Sveriges geologiska undersökning

Detrital zircon ages of metasedimentary rocks in Västernorrland County



Martiya Sadeghi, Stefan Persson, Edward P. Lynch,
Tonny B. Thomsen & Benjamin D. Heredia

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Author: Martiya Sadeghi, Stefan Persson, Edward P. Lynch,
Tonny B. Thomsen & Benjamin D. Heredia
Reviewed by: Stefan Bergman
Head of unit: Ann Allen
Editor: Lina Rönnåsen

Cover: Mapping area in Ullånger.
Photographer: Martiya Sadeghi

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Geological Survey of Sweden
Box 670, 751 28 Uppsala
phone: 018-17 90 00
e-mail: sgu@sgu.se
www.sgu.se

Contents

Abstract 4
Sammanfattning 5
Introduction 6
Selection of sampling sites and methods 7
Analytical methods: Laser Ablation ICP-MS analysis 8
Results 10
  Description of rock samples 13
    Sollefteå (Sample MSI220061A) 13
    Järkvissle (Sample ELH220054A) 15
    Jamttjärnen (sample SPN221091A) 17
    Norra Kattviken (Sample SPN221080B) 19
    Lidens-Backen (Sample ELH230109A) 21
    Lappberget (Sample ELH230119A) 23
    Grundsjön-Tallmyran (Sample SPN230523A) 25
    Grössjön (Sample SPN230551A) 27
    Trehörningen (Sample SPN230583A) 29
    Gräsmyrberget (Sample MSI230099A) 31
  Palaeoproterozoic zircons 33
  Archean zircons 36
Lithogeochemistry 38
Summary and discussion 40
Acknowledgment 49
References 49
Appendix 1. Descriptive statistics for U, Th and Pb concentrations 52
Appendix 2. Lithogeochemical analysis results 57
Appendix 3. Sample-level age statistics 59

Abstract

The Geological Survey of Sweden (SGU) has conducted geochronological analyses of zircons from metasedimentary rocks in Västernorrland County. The work was carried out as part of a larger bedrock mapping project focused on critical metals and minerals. This project forms part of SGU's ongoing mapping programme for 2021 to 2027.

Twelve samples of clastic metasedimentary rocks were collected from several metasupracrustal areas in Västernorrland County and its surroundings. The samples have been collected, analysed, and studied to obtain provenance zircon U-Pb ages within the Bothnia–Skellefteå lithotectonic unit (Bothnian basin).

Of these twelve samples, ten contain zircon, while two lacked zircons. A total of approximately 1,115 analyses were conducted, with each sample yielding between 112 and 123 analyses – except for one sample, which had a total of 60 analyses. The zircons were analyzed using Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) at the Geological Survey of Denmark and Greenland (GEUS). The analysed zircon populations allow for statistical analysis of the geochronology results.

The zircons in the metasedimentary rock samples reveal $^{207}Pb/^{206}Pb$ ages ranging from **3619 Ma to 1674 Ma**. The maximum depositional ages estimated for the ten zircon-bearing samples range from **1924 Ma** to **1887 Ma**. The oldest zircons in this study include a **3619 Ma** (Eoarchaean) grain from the Järkvissle area, a **3548 Ma** grain from Sollefteå, and a **3498 Ma** grain from the Liden-Bäcken area.

Based on the obtained results, the detrital zircon populations of all samples are broadly similar, predominantly showing a bimodal age distribution. A density plot of all samples reveals two primary age population domains, in the ranges **1.91–2.02 Ga** and **2.71–2.75 Ga**. However, some samples from the eastern part of the study area show three distinct age peaks. The maximum (youngest) depositional ages of individual samples are interpreted as **1.88–1.92 Ga**.

The metasedimentary units with the detrital zircon populations are interbedded with arc volcanic rocks in the southern part of the study area, which suggests deposition of source sediments before or at the same time as the onset of arc volcanism. In contrast, in the western and northern parts of the study area sedimentary rocks appear to have formed slightly before volcanism, which subsequently deposited volcanic rocks atop the sedimentary layers in the Räggen and Sollefteå regions.

In general, the largest proportion of Archaean zircon grains is found in the southern part of the study area, extending toward the Ostrobothnia basin in Finland. This suggests that most Archaean zircons were derived from the central Svecofennian depositional basin (Bothnian basin). However, the distinct zircon age signature and higher proportion of Archaean zircons in Kattviken indicate a different source of material compared to other areas in Västernorrland. Further zircon provenance studies are needed to make a proper interpretation there and in the adjacent areas.

Sammanfattning

Sveriges geologiska undersökning (SGU) har genomfört åldersbestämningar av zirkoner från metasedimentära bergarter i Västernorrlands län. Arbetet ingick som en del i ett större kartläggningsprojekt av berggrunden som fokuserar på kritiska metaller och mineral. Detta projekt är en del av SGU:s pågående kartläggningsprogram (2021–2027).

Tolv prover av klastiska metasedimentära bergarter samlades in från flera metasuprakrustala områden i Västernorrlands län och dess omgivningar. Proven samlades in, analyserades och studerades för att erhålla proveniens med hjälp av U-Pb-datering av zirkoner inom den litotektoniska enheten Bothnia–Skellefteå (Bottniska bassängen).

Av de tolv proverna innehöll tio zirkoner, medan två saknade zirkoner. Totalt genomfördes cirka 1 115 analyser. I varje enskilt prov gjordes mellan 112 och 123 analyser, förutom ett prov som hade totalt 60 analyser. Zirkonerna analyserades med LA-ICP-MS (eng. *Laser Ablation Inductively Coupled Plasma Mass Spectrometry*) vid Danmarks och Grönlands geologiska undersökning (GEUS). Resultaten av de analyserade zirkonpopulationerna är tillräckliga för en statistisk analys.

Zirkonerna i de metasedimentära bergartsproverna visar $^{207}Pb/^{206}Pb$-åldrar som varierar från **3 619 Ma** till **1 674 Ma**. De maximala deponeringsåldrarna för de tio zirkonförande proverna uppskattas variera från **1 924 Ma** till **1 887 Ma**. De äldsta zirkonerna i studien omfattar ett **3 619 Ma** gammalt korn från Järkvissle, ett **3 548 Ma** gammalt korn från Sollefteå och ett **3 498 Ma** gammalt korn från Liden-Bäckenområdet.

Baserat på de erhållna resultaten så är de detritiska zirkonpopulationerna hos alla prover i stort sett lika och visar huvudsakligen en bimodal åldersfördelning. En täthetsplot av alla prover visar två huvudsakliga ålderspopulationer i intervallen **1,91–2,02 Ga** och **2,71–2,75 Ga**. En del prover från den östra delen av studieområdet visar dock tre distinkta ålderstoppar. De maximala (yngsta) avsättningsåldrarna för enskilda prover tolkas vara **1,88–1,92 Ga**.

De metasedimentära enheterna med de detritiska zirkonpopulationerna är växelvis lagrade med vulkaniska bergarter av öbågetyp i den södra delen av studieområdet, vilket antyder en avsättning av källsediment innan eller samtidigt som början av öbågevulkanismen. Däremot verkar sedimentära avsättningar i de västra och norra delarna av studieområdet ha bildats strax innan vulkanutbrott, som avsatte vulkaniska bergarter ovanpå de sedimentära lagren i Räggen- och Sollefteåregionerna.

Generellt sett så finns den största andelen zirkonkorn av arkeisk ålder i den södra delen av studieområdet, med utbredning mot den Österbottniska bassängen. Detta tyder på att de flesta zirkoner av arkeisk ålder härstammar från den centrala Svekofenniska avsättningsbassängen (Bottniska bassängen). Däremot indikerar den distinkta zirkonålderssignaturen och den jämförelsevis högre halten av arkeiska zirkoner i Kattviken en annan materialkälla jämfört med andra områden i Västernorrland. Ytterligare studier av zirkoners ursprung behövs för att göra en korrekt tolkning där och i de angränsande områdena.

Introduction

Detrital zircons are zircon crystals that have been eroded, weathered, and transported from their original source to become part of new sedimentary deposits. Due to their uranium (U) and thorium (Th) contents, detrital zircon crystals are highly suitable for radiometric dating. Determining the maximum depositional age and the characteristics of detrital zircon populations makes it possible to infer the timing and duration of sedimentation, as well as the regional-scale tectonic setting. Accordingly, dating individual detrital zircons helps assess the source rocks and estimate the maximum depositional age of sedimentary rock units (e.g., Fedo et al., 2003).

The Bothnian basin (Hietanen 1975) in Sweden predominantly consists of metasedimentary rocks dominated by metagreywacke and mica schist, belonging to the lower Svecofennian informal Bothnian supergroup (cf. Lundqvist 1987; Lundqvist et al. 1990). The Skellefteå group, an extension of the lower Svecofennian units to the north, is primarily composed of 1.90–1.88 Ga metavolcanic rocks (Allen et al. 1996). The Bothnian basin is bounded to the south by the 1.86–1.84 Ga calc-alkaline Ljusdal batholith (Delin 1993), which is cut by the 1.8 Ga steep dextral Hassela shear zone (Bergman & Sjöström 1994). In the eastern part of the Ljusdal batholith, metasedimentary rocks are mostly folded and migmatised, but a well-preserved supracrustal sequence is exposed in the Hamrånge synform, including the Naggen quartzite (Kathol et al. 2020).

The Västernorrland area is located in the southern part of the Bothnian basin, a regionally extensive Palaeoproterozoic sedimentary–volcanic domain in central and northern Sweden (Fig. 1; e.g., Skyttä et al. 2020, and references therein). The metasupracrustal rocks of the Bothnian basin have been assigned to several informal stratigraphic units, including the Härnö, Knaften, and Robertsfors groups. Collectively, these units form part of the informal Bothnian supergroup, which has an estimated apparent thickness of approximately 10 km (e.g., Kousa & Lundqvist 2000). This sedimentary–volcanic package is interpreted as a dominantly marine turbiditic sequence deposited along a continental margin or within an accretionary arc environment prior to or during the 2.0–1.8 Ga Svecokarelian/Svecofennian orogeny (Kousa & Lundqvist 2000; Lahtinen et al. 2009; Skyttä et al. 2020).

Previous detrital zircon analyses indicate that the metasedimentary rocks of the Bothnian supergroup and quartzites located along the southern boundary of the Bothnian basin (Naggen group) show major source component age peaks at approximately 2.9–2.5 Ga, 2.1–2.0 Ga, and 1.88–1.87 Ga (e.g., Claesson & Lundqvist 1995; Kathol et al. 2020). In the southern part of the study area, within the Bergslagen region, detrital zircon dates from metasedimentary rocks range from 2.97 to 1.83 Ga (Claesson et al. 1993; Stephens & Andersson 2015; Johansson & Stephens 2017; Kathol et al. 2020).

Lahtinen et al. (2015) presented a similar approach in the Uusimaa Belt in southern Finland, correlating it with Bergslagen, while Salminen and Kurhila (2023) recently reported maximum depositional ages of 1.96–1.89 Ga in the Häme and Uusimaa belts. Additionally, Bergman et al. (2008) compared four samples from southern Finland and central Sweden, specifically from the Hamrånge area, and determined a maximum depositional age of 1855 ± 10 Ma. Their findings suggest strong correlations between Paleoproterozoic sedimentary rock units from central Sweden and southern Finland.

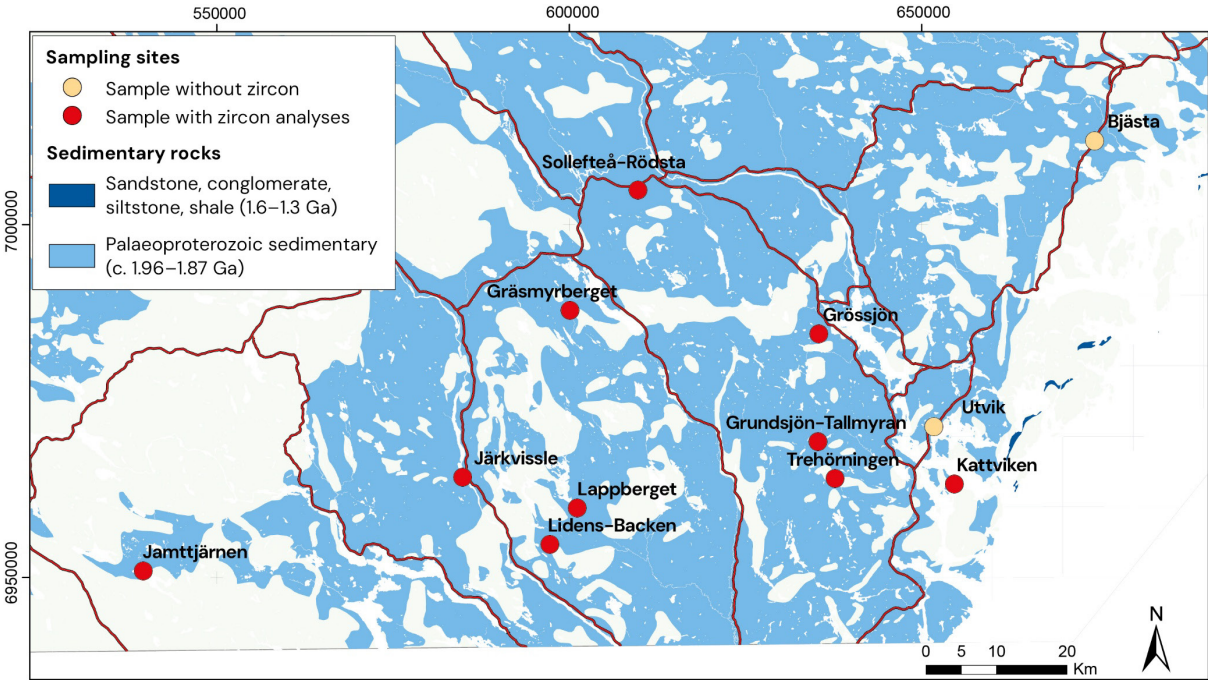


Figure 1. The study area, locations and label of samples for provenance zircon dating. Background map extracted from 1:1 million scale bedrock map at SGU shows distribution of sedimentary rocks within study area. Coordinate system: SWEREF99_TM.

Selection of sampling sites and methods

During the ongoing SGU mapping project called "Västernorrland lithium" between 2021–2023, several samples were collected for provenance studies of sedimentary rocks in the Bothnian basin (Fig. 1). Sampling sites were selected based on the extent of the mapping area. Given the widespread migmatisation throughout the study area, it was considered essential to target locations where the metamorphic grade was relatively low (lower amphibolite facies), ensuring that the sedimentary rocks were well-preserved and less affected by overprinting metamorphic events (Sadeghi et al. 2022).

Relevant literature was also consulted, particularly to gather information on stratigraphic position and variations in stratigraphy across sampling areas. Sampling localities were chosen to represent the broadest possible range of the sedimentary sequence, as well as areas adjacent to volcanic rocks-either where volcanic rocks were already known to be present or newly discovered during the mapping program.

At each sampling site, separate samples were collected for zircon U-Pb dating, whole rock lithogeochemical analysis, and thin section preparation. Sample site documentation followed the structure of SGU:s observation database (halldb-database). Additionally, photographs were taken of the sampling sites in the field, along with images of hand specimens.

Analytical methods: Laser Ablation ICP–MS analysis

Zircon U-Pb geochronology was conducted on mineral separates embedded in epoxy mounts using laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) at the Geological Survey of Denmark and Greenland (GEUS). The analyses were performed using an NWR213 frequency-quintupled solid-state Nd:YAG laser system from Elemental Scientific Lasers (ESI), equipped with a two-volume TV2 ablation cell. The laser system was coupled to an ELEMENT 2 double-focusing single-collector magnetic sector-field ICP-MS from Thermo Fisher Scientific.

The mass spectrometer was fitted with a Fassel-type quartz torch, shielded with a grounded Pt electrode, and a quartz bonnet. The operating conditions and data acquisition parameters are detailed in Table 1.

Table 1. La-ICP-MS operating conditions and data acquisition parameters.

Parameter	Value
Laser system	
Instrument	New Wave Research NWR213 solid state Nd:YAG laser with aperture imaging
Laser wavelength	213 nm (Nd:YAG)
Laser mode	Q-switched (Nd:YAG)
Nominal pulse width	4 ns (Nd:YAG)
Repetition rate	10 Hz
Spot sizes (diameter)	25 μm
Incident pulse energy	0.05 mJ per pulse (at 25 μm beam size; 60%)
Energy density on sample	5-6 J/cm^2 (homogenized energy distribution)
Ablation cell	TV2 with custom sample holder
Ablation cell gas flow rates	850–920 ml/min He
Tubing for gas flow	Tygon S3 B44-3 and S-50 HL
Laser beam focus	Fixed at sample surface
ICP-MS instrument	
Instrument	Thermo-Fisher Scientific ELEMENT 2 double-focusing magnetic sector-field ICP-MS
Interface cones	Ni Jet and H-type skimmer cone
Detector type	single-collector discrete dynode electron multiplier
Detector mode	cross-calibrated pulse counting and analogue
Detector vacuum	10^{-7} mbar (during analysis)
Argon gas flow rates (l/min):	
• Plasma	16
• Auxiliary	0.85
• Sample	0.940–0.995
• RF power	1350 W (tuned every day)
Lenses (V):	
• Extraction	-2000
• Focus	-1050 to -1075
• X-Deflection	4.39

Parameter	Value
• Y-Deflection	-3.41
• Shape	111
• SEM potential	210 V
Data acquisition	
Isotopes measured (sampling time in brackets)	^{202}Hg (10), Mass 204 (^{204}Hg + ^{204}Pb) (20), ^{206}Pb (20), ^{207}Pb (50), ^{208}Pb (10), ^{232}Th (10), ^{238}U (20)
Settling times	1 ms
Search and integration window	4%
Samples per peak	100
Aquisition mode	Time resolved analysis
Scan type	E-scan
Detection mode	Both
Integration type	Average
Mass resolution	300 (low resolution)
Oxide production rate	Tuned to ≤ 0.3% UO (^{254}UO/^{238}U)
Analysis duration	30 s. blank, 35 s. ablation and 30 s. washout.
Data processing	
Software	Iolite vers. 2.5 (Hellstrom et al. 2008) including VizualAge DRS (Petrus & Kamber 2012)
External standardization	GJ-1 (with Harvard 91500 and Plesovice zircons for secondary control)
Internal standard isotope	^{238}U

To ensure stable laser output energy, a laser warm-up time of at least 15 minutes was applied before operation, providing stable laser power and flat ablation craters by a "resonator-flat" laser beam. The mass spectrometer was run for at least one hour before analyses to stabilise the background signal. Prior to loading, samples and standards were carefully cleaned with ethanol to remove surface contamination. After insertion, the ablation cell was flushed with helium gas to minimise the gas blank level. The ablated material was swept by the helium carrier gas and mixed with argon gas c. 0.5 m before introduction into the plasma in the interface region of the mass spectrometer.

Just before the beginning of analysis, the ICP-MS was optimised at dry plasma conditions through continuous linear ablation of the GJ-1 zircon standard. The signal-to-noise ratio for the heavy mass range of interest (i.e. from ^{202}Hg to ^{238}U), emphasising on ^{238}U and ^{206}Pb, was maximised, while at the same time opting for low element-oxide production level by minimising the ^{254}UO/^{238}U ratio. To minimise instrumental drift a standard-sample-standard analysis protocol was followed, bracketing eight sample analyses by three measurements of the standard GJ-1 zircon (Jackson et al. 2004). The standard zircons, Harvard 91500 (Wiedenbeck et al. 1995, 2004) and Plesovice (Slama et al. 2008) were inserted for quality control of the standard analyses, yielding an internal precision of <3% (2 S.E.) and an average age accuracy within 3% deviation from reference values. Data were acquired from single spot analysis of 25 μm in the zircon grains. Analyses were run with a nominal laser fluence of ~5-6 J/cm^2 and a repetition rate of 10 Hz. Total acquisition time for single analysis was c. 1.5 minutes, including 30 seconds background measurement followed by laser ablation for 35 seconds and washout for 30 seconds. Factory-supplied software was used for the acquisition of the transient data, obtained through automated running mode of pre-set analytical locations. Data reduction was performed off-line through the software Iolite v. 2.5 and iolite4 (Hellstrom et al. 2008, Paton et al. 2011), using the visualisations plugin VizualAge data reduction scheme (DRS) routine (Petrus & Kamber 2012),

which includes a correction routine for down-hole isotopic fractionation (Paton et al. 2010), and provides routines for data that require correction for common Pb.

Spot analysis locations were selected on basis of the "best spot location", i.e. where there are a minimum number of inclusions, cracks or other impurities (optimally there are none), and preferably where zoning is controllable or visible (at least in 2D flat surface perspective). Also, other parameters as e.g. thickness of the grain that benefits optimal conditions for the analysis were considered.

Depending on the number of zircon analyses and the number of age populations that occur in a given rock sample, statistics then provide an estimate of the age proportions that are representative of the rock. There is always a possibility for some bias and variation, especially if there are many different input age populations.

The results of the analyses are presented in stacked diagrams for each sampling area. The diagrams show combined 1,500–3,500 Ma binned frequency histograms and kernel density estimates (e.g. Vermeesch 2012). They also show calculated maximum probability ages for distinct distribution peaks of zircon populations from a single sample, using coupled $^{206}Pb/^{238}U$ and $^{207}Pb/^{206}Pb$ age pairs. A fixed bin size of 35 m.yr./bin and a Concordia Filter of ± 10% were used.

Results

All samples were collected as part of the Västernorrland Lithium Bedrock Mapping Project (2021–2027) within the Bothnia–Skellefteå lithotectonic unit (Stephens & Bergman 2020). The descriptions of the rock samples in this report are mainly based on field observations. When available, grain size determinations were obtained from thin-section analyses.

A compilation of data for all samples is provided in Table 2.

Tabel 2. Sample list in order of description. Z= zircon analysis, G=geochemical analysis, T=Thin section. Coordinates are given in the reference system SWEREFF 99 TM.

No	Sample	Locality	Analysis type	N	E	Rock type
1	MSI220061A	Sollefteå-Rödsta	Z, G, T	7004955	609765	Meta-greywacke to quartz wacke
2	ELH220054A	Järkvissle power plant	Z, G, T	6964209	584884	Meta-greywacke
3	SPN221091A	Jamttjärnen	Z, G, T	6950943	539596	Meta-greywacke
4	SPN221080B	North of Kattviken	Z, G, T	6963287	654618	Meta-greywacke
5	MSI230099A	Gräsmyrberget	Z, G, T	6985206	614707	Sand rich meta-sedimentary rock
6	ELH230109A	Lidens-Backen	Z, G, T	6954701	597246	Metasedimentary rock with volcaniclastic interbed
7	ELH230119A	Lappberget	Z, G, T	6959863	601148	Well sorted sand rich metasedimentary rock
8	SPN230583A	Trehörningen	Z, G, T	6964028	637691	Metagreywacke to siltstone
9	SPN230551A	Grössjön	Z, G, T	6984545	635369	Migmatised metagreywacke
10	SPN230523A	Grundsjön-Tallmyran	Z, G, T	6969279	635257	Moderately to poor sorted metagreywacke
11	MSI210053A	Utvik	G, T	6971416	651708	Meta- greywacke
12	ELH220153A	Bjästa	G, T	7011941	674536	Foliated, folded metagreywacke

Of a total of 12 samples, two samples (ELH220153A and MSI210053A) did not contain zircon, while the remaining 10 samples yielded 1,112 zircon U-Pb analyses. Among these, 228 zircons were corrected for common lead content. All valid analyses fall within the 90–110% concordance interval compared to the Concordia (100%) on a Wetherill (1956) diagram, which was used for interpretation in this study. From the 1,112 analyses, four percentage ranges were selected to classify zircon ages in 50-million-year (50 Myr) intervals. The ranges were

- <2%
- ≥2% to <8%
- ≥8% to <18%
- ≥18%.

This classification method follows the approach of Kathol et al. (2020), allowing for a comparison of results with the southern extension of the Bothnian basin in the study area. A summary of the analyses is provided in Appendix 1 and illustrated in Figures 2–4.

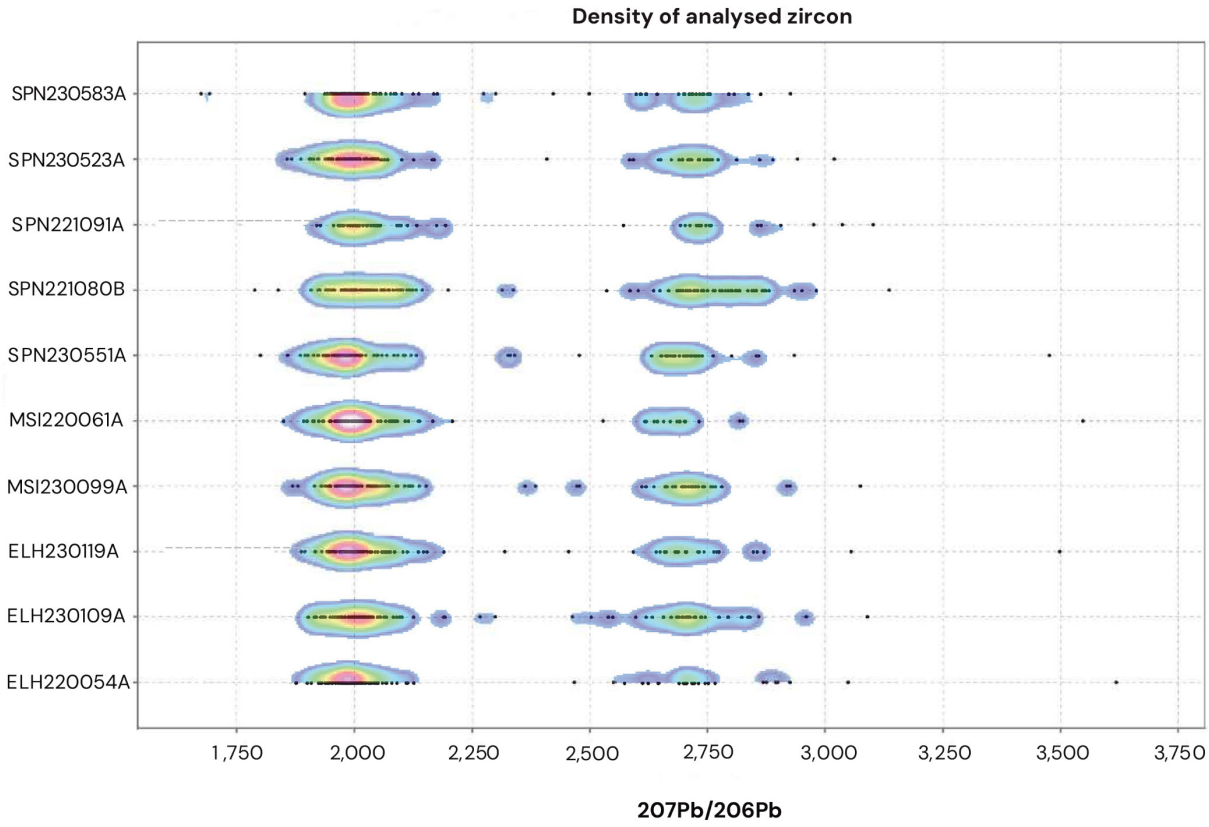


Figure 2. The density of detrital zircon $^{207}Pb/^{206}Pb$ ages for zircons respective sample site. Red represents a higher concentration of zircons. Visually the figure shows two distinct ages of 1.95–2.05 and 2.65–2.75 Ma population for all samples.

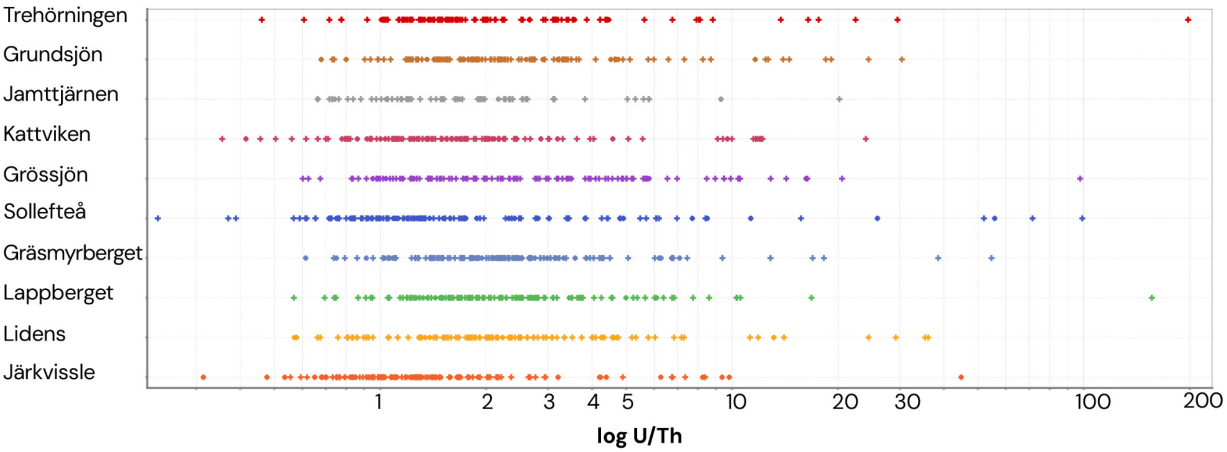


Figure 3. The range of U/Th contents of detrital zircons from the respective samples.

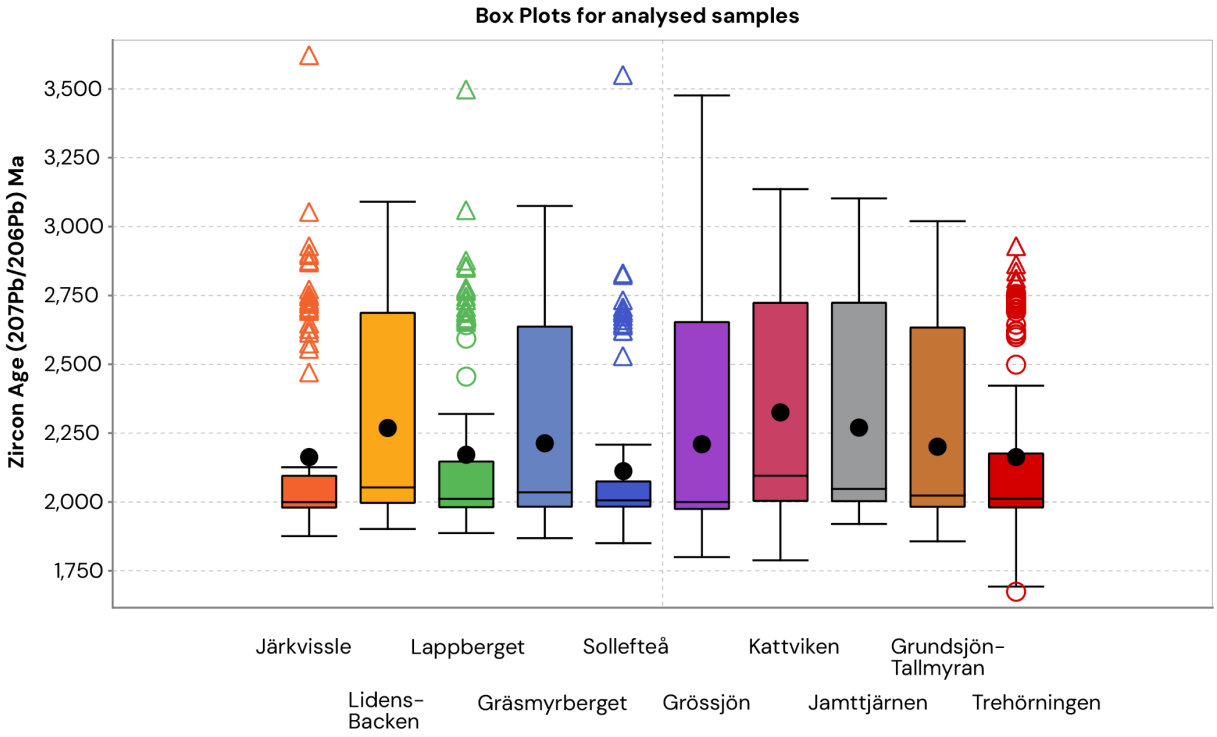


Figure 4. Box-and-whisker diagram for the zircon ages of the respective samples. Each box plot shows the Q1 (bottom of the box), median (line), Q3 (top of the box) and mean (black circle). The central box is the middle 50% of data from Q1 to Q3. An outlier (circle) is further than 1.5* (Q3-Q1) from the box. A far outlier (triangle) is further than 3.0* (Q3-Q1) from the box. The Whisker are the extreme values that are not outliers.

Description of rock samples

Sollefteå (Sample MSI220061A)

This sample were taken from a quarry near to Sollefteå–Rödsta mostly dominated of foliated and moderately sorted metagreywacke (Fig 5A–B) and partly show weak alteration mostly close to the faults and fractures structures. In this sample, 123 zircon U–Pb dates were obtained. Of these, 87 analyses fall within the 90–110% Concordia interval, while 35 zircon dates required correction for common lead.

The U/Th ratios range from 0.233 to 99 ppm, with a mean of 4.58 ppm and a median of 1.3 ppm. The 25th and 75th percentile U/Th ratios are 0.92 and 2.81, respectively (Appendix 1). Notably, 87% of the analysed zircons have U/Th ratios below 5.0.

The zircon age distribution shows the following:

- 33% of the zircons fall within the 1,950–1,999 Ma range, with a maximum probability peak at 1,978 Ma.
- 30% of the zircons fall within the 2,000–2,049 Ma range, with peaks at 2,030 Ma and 2,040 Ma.
- 8% of the zircons date to 2,050–2,099 Ma.
- The youngest zircon is dated to 1,850 Ma, while the oldest is 3,548 Ma (Fig. 6).
- 15% of the zircons are of Archaean age, with a maximum at 2,700 Ma, while 5% fall within the 2,650–2,699 Ma range (Fig. 6).

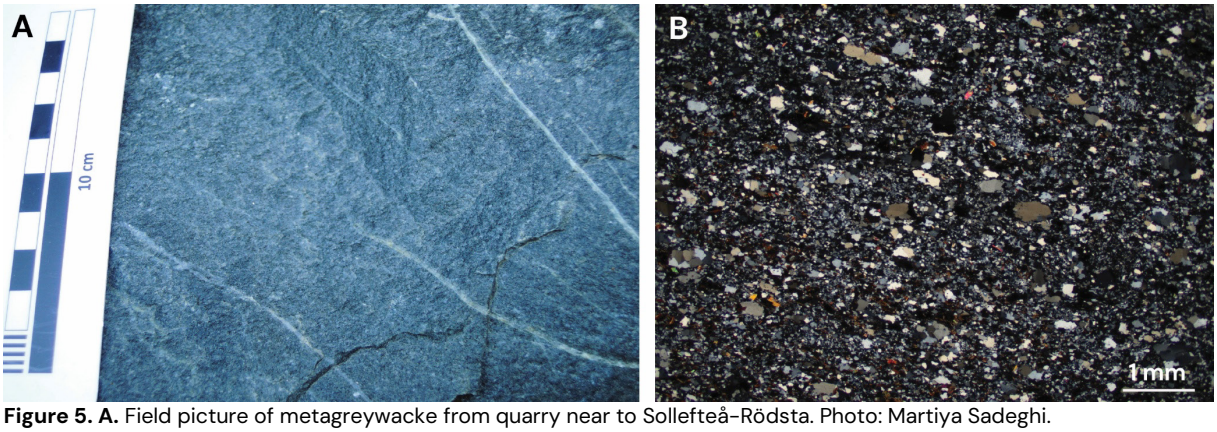


Figure 5. A. Field picture of metagreywacke from quarry near to Sollefteå–Rödsta. Photo: Martiya Sadeghi.
B. Photomicrograph of slightly foliated, moderately sorted metagreywacke with altered zones of chloritization and sericitization in proximity to healed fractures. Crossed nicols. Photo: Pauline Jeanneret.

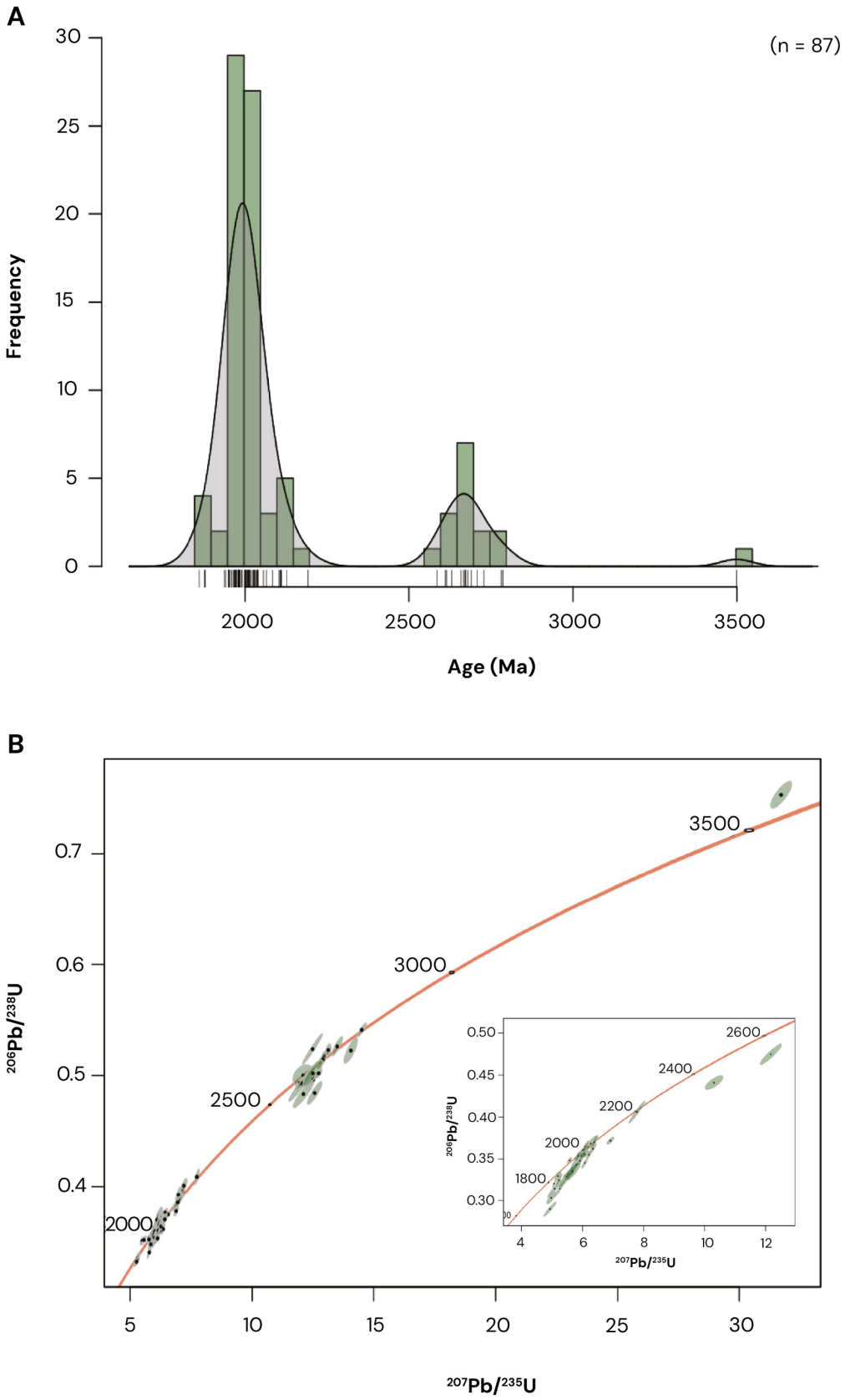


Figure 6. A. Combined binned frequency histogram and kernel density estimate (KDE) from the Sollefteå area sample with calculated maximum probability ages for distinct distribution peaks of zircon populations, using $^{207}Pb/^{206}Pb$ single zircon mineral dates. A fixed bin size of 35 m.yr./bin and a concordant filter of ± 10% are used. **B.** Concordia plot for zircons analysed from this sample, with the inset diagram showing the concordia for Pb-common-corrected zircons.

Järkvissle (Sample ELH220054A)

This sample is dominantly metapelitic schist consisting of quartz and biotite and characterised by biotite schistosity. There are quartz-rich layers affected by shear-band associated with chlorite. In this sample (Fig. 7), 122 zircon U–Pb dates were obtained. Of these, 70 zircon dates fall within the 90–110% concordia interval, while 52 dates required correction for common lead.

The U/Th ratios range from 0.314 to 44.8 ppm, with a mean of 2.2 ppm and a median of 1.26 ppm. The 25th and 75th percentile U/Th ratios are 0.96 and 1.90, respectively (Appendix 1). Notably, 92.7% of the analysed zircons have U/Th ratios below 5.0.

The zircon age distribution shows the following:

- 39% of the zircons fall within the 1,950–1,999 Ma range, with maximum probability peaks at 1,983 Ma and 1,988 Ma.
- 20% of the zircons fall within the 2,000–2,049 Ma range, with peaks at 1,999 Ma and 2,008 Ma.
- 6% of the zircons date to 1,900–1,949 Ma.
- The youngest zircon is dated to 1,876 Ma, while the oldest is 3,619 Ma (Fig. 8).
- 22% of the zircons are of Archaean age, with 7% falling within the 2,700–2,749 Ma range (Fig. 8).

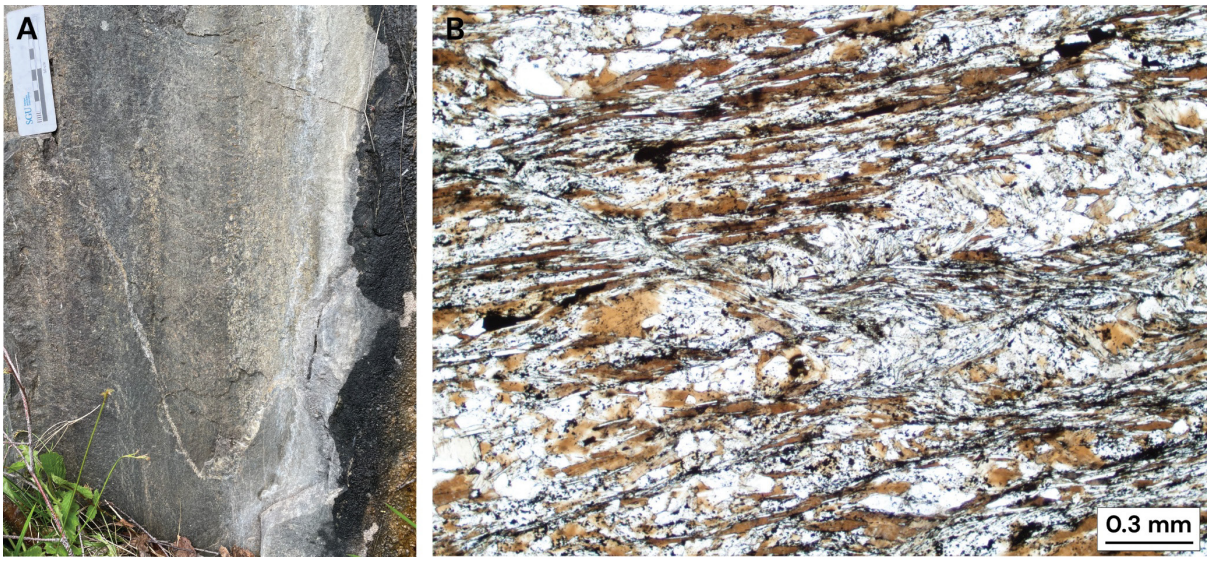


Figure 7. A. Field picture of the sample taken 100 m SE of sample location within the same rock unit. Photo: Edward Lynch. **B.** Photomicrograph of metapelitic schist consisting of 40% quartz, 25% biotite and 30 % sillimanite. The main schistosity is characterised by biotite, sillimanite, and quartz-rich layers, and is later affected by shear bands associated with chlorite, Plane-polarised light (PPL). Photo: Pauline Jeanneret.

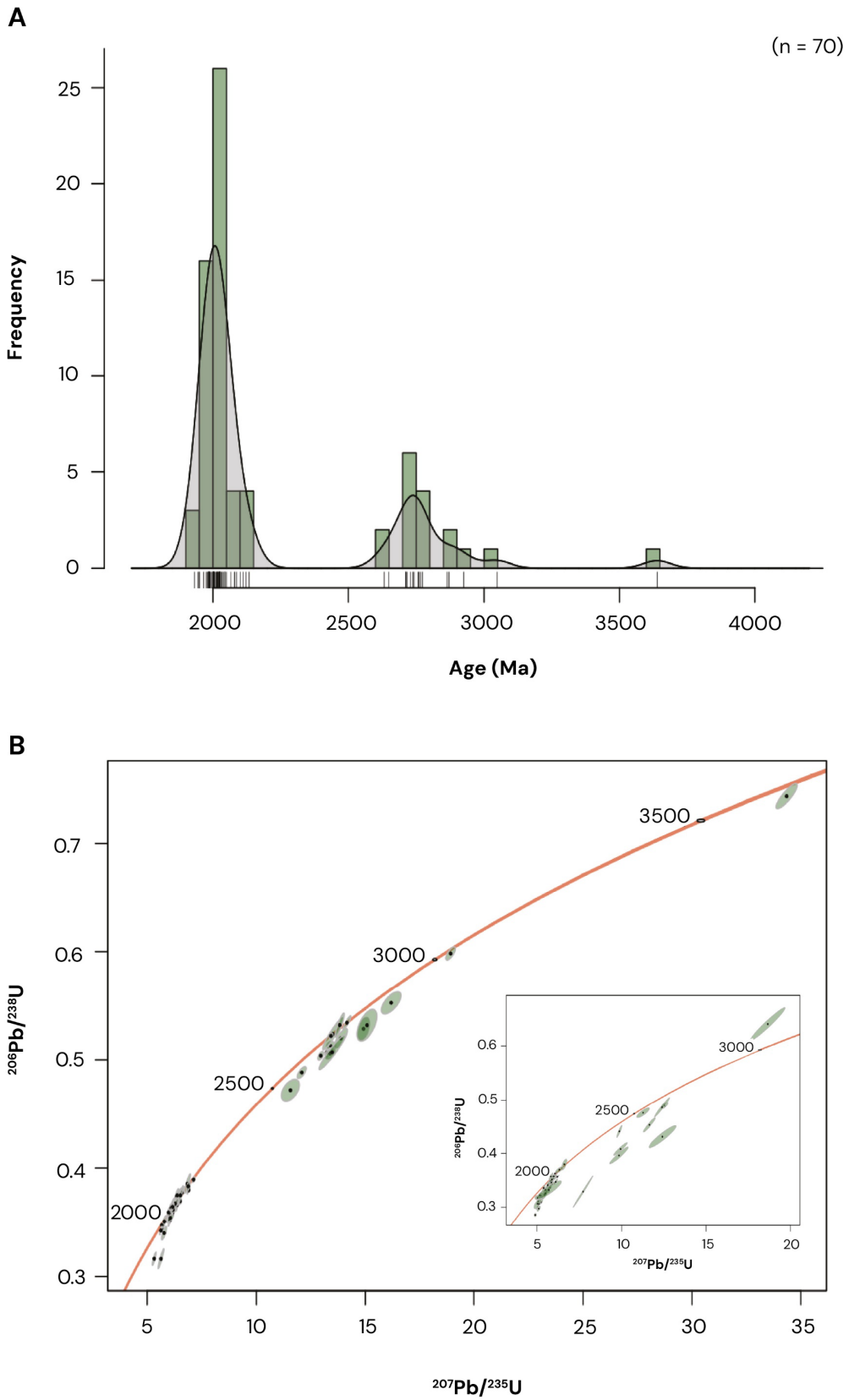


Figure 8. A. Combined binned frequency histogram and kernel density estimate (KDE) from the Järkvissle sample with calculated maximum probability ages for distinct distribution peaks of zircon populations, using $^{207}Pb/^{206}Pb$ single zircon mineral dates. A fixed bin size of 35 m.yr./bin and a concordant filter of ± 10% are used. **B.** Concordia plot for zircons analysed from this sample, with the inset diagram showing the concordia for Pb-common-corrected zircons.

Jamttjärnen (sample SPN221091A)

The sample is well sorted, layered, foliated and folded metagreywacke with phyllitic layers. The grain size in the sandy layer is very fine to fine sand (<0.25 mm). The phyllitic layer has grain sizes of about 0.005 to 1 mm. In this sample (Fig. 9), 60 zircon U–Pb dates were obtained. Of these, 54 analyses fall within the 90–110% concordia interval, while 6 zircon dates required correction for common lead.

The U/Th ratios range from 0.664 to 20.2 ppm, with a mean of 2.28 ppm and a median of 1.64 ppm. The 25th and 75th percentile U/Th ratios are 1.1 and 2.45, respectively (Appendix 1). Notably, 88.4% of the analyzed zircons have U/Th ratios below 5.0.

The zircon age distribution shows the following:

- 28% of the zircons fall within the 2,000–2,049 Ma range, with maximum probability peaks at 2,003 Ma and 2,009 Ma.
- 20% of the zircons fall within the 1,950–1,999 Ma range, with a peak at 1,976 Ma.
- 8% of the zircons date to 2,050–2,099 Ma.
- The youngest zircon is dated to 1,920 Ma, while the oldest is 3,102 Ma (Fig. 10).
- 33% of the zircons are of Archaean age, with 15% falling within the 2,700–2,749 Ma range (Fig. 10).

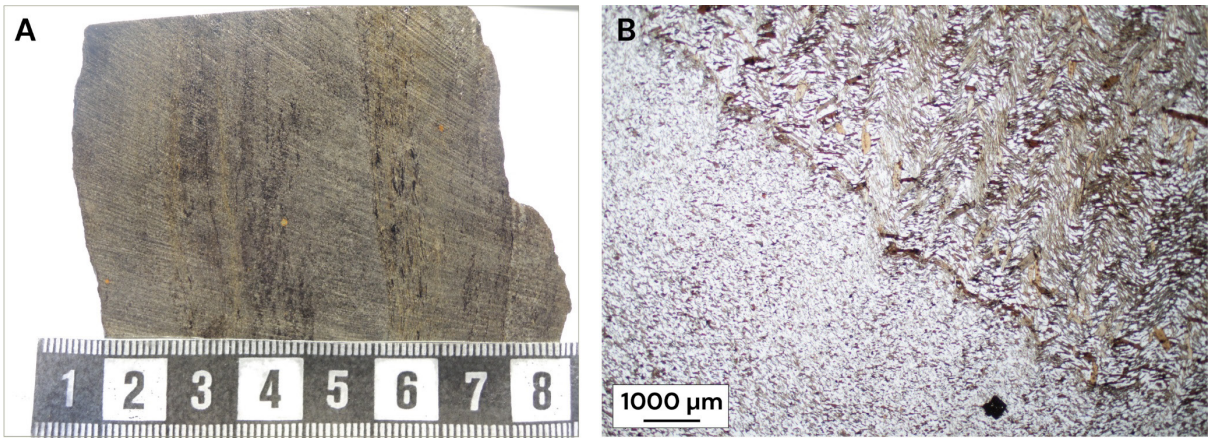


Figure 9. A. Hand specimen of the sample representing a well sorted, layered, foliated and folded metagreywacke with phyllitic layers. Photo: Stefan Persson. **B.** Photomicrograph of the sample show well-developed crenulation schistosity. The compositional layering is preserved and marked by the mica content. The grain size in the sandy layer is very fine to fine sand (is mostly below 0.25 mm) and the grain sizes are 0.005-1 mm in the phyllite layers. Plane-polarised light (PPL), Photo: Pauline Jeanneret.

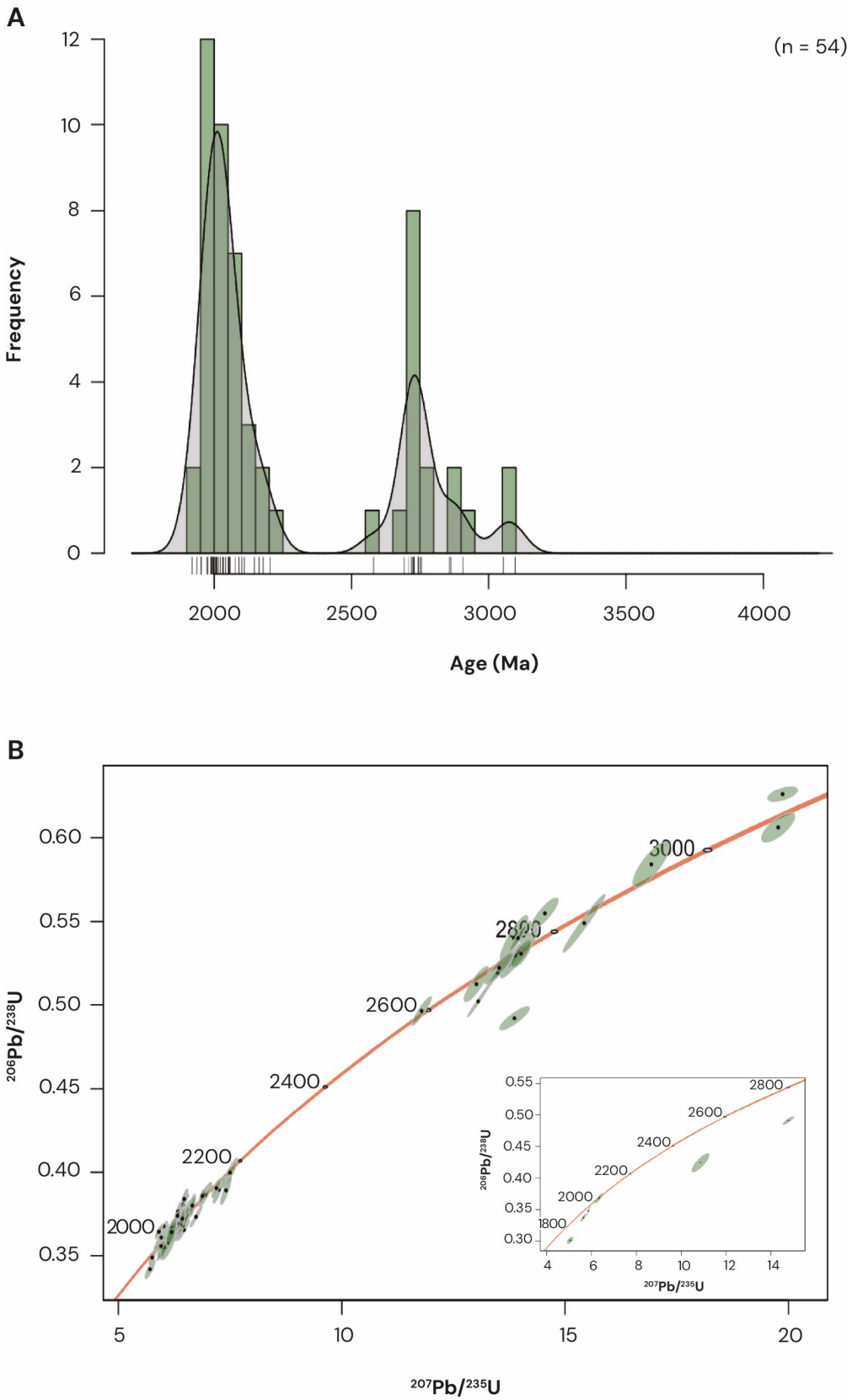


Figure 10. A. Combined binned frequency histogram and kernel density estimate (KDE) from the Jamttjärnen sample with calculated maximum probability ages for distinct distribution peaks of zircon populations, using $^{207}Pb/^{206}Pb$ single zircon mineral dates. A fixed bin size of 35 m.yr./bin and a concordant filter of ± 10% are used. **B.** Concordia plot for zircons analysed from this sample, with the inset diagram showing the concordia for Pb-common-corrected zircons.

Norra Kattviken (Sample SPN221080B)

This sample is a moderately sorted, layered and foliated metagreywacke with porhyroblasts of mica in metapelitic layers. The grain size in the sandy layer is very fine to coarse sand (0.05–0.9 mm). The metapelitic layer has grain sizes of about 0.005 to 1 mm. The metagreywacke occurs as small to large xeonliths in sizes from dm to tens of meters in granite. Both granite and metagreywacke are cut by younger granitic pegmatite at this location. In this sample (Fig. 11), 122 zircon U–Pb dates were obtained. Of these, 86 analyses fall within the 90–110% concordia interval, while 36 zircons dates required correction for common lead.

The U/Th ratios range from 0.355 to 24 ppm, with a mean of 2.6 ppm and a median of 1.5 ppm. The 25th and 75th percentile U/Th ratios are 1.1 and 2.25, respectively (Appendix 1). Notably, 89.3% of the analysed zircons have U/Th ratios below 5.0.

The zircon age distribution shows the following:

- 16% of the zircons fall within the 2,050–2,099 Ma range, with a maximum probability peak at 2,061 Ma.
- 13% of the zircons fall within the 1,950–1,999 Ma and 2,000–2,049 Ma ranges, with peaks at 1,957 Ma and 2,041 Ma, respectively.
- 9% of the zircons date to 1,900–1,949 Ma.
- The youngest zircon is dated to 1,788 Ma, while the oldest is 3,136 Ma (Fig. 12).
- 42% of the zircons are of Archaean age, with 11% falling within the 2,700–2,749 Ma range and 6% falling within the 2,650–2,699 Ma, 2,750–2,799 Ma, and 2,800–2,849 Ma intervals (Fig. 12). The maximum peak in the Archaean zircons occurs at 2,723 Ma.

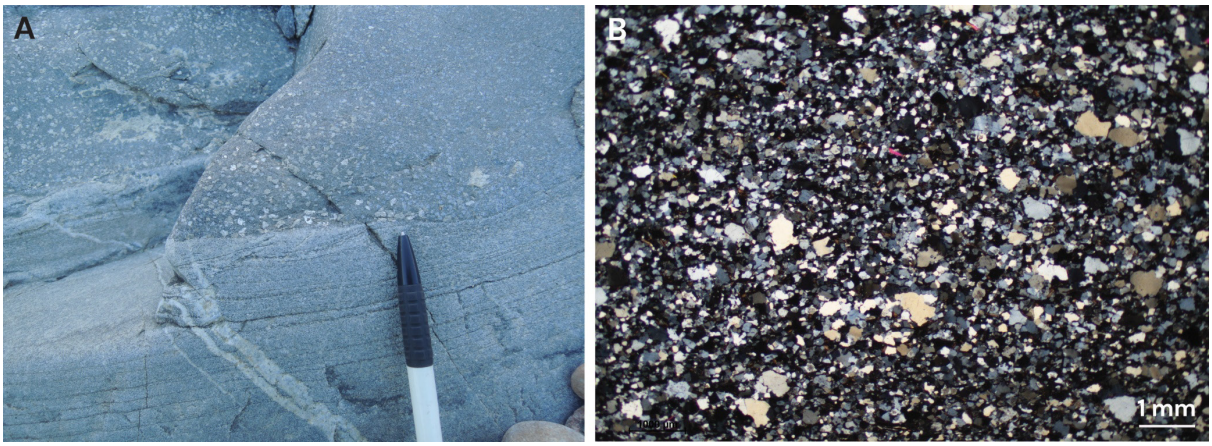


Figure 11. A. Field picture of the outcrop where the sample was taken. Layered, moderately sorted metagreywacke with a sharp layer boundary to a metapelitic layer showing porphyroblasts of muscovite, (upper part of picture). Photo: Stefan Persson. **B.** Photomicrograph of the moderately sorted metagreywacke, the grain size is mostly of 0,1-0,4 mm size but larger clasts of 0,4-0,9 mm are common. Crossed nicols. Photo: Pauline Jeanneret.

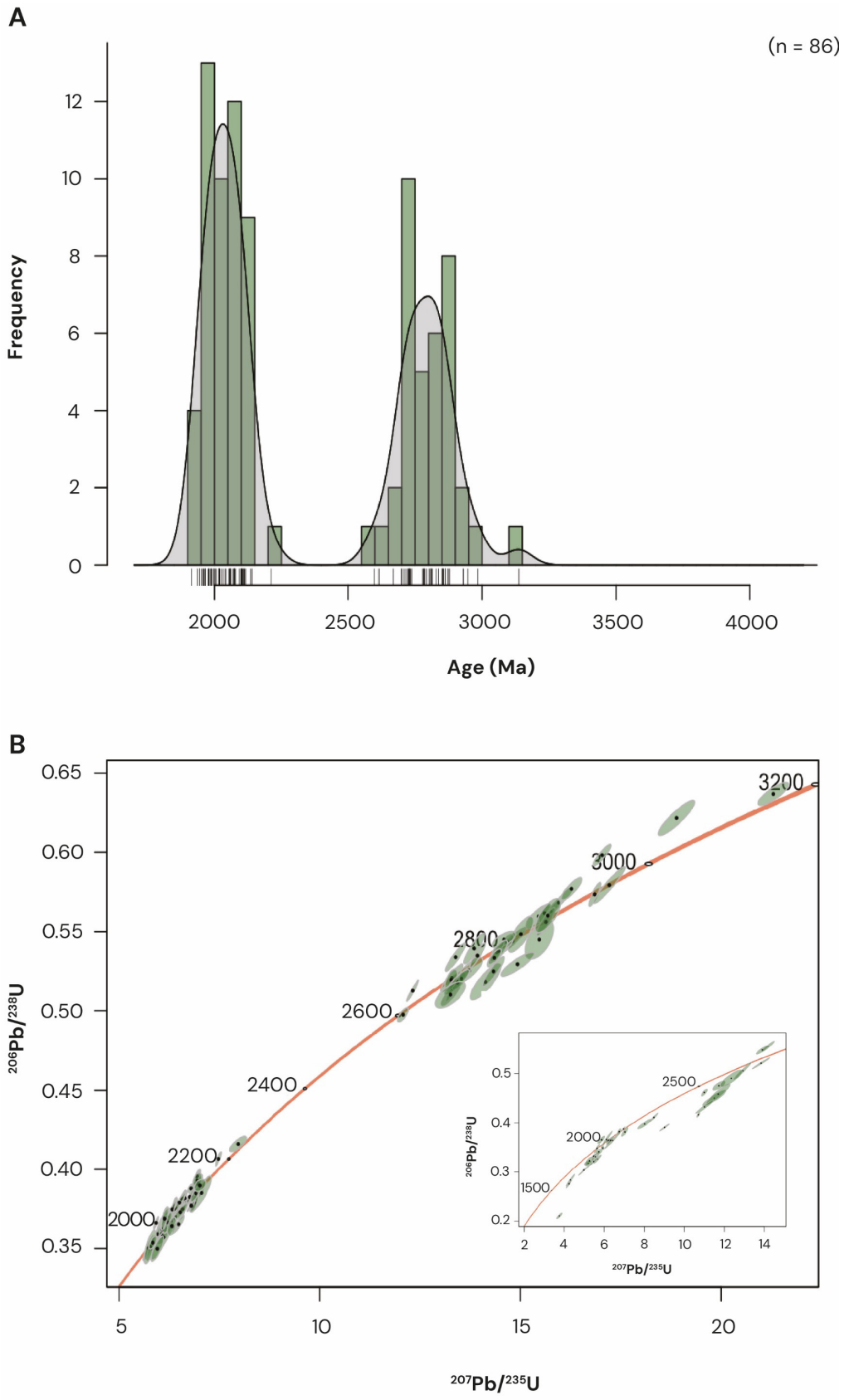


Figure 12. A. Combined binned frequency histogram and kernel density estimate (KDE) from the Norra Kattviken sample with calculated maximum probability ages for distinct distribution peaks of zircon populations, using $^{207}Pb/^{206}Pb$ single zircon mineral dates. A Fixed bin size of 35 m.yr./ bin and a concordant filter of ± 10% are used. **B.** Concordia plot for zircons analysed from this sample, with the inset diagram showing the concordia for Pb-common-corrected zircons.

Lidens-Backen (Sample ELH230109A)

In this sample (Fig. 13), 109 zircon U–Pb dates were obtained. Of these, 96 analyses fall within the 90–110% concordia interval, while 13 dates from zircons required correction for common lead.

The U/Th ratios range from 0.57 to 36.1 ppm, with a mean of 3.85 ppm and a median of 2.1 ppm. The 25th and 75th percentile U/Th ratios are 1.44 and 3.51, respectively (Appendix 1). Notably, 86.2% of the analyzed zircons have U/Th ratios below 5.0.

The zircon age distribution shows the following:

- 22% of the zircons fall within the 2,000–2,049 Ma range, with a maximum probability peak at 2,000 Ma.
- 17% of the zircons fall within the 1,950–1,999 Ma range, with a peak at 1,987 Ma.
- 11% of the zircons date to the 1,900–1,949 Ma range, with peaks at 1,918 Ma and 1,932 Ma.
- The youngest zircon is dated to 1,901 Ma, while the oldest is 3,090 Ma (Fig. 14).
- 36% of the zircons are of Archaean age, with 13% falling within the 2,700–2,749 Ma range, and 7% falling within the 2,650–2,699 Ma interval (Fig. 14). The maximum peak in the Archaean zircons occurs at 2,709 Ma.

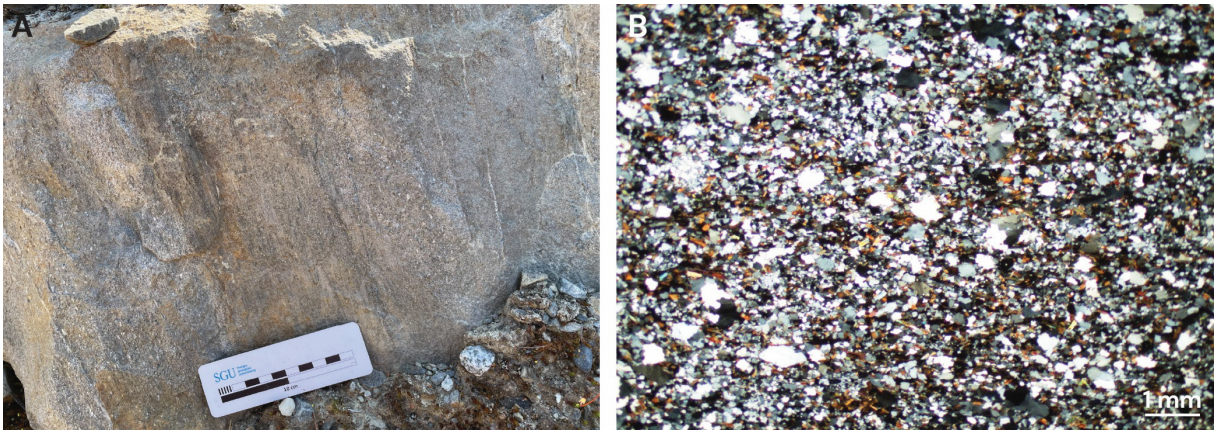


Figure 13. A. Field picture of well sorted to poorly sorted, sand rich and foliated metasedimentary rock with interlayers or interbeds containing deformed feldspar clasts. Photo: Edward Lynch. **B.** Photomicrograph shows a poorly sorted metagreywacke with a dominating grainsize of 0,05 to 1 mm but grains up to about 2 mm of quartz do occur. Crossed nicols. Photo: Pauline Jeanneret.

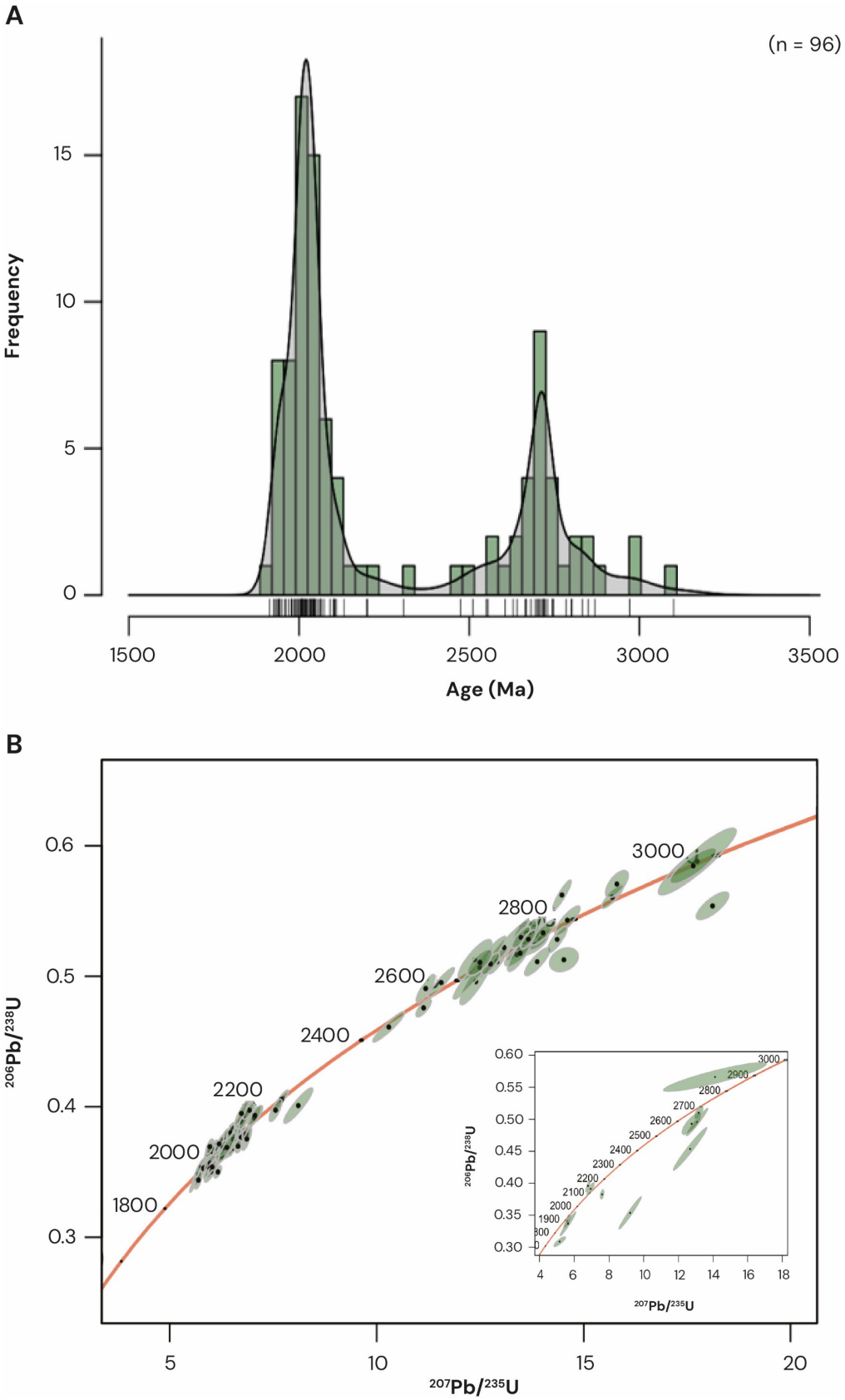


Figure 14. A. Combined binned frequency histogram and kernel density estimate (KDE) from the Lidens-Backen sample with calculated maximum probability ages for distinct distribution peaks of zircon populations, using $^{207}Pb/^{206}Pb$ single zircon mineral dates. A Fixed bin size of 35 m.yr./ bin and a concordant filter of ± 10% are used. **B.** Concordia plot for zircons analysed from this sample, with the inset diagram showing the concordia for Pb-common-corrected zircons.

Lappberget (Sample ELH230119A)

This sample is a pelitic metasedimentary rock (Fig. 15) from which 111 zircon U–Pb dates were obtained. Of these, 98 dates from zircons fall within the 90–110% concordia interval, while 13 analyses required correction for common lead.

The U/Th ratios range from 0.57 to 156 ppm, with a mean of 4.22 ppm and a median of 2.1 ppm. The 25th and 75th percentile U/Th ratios are 1.48 and 3.1, respectively (Appendix 1). Notably, 86.4% of the analysed zircons have U/Th ratios below 5.0.

The age distribution of zircons shows the following:

- 32% of the zircons fall within the 1,950–1,999 Ma range, with maximum probability peaks at 1,969–1,979 Ma and 1,981 Ma.
- 20% of the zircons fall within the 2,000–2,049 Ma range, with peaks at 2,008 and 2,010 Ma.
- Approximately 10% of the zircons date to the 2,050–2,099 Ma range, with a peak at 2,085 Ma.
- The youngest zircon is dated to 1,887 Ma, and the oldest to 3,498 Ma (Fig. 16).
- 21% of the zircons are of Archaean age, with 5% falling within the 2,650–2,749 Ma interval (Fig. 16). The maximum peak in the Archaean zircons is at 2,685 Ma.

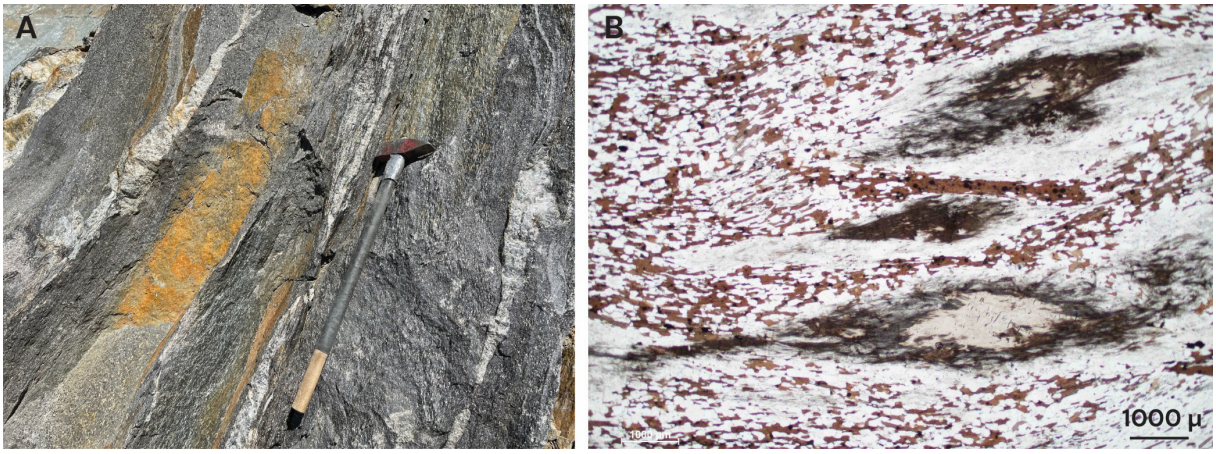


Figure 15. A. View to the 50-degree NE, inclined vertical surface showing pelitic metasedimentary rock with S1 schistosity planes, a well-developed L1-2 mineral lineation fabric, and stretched cordierite porphyroblasts. White domains are quartz ± feldspar veins with biotite-rich selvages. Photo: Edward Lynch. **B.** Photomicrograph of the sample shows fine grained, well sorted quartz-biotite-feldspar schist with porphyroblasts of fibrolitic sillimanite (grey) and flattened prismatic sillimanite cores (pale yellow). The main schistosity and lineation are defined by sillimanite-biotite. Plane-polarised light. Photo: Pauline Jeanneret.

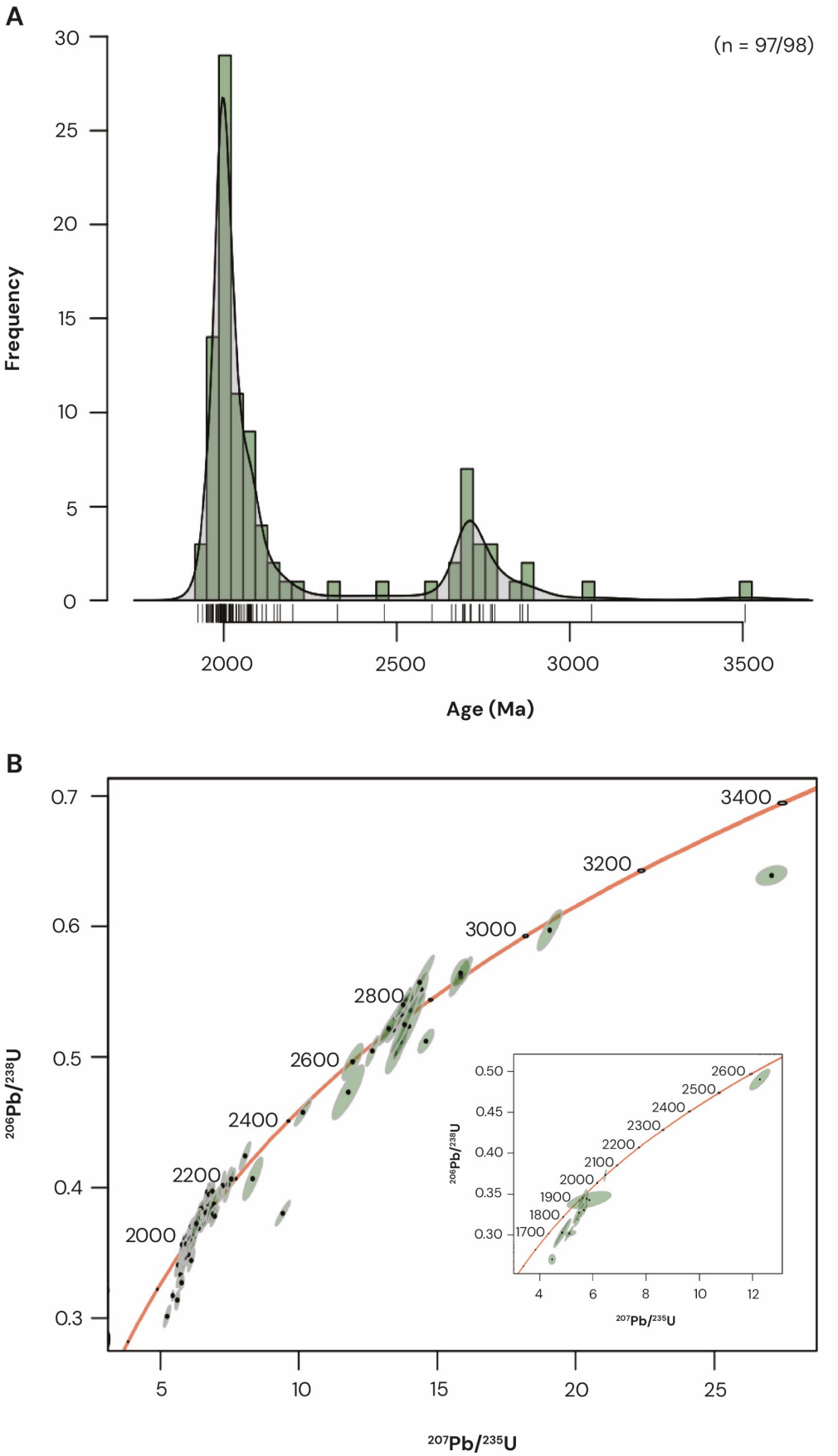


Figure 16. A. Combined binned frequency histogram and kernel density estimate (KDE) from the Lappberget sample with calculated maximum probability ages for distinct distribution peaks of zircon populations, using $^{207}Pb/^{206}Pb$ single zircon mineral dates. A fixed bin size of 35 m.yr./ bin and a Concordia Filter of ± 10% are used. **B.** Concordia plot for zircons analysed from this sample, with the inset diagram showing the concordia for Pb-common-corrected zircons.

Grundsjön–Tallmyran (Sample SPN230523A)

This sample is a moderately to poorly sorted, layered, recrystallised, L>S-tectonic and folded metagreywacke. The grain size in the groundmass is about 0,05 to 1 mm. Poorly sorted layers has grains up to 2–5 mm in size. In field, occurrence of calc-silicate pods and quartz veins was noted. (Fig. 17). In the sample, 112 zircon U–Pb dates were obtained. Of these, 90 analyses fall within the 90–110% concordia interval, and 22 dates required correction for common lead.

The U/Th ratios range from 0.67 to 30.4 ppm, with a mean of 3.66 ppm and a median of 2.1 ppm. The 25th and 75th percentile U/Th ratios are 1.51 and 3.35, respectively (Appendix 1). Approximately 85.74% of the analysed zircons have U/Th ratios below 5.0.

The age distribution of zircons shows the following:

- 25% of the zircons fall within the 1,950–1,999 Ma range, with a maximum probability peak at 1,983 Ma.
- 23% of the zircons fall within the 2,000–2,049 Ma range, with peaks at 2,012 Ma and 2,035 Ma.
- About 11% of the zircons fall within the 1,900–1,949 Ma range.
- The youngest zircon was dated to 1,857 Ma, and the oldest to 3,020 Ma (Fig. 18).
- 28% of the zircons are of Archaean age, with 10% falling within the 2,700–2,749 Ma interval, and 6% of the zircons fall within the 2,650–2,699 Ma range (Fig. 18).

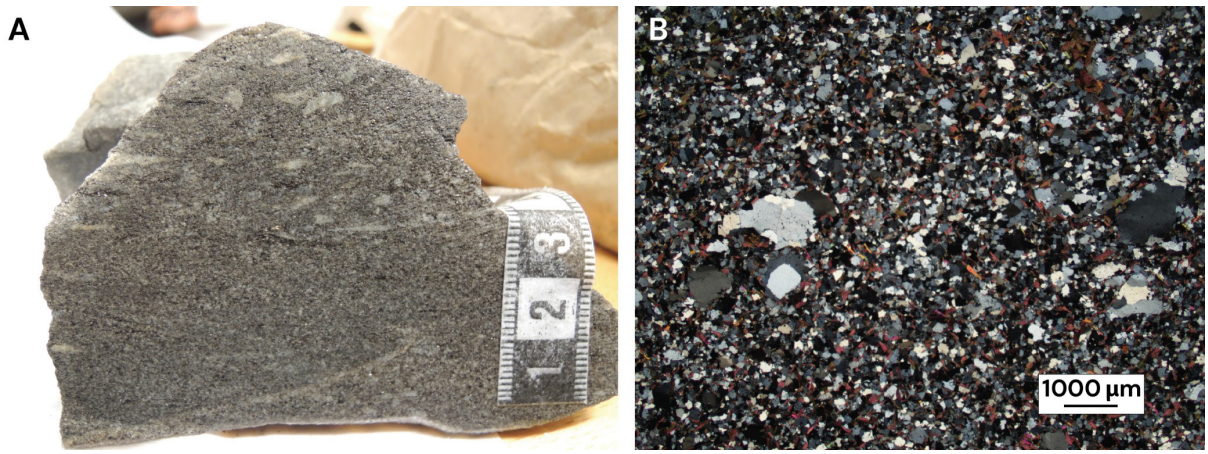


Figure 17. A. Hand-specimen of moderately to poorly sorted, layered, foliated metagreywacke, partly recrystallised, L>S-tectonic and folded metagreywacke. **B.** Photomicrograph of the thin section shows the grain size of groundmass is about 0.05-0,3 mm but there are layers with coarser grains of 2-5 mm. Crossed nicols. Photo: Pauline Jeanneret.

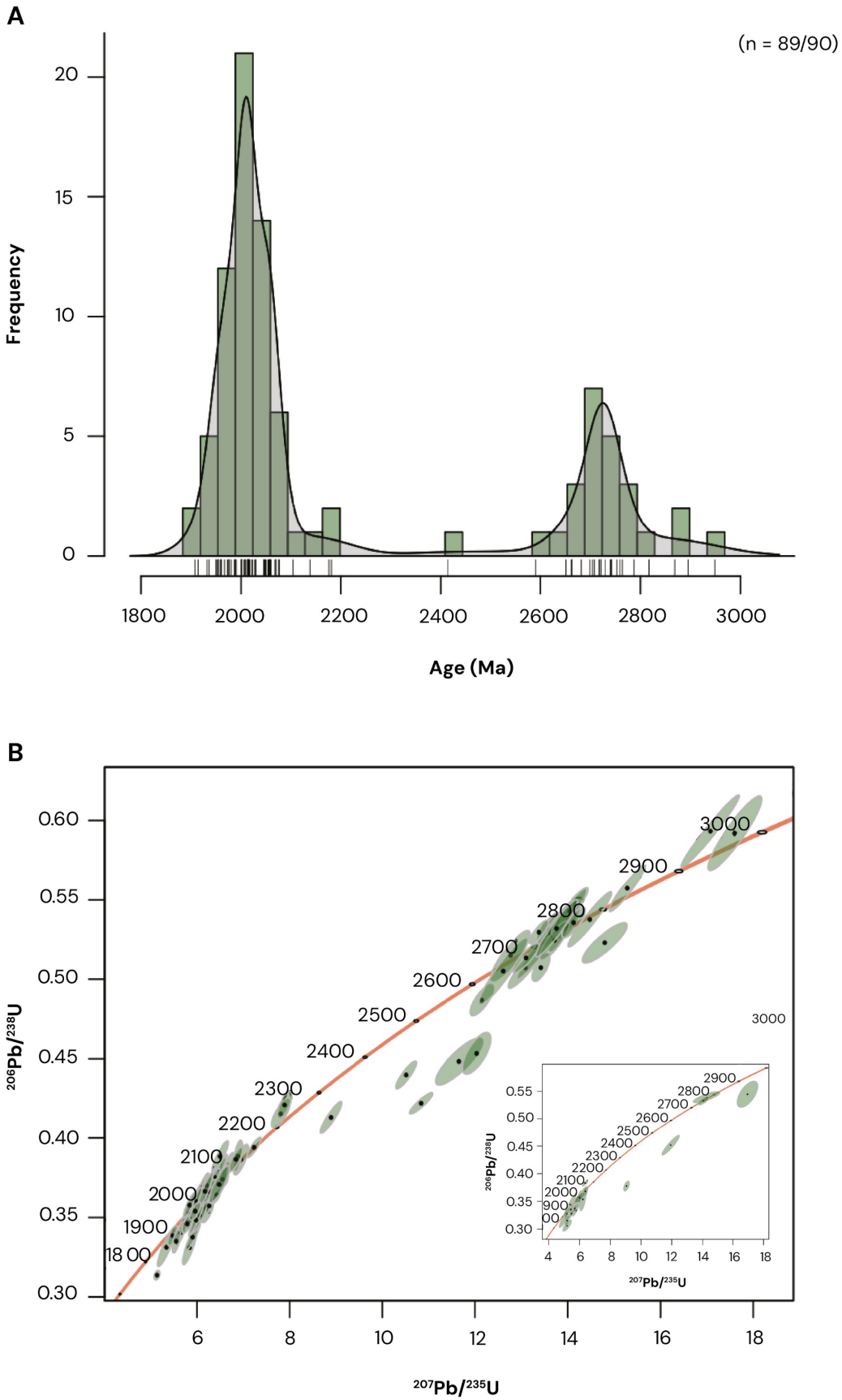


Figure 18. A. Combined binned frequency histogram and kernel density estimate (KDE) from the Grundsjön-Tallmyran area with calculated maximum probability ages for distinct distribution peaks of zircon populations, using $^{207}Pb/^{206}Pb$ single zircon mineral dates. A fixed bin size of 35 m.yr./ bin and a Concordia Filter of ± 10% are used. **B.** Concordia plot for zircons analysed from this sample, with the inset diagram showing the concordia for Pb-common-corrected zircons.

Grössjön (Sample SPN23O551A)

This sample is moderately to poorly sorted, layered, foliated, folded and recrystallised, rusty metagreywacke with schistose layers, containing graphite and sulfide minerals. Surrounding rock shows migmatitic veining. The grain size of the groundmass is 0,05 to 3 mm.

In the sample (Fig. 19), 114 zircon U–Pb dates were obtained. Of these, 105 dates fall within the 90–110% concordia interval, and 9 analyses required correction for common lead.

The U/Th ratios range from 0.60 to 97.6 ppm, with a mean of 4.49 ppm and a median of 2.27 ppm. The 25th and 75th percentile U/Th ratios are 1.38 and 4.56, respectively (Appendix 1). Approximately 78% of the analysed zircons have U/Th ratios below 5.0.

The age distribution of zircons shows the following:

- 34% of the zircons fall within the 1,950–1,999 Ma range, with a maximum probability peak at 1,985 Ma.
- About 11% of the zircons fall within the 1,900–1,949 Ma and 2,000–2,049 Ma intervals.
- The youngest zircon was dated to 1,799 Ma, and the oldest to 3,476 Ma (Fig. 20).
- 28% of the zircons are of Archaean age, with 12% falling within the 2,650–2,699 Ma range and 10% in the 2,700–2,749 Ma interval.
- The maximum peak of the Archaean zircons is at 2,653 Ma (Fig. 20).

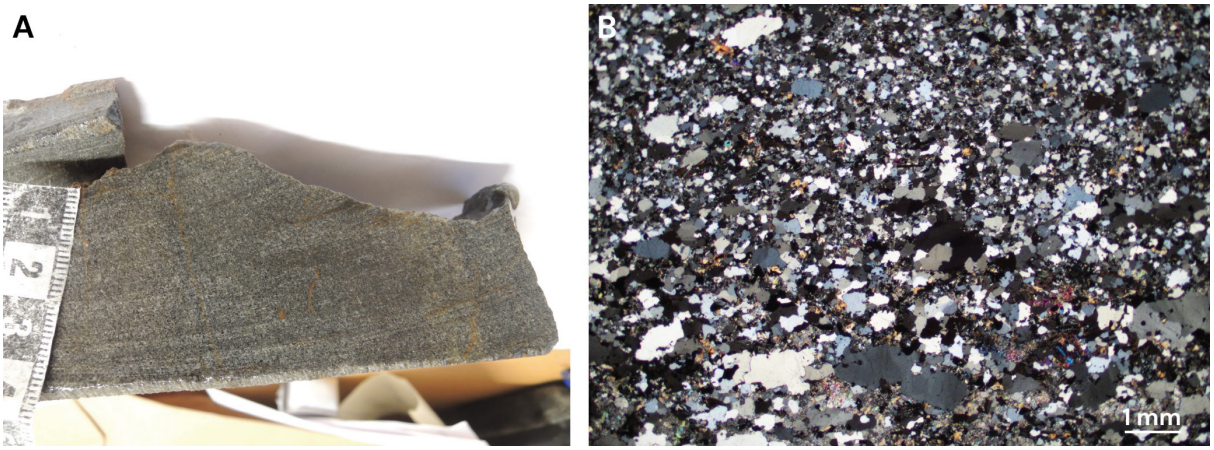


Figure 19. A. Hand-specimen of moderately to poorly sorted metagreywacke with rusty streaks containing iron sulphides. Photo: Stefan Persson. **B.** Photomicrograph shows a recrystallised metagreywacke with varying grainsize. Crossed nicols. Photo: Pauline Jeanneret.

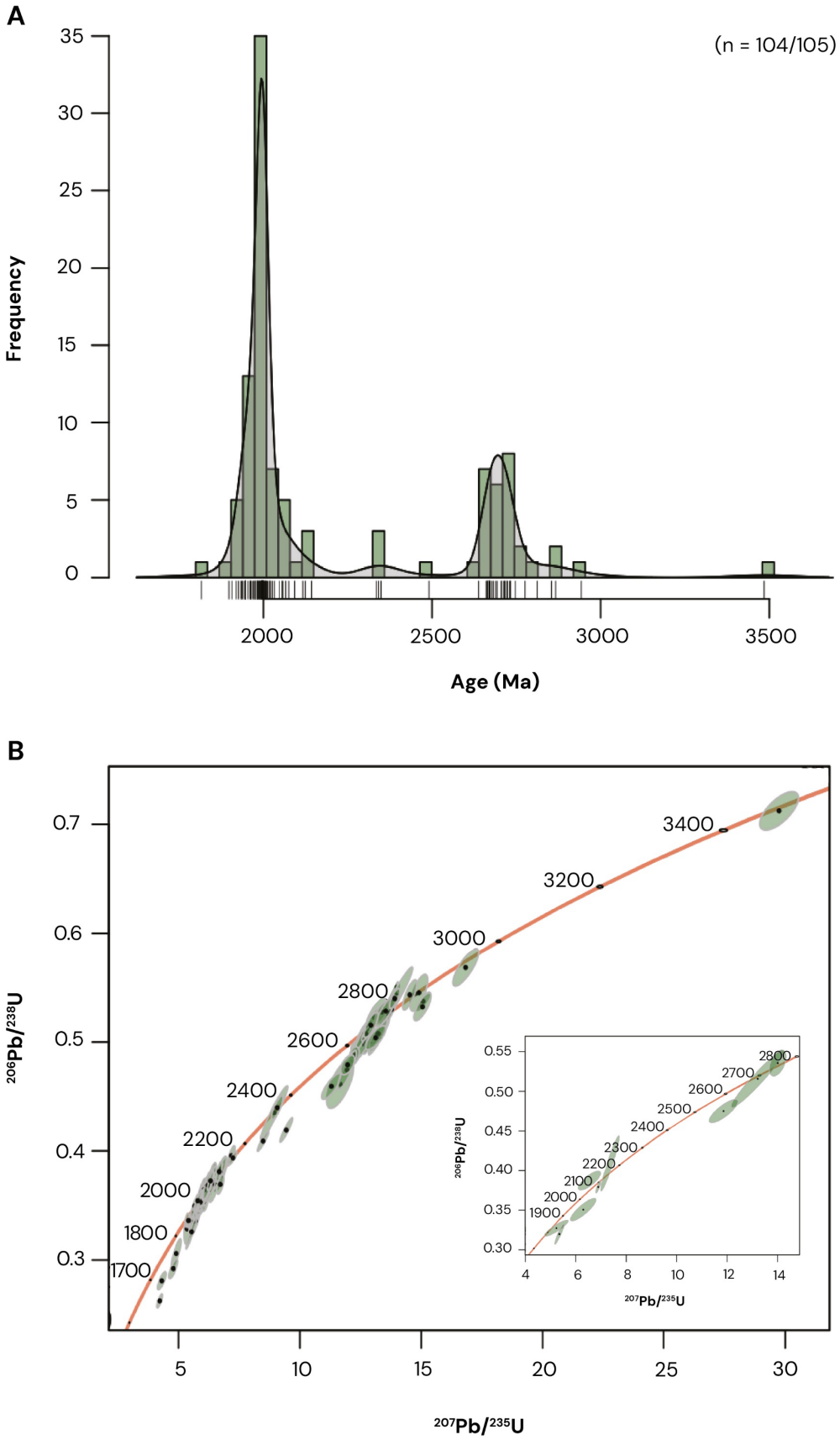


Figure 20. A. Combined binned frequency histogram and kernel density estimate (KDE) from the Grössjön area sample with calculated maximum probability ages for distinct distribution peaks of zircon populations, using $^{207}Pb/^{206}Pb$ single zircon mineral dates. A fixed bin size of 35 m.yr./ bin and a Concordia Filter of ± 10% are used. **A.** Concordia plot for zircons analysed from this sample, with the inset diagram showing the concordia for Pb-common-corrected zircons.

Trehörningen (Sample SPN230583A)

This sample is a mica-rich, folded, metapelitic schist with a well-developed schistosity. The grain size in the groundmass is 0,05–1,5 mm (Fig. 21). In the sample, 119 zircon U–Pb dates were obtained. Of these, 108 analyses of zircons fall within the 90–110% concordia interval, and 11 dates required correction for common lead.

The U/Th ratios range from 0.60 to 97.6 ppm, with a mean of 4.6 ppm and a median of 1.7 ppm. The 25th and 75th percentile U/Th ratios are 1.3 and 3.1, respectively (Appendix 1). 89.9% of the analysed zircons have U/Th ratios below 5.0.

The age distribution of zircons shows the following:

- 38% of the zircons fall within the 1,950–1,999 Ma range, with a maximum probability peak between 1,979–1,989 Ma.
- About 22% of the zircons fall within the 2,000–2,049 Ma range, with a maximum probability peak at 2,012 Ma.
- The youngest zircon was dated to 1,674 Ma, and the oldest to 2,926 Ma (Fig. 22).
- About 21.5% of the zircons are of Archaean age, with 8% falling within the 2,700–2,749 Ma range (Fig. 22).

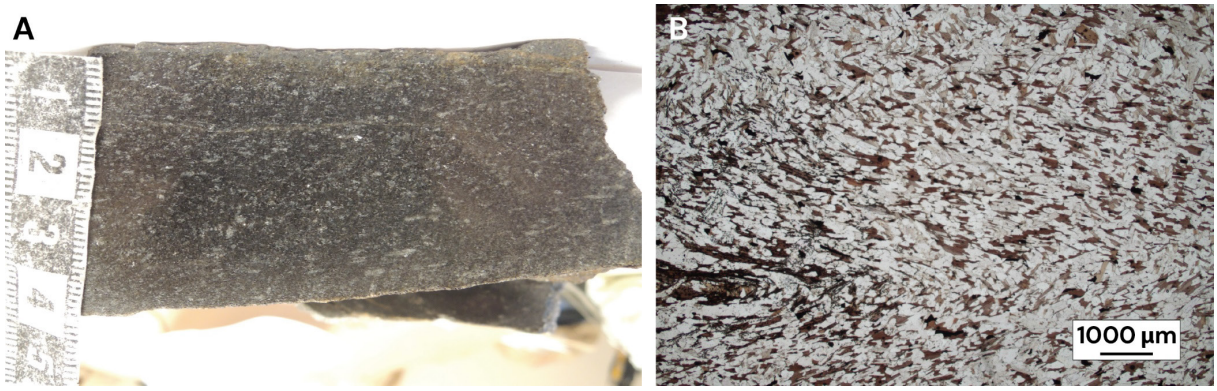


Figure 21. A. Hand-specimen of the sample, mica-rich, folded, metapelitic schist with a well-developed schistosity. The grain size in the groundmass is 0,05-1,5 mm. Photo: Stefan Persson. **B.** Photomicrograph of the sample shows biotite-muscovite rich pelitic schist showing isoclinal folds defined by muscovite-biotite. Plane-polarized light. Photo: Pauline Jeanneret.

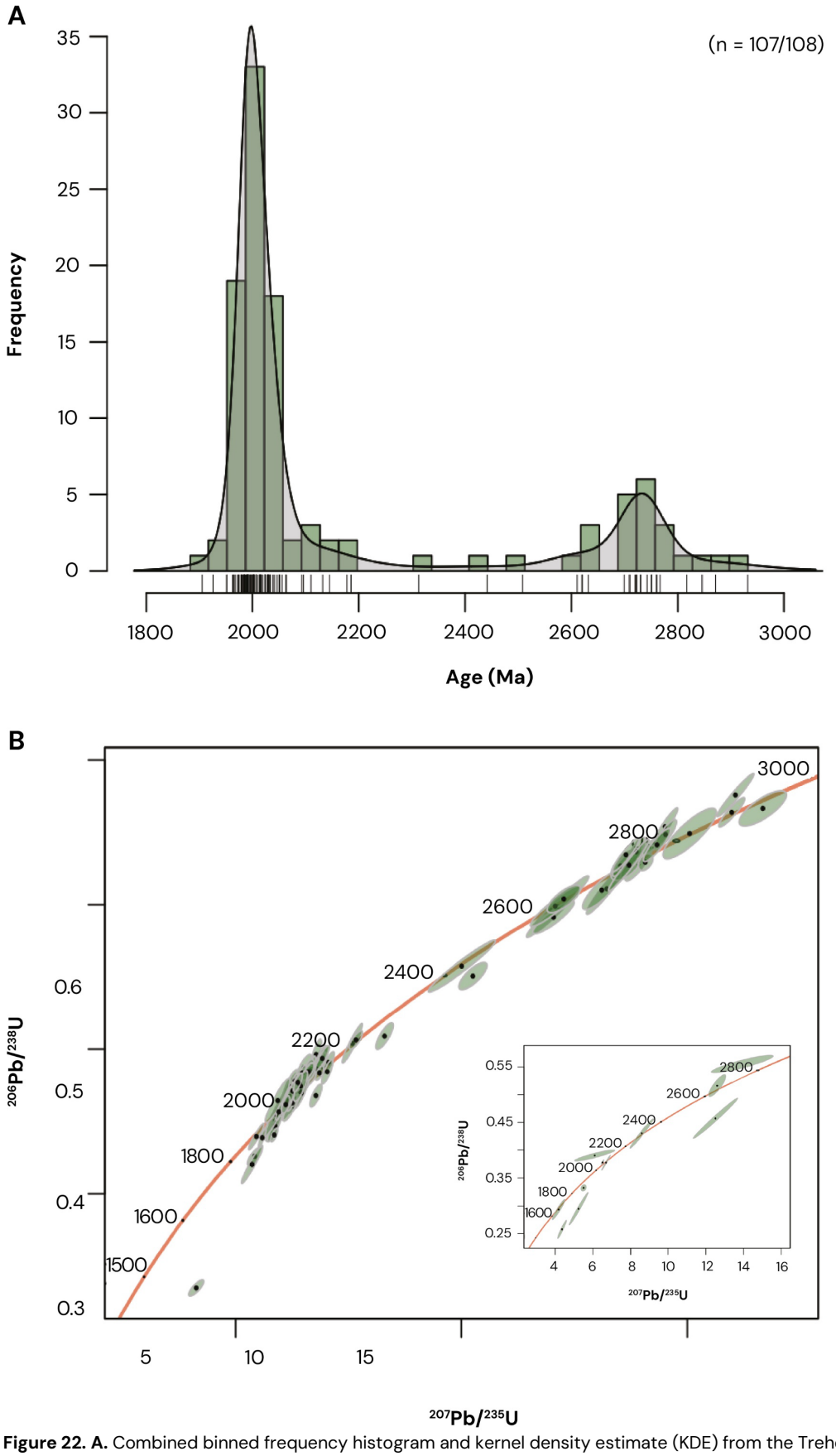


Figure 22. A. Combined binned frequency histogram and kernel density estimate (KDE) from the Trehörningen area sample with calculated maximum probability ages for distinct distribution peaks of zircon populations, using $^{207}Pb/^{206}Pb$ single zircon mineral dates. A fixed bin size of 35 m.yr./ bin and a Concordia Filter of ± 10% are used. **B.** Concordia plot for zircons analysed from this sample, with the inset diagram showing the concordia for Pb-common-corrected zircons.

Gräsmyrberget (Sample MSI230099A)

In this sample, mostly dominated by well sorted greywacke with weak foliation (Fig. 23), 123 zircon U–Pb dates were obtained. Of these, 93 analyses fall within the 90–110% concordia interval, and 30 dates required correction for common lead.

The U/Th ratios range from 0.61 to 54.6 ppm, with a mean of 3.58 ppm and a median of 2.2 ppm. The 25th and 75th percentile U/Th ratios are 1.50 and 3.0, respectively (Appendix 1). 87.8% of the analysed zircons have U/Th ratios below 5.0.

The age distribution of zircons shows the following:

- 32% of the zircons fall within the 1,950–1,999 Ma range, with a maximum probability peak at 1,978 Ma.
- About 15% of the zircons fall within the 2,000–2,049 Ma range.
- The youngest zircon was dated to 1,868 Ma, and the oldest to 3,074 Ma (Fig. 24).
- About 27% of the zircons are of Archaean age, with 12% falling within the 2,700–2,749 Ma range and 7% in the 2,659–2,699 Ma range (Fig. 24).
- The maximum peak in the Archaean zircons occurs at 2,700 Ma.

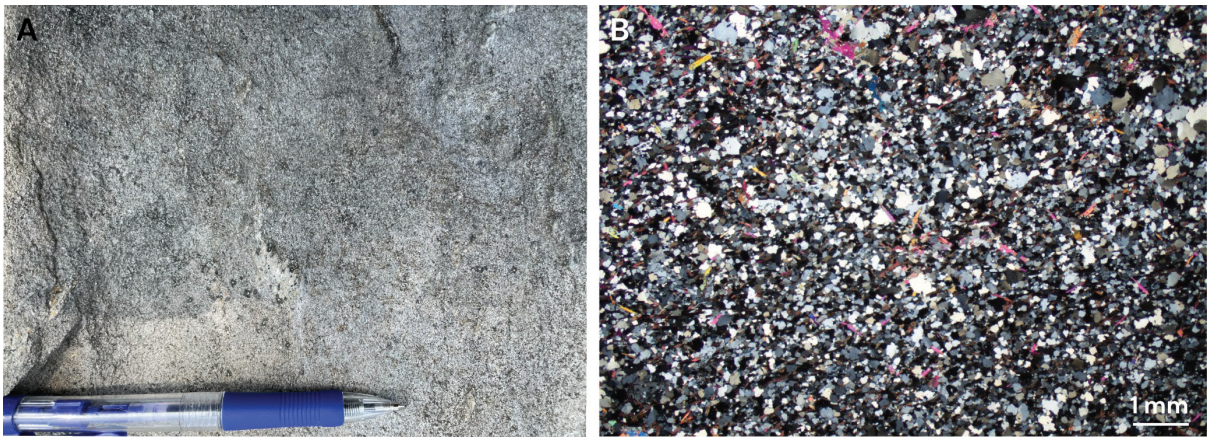


Figure 23. A. Field picture of well sorted and weakly foliated metagreywacke. Photo: Martiya Sadeghi. **B.** Photomicrograph shows a well sorted and weakly foliated metagreywacke. Crossed nicols. Photo: Pauline Jeanneret.

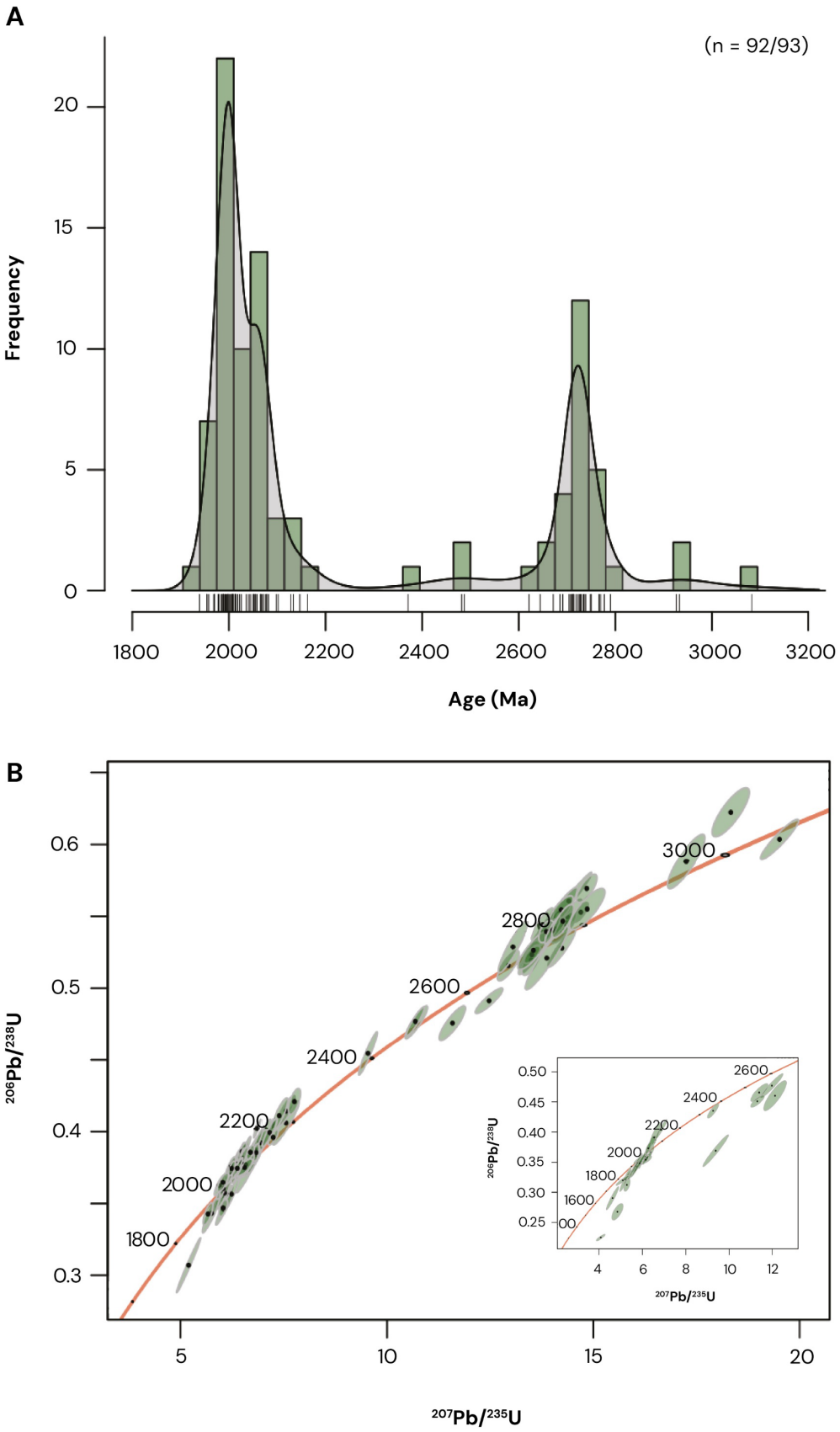


Figure 24. A. Combined binned frequency histogram and kernel density estimate (KDE) from the Gräsmyrberget area sample with calculated maximum probability ages for distinct distribution peaks of zircon populations, using $^{207}Pb/^{206}Pb$ single zircon mineral dates. A fixed bin size of 35 m.yr./ bin and a Concordia Filter of ± 10% are used. **B.** Concordia plot for zircons analysed from this sample, with the inset diagram showing the concordia for Pb-common-corrected zircons.

Palaeoproterozoic zircons

Table 3 summarises the results of detrital zircon dates for each sample, along with the location and the counts of zircon age peaks grouped into specific time intervals of 50 Ma. Many of the samples show significant peaks in the 1,950–1,999 Ma and 2,000–2,049 Ma intervals. Among these, the 1,950–1,999 Ma interval appears most frequently as the first-order peak.

The oldest maximum zircon populations are found in the 2,050–2,099 Ma interval, which occurs in sample SPN221088B in the north of Kattviken.

This table provides a general overview of the maximum probability peaks, combined with the 1st and 2nd order peaks within 50 million-year intervals. However, the detailed interpretation of the data is more complex than what is presented in Table 3.

The majority of the 1st-order peak ages occur in the 1,950–1,999 Ma interval, which slightly differs from what Kathol et al. (2020) reported in Bergslagen, where 1st-order peak ages were around 1,850–1,899 Ma. This suggests that most of the detrital zircons in Västernorrland are similar to findings from the Naggen area but they are slightly older than those findings (according to Kathol et al. 2020) in Bergslagen.

The sedimentary material source likely derives from > 1.95 Ga Svecokarelian intrusive and volcanic rocks. These magmatic and metamorphic rocks eroded to supply sediment to the developing Palaeoproterozoic basin, contributing zircon grains with ages around 1.9–2.0 Ga. Two samples in the listed study area show 1st-order peaks in the 2,000–2,049 Ma interval (in Jämtjärnen) and 2,050–2,099 Ma interval (in north of Kattviken). (see Figure 25 & 26 and Table 3).

Several previous researchers (e.g., Claesson et al. 1993, Bergman et al. 2008, Sultan et al. 2005 and Lahtinen et al. 2002) have observed detrital zircons aged up to 2.12 Ga and suggested that the Sarmatian segment could be a possible provenance area for the 2.1–1.95 Ga clastic zircon population in the southern Svecofennian orogen.

The contribution of the Sarmatian segment to sediments in Sweden and Finland is linked to geological and sedimentary processes. According to Patchett et al. (1987), central Sweden shows significant inputs of Archaean material (up to 40%) in its turbidite sediments, as shown by neodymium isotopic data. These sediments highlight contributions of older crustal material recycled into sedimentary deposits. Sultan et al. (2005) suggested mixing from multiple sources in Västervik, a statement also supported by Welin et al. (1993).

Table 3. The table summarises the zircon ages in Palaeoproterozoic in percentage proportion with an interval of 50 million years. The 1st and 2nd order probability peaks (1st order probability peaks that correspond to significant episodes of magmatic or metamorphic activity, and 2nd order probability peaks may rise processes such as sediment recycling, mixing of sediments from multiple sources, or lesser magmatic events) are counted from the combination frequency histograms and probability density distribution plots for 1650–3650 Ma age interval. Different colours represent percentage proportion with an interval in 50 m.y. blue: < 2%, orange: 2–8%, green: 9–18%, and brown: >18%, I and II represent 1st and 2nd order probability, respectively.

Sample ID	Sample site	N	1650–1699	1700–1749	1750–1799	1800–1849	1850–1899	1900–1949	1950–1999	2000–2049	2050–2099	2100–2149	2150–2199	2200–2249	2250–2299	2300–2349	2350–2399	2400–2449	2450–2499
MSI220061A	Query Sollefteå-Rödsta	123							I	II									
ELH220054A	Järkvissle power plant	122							I	II									
SPN221091A	Jamttjärnen	60							II	I									
SPN221080B	North of Kattviken	122								II	I								
ELH230109A	Lidens-Backen	109								I									
ELH230119A	Lappberget	111							I	II									
SPN230523A	Grundsjön-Tallmyran	112							I	II									
SPN230551A	Grössjön	114							I										
SPN230583A	Trehörningen	119							I	II									
MSI230099A	Gräsmyrberget	123							I										

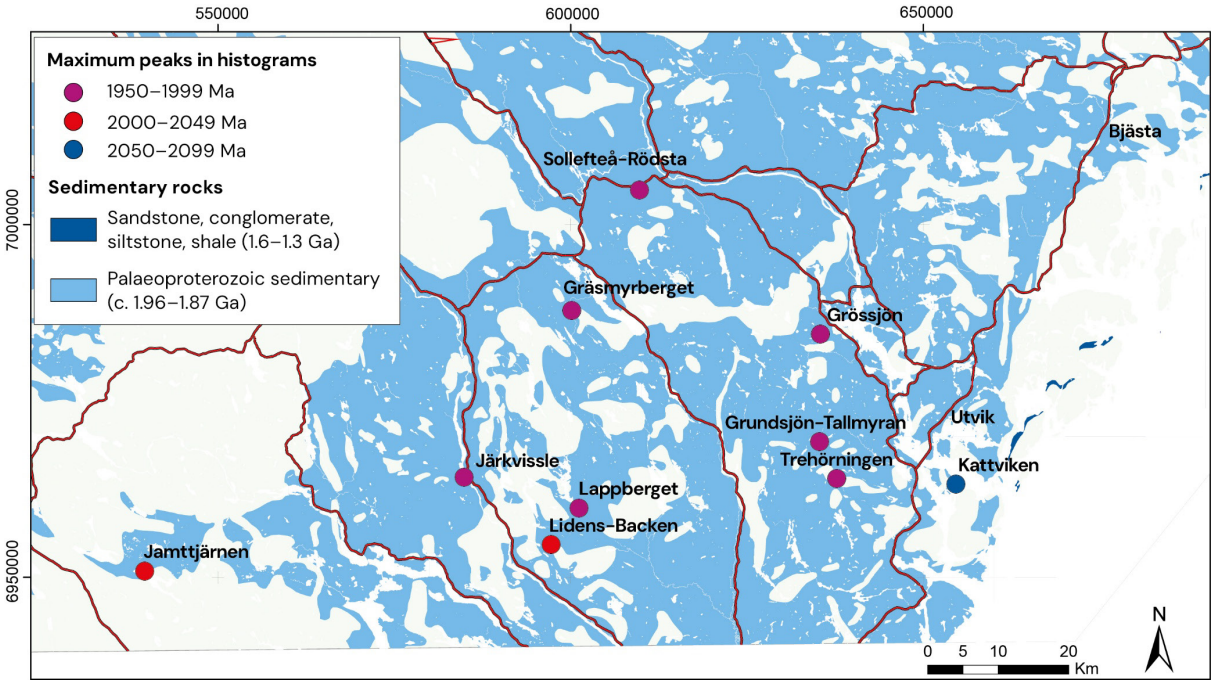


Figure 25. A simplified map showing the spatial distribution of age intervals with the 1st order peak.

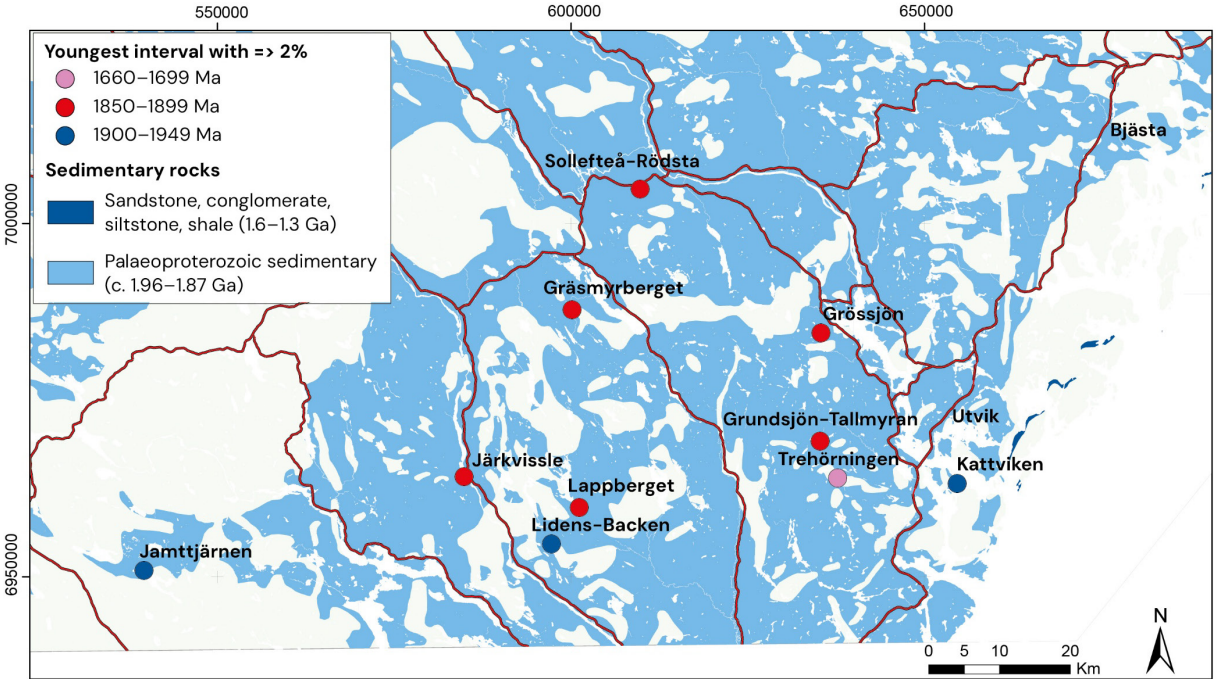


Figure 26. A simplified map showing the spatial distribution of the youngest populations in Västernorrland that interval bins have more than two percent of the analysed zircon.

Archean zircons

According to the summarised data in Table 4, with a 50-million-year interval derived from Archaean zircon ages, the most populated interval lies between 2,700–2,749 Ma, with a range of 2,600–2,899 Ma. This interval contains zircon concentrations of more than 3% with Archaean ages. Fewer zircons older than 3,450–3,649 Ma are observed in the dataset (Table 4).

In Sollefteå, the largest population of Archaean zircons falls within the 2,650–2,699 Ma interval. The oldest zircon in this sample was dated to the 3,500–3,549 Ma range, with a total contribution of 15% Archaean zircons.

In Järkvissle, the peak of Archaean zircons, comprising 7% of the sample, falls within the 2,700–2,749 Ma interval. The oldest zircon in this region is dated to 3,600–3,650 Ma, marking the oldest Archaean zircon found in the entire Västernorrland area. The total contribution of Archaean zircons in this sample is 22%.

In Jämttjärnen, the peak of Archaean zircons with 15% of the population falls within the 2,700–2,749 Ma interval, with a total of 33% Archaean zircons in the sample.

In the north of Kattviken, the sample represents 42% Archaean zircons, with a peak of 11% in the 2,700–2,749 Ma interval. This suggests that the Archaean zircons from Kattviken likely originate from the Sarmatia region in the southeast, rather than from the Archaean core in the north and northeast. The reason is that, according to studies on Paleoproterozoic metasedimentary rocks from Norrbotten (Sultan et al. 2009), approximately 25–30% of the detrital zircons are of Archean age, with the remaining 75% being Paleoproterozoic. If this population is accurate, it is likely that the Archean zircons found north of Kattviken originated from sources other than just the Archean rocks of Norrbotten.

A sample from Lidens-Backen reveals that 36% of the zircon population is Archaean, with a peak of 13% Archaean zircons in the 2,700–2,749 Ma interval, similar to many other samples.

In Lappberget, zircons were dated in the 3,450–3,499 Ma interval, with a total of 21% Archaean zircons and a peak in the 2,650–2,749 Ma range.

In the Grundsjön-Tallmyran region, 28% of zircons are of Archaean age, with a peak of 10% in the 2,700–2,749 Ma interval.

In Grössjön, the peak of Archaean zircons falls within the 2,650–2,699 Ma interval (12% Archaean zircons), and the total population of Archaean zircons is 29%. The oldest zircon was dated in the 3,450–3,499 Ma interval.

In Trehörningen, the Archaean zircon population is 21.5%, with a peak in the 2,700–2,749 Ma interval.

Lastly, in Gräsmyrberget, Archaean zircons make up 27% of the total zircon population, with 12% of these zircons falling in the 2,700–2,749 Ma interval.

Figure 27 shows the spatial distribution of Archaean zircons in Västernorrland, with the highest proportion of Archaean zircon grains reported from the southern part of the study area, extending into the Ostrobothnia in Finland.

Tabel 4. The table summarises the zircon ages in Archaean in percentage proportion with an interval of 50 million years. The 1st and 2nd order probability peaks are counted from the combination frequency histograms and probability density distribution plots for 1650–3650 Ma age interval. Different colours represent percentage proportion with an interval in 50 m.y. blue: < = 1%, orange: 1–2.9%, green: 3–4.9%, and brown: >5%

Sample ID	Sample site	N	2500 –2549	2550 –2599	2600 –2649	2650 –2699	2700 –2749	2750 –2799	2800 –2849	2850 –2899	2900 –2949	2950 –2999	3000 –3049	3050 –3099	3100– 3149	3150– 3199	3200 –3249	3250– 3299	3300 –3349	3350 –3399	3400 –3449	3450– 3499	3500 –3549	3550 –3599	3600 –3649
MSI220061A	Query Sollefteå-Rödsta	123																							
ELH220054A	Järkvissle power plant	122																							
SPN221091A	Jamt-tjärnen	60																							
SPN221080B	North of Kattviken	122																							
ELH230109A	Lidens-Backen	109																							
ELH230119A	Lapp-berget	111																							
SPN230523A	Grundsjön -Tallmyran	112																							
SPN230551A	Grössjön	114																							
SPN230583A	Trehör-ningen	119																							
MSI230099A	Gräsmyr-berget	123																							

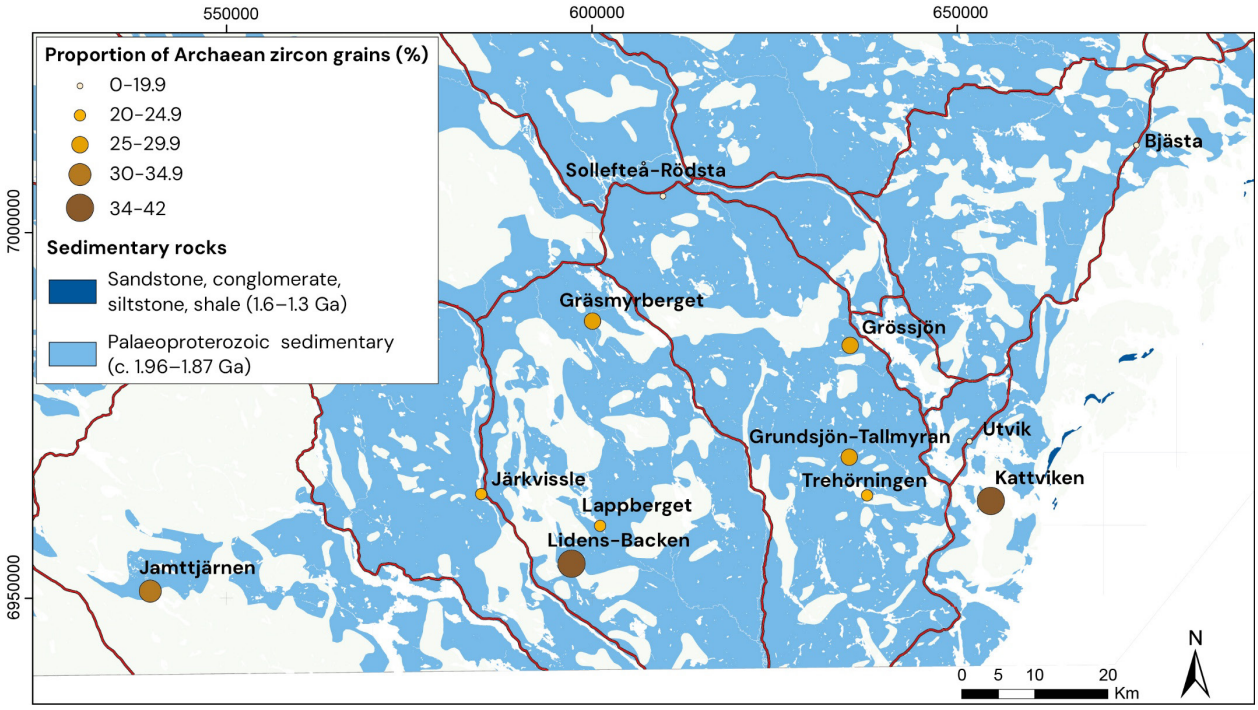


Figure 27. A simplified map on proportion of Archaean zircon grain in Västernorrland area.

Lithogeochemistry

During the geological mapping of the study area, lithogeochemical analyses were conducted on all data samples at the ALS Scandinavia AB laboratory. The samples were leached using lithium metaborate/tetraborate fusion, followed by acid digestion, and subsequently analysed by ICP-AES and ICP-MS. These analyses covered major, minor, and trace elements, including REEs. The results are provided in Appendix 2.

Lithogeochemical data serves as a complementary tool for discriminating tectonic environments and has been applied to provenance studies in Bergslagen (Kathol et al. 2020). However, due to the metamorphosed nature of the terrain in the study area, there are some uncertainties in the interpretation. Therefore, the findings should be considered and used with caution.

One of the commonly used discrimination diagrams for the tectonic setting of sedimentary rocks is based on the K_2O/Na_2O versus SiO_2 ratio, as proposed by Roser & Korsch (1986). According to this diagram, all samples plot within the active continental margin field, except for one sample from Grössjön, which is plotted near the boundary between the active continental margin and island arc fields (Fig. 28).

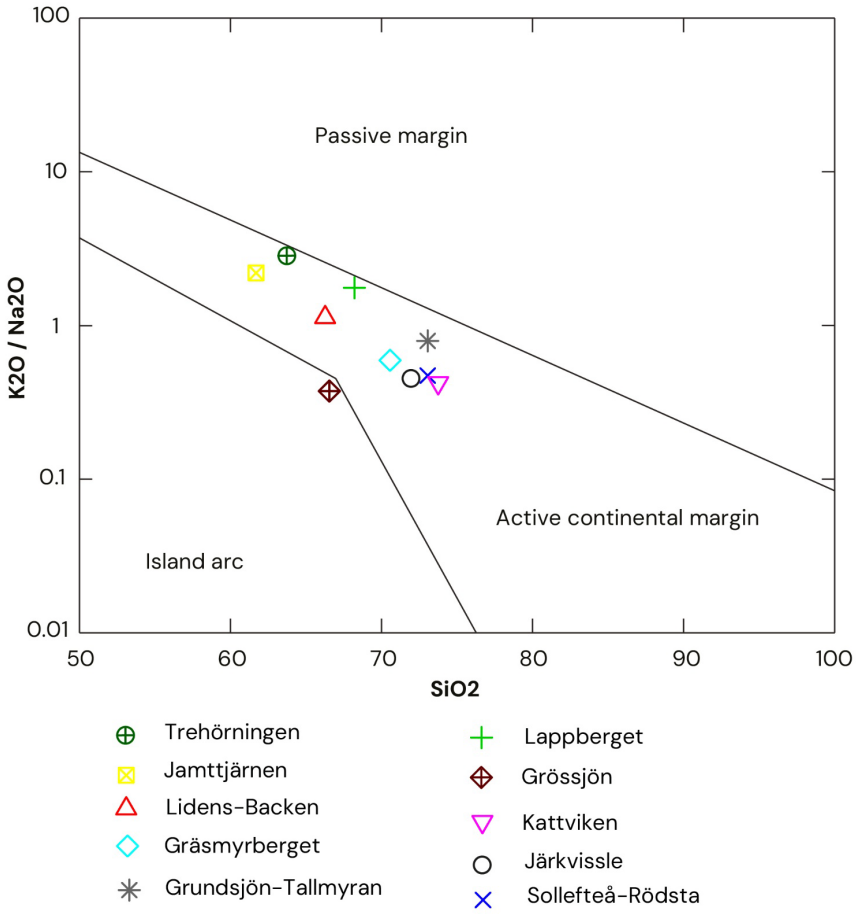


Figure 28. Discrimination diagram (Roser & Korsch 1986) for sedimentary rocks, based on K2O/Na2O versus SiO2.

A discrimination functions formula developed by Bhatia (1983) can be used for classifying sedimentary tectonic settings, particularly for sandstone. This diagram utilises geochemical data of major elements for the classification of tectonic settings. Bhatia (1983) defined two linear discrimination functions (DF1 and DF2), which are calculated by applying specific weighting to the major oxides. The formulas for DF1 and DF2 are:

$$DF1 = a_1X_1 + a_2X_2 + a_3X_3 + \ldots + a_nX_n$$
$$DF2 = b_1X_1 + b_2X_2 + b_3X_3 + \ldots + b_nX_n$$

Where X_n represents the oxide concentrations, and a_n and b_n are coefficients empirically derived for the diagram (see more details in Bhatia (1983).

In general, sediments from oceanic island arcs show higher MgO and Fe_2O_3 and lower SiO_2 due to mafic provenance. Continental island arc sediments have higher Al_2O_3 and moderate TiO_2, indicating intermediate to felsic compositions. Active continental margin sediments show higher SiO_2 and K_2O, often reflecting granitic or recycled sources. Finally, passive margin sediments, which are typically quartz-rich, have high SiO_2 and low TiO_2, originating from stable continental regions (Fig. 29).

One limitation of this calculation formula is that the results can be influenced by post-depositional processes, such as weathering or diagenesis, which may yield ambiguous results, particularly for mixed or recycled sediments.

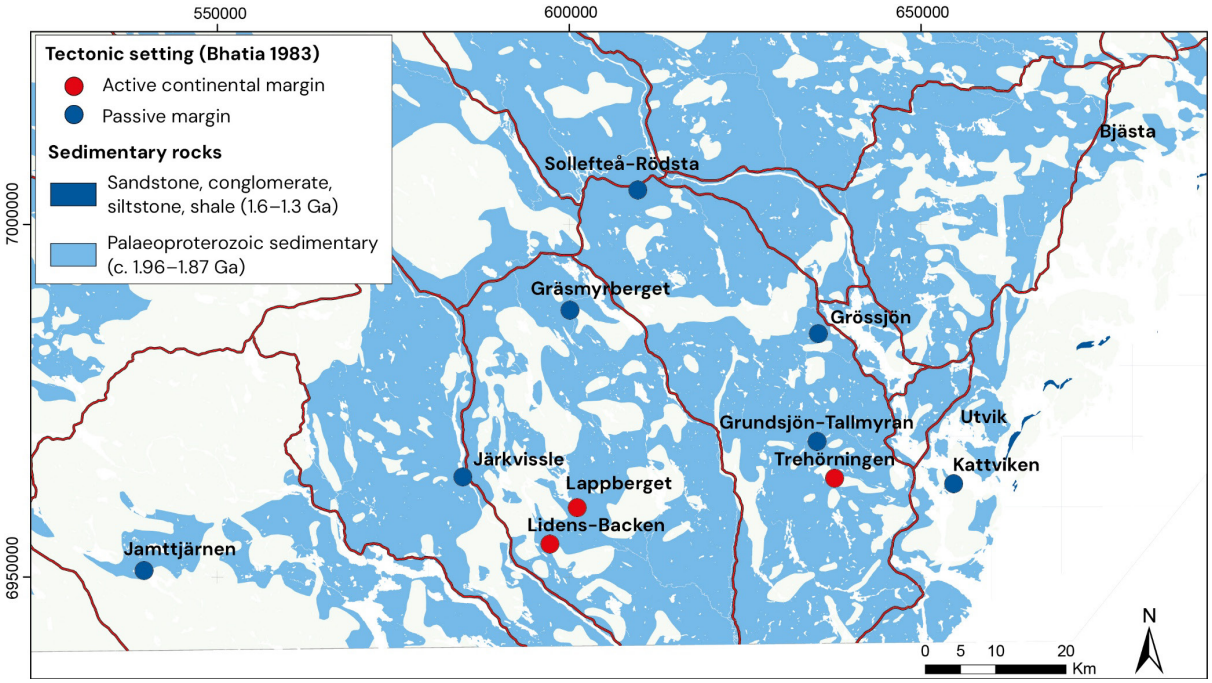


Figure 29. Map showing the tectonic setting classification according to Bhatia (1983) in Västernorrland.

However, geochemical discrimination for tectonic settings indicates an active continental margin in the southern part of the study area and a passive margin to the north. This observation supports the hypothesis proposed by Skiöld and Rutland (2006), that the Svecofennian orogeny involved the accretion of marginal basins. The observation that the metasedimentary units are interbedded with arc volcanic rocks in the southern part of the study area suggests that the sediments and volcanics were broadly coevally deposited. In contrast, in the western and northern of the region metavolcanic rocks are overlying metasedimentary rocks.

Summary and discussion

The corrected and uncorrected zircon U-Pb age data from the analysed samples (Figure 30) illustrate the range and variability of measured $^{207}Pb/^{206}Pb$ dates. Most ages fall between 1900 Ma and 2900 Ma, with four dates extending beyond 3200 Ma, indicating the presence of older Archaean source material. The observed spread in age distributions across individual samples reflects varying geological histories, potentially due to mixed sources and complex geological processes.

This study represents the most comprehensive detrital zircon provenance analysis conducted in the Västernorrland region. Prior studies have shown a temporal gap with minimum source material in the 2.5–2.2 Ga age interval across similar metasedimentary-bearing domains in other regions of Fennoscandia. For instance, Kathol et al. (2020) and Bergman et al. (2008) reported minimal zircon U-Pb ages within the 2.5–2.2 Ga timespan from the Bergslagen and Hamrånge areas, respectively. Sultan et al. (2005) did not report any zircon dates in the age interval 2.68–2.13 Ga from quartzites in Västervik in southeastern Sweden. Similarly, Williams et al. (2009) identified only a few zircons in the 2.6–2.1 Ga range from their samples in Poland, and Claesson et al. (1993) suggested there is no evidence for 2.6–2.1 Ga protoliths in the Svecofennian sedimentary rocks of central Sweden and southern Finland. Salminen and Kurhila (2023) concluded that an obtained 2.1–2.0 Ga range of $^{207}Pb/^{206}Pb$ dates for metasedimentary rocks in southern Finland aligns with data from the Bergslagen region in Sweden. Our study partly

supports these findings, with only 3.2% of all analysed zircons (36 out of 1115) falling within the 2.6–2.2 Ga interval, confirming a regional scarcity of mainly Siderian to Rhyacian source material. This scarcity overlaps with a recognised globally significant period of low continental crustal growth and magmatism from c. 2.5–2.2 Ga (e.g., Condie et al. 2009).

Maximum depositional ages for each sample were determined using either the youngest single zircon $^{207}Pb/^{206}Pb$ date, provided the associated error falls within an acceptable range (2σ uncertainty less than 10 Ma) or the youngest coherent age cluster, defined as a group of similar age within ± 5 Ma. These results are summarised in Table 5. The youngest interpreted depositional ages range from 1.94 Ga to 1.87 Ga, providing a temporal framework for sedimentation events in the region.

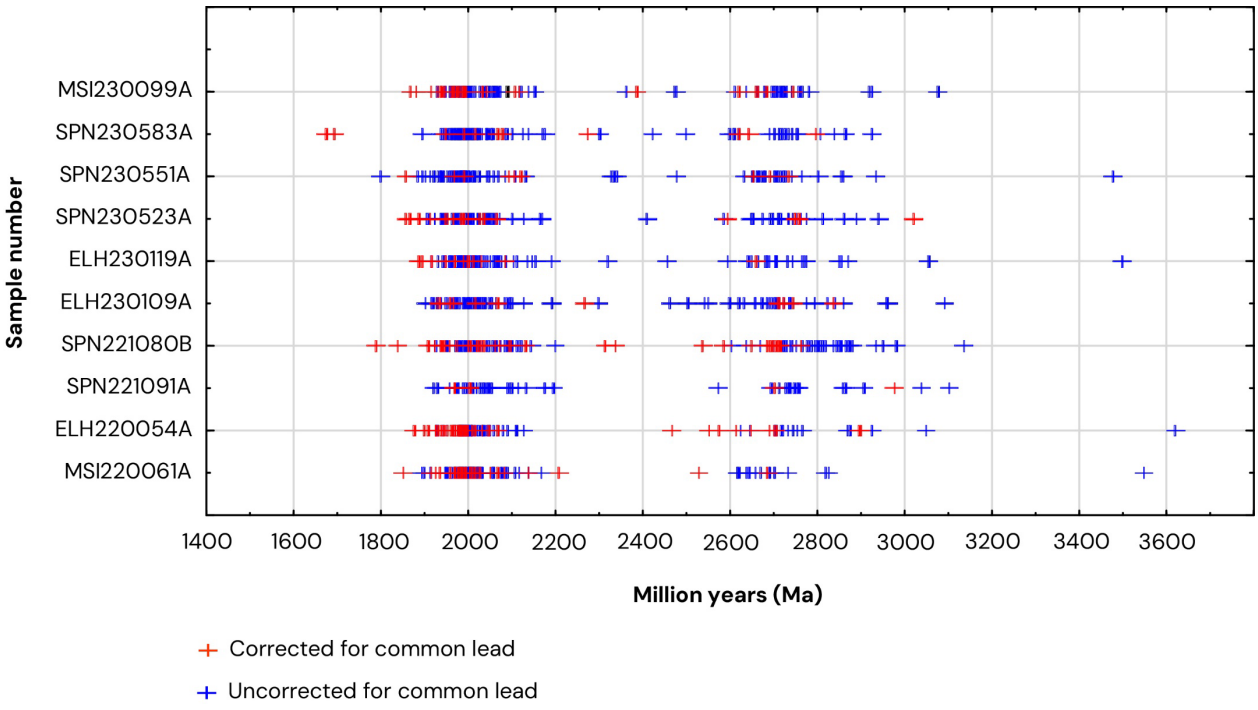


Figure 30. Summary of the obtained $^{207}Pb/^{206}Pb$ ages of all analyses which are lying in the 90–110% concordia interval according to Wetherill (1956). The samples are marked as corrected and uncorrected for common lead in red and blue colour, respectively.

Table 5. Summary of maximum depositional ages based on youngest single zircon $^{207}Pb/^{206}Pb$ age or youngest coherent age cluster.

Sample ID	Location	Number of analysed zircons	207Pb/206Pb dates (oldest zircon)	207Pb/206Pb dates (youngest zircon)	Youngest zircon cluster (average)	Interpreted maximum depositional age
MSI220061A	Sollefteå-Rödsta	123	3548±7.9	1850±20	1901	1901
ELH220054A	Järkvissle power plant	122	3619±11	1876±48	1894	1894
SPN221091A	Jamttjärnen	60	3102±16	1920±9.4	1924	1924
SPN221080B	North of Kattviken	122	3136±14	1788±16	1907	1907

Sample ID	Location	Number of analysed zircons	207Pb/206Pb dates (oldest zircon)	207Pb/206Pb dates (youngest zircon)	Youngest zircon cluster (average)	Interpreted maximum depositional age
MSI230099A	Gräsmyrberget	109	3074±11	1879±19	1887	1887
ELH230109A	Lidens-Backen	111	3102±16	1920±9	1924	1924
ELH230119A	Lappberget	112	3498±24	1886±27	1890	1890
SPN230583A	Trehörningen	114	2926±25	1674±59	1924	1924
SPN230551A	Grössjön	119	3476±24	1799±38	1879	1879
SPN230523A	Grundsjön-Tallmyran	123	2940±20	1856±14	1870	1870

According to Lahtinen et al. (2023), detrital zircon U-Pb age populations between c. 2.1–1.9 Ga are typical for Paleoproterozoic orogenic domains of the Fennoscandian Shield. Svecofennian metasedimentary rocks are generally categorised into older sequences with maximum depositional ages older than 1.91 Ga, and younger sequences deposited at around 1.90–1.87 Ga. The older sequences are dominated by 2.03–1.96 Ga detrital zircons, while younger sequences often represent arc-related depositional settings. In our study, most of the metasedimentary samples align with the former model, with major detrital zircon peaks identified at 2.03–1.96 Ga and corresponding youngest zircon ages of around 1.92–1.89 Ga, suggesting deposition of volcano-sedimentary source material mainly occurred during orogenic intra-arc basin development. Two samples (SPN210551A and SPN230523A) show maximum depositional ages of ~1.88–1.87 Ga indicating a younger phase of sedimentation also locally occurred (Table 5).

Skiöld and Rutland (2006) reported similar detrital zircon age populations in the Robertsfors group (north-eastern Bothnian Basin), with dominant age peaks at around 1.98 Ga and minor ones near 1.93 Ga. These age patterns are also reflected in our Västernorrland samples, suggesting a shared provenance history characterised by significant sedimentary input from crustal source rocks formed between 2.03 and 1.96 Ga, with deposition mainly occurring at around 1.92–1.89 Ga during syn-orogenic basin formation. Although source rocks with c. 2.0–1.96 Ga ages are presently unknown in the Bothnian Basin, c. 1.95–1.94 Ga intermediate to felsic magmatic rocks with continental arc-type geochemical characteristics occur in the Knaften area (Wasström et al. 2019), indicating older pre-1.94 Ga source rocks, poorly exposed at the current erosion level, may be present in the region. Also, the Robertsfors group, characterised by preserved D1 structures and zircon overgrowth ages around 1916 ± 5 Ma, is interpreted to represent pre-1.92 Ga sedimentary deposition that was later subjected to tectonothermal overprinting. This interpretation implies that substantial crustal components were formed and underwent erosion before the onset of the main phase of Svecofennian arc magmatism (~1.90–1.87 Ga), supporting a revised model of early-orogenic sediment recycling and crustal evolution before c. 1.94–1.92 Ga.

Figures 31–40 presents summaries of Paleoproterozoic zircon age distributions across all samples, highlighting dominant age peaks between 2.05 Ga and 1.90 Ga, with frequent clustering near 1.98 Ga. Samples SPN230583A and ELH230109A display wider age ranges, indicating clearly mixed sources or prolonged sediment recycling. Zircons older than 2.1 Ga, such as those in MSI220061A and SPN230523A, suggest erosional input from ancient cratonic sources (e.g., Norrbotten-Karelia). The youngest concordant zircon U-Pb ages across most samples, between 1.88–1.87 Ga, align with sedimentation occurring in a syn-orogenic, intra-arc basinal environment during the Svecofennian orogeny.

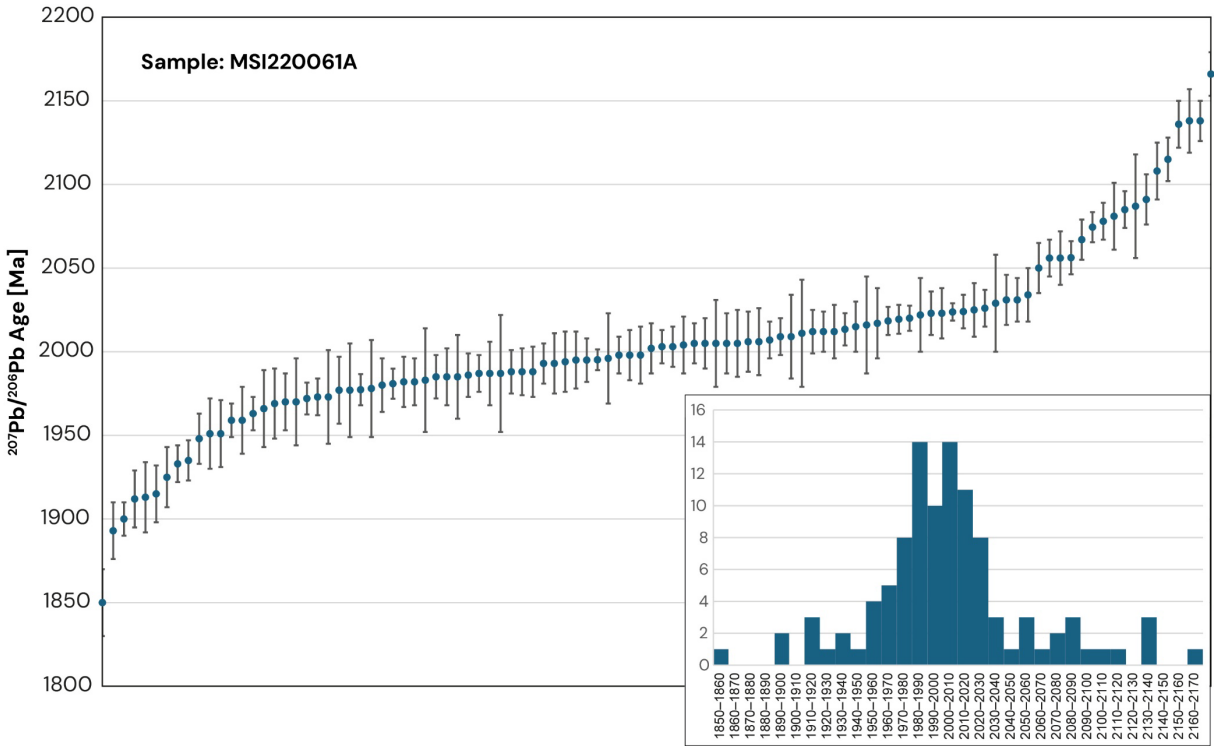


Figure 31. Summary of the obtained $^{207}Pb/^{206}Pb$ Paleoproterozoic age distribution for sample MSI220061A showing analyses within the 90-110% concordia interval according to Wetherill (1956). The plot shows individual zircon ages with uncertainty bars, together with an inset histogram of age frequency (10 Ma intervals).

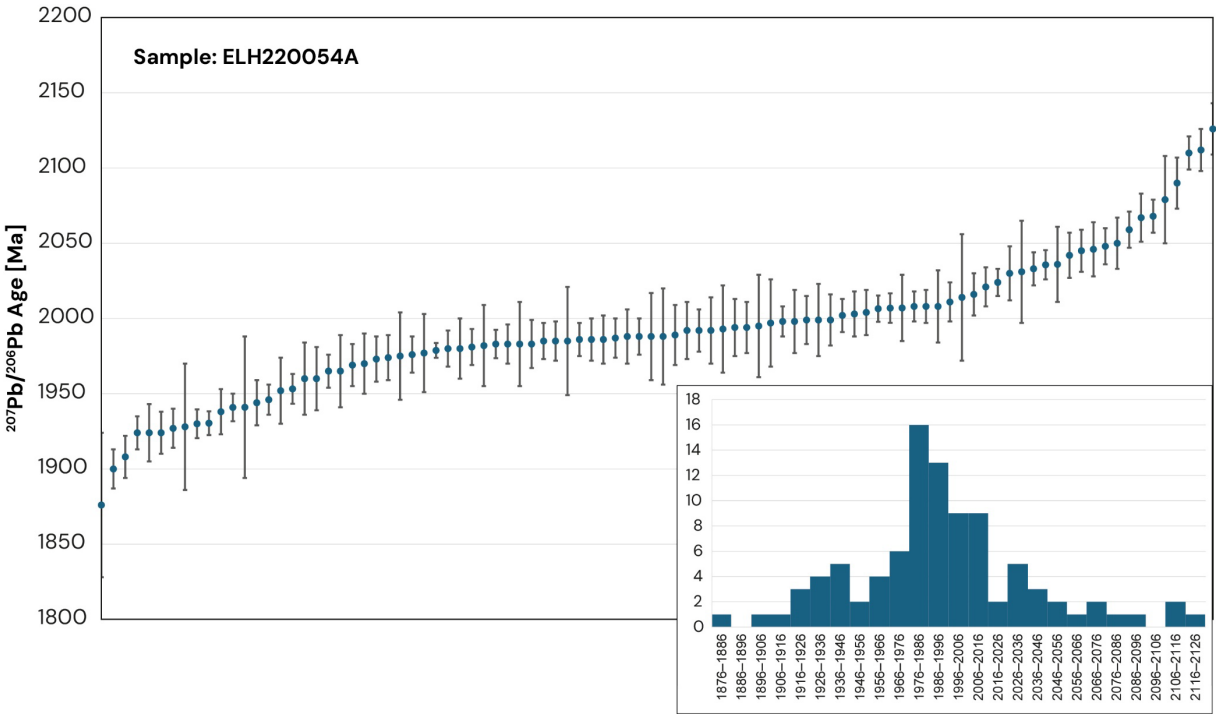


Figure 32. Summary of the obtained $^{207}Pb/^{206}Pb$ Paleoproterozoic age distribution for sample ELH220054A showing analyses within the 90-110% concordia interval according to Wetherill (1956). The plot shows individual zircon ages with uncertainty bars, together with an inset histogram of age frequency (10 Ma intervals).

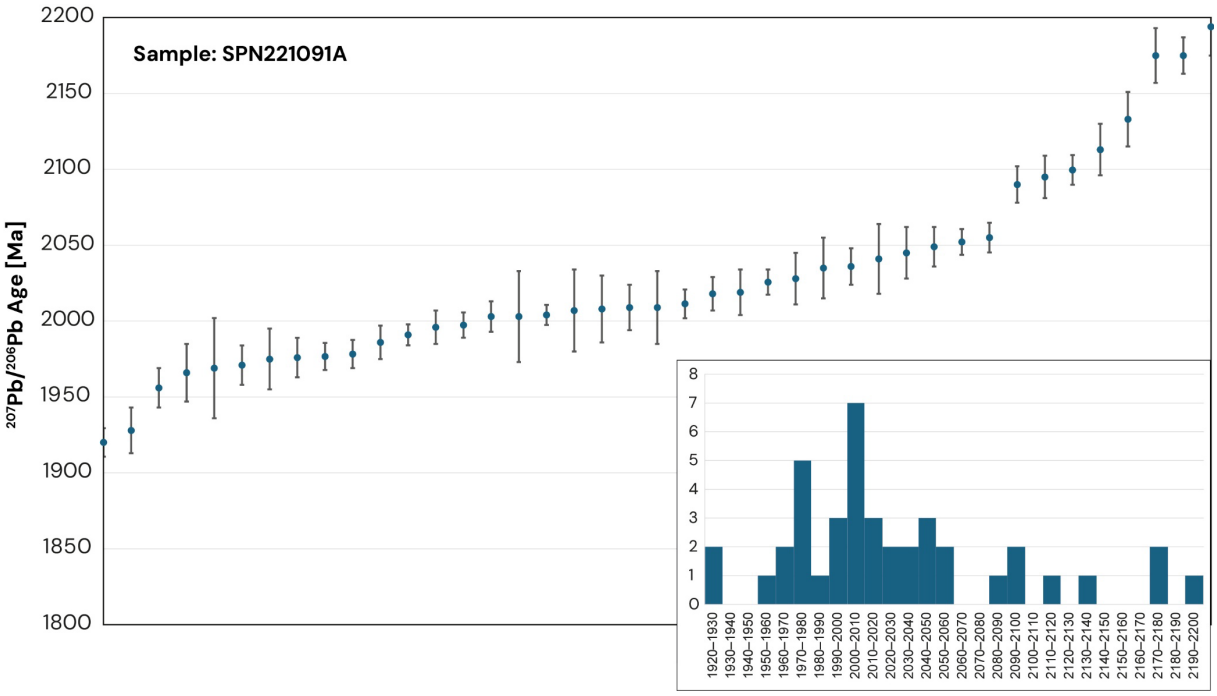


Figure 33. Summary of the obtained $^{207}Pb/^{206}Pb$ Paleoproterozoic age distribution for sample SPN221091A showing analyses within the 90-110% concordia interval according to Wetherill (1956). The plot shows individual zircon ages with uncertainty bars, together with an inset histogram of age frequency (10 Ma intervals).

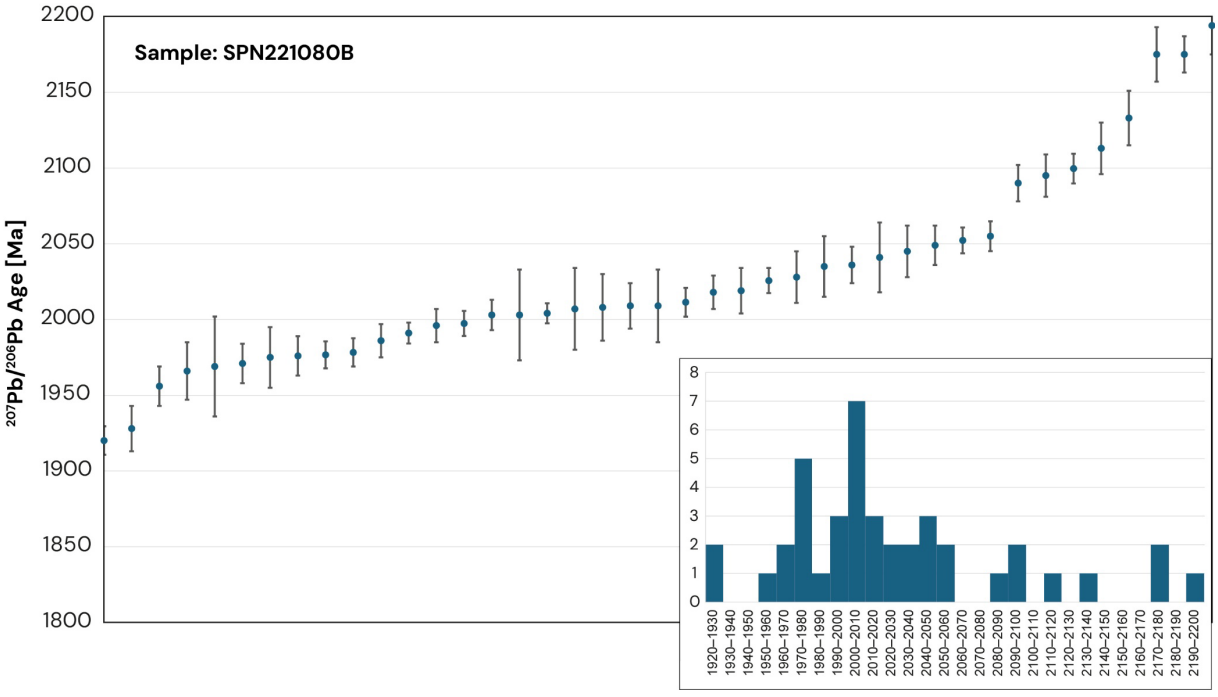


Figure 34. Summary of the obtained $^{207}Pb/^{206}Pb$ Paleoproterozoic age distribution for sample SPN221080B showing analyses within the 90-110% concordia interval according to Wetherill (1956). The plot shows individual zircon ages with uncertainty bars, together with an inset histogram of age frequency (10 Ma intervals).

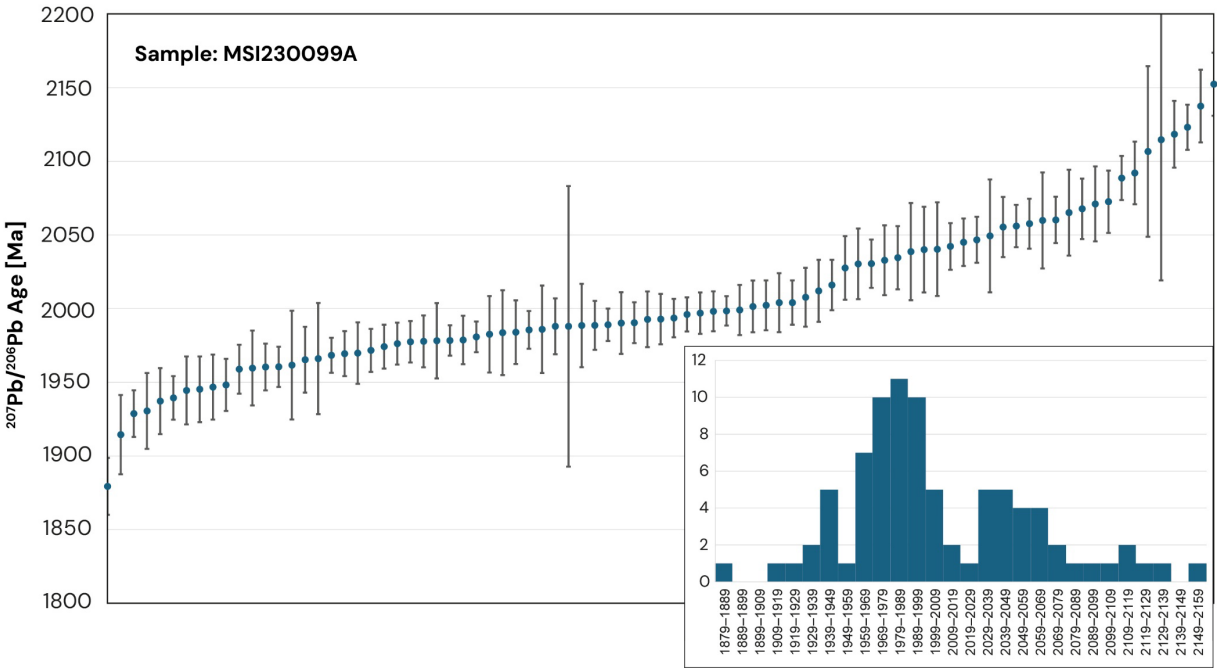


Figure 35. Summary of the obtained $^{207}Pb/^{206}Pb$ Paleoproterozoic age distribution for sample MSI230099A showing analyses within the 90–110% concordia interval according to Wetherill (1956). The plot shows individual zircon ages with uncertainty bars, together with an inset histogram of age frequency (10 Ma intervals).

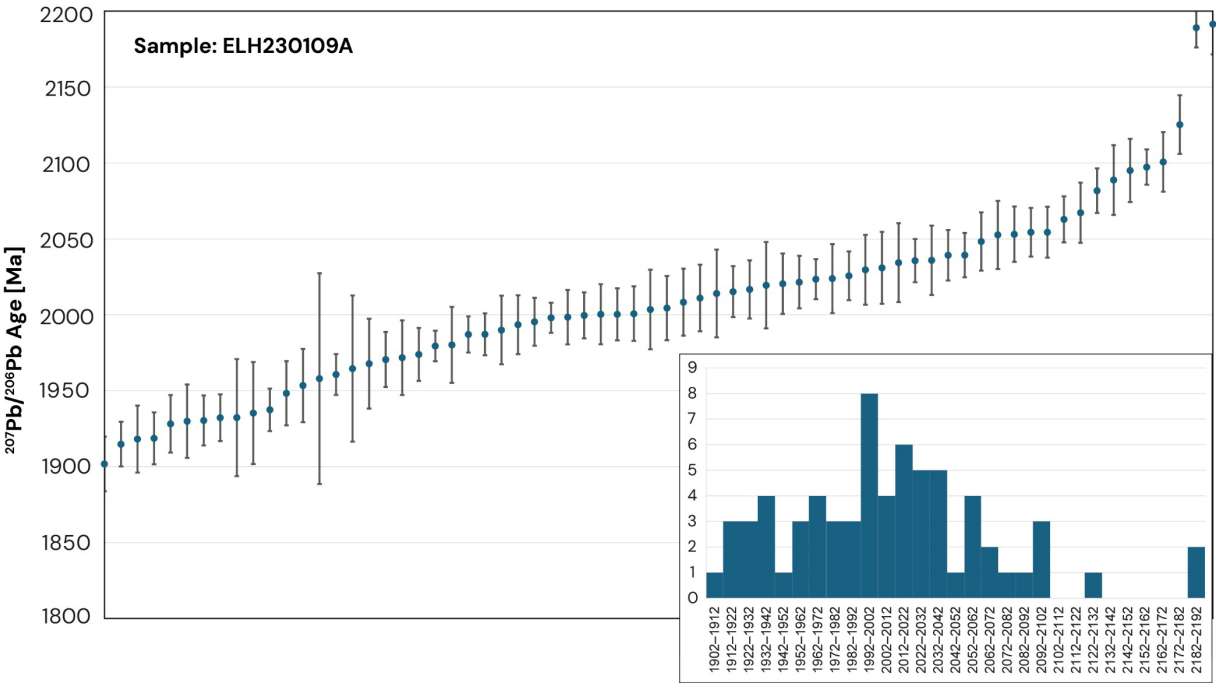


Figure 36. Summary of the obtained $^{207}Pb/^{206}Pb$ Paleoproterozoic age distribution for sample ELH230109A showing analyses within the 90–110% concordia interval according to Wetherill (1956). The plot shows individual zircon ages with uncertainty bars, together with an inset histogram of age frequency (10 Ma intervals).

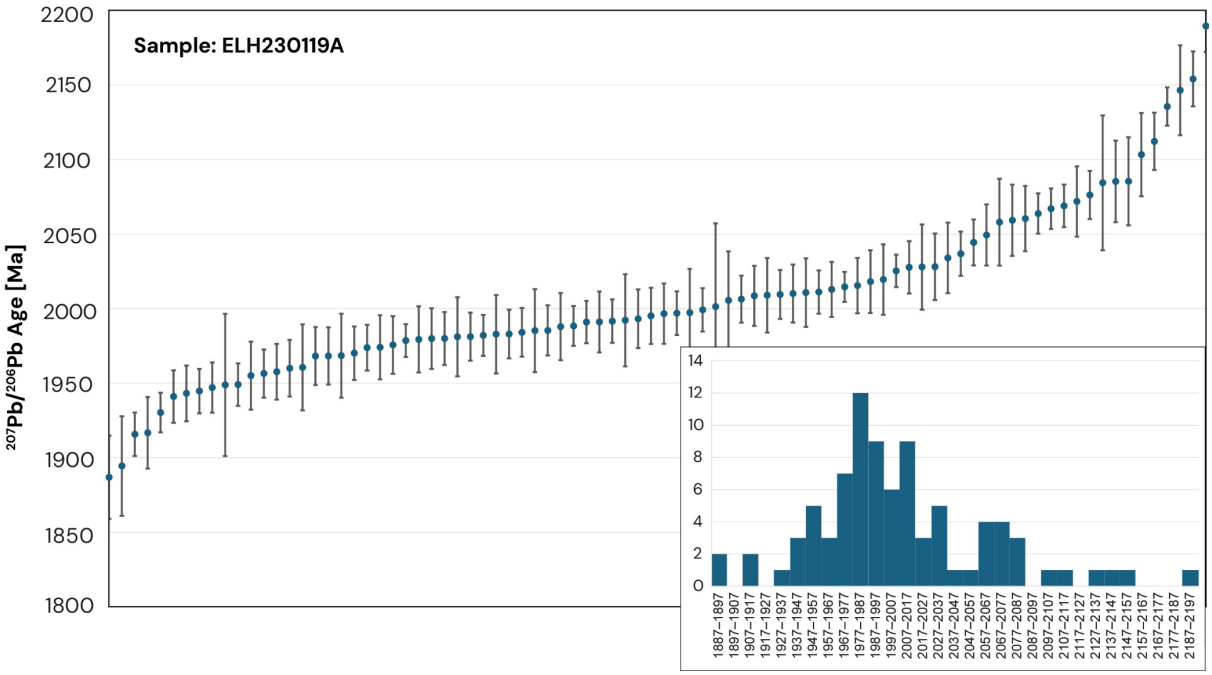


Figure 37. Summary of the obtained ^{207}Pb/^{206}Pb Paleoproterozoic age distribution for sample ELH230119A showing analyses within the 90–110% concordia interval according to Wetherill (1956). The plot shows individual zircon ages with uncertainty bars, together with an inset histogram of age frequency (10 Ma intervals).

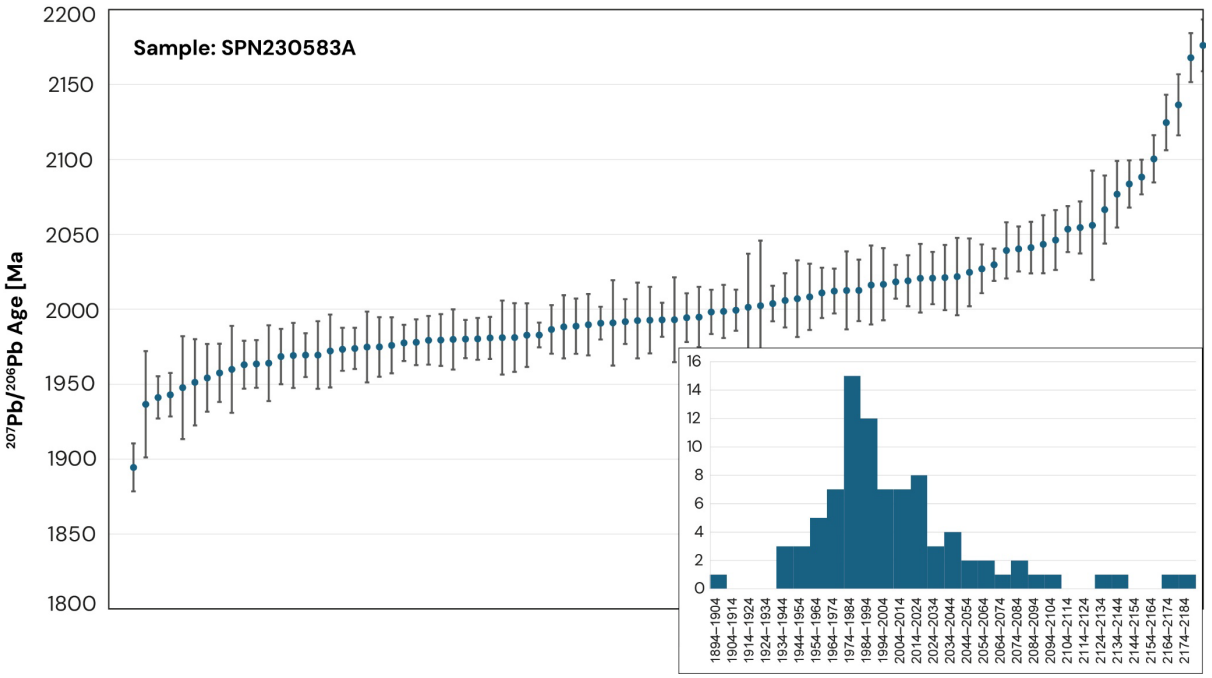


Figure 38. Summary of the obtained ^{207}Pb/^{206}Pb Paleoproterozoic age distribution for sample SPN230583A showing analyses within the 90–110% concordia interval according to Wetherill (1956). The plot shows individual zircon ages with uncertainty bars, together with an inset histogram of age frequency (10 Ma intervals).

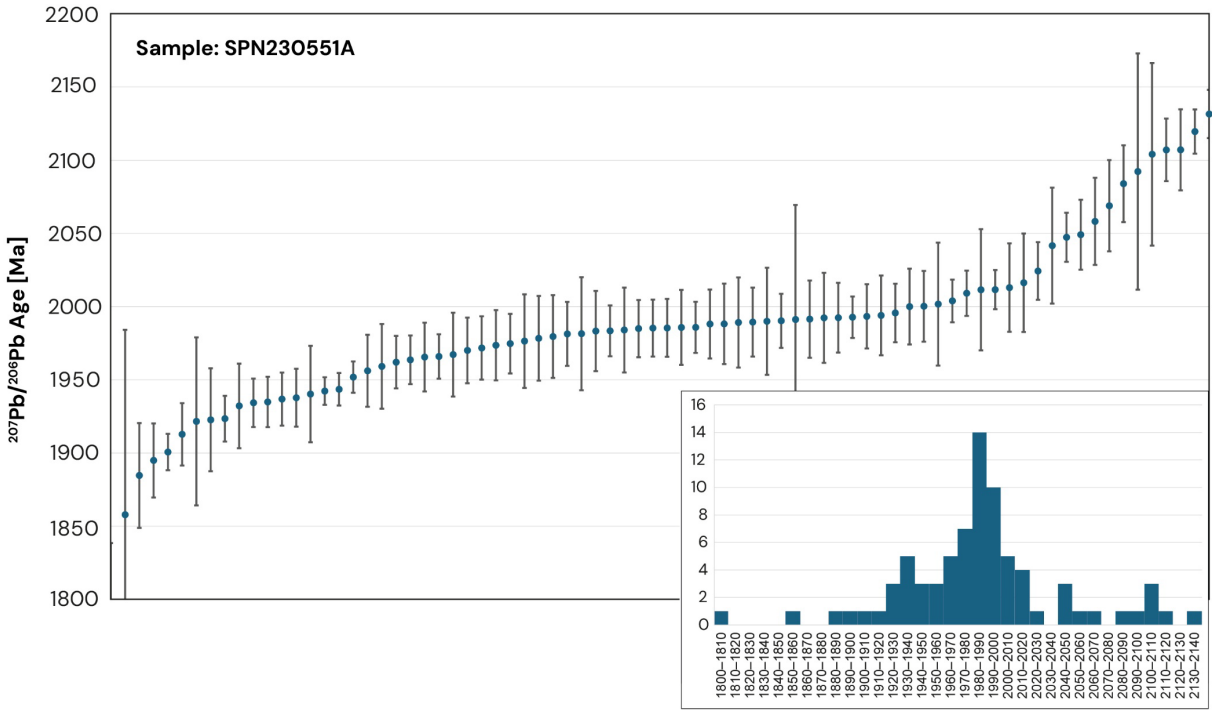


Figure 39. Summary of the obtained $^{207}Pb/^{206}Pb$ Paleoproterozoic age distribution for sample SPN230551A showing analyses within the 90-110% concordia interval according to Wetherill (1956). The plot shows individual zircon ages with uncertainty bars, together with an inset histogram of age frequency (10 Ma intervals).

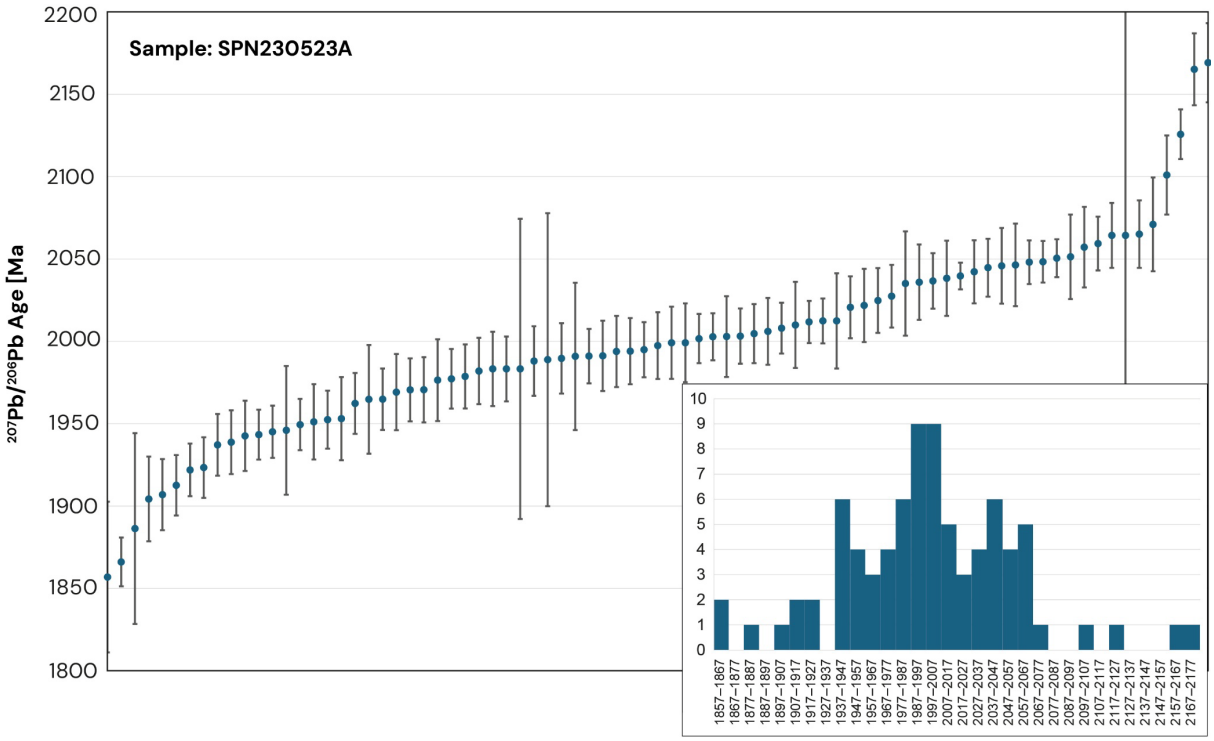


Figure 40. Summary of the obtained $^{207}Pb/^{206}Pb$ Paleoproterozoic age distribution for sample SPN230523A showing analyses within the 90-110% concordia interval according to Wetherill (1956). The plot shows individual zircon ages with uncertainty bars, together with an inset histogram of age frequency (10 Ma intervals).

The proportion of Archean detrital zircons in the Paleoproterozoic metasedimentary rocks from Västernorrland ranges from 15% to 42%, while the proportion in comparable metasedimentary rocks deposited within the Norrbotten craton ranges from approximately 15% to 30%. If Archean zircons in Västernorrland originated solely from Archean source rocks in the Norrbotten craton, one would expect a higher proportion of Archean zircons in Norrbotten metasedimentary rocks compared to those occurring further to the southwest like in Västernorrland. This discrepancy suggests that the Archean zircon population in Västernorrland likely includes an additional source, possibly from other cratonic regions like the Archean Karelian Province to the northeast in Finland or Sarmatian rocks of the Ukrainian Shield to the southeast.

Archaean detrital zircons in the older sample group with maximum depositional ages of c. 1.92–1.89 Ga show age signatures predominantly within a 2749–2700 Ma interval and have an overall range from 2899 to 2600 Ma. This age range is marginally younger though overlapping with the mainly 3,28–2,81 age range for Archaean detrital zircons in sedimentary rocks in Bergslagen (cf. Kathol et al. 2020). A small proportion of the Västernorrland zircon grains exceed 3450 Ma, highlighting the contribution of Paleoarchean or older crustal material to the sedimentary sequence in this part of the Bothnian basin. Also, the presence of a single zircon grain in sample ELH220054A (Järkvissle area) dated to 3619 ± 11 Ma (Table 5) represents the oldest continental crustal material so far identified in the Bothnian basin and indicates a rare source contribution from ancient Eoarchaean crust. This c. 3,62 Ga age signature is correlative with a 3,64 Ga age obtained for detrital zircons in the Västervik area in southeastern Sweden (Sultan et al., 2005) and with rare Eoarchean inherited zircons reported by Lauri et al. (2011) and Petersson et al. (2023) from the Pudasjärvi Gneiss Complex in northwestern Finland. Such an ancient source signature recorded in Västernorrland metasedimentary rocks extends northward the occurrence of rare >3.6 Ga sedimentary material in central Sweden. This material likely derived from enigmatic Eoarchean–Mesoarchaean cratonic nuclei presently located in the northeastern Fennoscandian Shield and/or from the 3,7–2,8 Ga Sarmatian rocks of the Ukrainian Shield and Voronezh Massif (Russia).

The most common Paleoproterozoic age peak for the Västernorrland samples occurs at 2.00–1.98 Ga, with local variations observed across different sample sites (Fig. 31). Most of the 1st order age peaks occur in the 1999–1950 Ma interval, but two localities in the study area show 1st order peaks in the 2049–2000 Ma and 2099–2050 Ma age intervals (Jamttjärnen and north of Kattviken, respectively). The detrital zircon geochronological data and age distributions indicate that sedimentation in the Västernorrland region occurred after ~1.92 Ga, within a tectonic framework consistent with ongoing syn-orogenic basin development. The dominance of 2.03–1.96 Ga detrital zircon components imply derivation from recycled metaigneous source sediments, likely deposited by ~1.92 Ga and incorporated into younger depositional sequences. This sediment was transported and deposited in a tectonic setting characterised by reduced volcanic activity, suggesting a passive margin or intra-arc basin environment at around 1.87 Ga. In summary, sedimentation appears to have continued from c. 2.0–1.92 Ga coincident with orogenesis and basin development, with some parts of the sequence deposited as late as c. 1.87 Ga. The latter upper age limit coincides with the onset of regional deformation and prograde regional metamorphism in the Skellefte–Bothnia lithotectonic domain marking a switch to a major phase of basin inversion and burial (cf. Skytta et al. 2020).

The consistent zircon age patterns observed in Västernorrland, in conjunction with similar findings from Finland (e.g., the Vammala migmatite belt), point to the existence of a large marginal basin formed after ~1.98 Ga. This basin was later inverted and accreted during major tectonothermal events around 1.92–1.91 Ga. The results challenge traditional models that emphasize post-1.9 Ga crustal growth via arc accretion alone and instead highlight the importance of earlier crustal assembly and sediment recycling in the tectonic evolution of the Svecofennian Domain.

In conclusion, this study underscores the complex sedimentary and tectonic history of southern Fennoscandia and provides crucial insights into the provenance, depositional timing, and crustal evolution processes that shaped the Västernorrland region.

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Appendix 1. Descriptive statistics for U, Th and Pb concentrations

Table A1.1. Descriptive statistics for U, Th and Pb concentrations, U/Th ratios, and $^{207}Pb/^{206}Pb$ ages obtained for sample MSI220061A from Sollefteå.

Variable	U [ppm]	Th [ppm]	Pb [ppm]	U/Th	$^{207}Pb/^{206}Pb$ (Ma)
Valid N	123	123	123	123,00	123
Mean	625	439	394	4,58	2111,88
Median	497	261	226	1,30	2006,00
Minimum	42	3	2	0,23	1850,00
Maximum	2990	3200	3690	99,00	3547,80
Lower Quartile (25%)	258	149	126	0,92	1983,00
Upper Quartile (75%)	730	510	508	2,81	2074,50
Percentile (10%)	165	86	67	0,73	1959,00
Percentile (20%)	216	113	104	0,89	1977,30
Percentile (30%)	304	173	147	0,98	1987,00
Percentile (40%)	395	224	186	1,16	1998,00
Percentile (50%)	497	261	226	1,30	2006,00
Percentile (60%)	567	350	288	1,62	2018,40
Percentile (70%)	658	440	385	2,41	2034,00
Percentile (80%)	889	650	620	3,44	2108,00
Percentile (90%)	1166	1010	884	6,10	2644,00
Standard deviation	552	499	481	12,81	273,30

Table A1.2. Descriptive statistics for U, Th and Pb concentrations, U/Th ratios, and $^{207}Pb/^{206}Pb$ ages obtained for sample ELH220054A from Järkvissle.

Variable	U [ppm]	Th [ppm]	Pb [ppm]	U/Th	$^{207}Pb/^{206}Pb$ (Ma)
Valid N	122	122	122	122,00	122
Mean	511	406	357	2,21	2163,03
Median	338	250	216	1,26	1999,00
Minimum	20	5	5	0,31	1876,00
Maximum	2110	3130	2690	44,80	3619,00
Lower Quartile (25%)	225	142	127	0,96	1980,00
Upper Quartile (75%)	642	498	367	1,90	2090,00
Percentile (10%)	140	61	61	0,75	1941,00
Percentile (20%)	185	123	114	0,89	1973,00
Percentile (30%)	243	159	143	1,01	1983,00
Percentile (40%)	299	190	189	1,11	1988,00
Percentile (50%)	338	250	216	1,26	1999,00
Percentile (60%)	421	319	267	1,42	2014,00
Percentile (70%)	550	417	337	1,68	2048,00
Percentile (80%)	705	616	520	2,14	2574,00
Percentile (90%)	1219	997	799	4,20	2719,00
Standard deviation	455	450	407	4,29	338,28

Table A1.3. Descriptive statistics for U, Th and Pb concentrations, U/Th ratios, and $^{207}Pb/^{206}Pb$ ages obtained for sample SPN221091A from Jamttjärnen.

Variable	U [ppm]	Th [ppm]	Pb [ppm]	U/Th	$^{207}Pb/^{206}Pb$ (Ma)
Valid N	60	60	60	60,00	60
Mean	540	341	355	2,38	2270,02
Median	457	264	261	1,64	2047,00
Minimum	43	64	55	0,66	1920,10
Maximum	1690	1100	1199	20,20	3102,00
Lower Quartile (25%)	325	134	138	1,10	2003,00
Upper Quartile (75%)	698	526	507	2,45	2720,00
Percentile (10%)	228	97	93	0,79	1973,00
Percentile (20%)	275	121	126	1,02	1993,50
Percentile (30%)	375	159	150	1,15	2007,50
Percentile (40%)	413	197	214	1,34	2022,35
Percentile (50%)	457	264	261	1,64	2047,00
Percentile (60%)	522	348	360	1,93	2106,30
Percentile (70%)	646	461	463	2,30	2632,50
Percentile (80%)	742	587	541	2,60	2734,05
Percentile (90%)	995	695	770	5,18	2807,50
Standard deviation	310	247	267	2,83	370,51

Table A1.4. Descriptive statistics for U, Th and Pb concentrations, U/Th ratios, and $^{207}Pb/^{206}Pb$ ages obtained for sample SPN221080B from Norra Kattviken.

Variable	U [ppm]	Th [ppm]	Pb [ppm]	U/Th	$^{207}Pb/^{206}Pb$ (Ma)
Valid N	122	122	122	122,00	122
Mean	548	358	358	2,59	2325,21
Median	401	219	227	1,50	2095,50
Minimum	78	36	36	0,36	1788,00
Maximum	2690	3280	3160	24,00	3136,00
Lower Quartile (25%)	236	134	129	1,10	2004,00
Upper Quartile (75%)	763	430	421	2,25	2723,00
Percentile (10%)	165	89	88	0,80	1950,00
Percentile (20%)	210	125	121	1,03	1992,00
Percentile (30%)	258	143	150	1,13	2022,00
Percentile (40%)	310	192	173	1,32	2061,00
Percentile (50%)	401	219	227	1,50	2095,50
Percentile (60%)	493	306	281	1,74	2536,00
Percentile (70%)	583	374	375	2,08	2703,90
Percentile (80%)	855	482	474	2,44	2750,00
Percentile (90%)	1160	721	728	5,07	2835,80
Standard deviation	439	408	420	3,36	377,35

Table A1.5. Descriptive statistics for U, Th and Pb concentrations, U/Th ratios, and $^{207}Pb/^{206}Pb$ ages obtained for sample ELH230109A from Lidens-Backen.

Variable	U [ppm]	Th [ppm]	Pb [ppm]	U/Th	$^{207}Pb/^{206}Pb$ (Ma)
Valid N	109	109	109	109	109
Mean	411	200	2061	3,86	2268,45
Median	292	130	1387	2,09	2052,64
Minimum	38	11	138	0,57	1901,80
Maximum	2939	1006	13296	36,09	3090,04
Lower Quartile (25%)	213	71	797	1,44	1998,07
Upper Quartile (75%)	516	238	2677	3,51	2684,55
Percentile (10%)	112	48	419	0,86	1937,47
Percentile (20%)	182	66	677	1,29	1980,23
Percentile (30%)	242	81	915	1,56	2000,75
Percentile (40%)	264	100	1115	1,82	2023,49
Percentile (50%)	292	130	1387	2,09	2052,64
Percentile (60%)	361	177	1842	2,49	2125,28
Percentile (70%)	457	220	2237	3,08	2632,74
Percentile (80%)	581	256	3075	4,26	2709,12
Percentile (90%)	780	468	4341	6,84	2745,02
Standard deviation	370	205	1994	5,96	351,92

Table A1.6. Descriptive statistics for U, Th and Pb concentrations, U/Th ratios, and $^{207}Pb/^{206}Pb$ ages obtained for sample ELH230119A from Lappberget.

Variable	U [ppm]	Th [ppm]	Pb [ppm]	U/Th	$^{207}Pb/^{206}Pb$ (Ma)
Valid N	111	111	111	111	111
Mean	474	239	2365	4,22	2171,46
Median	357	145	1434	2,11	2011,11
Minimum	41	3	65	0,57	1886,86
Maximum	2454	3303	30098	156,09	3498,25
Lower Quartile (25%)	222	94	858	1,48	1981,07
Upper Quartile (75%)	554	256	2485	3,11	2146,43
Percentile (10%)	167	62	597	1,06	1954,99
Percentile (20%)	211	89	816	1,32	1975,61
Percentile (30%)	232	103	993	1,57	1985,20
Percentile (40%)	286	114	1140	1,79	1996,89
Percentile (50%)	357	145	1434	2,11	2011,11
Percentile (60%)	417	185	1756	2,49	2036,79
Percentile (70%)	514	227	2151	2,78	2084,38
Percentile (80%)	614	312	2990	3,69	2592,78
Percentile (90%)	888	466	4724	6,02	2706,05
Standard deviation	413	351	3366	14,75	326,26

Table A1.7. Descriptive statistics for U, Th and Pb concentrations, U/Th ratios, and $^{207}Pb/^{206}Pb$ ages obtained for sample SPN230523A from Grundsjön-Tallmyran.

Variable	U [ppm]	Th [ppm]	Pb [ppm]	U/Th	$^{207}Pb/^{206}Pb$ (Ma)
Valid N	112	112	112	112	112
Mean	557	297	3031	3,66	2200,48
Median	448	174	1979	2,09	2023,30
Minimum	45	7	60	0,68	1856,93
Maximum	3184	2131	27384	30,39	3019,58
Lower Quartile (25%)	269	98	1098	1,51	1982,64
Upper Quartile (75%)	671	349	3585	3,35	2619,93
Percentile (10%)	212	57	565	1,19	1943,36
Percentile (20%)	261	85	920	1,42	1970,54
Percentile (30%)	295	117	1234	1,56	1989,66
Percentile (40%)	371	146	1518	1,84	2002,79
Percentile (50%)	448	174	1979	2,09	2023,30
Percentile (60%)	522	230	2481	2,47	2048,07
Percentile (70%)	636	329	3265	3,11	2125,70
Percentile (80%)	759	386	4426	3,67	2696,16
Percentile (90%)	938	577	6091	7,32	2743,04
Standard deviation	446	365	3528	4,70	335,93

Table A1.8. Descriptive statistics for U, Th and Pb concentrations, U/Th ratios, and $^{207}Pb/^{206}Pb$ ages obtained for sample SPN230551A from Grössjön.

Variable	U [ppm]	Th [ppm]	Pb [ppm]	U/Th	$^{207}Pb/^{206}Pb$ (Ma)
Valid N	114	114	114	114	114
Mean	433	201	2087	4,50	2209,81
Median	328	124	1223	2,28	2000,10
Minimum	24	6	19	0,60	1799,73
Maximum	2019	1439	14791	97,62	3476,22
Lower Quartile (25%)	180	67	613	1,38	1974,67
Upper Quartile (75%)	607	241	2137	4,56	2653,11
Percentile (10%)	92	34	379	1,00	1934,85
Percentile (20%)	162	57	538	1,23	1965,47
Percentile (30%)	218	76	730	1,51	1983,24
Percentile (40%)	274	92	990	1,87	1989,36
Percentile (50%)	328	124	1223	2,28	2000,10
Percentile (60%)	415	154	1535	2,96	2049,08
Percentile (70%)	515	199	1983	3,91	2331,43
Percentile (80%)	702	299	2902	5,19	2671,54
Percentile (90%)	828	422	4638	9,48	2717,26
Standard deviation	346	235	2592	9,53	350,72

Table A1.9. Descriptive statistics for U, Th and Pb concentrations, U/Th ratios, and $^{207}Pb/^{206}Pb$ ages obtained for sample SPN230583A from Trehörningen.

Variable	U [ppm]	Th [ppm]	Pb [ppm]	U/Th	$^{207}Pb/^{206}Pb$ (Ma)
Valid N	119	119	119	119	119
Mean	511	274	2895	4,62	2162,99
Median	373	186	1919	1,66	2012,14
Minimum	54	4	56	0,46	1674,19
Maximum	3871	2110	18542	197,96	2926,02
Lower Quartile (25%)	239	109	1116	1,32	1980,13
Upper Quartile (75%)	630	313	3202	3,10	2176,12
Percentile (10%)	145	62	610	1,05	1963,01
Percentile (20%)	225	97	1035	1,22	1975,93
Percentile (30%)	250	124	1207	1,42	1982,82
Percentile (40%)	315	153	1622	1,54	1994,41
Percentile (50%)	373	186	1919	1,66	2012,14
Percentile (60%)	450	212	2161	2,01	2027,02
Percentile (70%)	565	278	2909	2,54	2083,63
Percentile (80%)	659	345	3737	3,28	2607,75
Percentile (90%)	933	623	5987	5,63	2726,00
Standard deviation	518	302	3127	18,33	306,31

Table A1.10. Descriptive statistics for U, Th and Pb concentrations, U/Th ratios, and $^{207}Pb/^{206}Pb$ ages obtained for sample MSI230099A from Gräsmyrberget.

Variable	U [ppm]	Th [ppm]	Pb [ppm]	U/Th	$^{207}Pb/^{206}Pb$ (Ma)
Valid N	123	123	123	123	123
Mean	386	180	1990	3,58	2212,94
Median	301	131	1438	2,21	2034,59
Minimum	40	6	66	0,61	1868,29
Maximum	2704	1224	12541	54,66	3074,84
Lower Quartile (25%)	198	77	895	1,50	1982,58
Upper Quartile (75%)	465	206	2220	3,05	2636,60
Percentile (10%)	136	50	530	1,10	1959,67
Percentile (20%)	179	69	797	1,41	1977,51
Percentile (30%)	214	94	955	1,71	1987,97
Percentile (40%)	266	107	1184	1,94	1999,06
Percentile (50%)	301	131	1438	2,21	2034,59
Percentile (60%)	356	144	1735	2,40	2060,23
Percentile (70%)	414	193	1949	2,75	2362,44
Percentile (80%)	495	255	2875	3,58	2682,35
Percentile (90%)	725	333	3723	6,20	2724,03
Standard deviation	328	176	1994	6,23	329,08

Appendix 2. Lithogeochemical analysis results

Table A2. Major and trace element geochemical composition of ten rock samples (Major oxides in wt.% and trace elements in ppm).

Sample name	ELH220054A	ELH230109A	ELH230119A	MSI220061A	MSI230099A	SPN221080B	SPN221091A	SPN230523A	SPN230551A	SPN230583A
Sample	ELH220054	ELH230109	ELH230119	MSI220061	MSI230099	SPN221080	SPN221091	SPN230523	SPN230551	SPN230583
N	6964209	6954701	6959863	7004955	6987879	6963287	6950943	6969279	6984545	6964028
E	584884	597246	601148	609765	600110	654618	539596	635257	635369	637691
SiO2 (%)	69,3	64,9	66,3	69,8	68	70,3	61,6	69,8	65,1	63,2
Al2O3 (%)	13,9	16	15,8	13,65	14,15	12,85	17,45	13,1	11,6	16,9
Fe2O3 (%)	4,91	6,11	5,68	5,42	5,07	4,86	7,3	4,99	11,1	7,04
CaO (%)	2,32	1,84	1,37	2,33	2	1,61	0,66	1,56	3,28	0,98
MgO (%)	1,94	2,51	2,28	2,13	1,83	2,06	2,65	1,98	1,08	3,18
Na2O (%)	3,14	2,82	2,26	3,06	3,14	3,11	2,19	3,05	2	1,97
K2O (%)	2,16	3,55	3,82	2,16	2,58	2,04	4,29	3,04	1,21	4,59
Cr2O3 (%)	0,013	0,016	0,015	0,01	0,012	0,015	0,016	0,011	0,012	0,019
TiO2 (%)	0,54	0,6	0,56	0,57	0,57	0,59	0,72	0,52	0,46	0,67
MnO (%)	0,07	0,07	0,06	0,07	0,06	0,05	0,04	0,07	0,06	0,06
P2O5 (%)	0,13	0,14	0,11	0,14	0,12	0,17	0,13	0,11	0,16	0,14
C (%)	0,03	0,01	0,04	0,04	0,06	<0.01	0,21	0,29	1,63	0,01
Ba (ppm)	533	815	812	630	571	555	904	910	238	887
Ce (ppm)	73,3	72,4	73,2	77,6	72,9	93	77,2	62,9	77,9	87,6
Cr (ppm)	101	123	113	88	84	111	120	86	94	137
Cs (ppm)	8,24	19,05	8,99	3,61	5,4	19,55	33,6	9,29	8,55	14,55
Dy (ppm)	3,86	3,87	4,35	4,48	3,67	4,36	4,2	3,41	4,37	4,72
Er (ppm)	2,15	2,11	2,4	2,29	2,2	2,25	2,49	1,82	2,53	2,65
Eu (ppm)	1,12	1,19	1,1	1,15	1,22	1,09	1,21	1,19	1,16	1,3
Ga (ppm)	20,7	20,2	20	19,4	18	18,9	28,1	17,2	14,2	19,9
Gd (ppm)	4,67	4,57	4,36	4,81	4,71	5,51	5,22	3,9	5,03	5,62
Hf (ppm)	4,82	5,46	4,71	5,87	4,74	6,9	4,5	4,21	4,21	3,39
Ho (ppm)	0,8	0,81	0,87	0,78	0,68	0,88	0,91	0,71	0,9	0,91
La (ppm)	36,4	37,9	39	39,5	35,7	45,4	39,4	29,8	38,5	44,2
Lu (ppm)	0,34	0,31	0,35	0,37	0,37	0,39	0,39	0,3	0,34	0,36
Nb (ppm)	11,05	10,9	10,8	10,05	9,59	12,75	15,45	9,22	10,4	11,9
Nd (ppm)	30,5	32	31,7	32,6	32,1	38,5	34,3	27,5	33,3	36,4
Pr (ppm)	8,35	8,76	8,73	9,29	8,66	10,1	9,06	7,09	8,78	9,89
Rb (ppm)	100,5	148	157	82,1	110,5	220	211	108,5	88,2	220
Sm (ppm)	5,56	5,95	6,02	6,03	5,66	7,36	6,46	4,6	5,39	6,69
Sn (ppm)	1,3	10,8	2,4	1,8	1,6	5,5	8,4	1,7	1,8	2,6
Sr (ppm)	251	224	171,5	267	229	262	139,5	229	187,5	124,5
Ta (ppm)	0,8	1	1	0,8	0,4	1	1	0,7	1	0,8
Tb (ppm)	0,66	0,68	0,66	0,69	0,69	0,75	0,72	0,53	0,74	0,84
Th (ppm)	10,85	12	13,2	12,25	10,85	15,8	13,4	9,99	12,15	10,6
Tm (ppm)	0,3	0,57	0,48	0,38	0,35	0,38	0,42	0,32	0,37	0,36
U (ppm)	2,69	3,3	3,32	2,79	2,72	3,27	3,77	2,36	4,21	3,71
V (ppm)	86	110	102	103	84	83	130	80	139	125
W (ppm)	1,4	1,9	1,5	<0.5	1,7	0,6	2,9	0,5	1,1	1,8
Y (ppm)	21,1	21,5	23,3	23,6	20,5	23,2	22,3	17,2	21,7	26
Yb (ppm)	2,05	2,14	2,33	2,28	2,08	2,25	2,29	1,98	2,28	2,34
Zr (ppm)	188	194	167	203	178	279	169	160	166	139
As (ppm)	8,6	5,9	0,8	1,6	4,5	0,8	1,3	0,5	5,3	0,8
Bi (ppm)	0,22	0,37	0,43	0,18	0,18	0,37	0,36	0,13	0,77	0,17
Hg (ppm)	<0.005	<0.005	0,019	0,01	0,016	<0.005	<0.005	<0.005	<0.005	0,007
Sb (ppm)	<0.05	<0.05	<0.05	0,05	<0.05	<0.05	0,05	<0.05	<0.05	<0.05
Se (ppm)	0,2	0,3	0,3	0,3	0,3	<0.2	0,3	0,2	6,8	0,8
LOI (%)	0,97	0,02	0,05	1,45	0,96	1,39	2,13	1,01	5,31	1,71
Total (%)	99,48	99,76	100,3	100,88	98,57	99,14	99,29	99,37	101,42	100,57
Pb (ppm)	15	9	12	20	19	13	17	17	10	13
Sc (ppm)	12	14	14	13	12	11	17	12	8	17
Zn (ppm)	63	67	78	66	69	68	124	67	92	121
Ag (ppm)	0,06	0,06	0,06	0,05	0,06	0,03	0,05	0,02	0,63	0,12
Al (%)	2,05	2,73	2,47	1,88	2,13	2,16	3,23	2,3	1,86	3,24

Sample name	ELH220054A	ELH230109A	ELH230119A	MSI220061A	MSI230099A	SPN221080B	SPN221091A	SPN230523A	SPN230551A	SPN230583A
Sample	ELH220054	ELH230109	ELH230119	MSI220061	MSI230099	SPN221080	SPN221091	SPN230523	SPN230551	SPN230583
N	6964209	6954701	6959863	7004955	6987879	6963287	6950943	6969279	6984545	6964028
E	584884	597246	601148	609765	600110	654618	539596	635257	635369	637691
As (ppm)	8,4	5,4	0,7	1,6	4,8	0,8	1,3	0,4	5,6	0,7
Au (ppm)	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
B (ppm)	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Ba (ppm)	260	230	100	80	150	240	300	160	120	330
Be (ppm)	0,26	0,17	0,42	0,29	0,21	1,13	0,99	0,14	0,75	0,45
Bi (ppm)	0,22	0,33	0,43	0,18	0,17	0,35	0,35	0,14	0,83	0,17
Ca (%)	0,25	0,14	0,18	0,47	0,21	0,42	0,07	0,11	0,89	0,1
Cd (%)	0,08	0,04	0,06	0,06	0,05	0,08	0,04	0,01	0,55	0,09
Co (ppm)	13,9	15,3	14,3	13,2	12,2	11,5	13,4	13,2	11,2	19
Cs (ppm)	7,89	19,85	7,93	2,55	4,89	16	30,3	9,91	6,45	15,6
Cu (ppm)	30,7	33	29,8	25,6	20,2	2,9	15	0,7	307	51,1
Fe (%)	3,33	4,25	3,89	3,59	3,39	3,23	4,93	3,63	7,87	4,78
Ga (ppm)	9,85	11,25	10,5	9,83	8,58	11	12,1	10,35	6,51	11,5
Ge (ppm)	0,14	0,16	0,12	0,18	0,08	0,22	0,19	0,12	0,12	0,12
Hf (ppm)	0,31	0,59	0,27	0,38	0,31	0,62	0,29	0,21	0,12	0,15
Hg (ppm)	<0.01	<0.01	<0.01	0,01	0,01	0,01	0,01	<0.01	<0.01	<0.01
In (ppm)	0,029	0,029	0,032	0,027	0,032	0,049	0,033	0,036	0,04	0,035
K (%)	1,26	1,94	1,32	0,54	1,29	0,93	2,07	1,66	0,45	2,38
Li (ppm)	42	87,9	48,2	30,1	38,6	145,5	174	127,5	33,8	156
Mg (%)	1,16	1,45	1,28	1,26	1,06	1,21	1,55	1,19	0,54	1,82
Mn (ppm)	500	533	444	584	469	408	317	471	329	484
Mo (ppm)	0,62	0,47	0,53	0,78	0,49	0,41	0,3	0,48	18,2	0,71
Na (%)	0,09	0,05	0,04	0,05	0,07	0,07	0,06	0,05	0,07	0,05
Nb (ppm)	0,31	0,63	0,3	0,4	0,36	0,68	0,69	0,36	1,16	0,47
Ni (ppm)	35	40,1	42	30,4	31	30,4	45,2	31,5	27,8	50,7
P (ppm)	540	560	380	660	470	650	430	450	640	520
Pb (ppm)	3,7	3,8	5,7	6,2	4,9	6,8	3,9	3,8	6,7	3,6
Rb (ppm)	79,9	128,5	96,6	31,8	92,3	132	169,5	102	50,5	181,5
Re (ppm)	<0.001	<0.001	<0.001	0,001	<0.001	<0.001	0,001	<0.001	0,015	<0.001
S (%)	0,09	0,11	0,06	0,04	0,04	<0.01	0,09	<0.01	0,82	0,24
Sb (ppm)	<0.05	<0.05	<0.05	0,05	<0.05	<0.05	0,05	<0.05	<0.05	<0.05
Sc (ppm)	10,9	10,7	9,6	10,3	10	10,4	8,5	11,6	7,7	8,4
Se (ppm)	0,2	<0.2	<0.2	0,3	<0.2	<0.2	0,3	0,2	7,1	0,7
Sn (ppm)	1,3	7,2	1,6	1,1	1	4,5	3,8	1,6	1,5	1,2
Ta (ppm)	<0.01	0,01	0,01	0,01	0,01	0,01	<0.01	0,01	0,01	<0.01
Te (ppm)	0,02	0,03	0,03	0,01	0,01	0,01	0,04	<0.01	0,17	0,05
Ti (ppm)	0,252	0,309	0,259	0,264	0,297	0,318	0,316	0,286	0,123	0,327
V (ppm)	72	82	72	78	70	76	79	78	115	78
W (ppm)	0,29	0,36	0,38	0,33	0,34	0,39	0,2	0,2	0,31	0,14
Tl (ppm)	0,41	0,65	0,54	0,16	0,49	0,86	1,08	0,49	0,36	1,14
In (ppm)	0,029	0,025	0,03	0,026	0,032	0,052	0,035	0,041	0,04	0,033
Re (ppm)	<0.001	0,001	0,001	0,001	0,001	<0.001	0,001	<0.001	0,014	<0.001

Appendix 3. Sample-level age statistics

Table A3. U–Pb zircon dates of ten samples from the study. The samples MSI210053A and ELH220153A are not analysed due to lack of enough zircons. The age statistics in the table use analyses within 10% concordance. Percentiles use linear interpolation between ordered ages and are rounded to the nearest Ma. Counts are zircon analyses, not independent rock samples.

Sample	Locality	Rock type	N (SWEREF 99 TM)	E (SWEREF 99 TM)	Concordant analyses (n)	Common-Pb corrected (n)	P10 (Ma)	P25 (Ma)	P50 (Ma)	P75 (Ma)	P90 (Ma)	P95 (Ma)
MSI220061A	Sollefteå-Rödsta	Silica-rich metagreywacke.	7004955	609765	123	36	1959	1984	2006	2071	2644	2692
ELH220054A	Järkvissle power plant	Pelitic schist.	6964209	584884	122	52	1941	1980	1999	2087	2719	2863
SPN221091A	Jamttärnen	Meta-greywacke.	6950943	539596	60	6	1975	2003	2047	2716	2768	2910
SPN221080B	North of Kattviken	Well-sorted metagreywacke.	6963287	654618	122	36	1950	2004	2096	2723	2834	2871
MSI230099A	Gräsmyrberget	Sandstone to silica-rich metagreywacke.	6985206	614707	123	30	1960	1983	2035	2628	2723	2756
ELH230109A	Lidens-Backen	Metasediment with volcaniclastic interbed.	6954701	597246	109	13	1946	1998	2053	2685	2738	2831
ELH230119A	Lappberget	Well-sorted pelitic schist.	6959863	601148	111	13	1955	1981	2011	2141	2706	2772
SPN230583A	Tregörningen	Meta-greywacke to siltstone.	6964028	637691	119	11	1963	1980	2012	2172	2721	2754
SPN230551A	Grössjön	Metagreywacke.	6984545	635369	114	9	1935	1975	2000	2653	2716	2748
SPN230523A	Grundsjön-Tallmyran	Non-well-sorted metagreywacke.	6969279	635257	112	22	1944	1983	2023	2607	2742	2766
Total					**1115**	**228**						

Interpretive note: These are descriptive statistics for mixed detrital zircon age populations. Sample quantiles and pooled proportions should not be presented as depositional ages. The oldest and youngest values may reflect minor age components; interpret populations with suitable plots and geological context.