deposited at different times and without relationship to one another. The sediments of the Tasmiyele Group were deposited at the same time or after those of the Oلونdo Greenstone Belt.

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