1 Tommy Creek LA-ICPMS Zircon Geochronology, June 2018

1.1 Introduction

Laser Ablation ICPMS analysis was performed on resin mounted zircon separates from 13 samples, and in-situ (thin section) on 1 sample on the 28th and 29th June 2018, at the Advanced Analytical Centre (AAC), James Cook University Townsville. It was also intended that U-Pb analyses be performed on titanites, however a test run on standards did not return satisfactory results. The following documents the results of this work

1.2 Samples

The below table outlines the samples that were analysed. A map with their locations and results is in **Error! Reference source not found.**.

Sample ID	Sample Type	Lithology	Grains mounted	Analyses performed
EX32127	Surface	medium to fine felsic rock with amph alt. unsure if volc or intrusive	~70	24
EX32129	Surface	qtz-fd porphyry, some foliation, minor muscovite. Some pyrite	~40	24
EX32145 (Thin Section)	Drill core	syenitic pegmatite with large 2-10mm titanite. HB, alkali fd qtz. Late infill siderite, minor py	2	3
EX21971	Surface	white and pink fine grained igneous rock, poss volc?. Small layer within graph schist (multiple layers in area)	3	7
EX21972	Coarse reject	coarse foliated amphibolite/gabbro	2	5
EX21973	Coarse reject	Fd porphyry, some bleaching	~30	24
EX21977	Reject Pulp	fine-med dolerite, with some fabric. High Zr	2 (suspect)	8
EX21980	Coarse Reject	granitic pegmatite	~25	22
EX21982	Surface	qtz-fd with bt clots to 20mm. Mod fabric, fine grained. Thought to be intrusive	~32	25
EX095747	Coarse reject	saprolite, probable volcanic in graph schist	1	4
EX096238	Surface	pinkish microgranite (tommy Creek Microgranite?)	>100	23
EX096246	¼ core	cc-bt-amph rock. This interval has xenoliths, but no xenolith material included in sample	>100	65
EX096247	¼ core	coarse biotite kspar with interstitial pyrite. Glimmerite	~35	32
EX096248	¼ core	alb-kspar- amph-cc-epi calc silicate 'Corella' unit. Sample avoided veining	~90	63

Table 1: Table of samples with zircons analysed. EX32145 is a polished thins section taken from drill core. Coarse reject is material crushed by commercial lab ALS from half drill core for the purpose of multi element assaying during the exploration program. Reject pulp is similar but has been pulverized by ALS to nominal 100micron. Both these sample types have higher risk of contamination than other sample types. ¼ core is material taken directly from drill core by the author

1.3 Methods

Samples were prepared in the Mineral Separation Laboratory at JCU. Coarse and pulp reject samples were crushed, and crushed and pulverised respectively at ALS Townsville under their normal exploration multielement geochemistry preparation protocols. Remaining samples were crushed using a hydraulic splitter and pulverized with a disc mill.

Pulverised material (except that pulverized at ALS) was sieved into 3 fractions: >500μm, 500μm< x >250μm, and <250μm.

Pulverised material was then treated on a shaker table to remove slimes and concentrate heavy minerals. The first attempts at this were performed on a plastic shaker table. Samples from EX096238 and higher were treated on a Holman-Wilfley table with fiberglass riffle deck. It is believed that this machine resulted in much superior results, with significantly more zircons, particularly smaller grains, recovered from these samples. In general, samples were recycled 2-4 times (mid and heavy fractions), and different sieved fractions were treated separately

The heavy fractions from the shaker table were dried and then magnetic materials were removed using a hand magnet and Frantz machine with maximum working current of 1.4 amps.

The least magnetic fraction was then treated with hot LST (Lithium polytungstate) density separation.

Zircons were picked from the heavy fraction and mounted in a resin puck, which was ground and polished to a high finished

Pucks were imaged with Cathode Luminescence and mineral identification checked with EDS on a Hitachi SU5000 SEM at the AAC

U-Pb analyses were performed by coupled Laser Ablation and quadrupole Mass Spectroscopy (LA-ICPMS) in the AAC. Sample spots were preprogrammed and 3 runs of between 2 and 7 hours in duration were performed. Zircon Standards GJ1 (calibration), FC1 and X91500 (check), as well as NIST610 and NIST612 glass. Two spots of each standard analysed for after brackets of 10 unknowns for zircon standards; NIST glass was analysed at the start, midpoint and end of each run.

The Laser was set to a spot size of 30μm, 5Hz and 2.5J/cm^2, with 45s on time and 60s offtime between samples. Run 3 (29/6/18) was performed using 20μm spot size to allow for smaller grain size of some samples.

The mass spectrometer was set to collect Pb 204, 206, 207, 208, Th 232, U 238 and Si29. It was also set to collect Ti for zircon thermometry, however Ti49 was mistakenly chosen, resulting in unusable data due to interferences on Zr94.

Data was reduced using iolite software package (each run independently), with signal integration periods chosen by quality of the Pb 207:206 signal. 29 of 329 analyses were rejected at this stage for inadequate signal quality.

Data processing and visualization used Isoplot 4.15 add in for excel and ioGAS.

1.4 QAQC

The following includes only results from standards analysed as part of the 3 sample runs

Standard	Age (MA)	Uncertainty (2σ)
GJ1	608.5	±0.4
FC1	1099	±0.6
X91500	1065	

1.4.1 GJ1

The GJ1 standard was used as the calibration standard, with a total of 72 analyses over the 3 runs

1.4.2 FC1

FC1 was used as a check standard, with a total of 64 analyses. Figure 1 and Figure 2 show the effect on precision with the reduced spot size in Run 3. The weighted mean 207-206 age is slightly under the standard age (1092.9 ± 2.3Ma vs 1099Ma). The Concordia diagram shows the 20µm spot analyses to be more discordant than the 30µm spots. The intercept age (model 2) is given as 1106 ±6.9Ma. However, Figure 3, Figure 4, and Figure 5 show a concerning pattern in the U data, which are significantly affected by the different spot sizes. Neither population matches the standard age well, with 30µm overestimating and 20µm underestimating. The 20µm population does not resolve well on a Concordia diagram (not shown here) yielding 1134±89, however this is improved significantly by anchoring the lower intercept to 0Ma (1112±16Ma). The 30µm population does better, with 1107±9.5Ma, but most analyses plot above the Concordia.

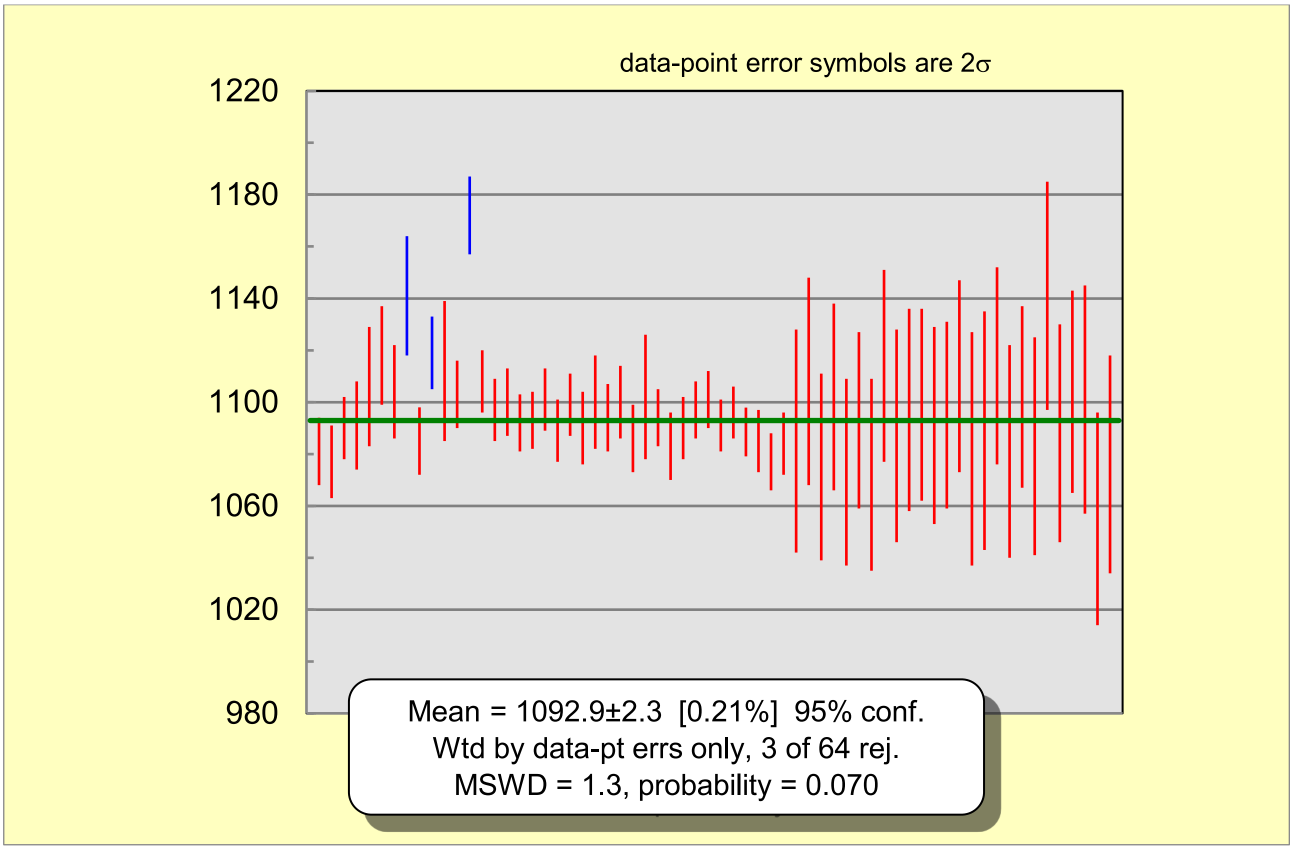


Figure 1: Weighted mean 207-206 age for FC1. The greater uncertainty in the latter part of the series relate to the 20µm spot size analyses

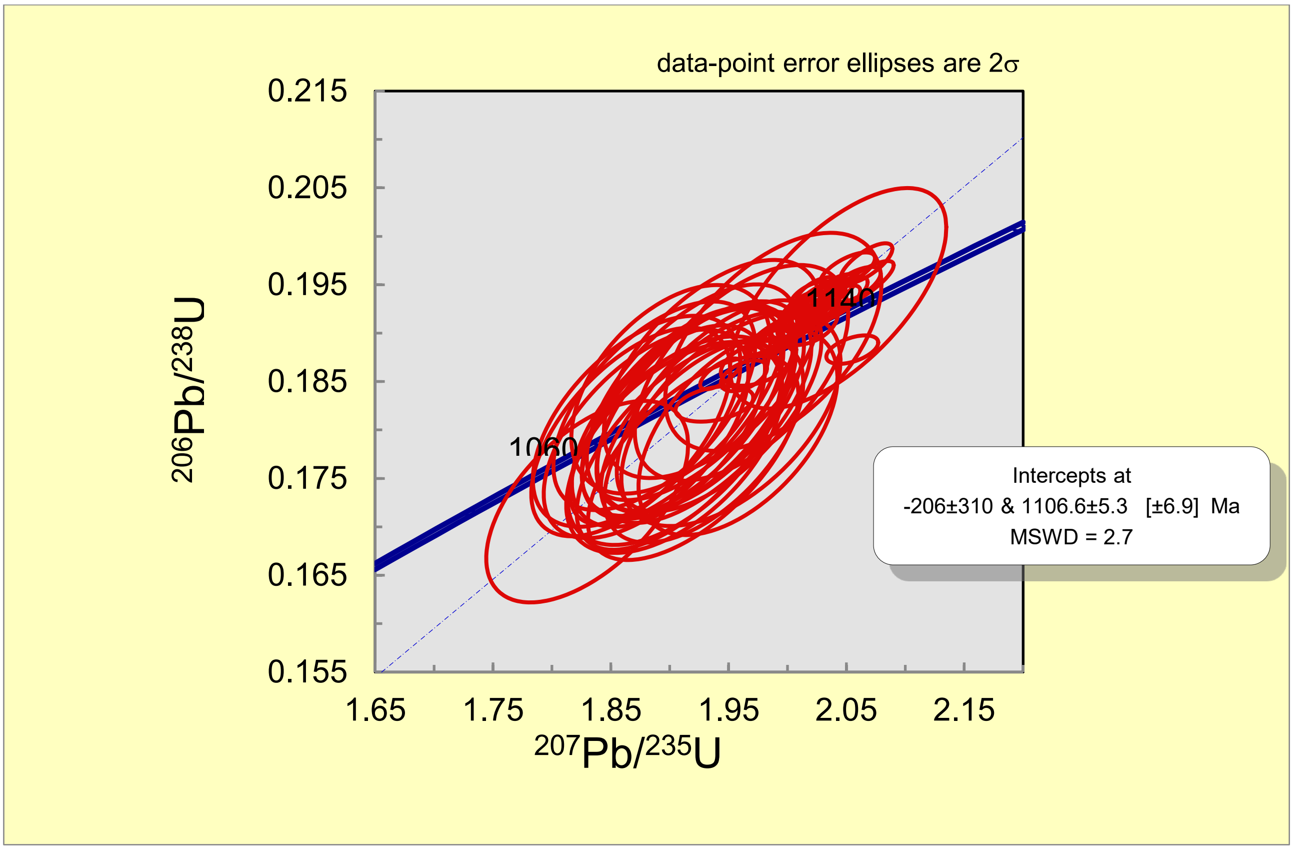


Figure 2: Wetherill Concordia diagram for FC1. Larger uncertainties relate to the 20μm spot analyses, which are also more discordant.

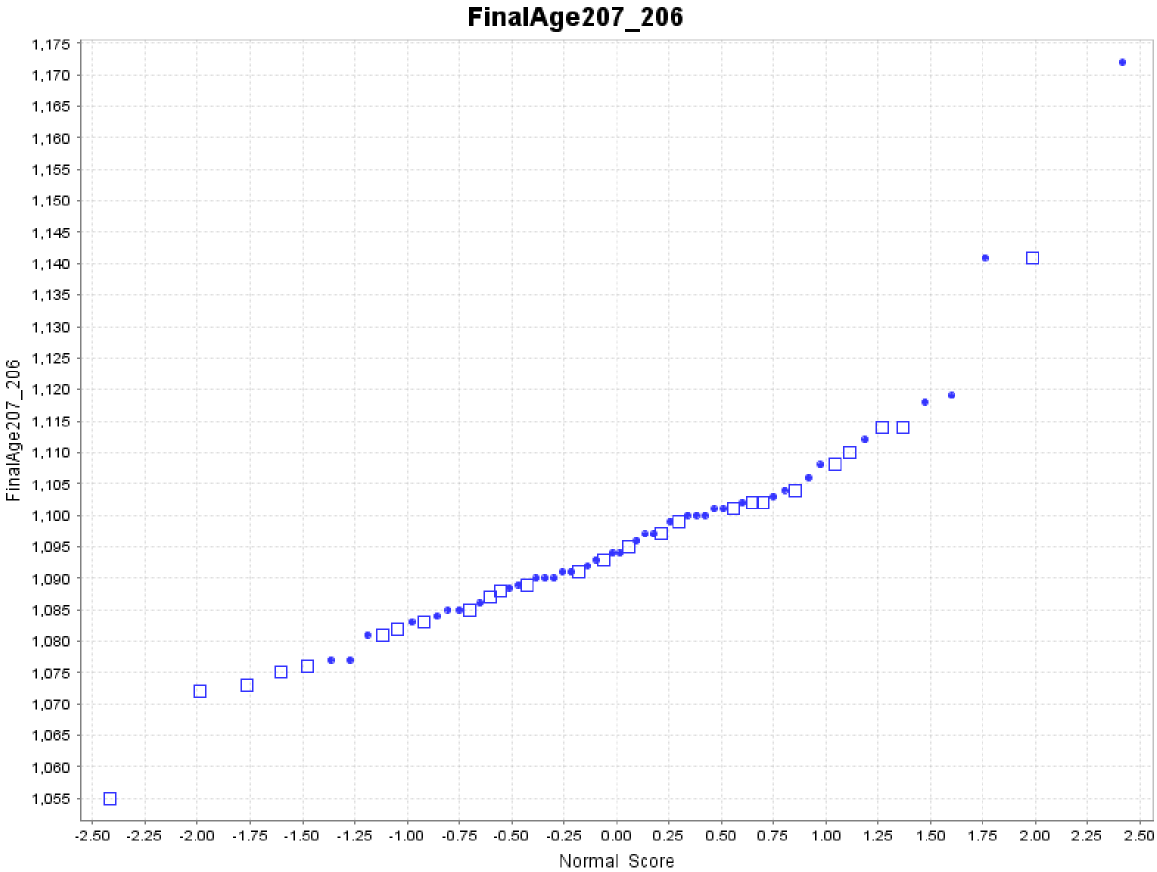


Figure 3; FC1 Probability plot for final Pb 207-206 age. Squares denote analyses taken with 20μm spot size, all others 30μm. Spot size does not appear to affect the result significantly

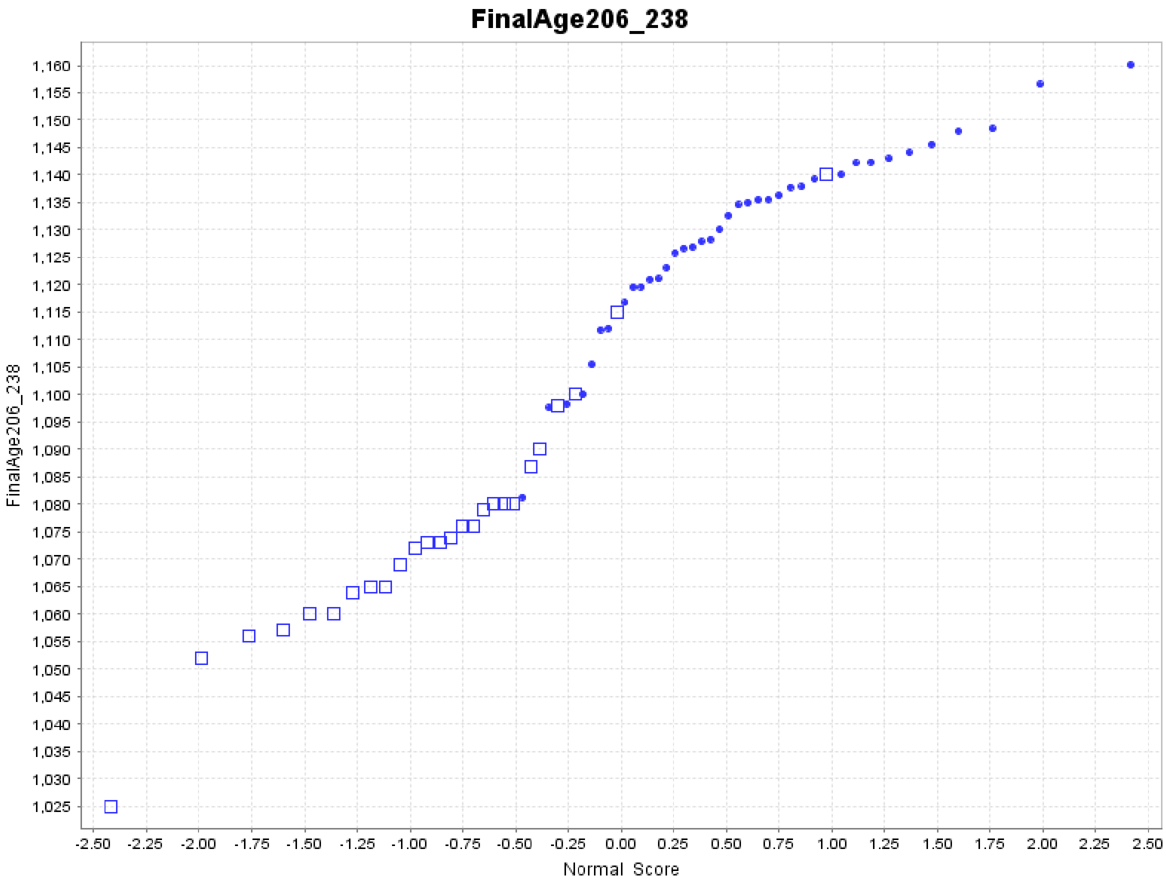


Figure 4:FC1 Probability plot for final Pb206 U238 age. Squares denote analyses taken with 20µm spot size, all others 30µm. It can be seen that spot size significantly affects this ratio. It can be seen that neither population mean is a satisfactory fit to the standard age

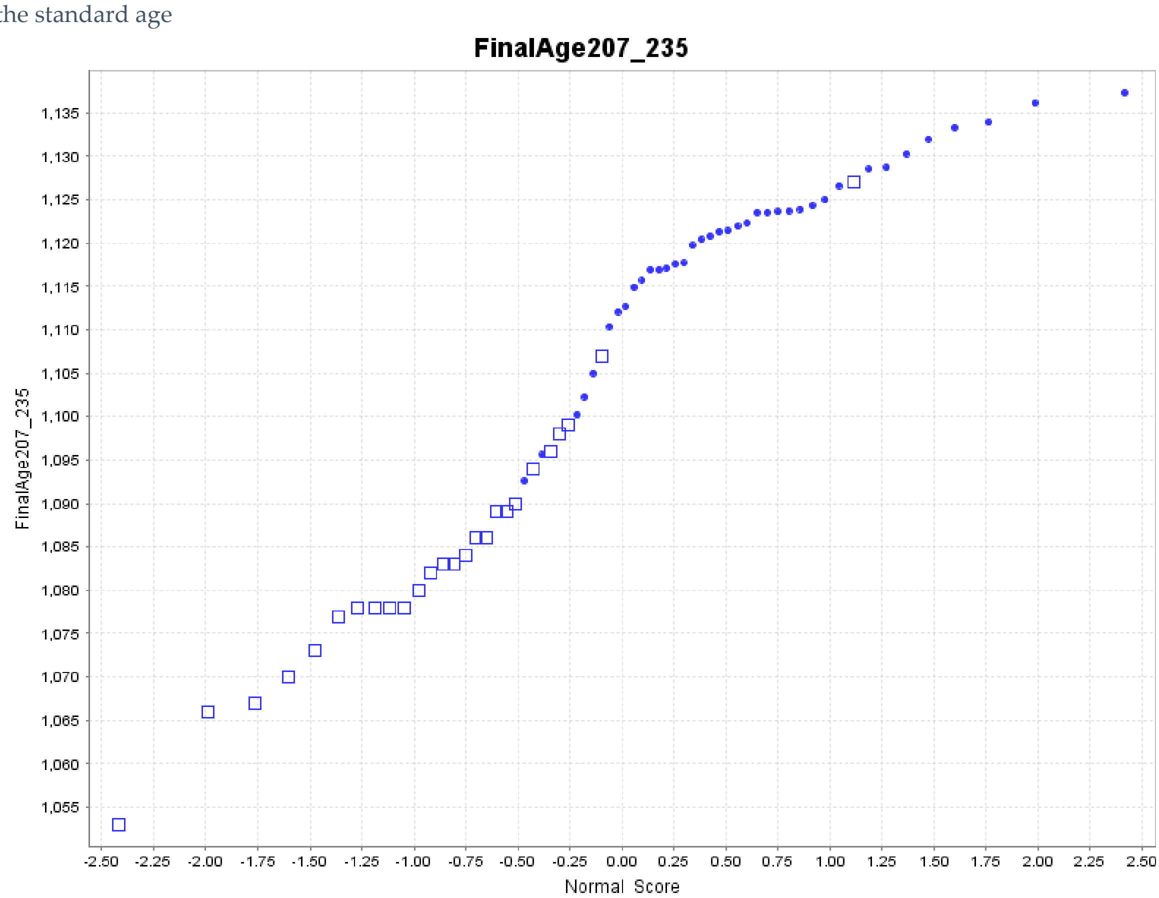


Figure 5: FC1 Probability plot for final Pb207 U235 age. Squares denote analyses taken with 20µm spot size, all others 30µm. It can be seen that spot size significantly affects this ratio. It can be seen that neither population mean is a satisfactory fit to the standard age

1.4.3 X91500

X91500 was used as a check standard, with a total of 62 analyses. Figure 6 and Figure 7 show the effect on precision with the reduced spot size in Run 3, although not as pronounced as that in FC1. The weighted mean 207-206 age is slightly under the standard age (1054.3 ± 5.3Ma vs 1065Ma). The Concordia diagram shows the 20µm spot analyses to be more discordant than the 30µm spots. The intercept age (model 2) is given as 1090±48Ma, which is a relatively poor result.

Figure 8, Figure 9 and Figure 10 show a similar pattern to FC1 in the U ratio data, which are significantly affected by the different spot sizes. Neither population matches the standard age well, with both underestimating. Neither population resolve well on a Concordia diagram (due to tight clustering) with 30µm yielding 1195±330Ma and 20µm 901±20Ma. If these intercepts are anchored with a lower intercept of 0Ma, 20µm yields 1111±38Ma, improving to 1086±19Ma upon the removal of 2 outliers. 30µm yields a satisfactory result of 1065.7±7.5Ma with a 0Ma anchored chord. (Figure 11 and Figure 12)

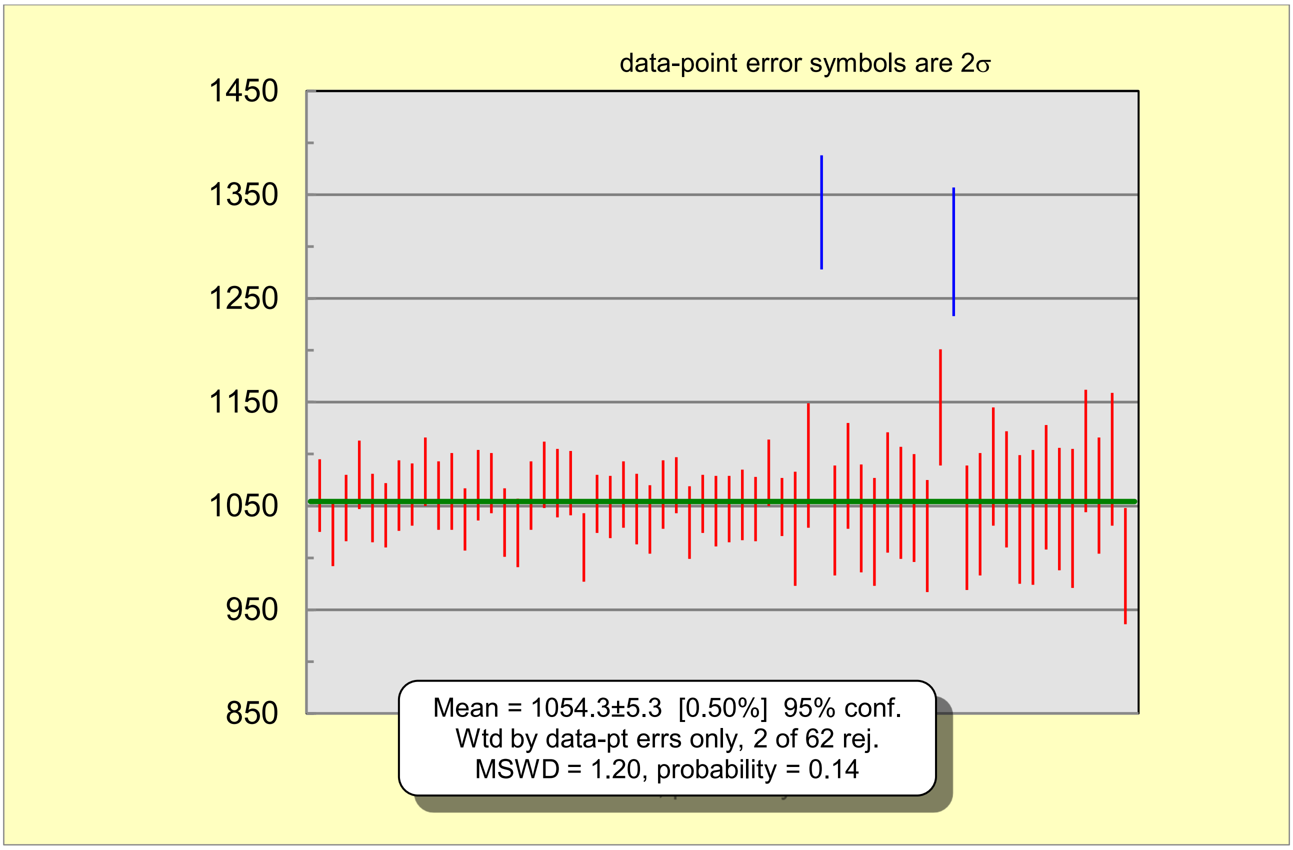


Figure 6: X91500 weighted mean Pb207-206 age. the increased uncertainty of the 20µm spot size in Run 3 is apparent but not as significant as for FC1. The age is slightly lower than standard value of 1065Ma.

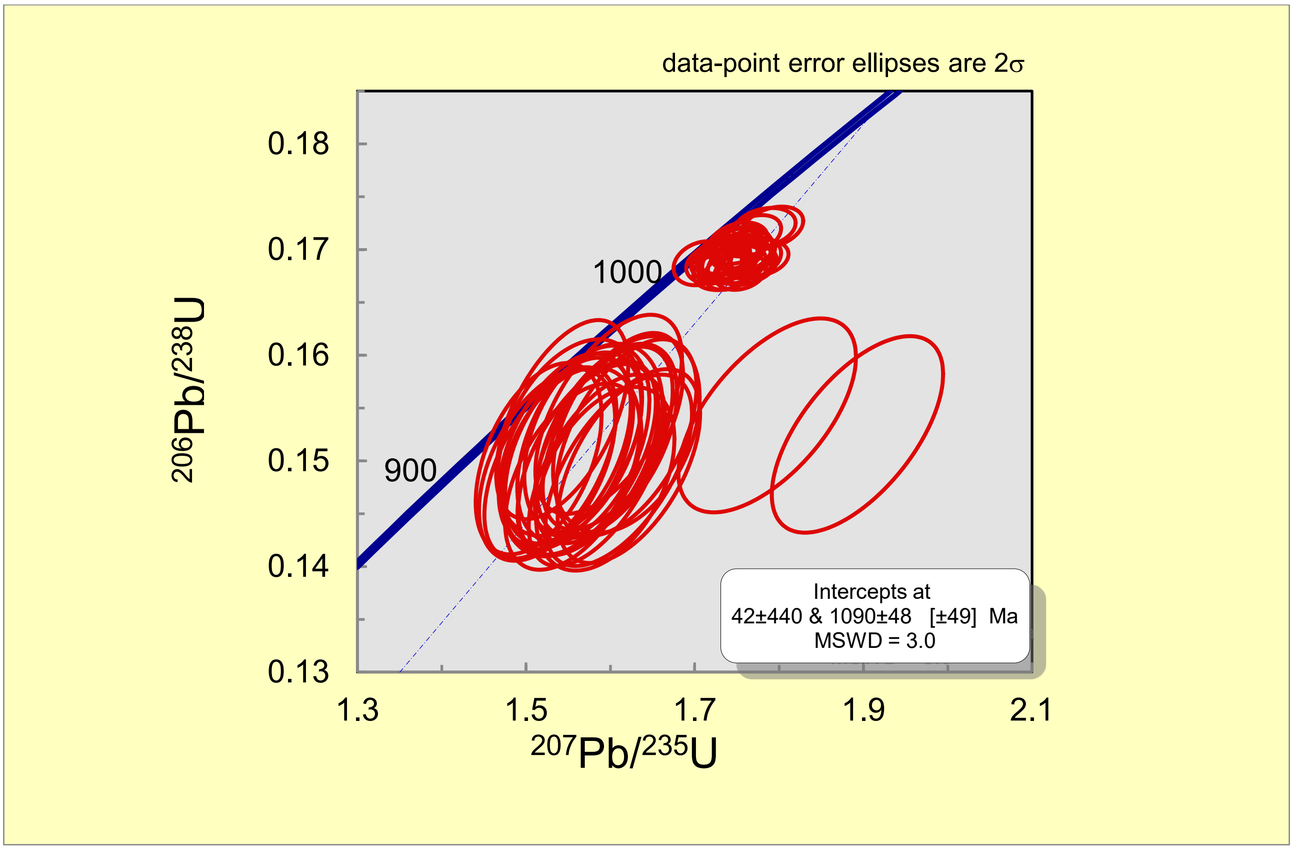


Figure 7: X91500 Wetherill Concordia Diagram. The uncertainty increases and higher discordance of the 20µm population is apparent. Intercept age is an overestimate although within the high uncertainty.

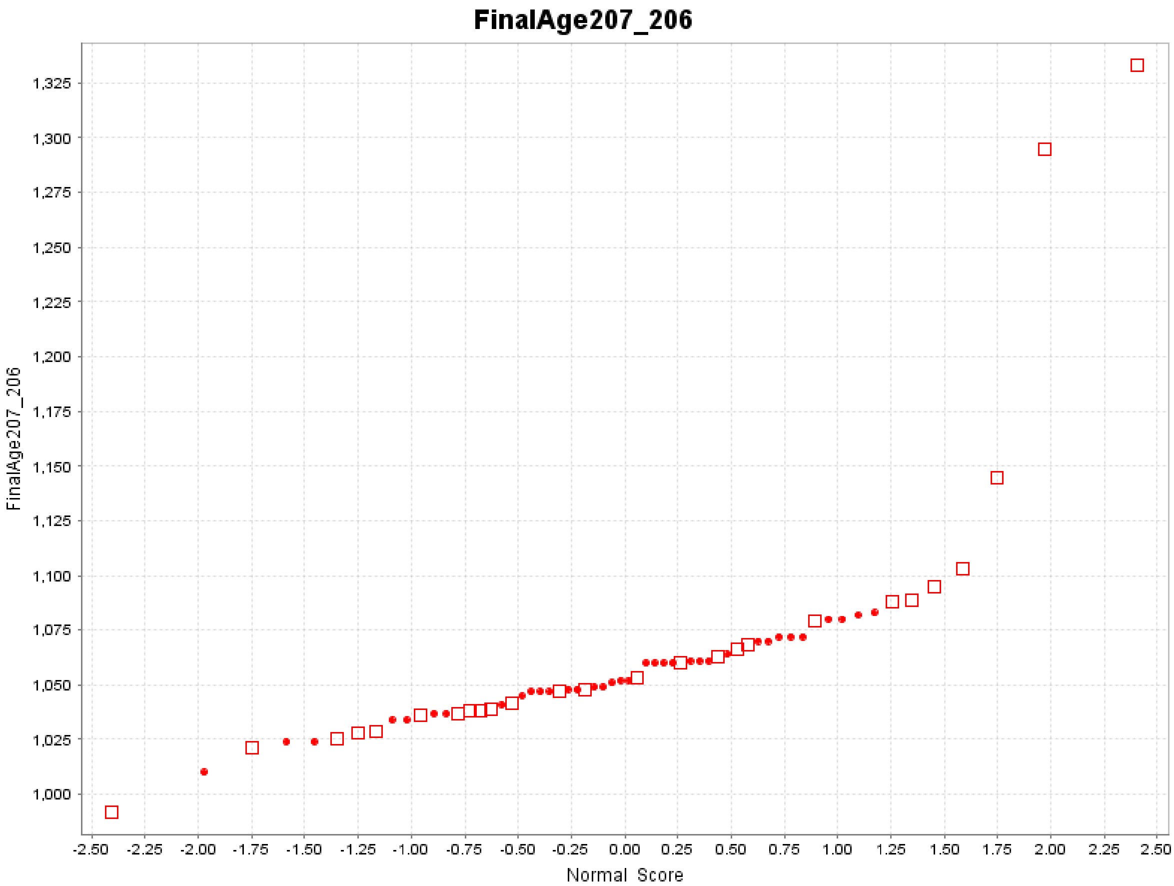


Figure 8: X91500 Probability plot for final Pb 207-206 age. Squares denote analyses taken with 20µm spot size, all others 30µm. Spot size does not appear to affect the result significantly

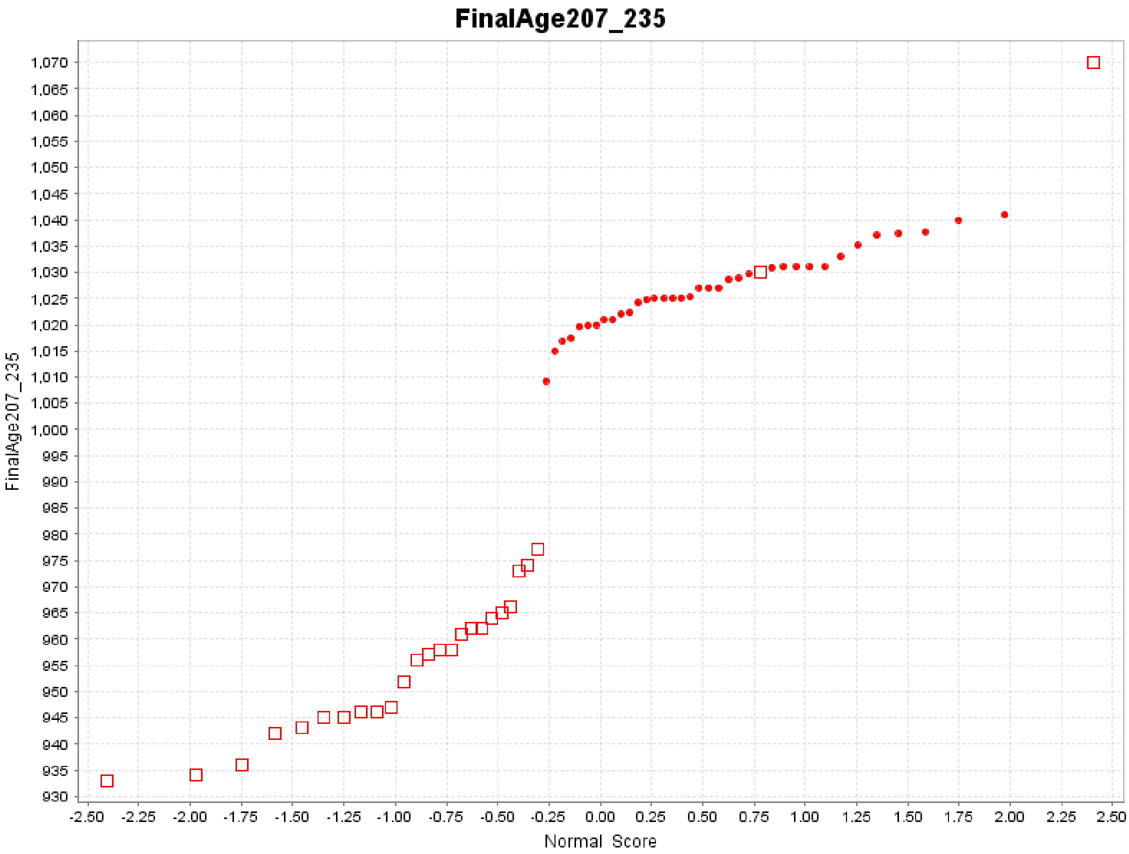


Figure 9: X91500 Probability plot for final Pb206 U238 age. Squares denote analyses taken with 20µm spot size, all others 30µm. It can be seen that spot size significantly affects this ratio. It can be seen that neither population mean is a satisfactory fit to the standard age

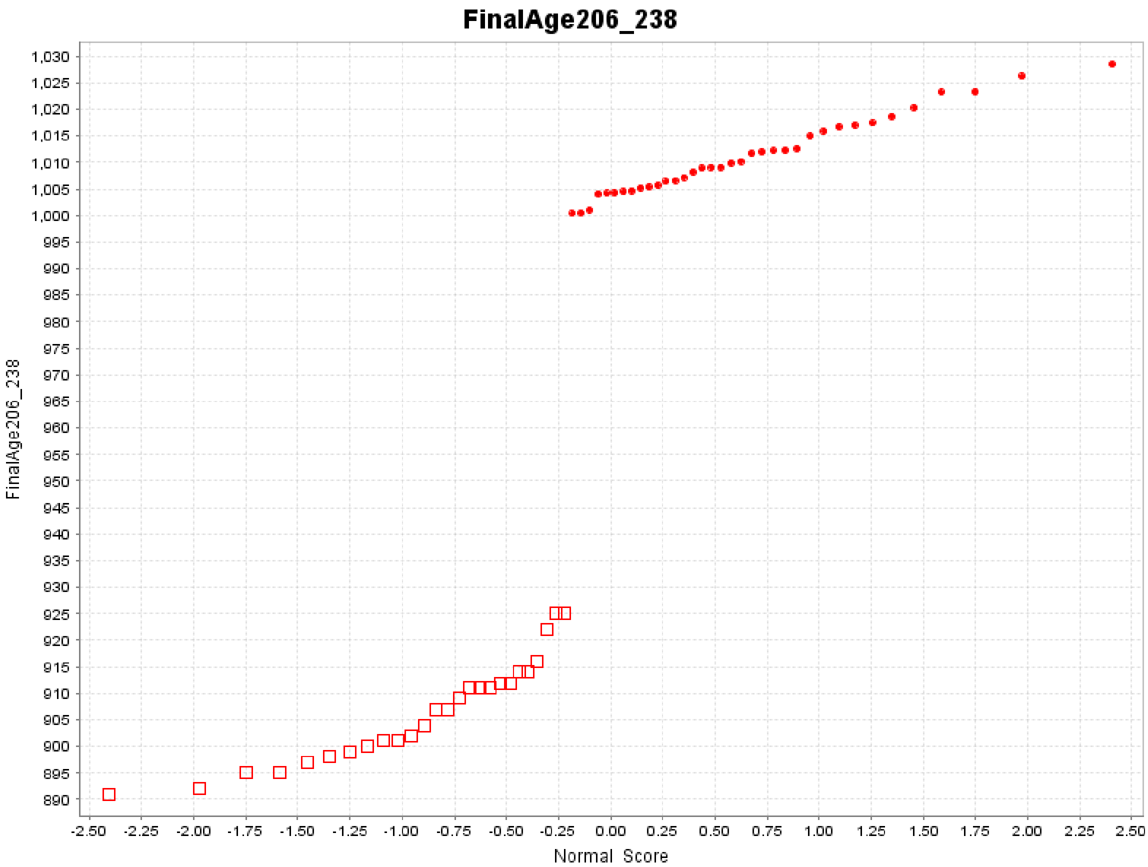


Figure 10: X91500 Probability plot for final Pb206 U238 age. Squares denote analyses taken with 20µm spot size, all others 30µm. It can be seen that spot size significantly affects this ratio. It can be seen that neither population mean is a satisfactory fit to the standard age

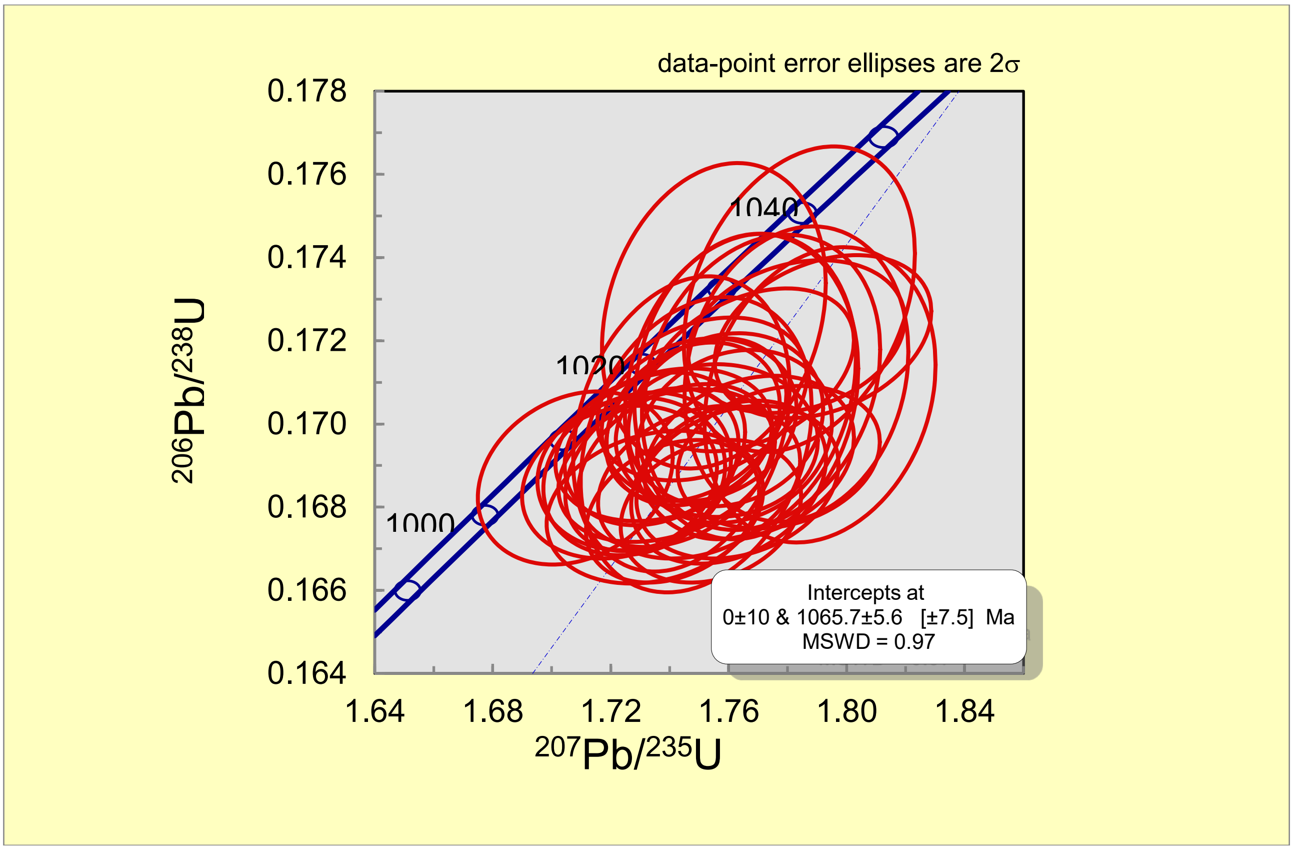


Figure 11: Wetherill concordia for X91500 30µm spot analyses only. Lower intercept was anchored to 0, yielding an intercept age with good fit to the standard age

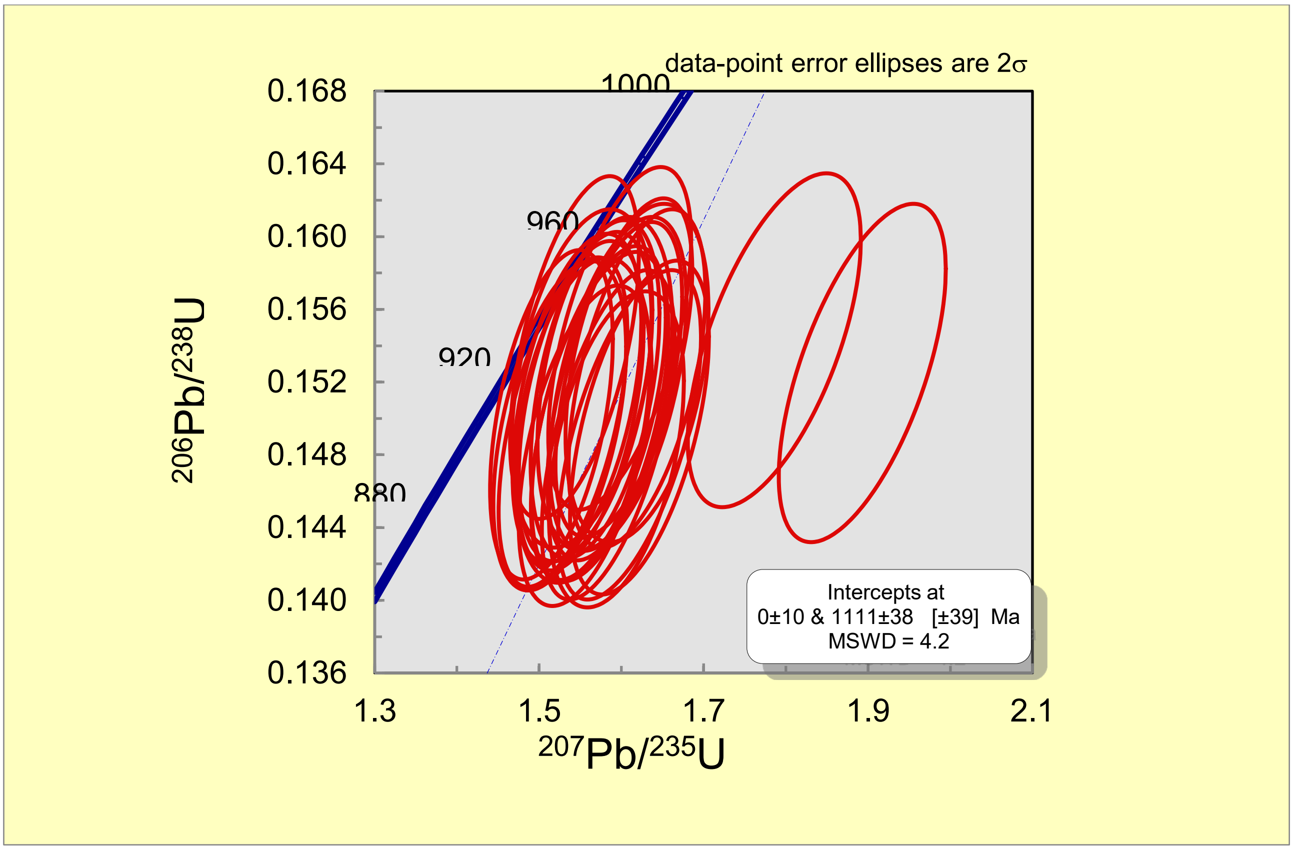


Figure 12: Wetherill concordia for X91500 20µm spot analyses only. Lower intercept was anchored to 0, yielding an intercept age with poor fit to the standard age removing the 2 outliers improves the result to 1086±19Ma

1.4.4 Summary

The results from the check standards in the Pb207-208 system appears to be reasonable. U ratio data is less than satisfactory, and in particular seems to be affected by spot size. Wetherill Concordia ages are showing high (compared to low in weighted average Pb207-206) ages, and are possibly being effected by the poor U data. It was also noted at the signal integration stage that Pb207-206 ratios were considerably more stable the either of the U-Pb ratios. It is possible that signal reprocessing focusing on stable U-Pb intervals instead of Pb-Pb intervals could improve results (put will result in a higher number of rejected samples and more analyses with short integration intervals).

As was expected, smaller spot sizes resulted in higher uncertainties.

Considering the expected ages and the better performance of the Pb-Pb ages, data interpretation will focus on the Pb-Pb ages and Tera-Wasserburg Concordia diagrams

1.5 Results

The following presents the results of each sample analysed. The results were interpreted using ioGAS and IsoPlot4.15 Excel addin, and includes the use of Tera-Wasserburg (TW) diagrams, Wetherill diagrams (W), Pb-Pb weighted averages, and Pb-Pb age histograms with gaussian deconvolution.

1.5.1 EX32127

Lithology: Medium to fine felsic rock with amphibole alteration. Generally massive appearance, possibly intrusive.

Run	Run2	Pb207-206 Age	NA
# Analyses	24	Concordia Age	1658.8±9.3, also 1677±13
# Analyses integrated	23	Multiple populations?	likely

This set of analyses may contain multiple source populations. An attempt to subset these populations was made by inspecting TW diagrams, probability plots of Pb-Pb ages, grains with multiple analyses, and cross referencing visible and CL images. Discordant arrays fit well to 2 subsets of the data at 1658.8±9.3Ma (pop A) and 1677±13Ma (pop B). A number of analyses do not plot well on either array, and inspection of visible light and CL images shows that these belong to quite dark grains. The uncertainty of each of these measurements is also high compared to most other measurements, and have been left out of the subset concordia ages.

The two ages have a small error overlap of between 1664 and 1668, and so it is possible that they represent subsets of an original population that have had different open system history.

These ages do not well match those previously seen in the Tommy Creek domain, and are similar to that found in the mid to upper parts of the Soldiers Cap group. It could also be very early component of the Tommy Creek Microgranite, although the two are radiometrically distinct.

If the sample represents a sedimentary source, then the age distribution is not as diverse as may be expected, e.g., as in EX096248.

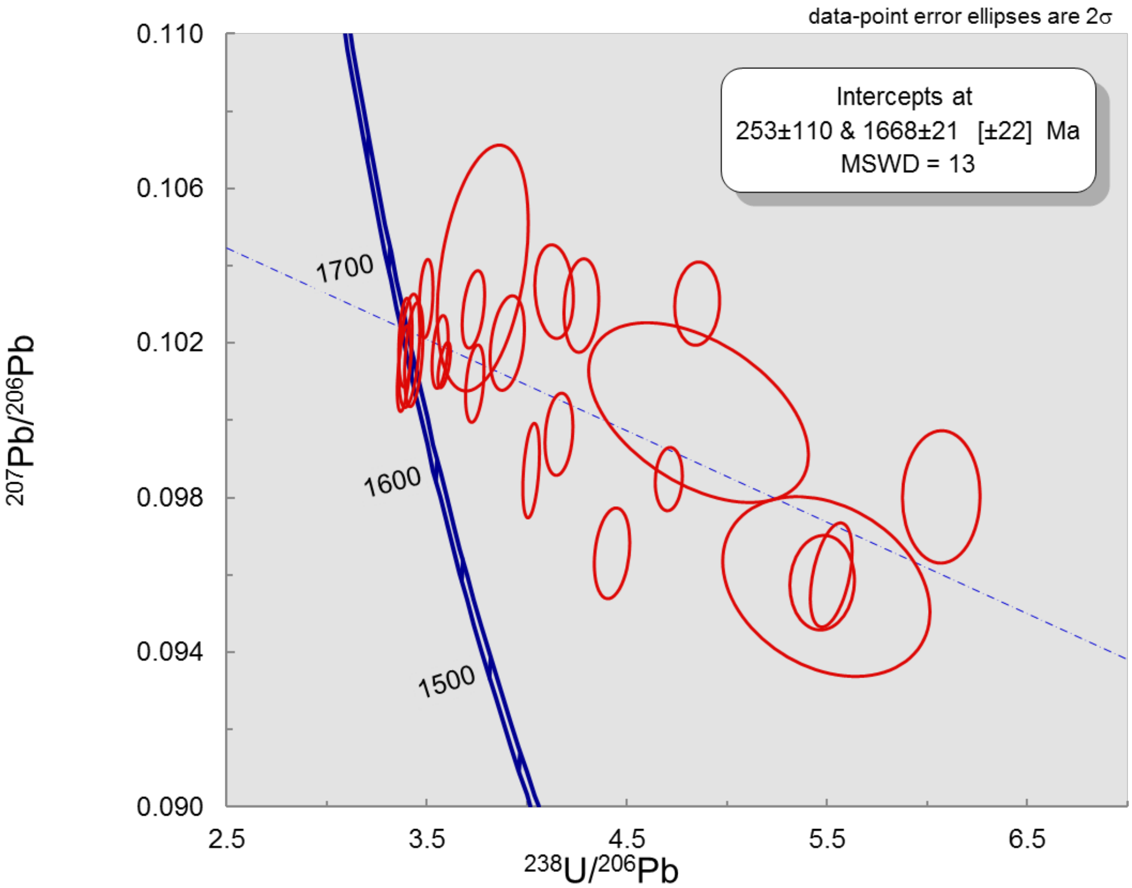


Figure 13: Tera-Wasserburg diagram for EX32127 as a single population. Many points are discordant, with a poor fit to a line, which may be explained by multiple populations

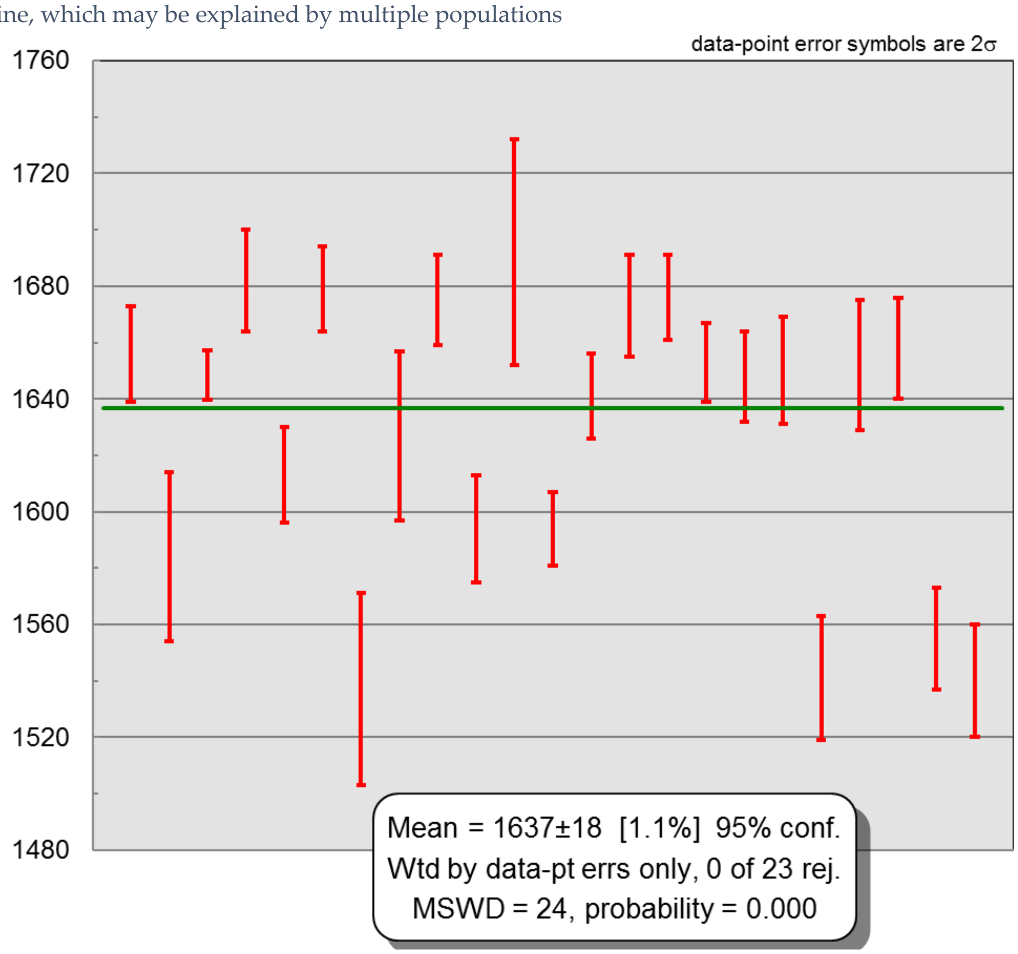


Figure 14: Weighted Mean Pb207-206 age for EX32127 as a single population

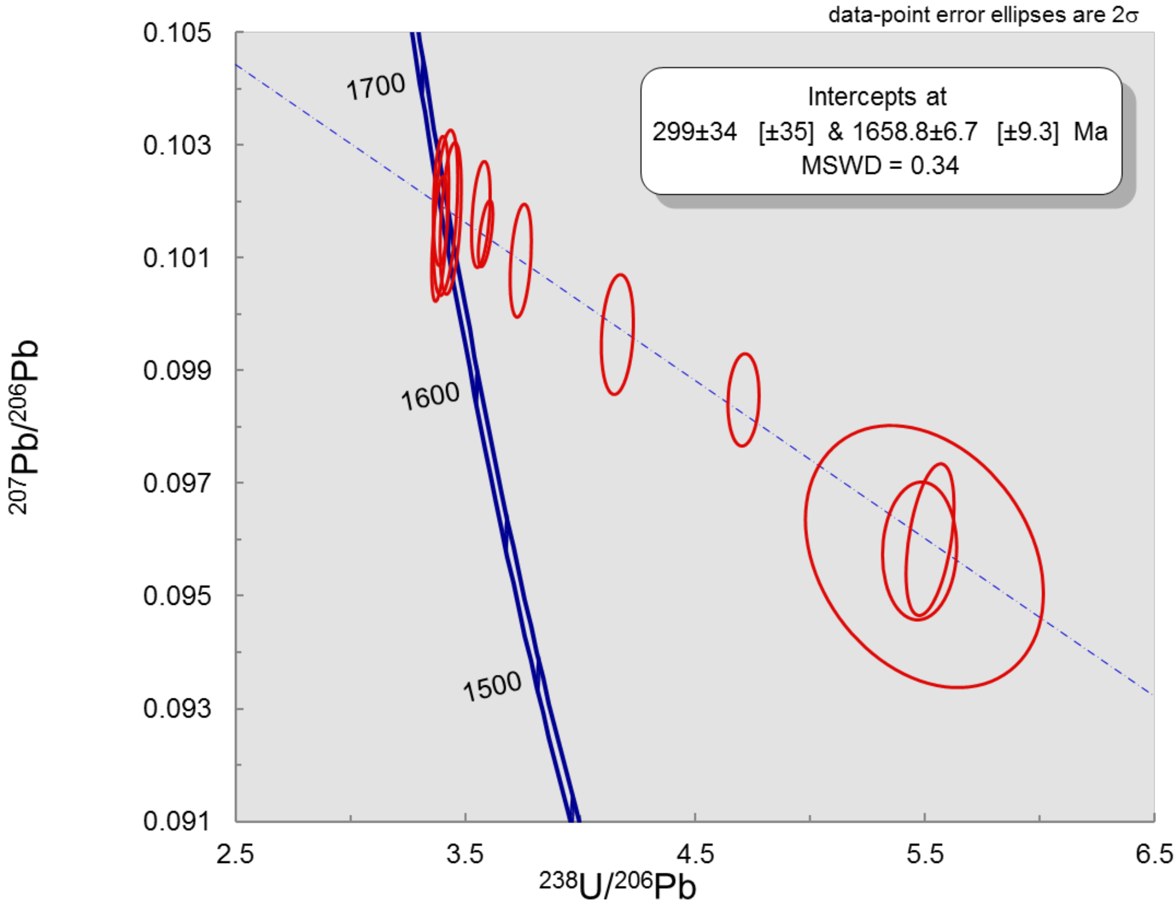


Figure 15: TW diagram for EX32127, population A

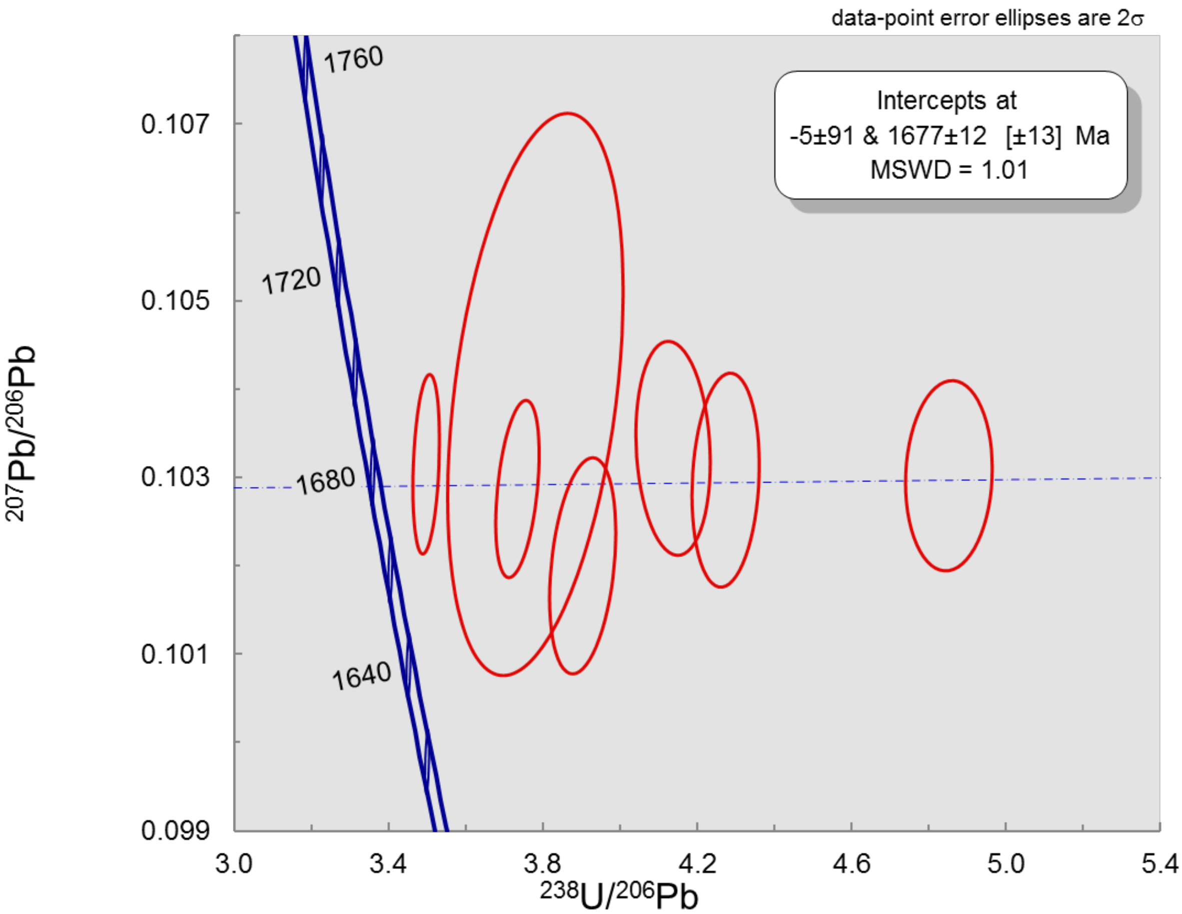


Figure 16: TW diagram for EX32127, population B

1.5.2 EX32129

Lithology: Quartz feldspar porphyry, with moderate to strong foliation defined by muscovite. Some pyrite. Expected age post Milo sediments

Run	Run2	Pb207-206 Age	1642±7.5
# Analyses	24	Concordia Age	1641.2±7.6Ma
# Analyses integrated	24	Multiple populations?	1 major

The analyses from this sample show a very large range of U-Pb ratios, most of which plots on a long discordant array consistent with modern Pb loss. Removal of 7 outliers appears to improve fit to yield an intercept age of 1641.2±7.6Ma. Of these outliers, 5 were also plotted, and show a poor fit to a modern Pb loss line with intercept age of 1548±69Ma. The final 2 outliers have Pb-Pb ages of 1387Ma and 1686Ma.

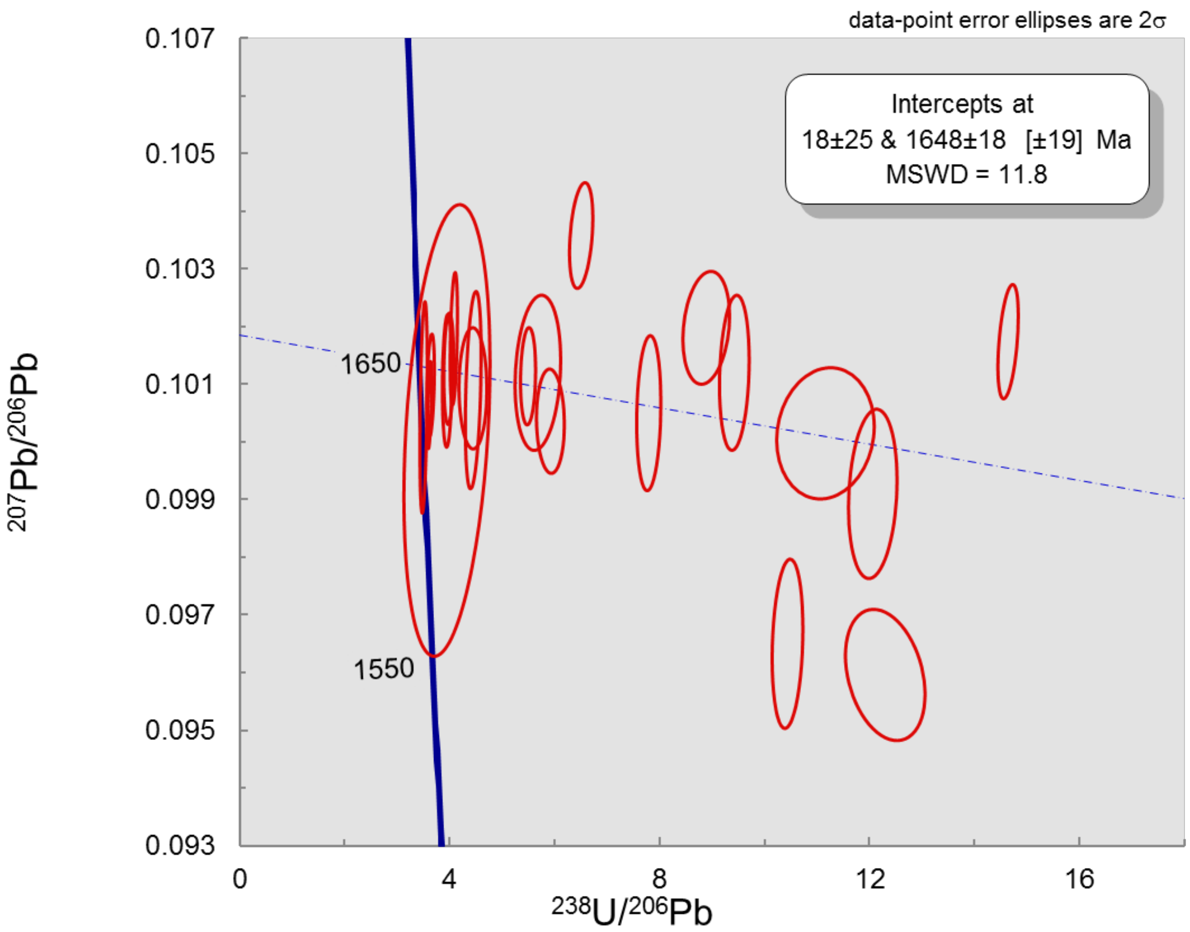


Figure 17: TW diagram for EX32129, all analyses

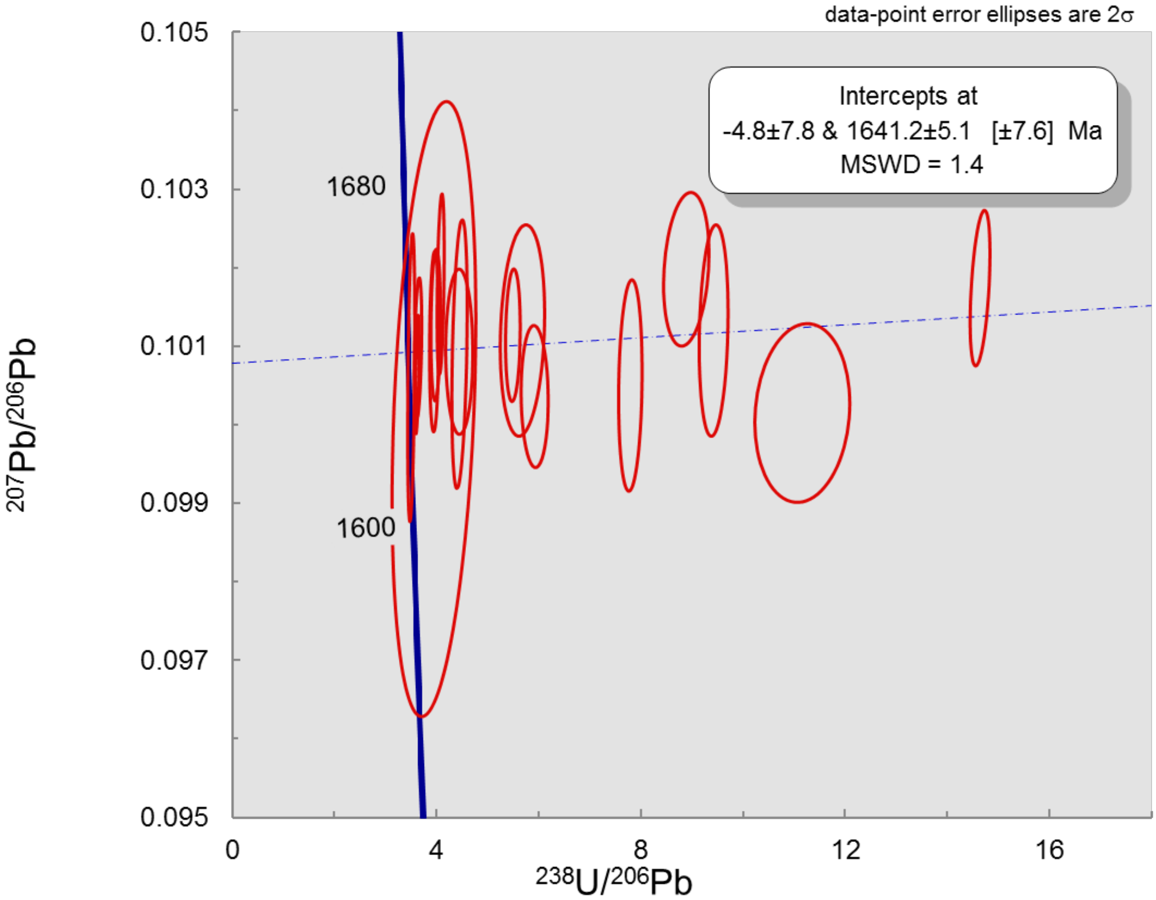


Figure 18: TW diagram for EX32129, with 7 outliers removed

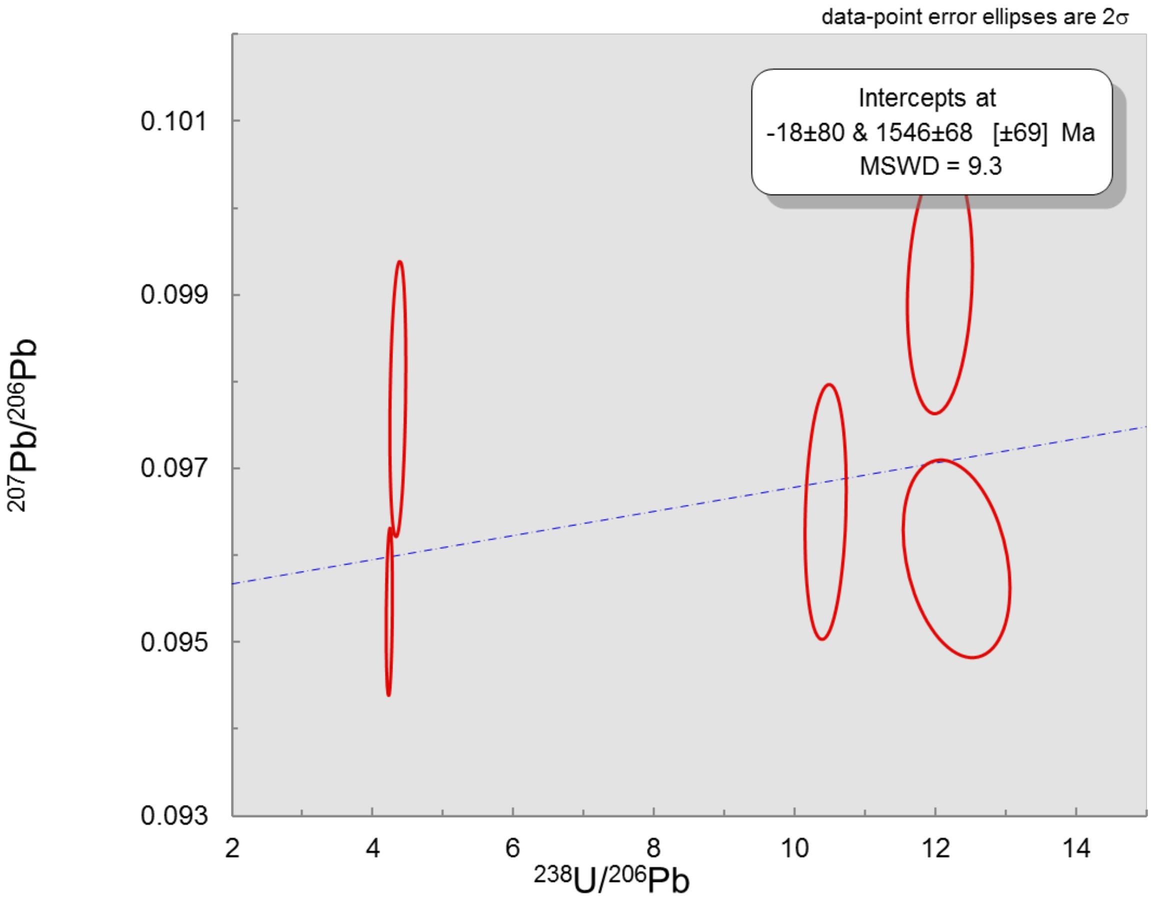
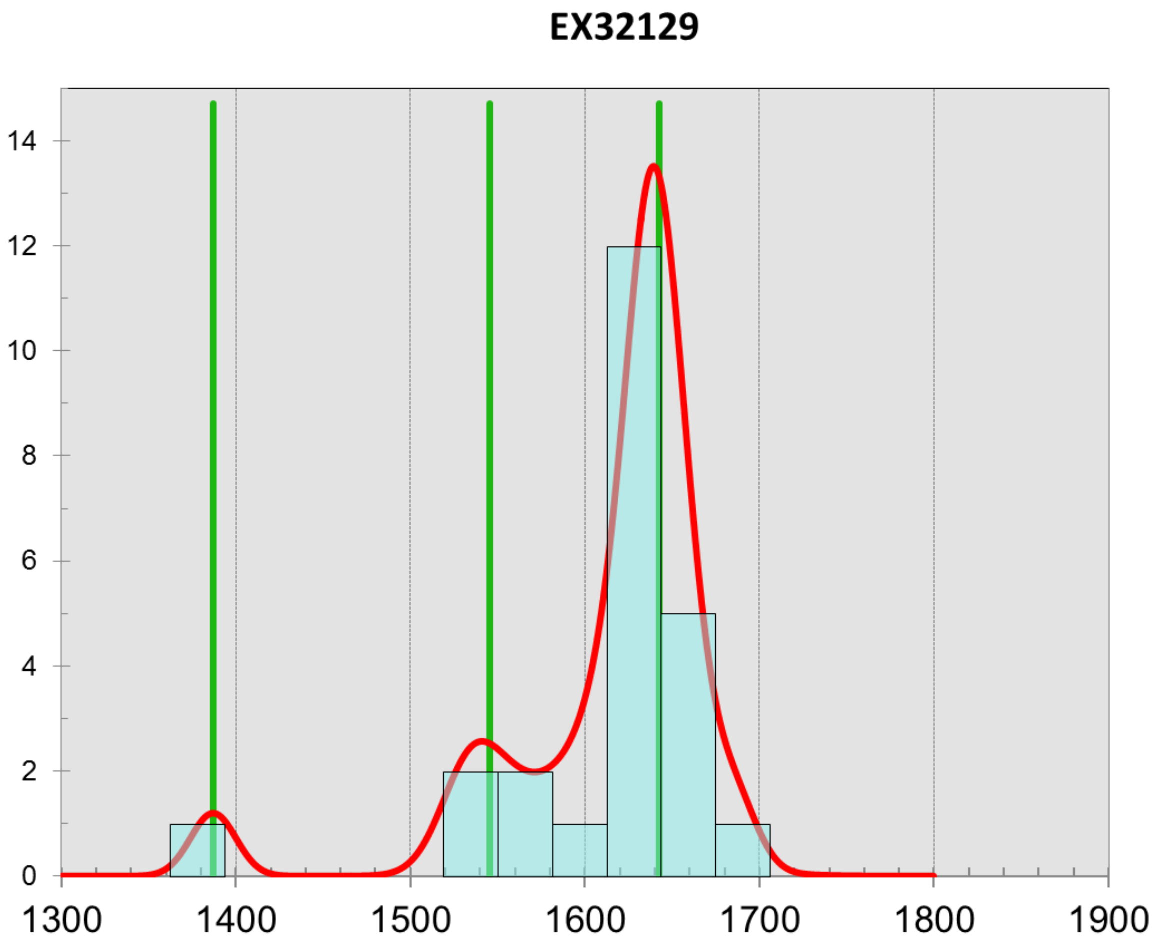


Figure 19: TW diagram of 5 of the 6 outliers removed from the main population. The fit is poor, but matches with that seen in the Pb-Pb age distribution



Sigma-Rho Matrix

	f1	f2	t1	t2	t3
f1	0.042	0.000	0.000	0.000	0.000
f2	0.000	0.084	0.000	0.012	0.004
t1	0.000	0.000	6.5	0.000	0.000
t2	0.000	0.012	0.000	4.96	0.015
t3	0.000	0.004	0.000	0.015	1.88

Age	±2σ	fraction	±2σ
1387	13	0.04	0.08
1545.7	9.9	0.17	0.17
1642.4	3.8	0.79	---

relative misfit = 0.145

Figure 20: Pb-Pb age distribution with population unmixing estimates using gaussian deconvolution. The peak ages have a good match for the 2 concordia arrays from above. The ~1400Ma is an extreme outlier but appear to show in several samples

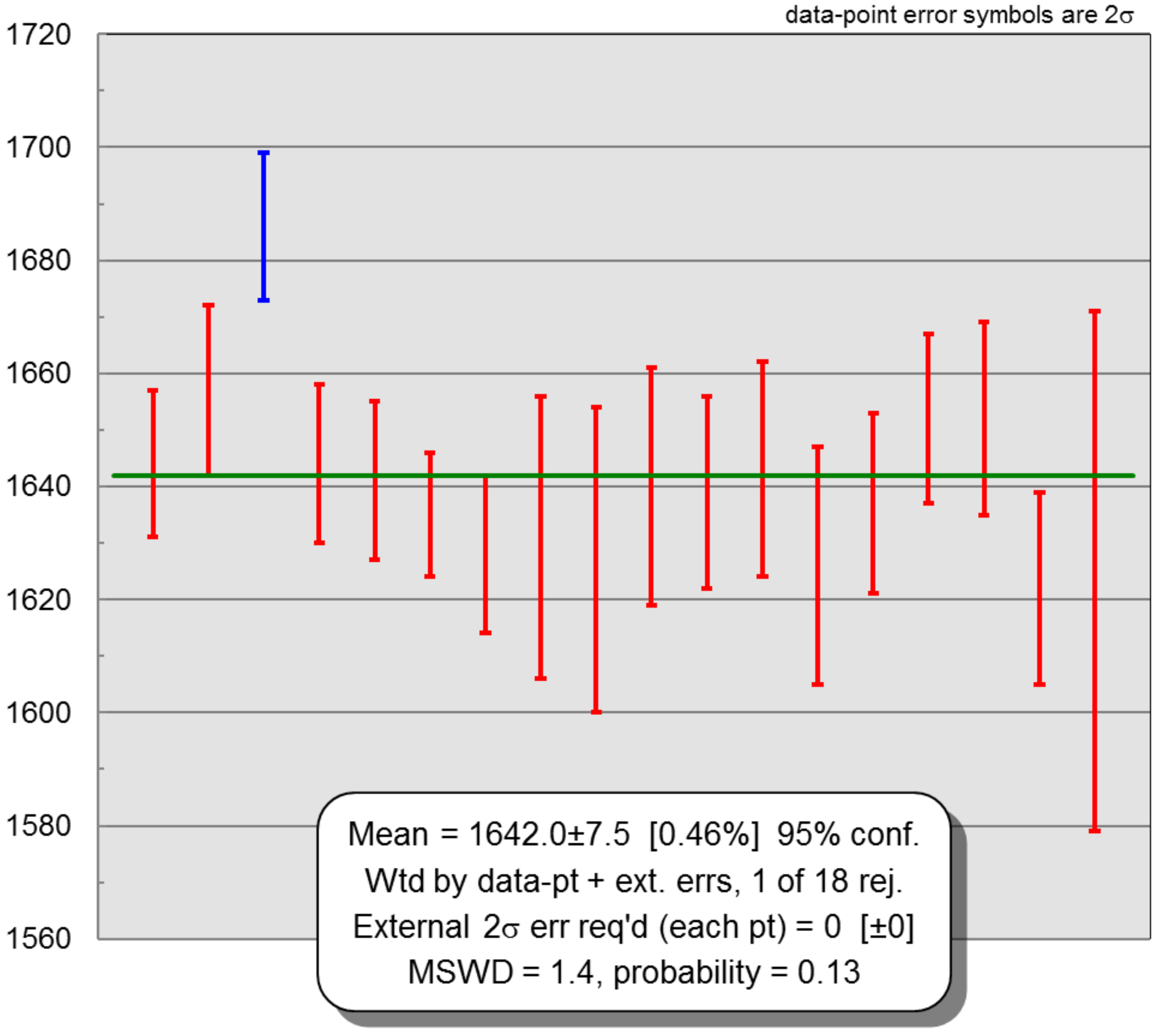


Figure 21: Weighted Average Pb-Pb of EX32129 with outliers removed. An additional outlier, which can also be seen as an outlier in the concordia diagrams, plots at 1686Ma

1.5.3 EX32145

Lithology: Coarse k feldspar-amphibole-biotite syenite with coarse titanite. Sample taken primarily for titanite age, however 2 large zircons were spotted within k feldspar crystals

Run	Run3	Pb207-206 Age	
# Analyses	3	Concordia Age	
# Analyses integrated	3	Multiple populations?	

Only 2 grains of zircon were analysed in this sample, which is primarily an in-situ titanite sample. The zircons were analysed opportunistically and for comparison with the titanite ages. Analyses 2 and 3 were shot close together on the same grain, but yielded ages ~100Ma apart, the second shot more closely resembling the other grain analysed. No conclusions can be made from this data, but it suggests an orogenic/Williams age is possible.

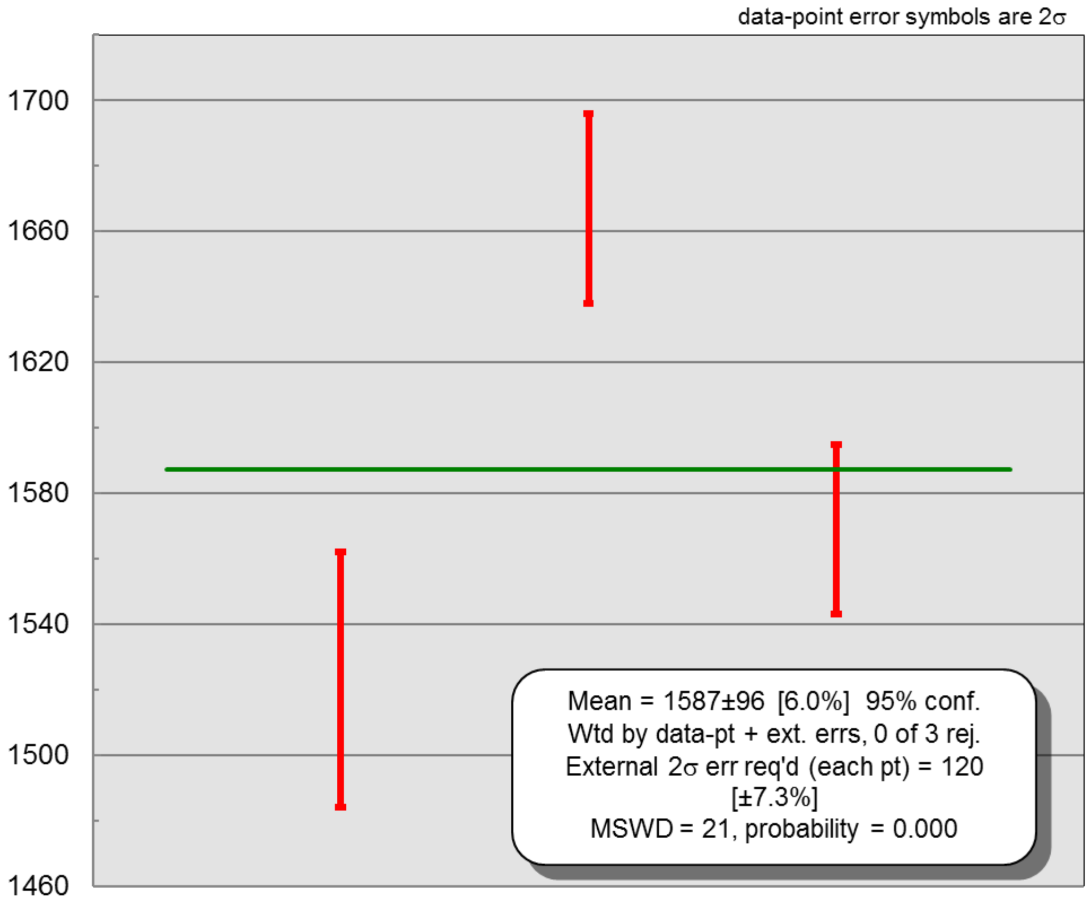


Figure 22: Pb-Pb ages for 3 analyses taken from 2 grains in EX32145. The 2nd and 3rd analyses are from the same grain

1.5.4 EX21971

Lithology: White to pinkish fine grained igneous rock as a small layer with graphitic phyllite (Milo beds), thought to be volcanic. One of a number such layers in area. Expected Age coeval with Milo beds (~1620Ma or younger)

Run	Run2	Pb207-206 Age	
# Analyses	7	Concordia Age	1653±29
# Analyses integrated	7	Multiple populations?	

A total of 7 analyses from 3 grains, with one a reasonably clear outlier at 1727Ma (Pb Pb). The remaining analyses look to form a discordant array with an intercept of 1653±29. The second grain yields ages close to concordant between 1660Ma and 1638Ma (±15). These ages do not match the initial expectations from the field, and more work on similar rocks is suggested.

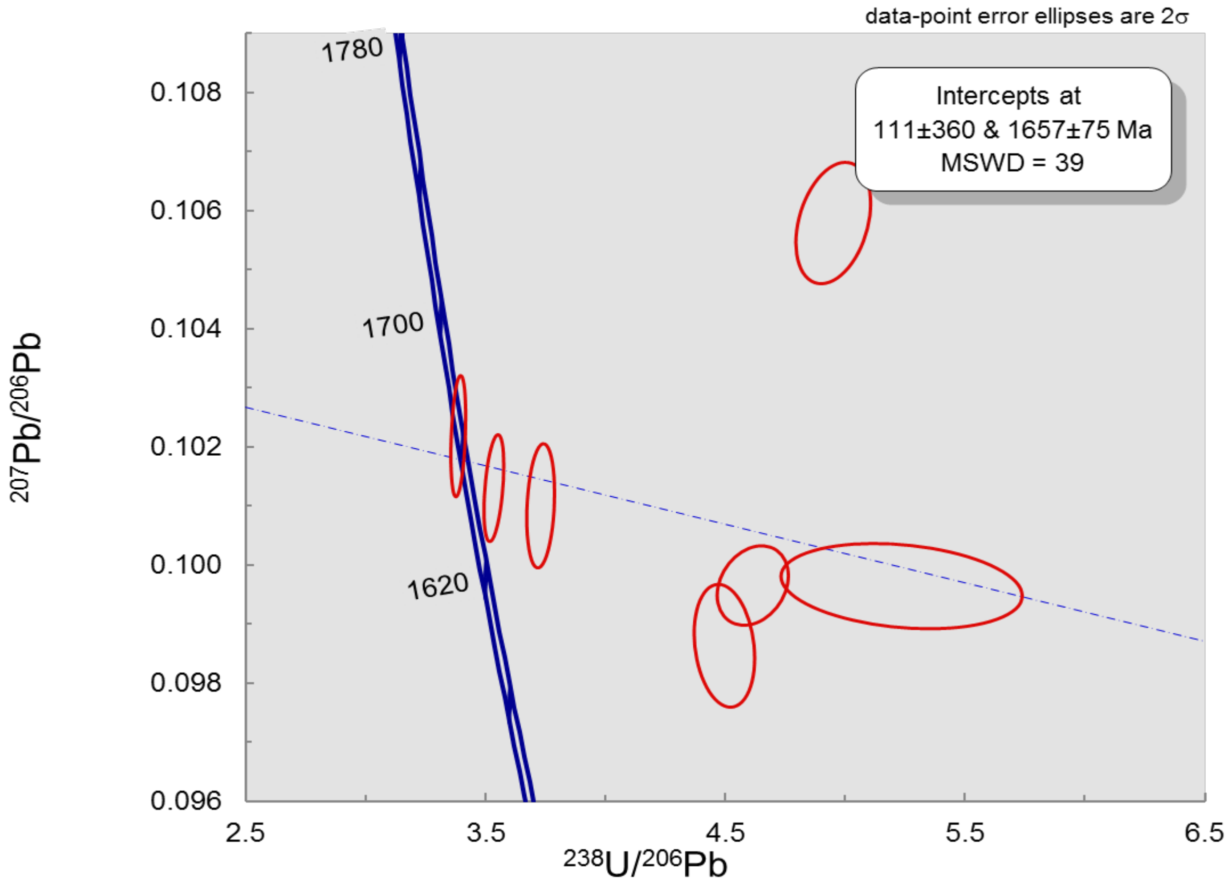


Figure 23: TW diagram for EX21971. There appears to be a clear outlier.

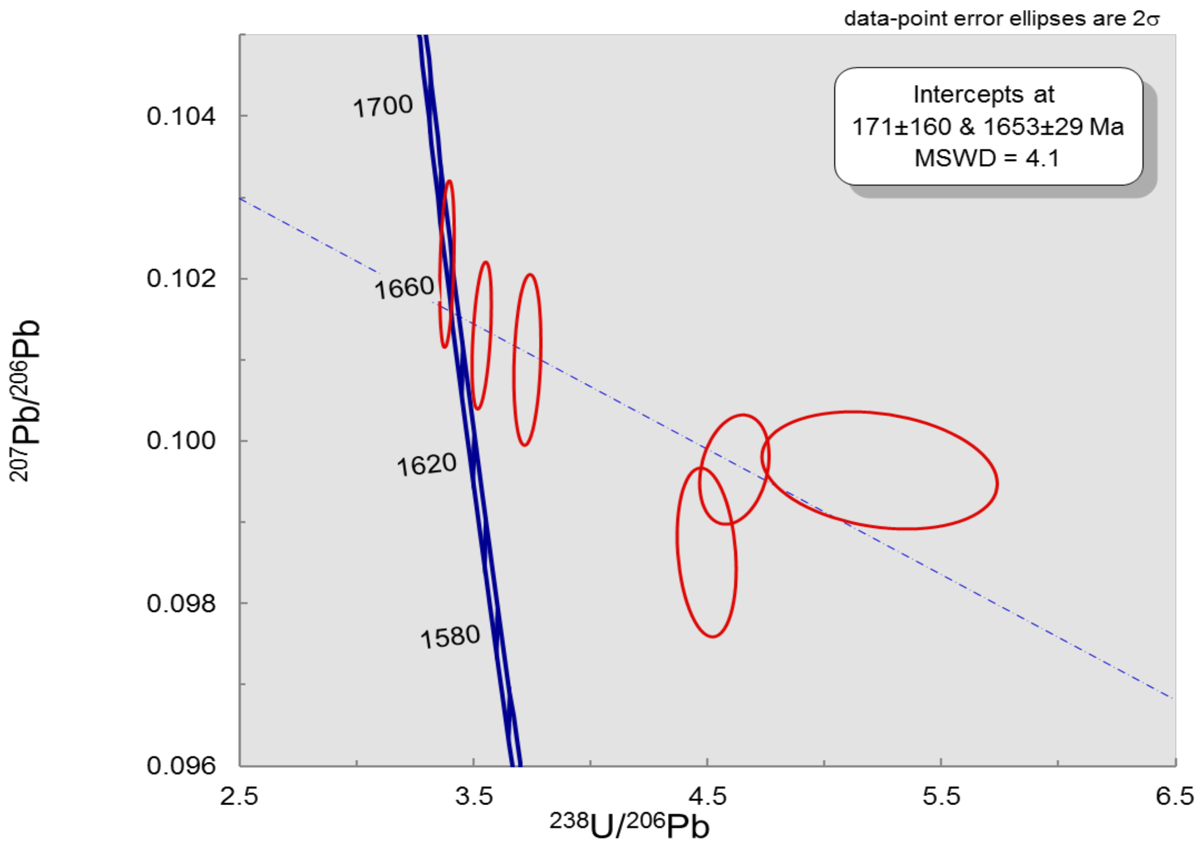


Figure 24: TW diagram for EX21971, with outlier removed, giving a much better fit

1.5.5 EX21972

Lithology: Coarse foliated amphibolite/gabbro

Run	Run2	Pb207-206 Age	
# Analyses	5	Concordia Age	
# Analyses integrated	5	Multiple populations?	

Five analyses from 2 grains, the second of which (2 shots) looks to have been too narrow. This may have contributed to the large difference in the results of the 2 analyses of 1736 and 1544Ma.

The first grain looks a little more reliable, with the 3 shots yielding discordant Pb-Pb ages of 2122, 2174 and 2245 (±45). These are clearly too old to have forming at emplacement of the mafic rock in this context.

1.5.6 EX21973

Lithology: Quartz feldspar porphyry with minor bleaching, foliation

Run	Run2	Pb207-206 Age	
# Analyses	24	Concordia Age	1642±10Ma
# Analyses integrated	19	Multiple populations?	Outliers @ ~1380, 1540

This sample has a high number of poor-quality zircons, reflected by the number of analyses rejected at signal integration (5) and several analyses with high uncertainty, mainly in the U-Pb ratios. With these, plus 2 outliers removed, a discordant array with good fit can be seen with an intercept age of 1642±10Ma. These two outliers removed have Pb-Pb ages of ~1380Ma and 1543Ma, which are both ages seen as 'outliers' in other samples, including the other Quartz feldspar porphyry sample (EX32129), which also shares the same age.

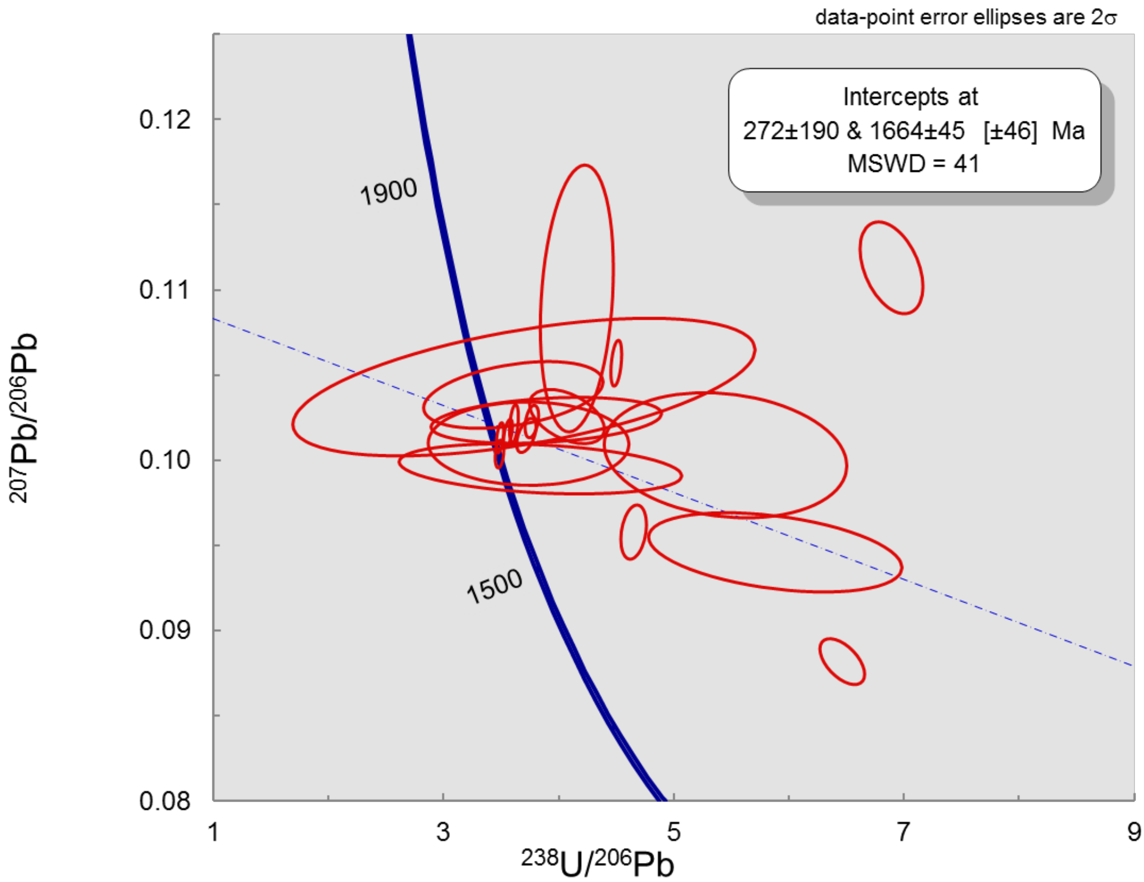


Figure 25: TW diagram for EX21973, all analyses. There are several high uncertainty (mainly U-Pb) and outliers

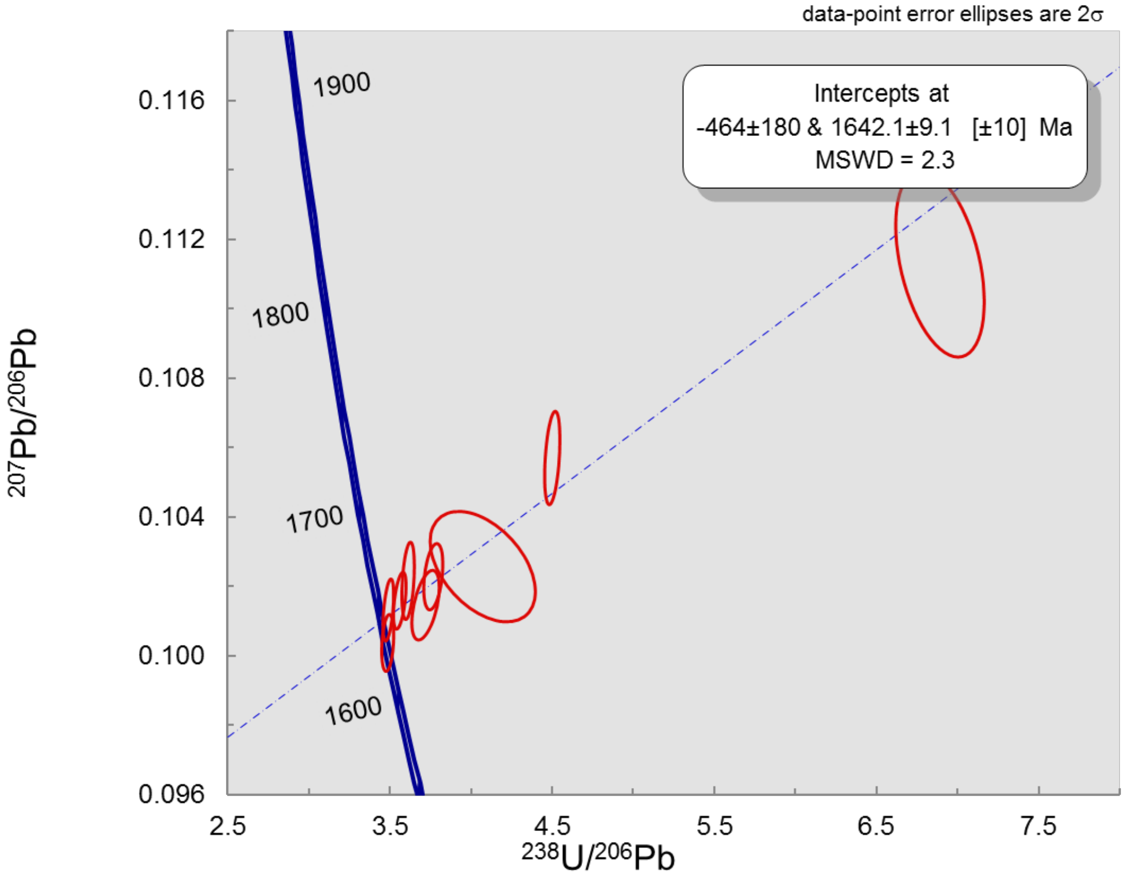


Figure 26: TW diagram of EX21973 with high uncertainty and outliers removed

1.5.7 EX21977

Lithology: fine –med grained dolerite sill in graphite schist with high Zr. Zircons suspected to be contamination prior to analyses performed.

Run	Run2	Pb207-206 Age	
# Analyses	8	Concordia Age	
# Analyses integrated	5	Multiple populations?	

Results of very young ages suggest the suspicion that these are exotic zircons are confirmed.

1.5.8 EX21980

Lithology: Granitic pegmatite from gossan/alteration zone

Run	Run2	Pb207-206 Age	
# Analyses	22	Concordia Age	
# Analyses integrated	13	Multiple populations?	

The results are extremely scattered, and do not appear to form any coherent pattern. A high number of analyses were rejected at the signal integration level, including 3 examples of 2 analyses per grain where 1 needed to be discarded. Two other paired analyses were made, with one set agreeing with each other, and the second set yielding Pb-Pb ages 200Ma apart. Inspection of the estimated U, Th and Pb abundance suggests that many of these zircons have considerably higher concentrations of U and Th. This may mean these zircons have been affected by severe radiation damage and disequilibrium.

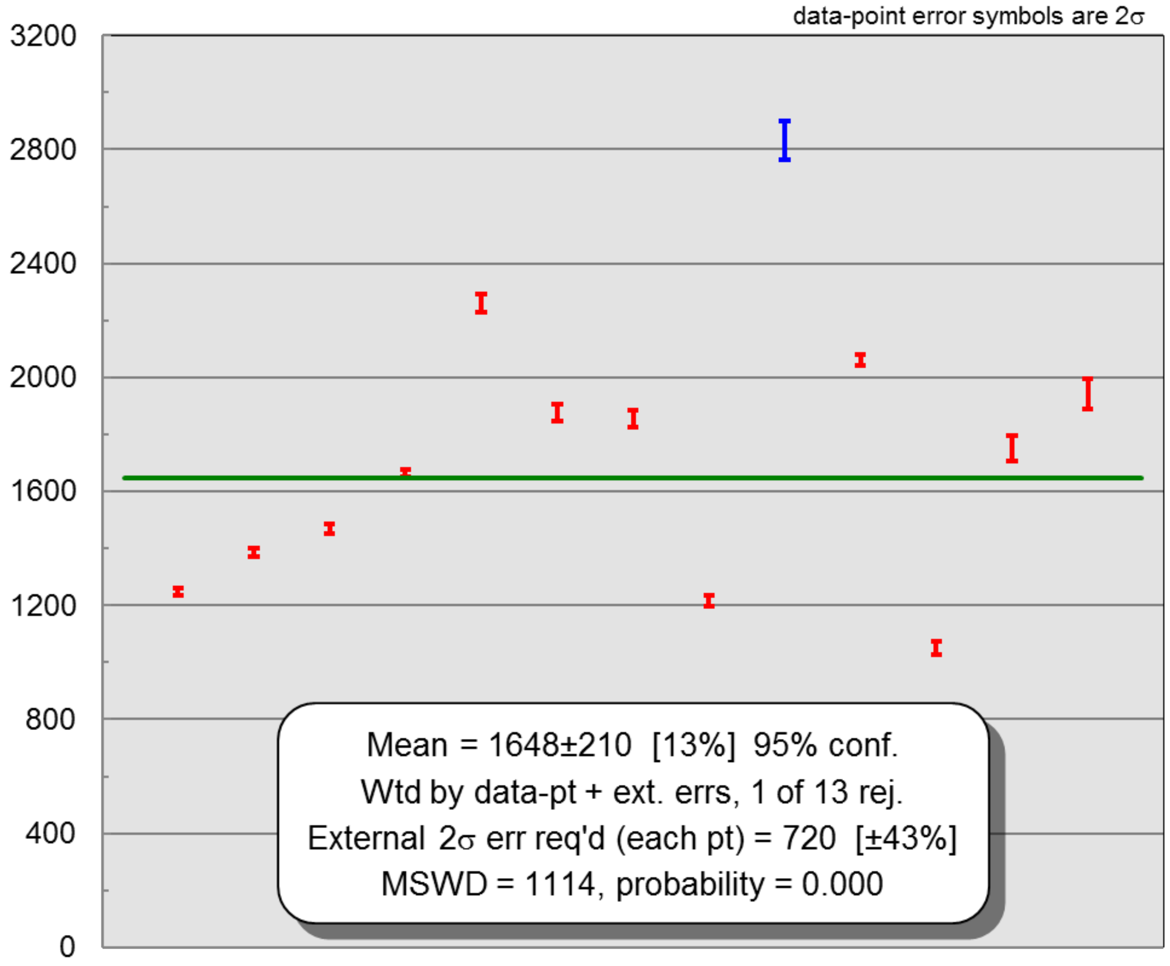


Figure 27: Weighted average plot for EX21980. This shows a high degree of scattering with no coherent populations.

1.5.9 EX21982

Lithology: fine quartz –feldspar-biotite stock intruding schists in hinge zone of large D3(local) fold. Biotite often as clots, possible ocelli.

Run	Run3 (20μm)	Pb207-206 Age	1605.7±6.3Ma
# Analyses	25	Concordia Age	1611±9Ma
# Analyses integrated	24	Multiple populations?	Outlier Pb-Pb 1465Ma

A reasonably tight, mostly concordant single population with 1 outlier analysis. The Tera Wasserburg plot without outlier suggests and age of 1611±9Ma, and a weighted average of the Pb-Pb yields 1605.7±6.3Ma.

The single outlier has a Pb-Pb age of 1465Ma

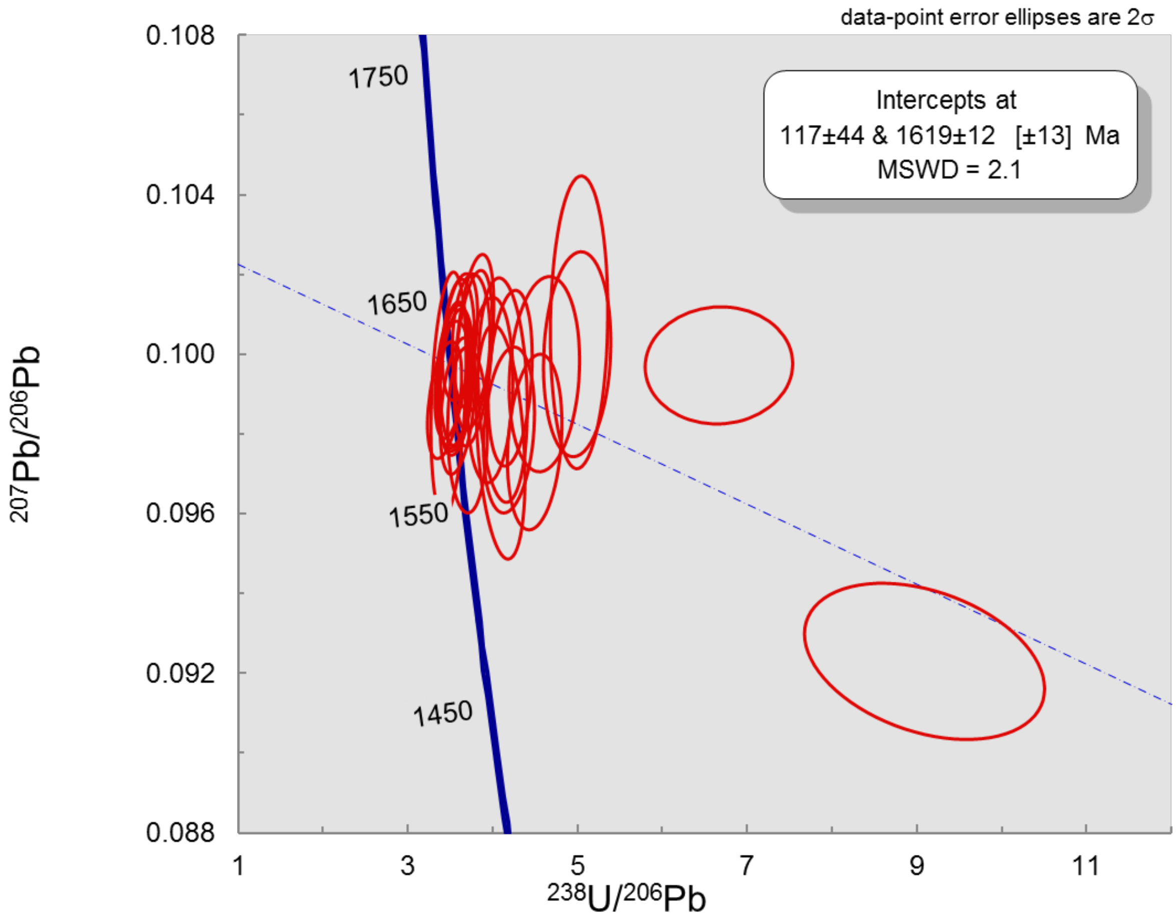


Figure 28: TW diagram for EX21982, all analyses. A large proportion is near concordant.

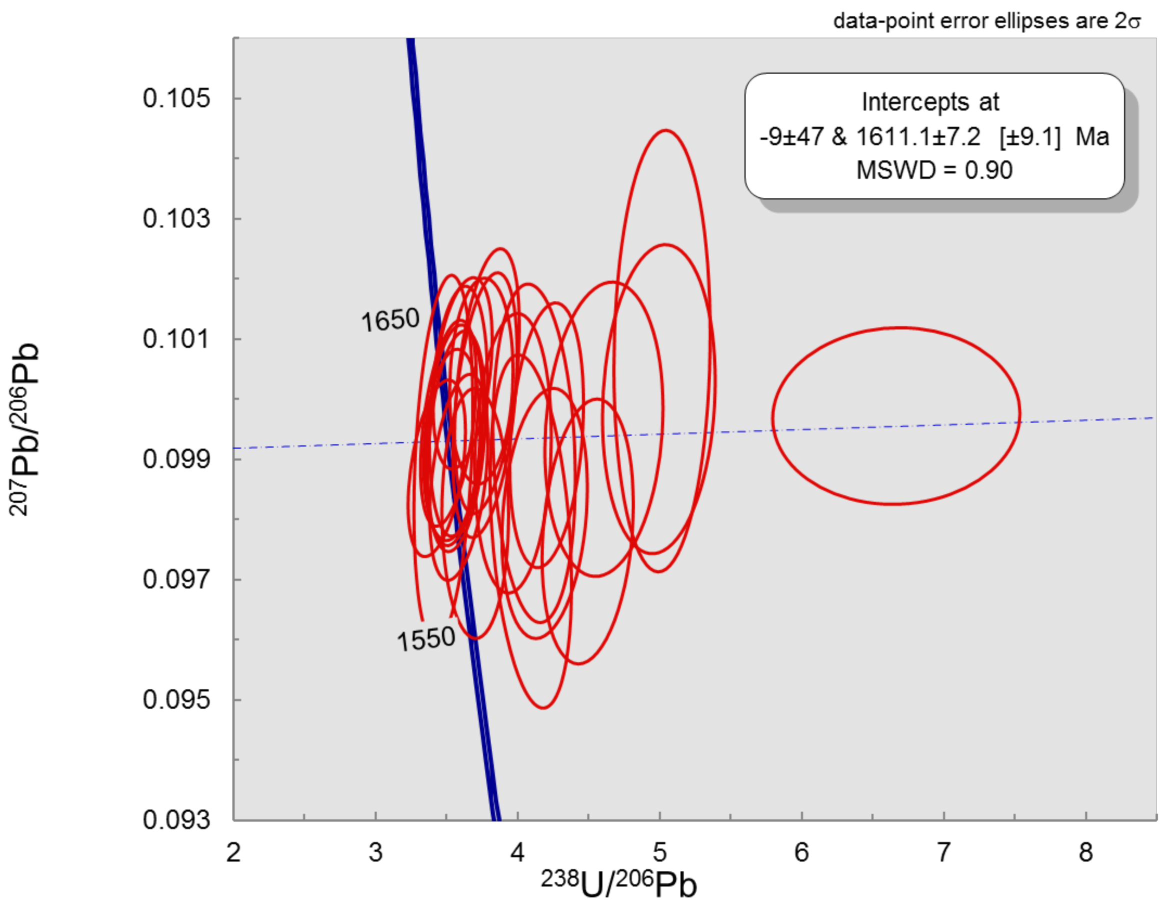


Figure 29: TW diagram for EX21982 with outlier removed, giving a much better fit

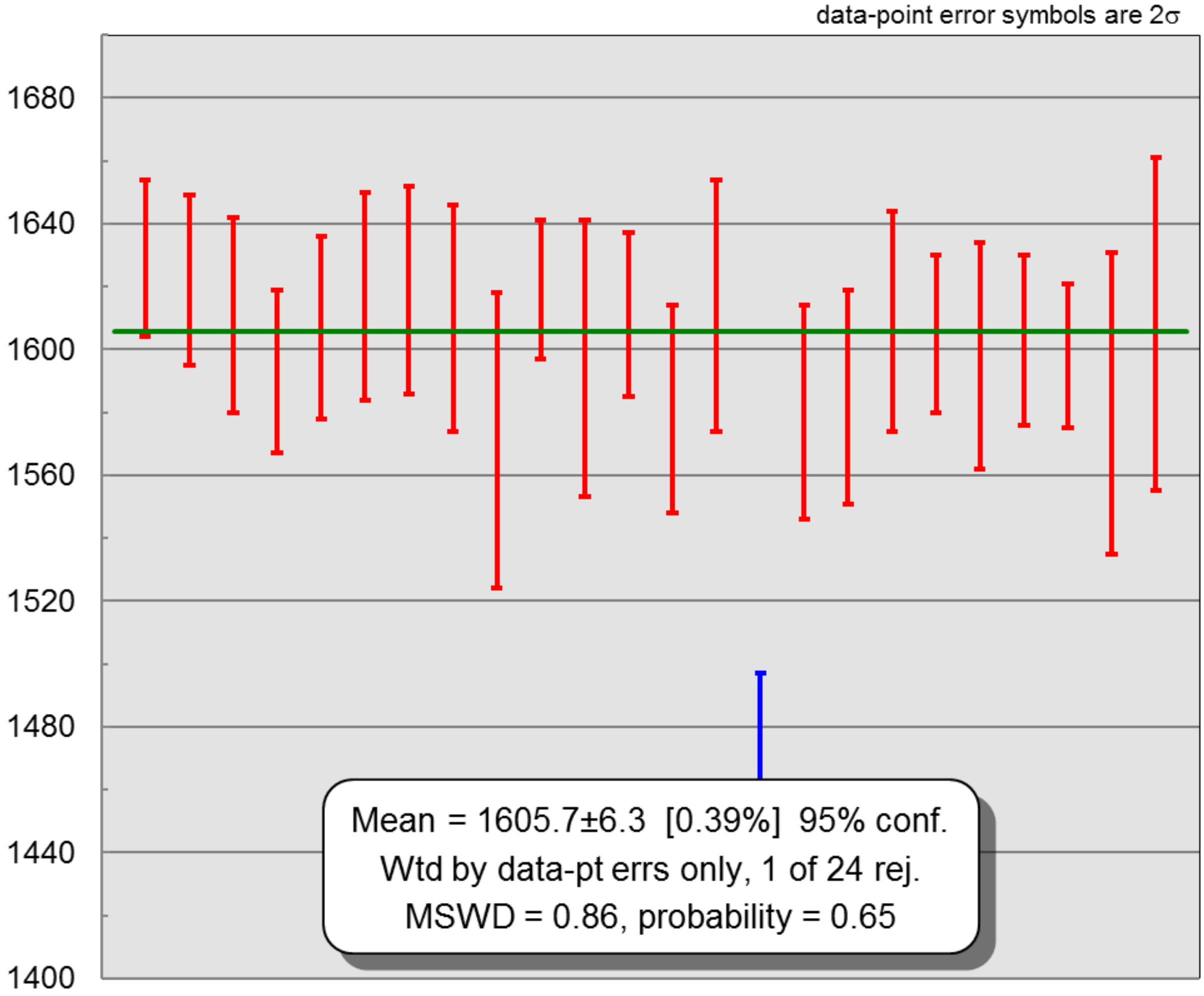


Figure 30: Weighted Average plot for EX21982, with single outlier value highlighted and excluded

1.5.10 EX095747

Lithology: Saprolitic (oxidized and clay) material thought to be derived from volcanic layer in graphitic phyllite. Taken from drill core, not exposed to surface. Expected age Milo beds.

Run	Run3	Pb207-206 Age	
# Analyses	4	Concordia Age	
# Analyses integrated	0	Multiple populations?	

No analyses were of sufficient quality to integrate.

1.5.11 EX096238

Lithology: Pink microgranite within calcsilicates on south side of major fault. At outcrop looks to be Tommy Creek Microgranite, however has a different radiometric response. Expected age either Tommy Creek Microgranite (~1640Ma), or similar to QFP

Run	Run1	Pb207-206 Age	1615.6±5.8Ma
# Analyses	23	Concordia Age	1616.8±8.5Ma
# Analyses integrated	23	Multiple populations?	2 outliers

A good set of 23 analyses showing a single population and 2 outliers. TW diagram shows many samples are close to concordant and yield an intercept age of 1616.8±8.5Ma. A weighted average Pb-Pb age yields 1615.6±5.8Ma. The two outliers have Pb-Pb ages of ~1760Ma and ~1560Ma.

This age suggests it is not part of the Tommy Creek Microgranite, and it also does not match the QFP ages in EX32129 and EX21973.

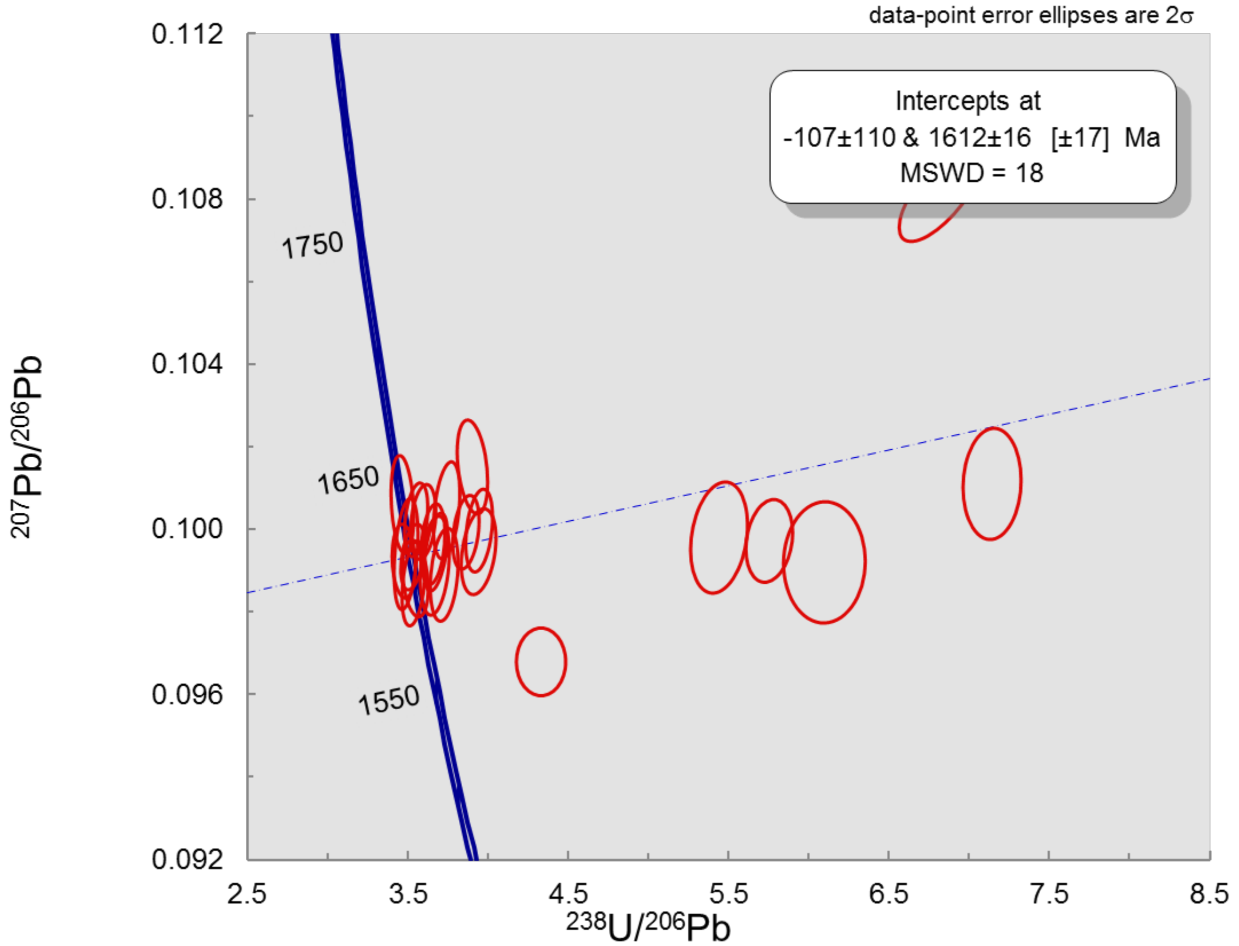


Figure 31: TW Diagram for EX096238 all analyses. A majority are close to concordant, and 2 outliers can be seen off the discordant array.

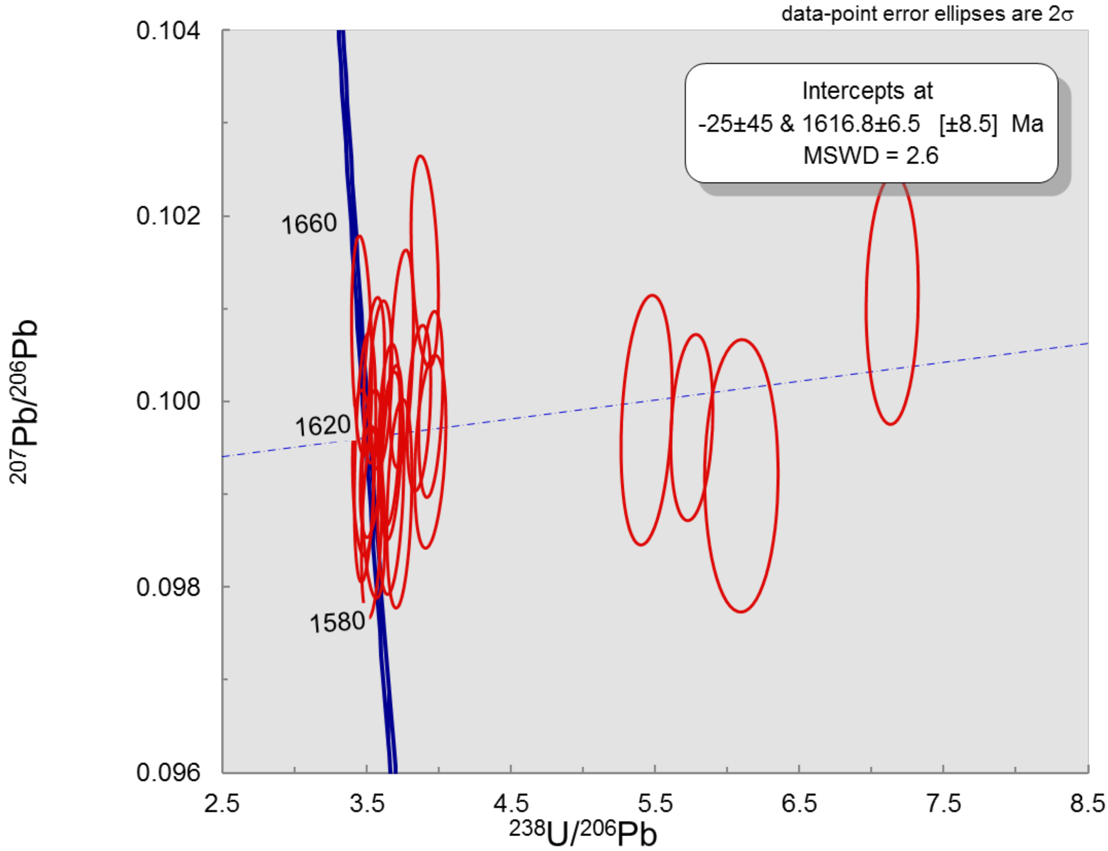


Figure 32: TW diagram for EX096238 with 2 outliers removed, showing a reasonable fit to a single discordant trend intersecting at 1616.8±8.5Ma. n=21

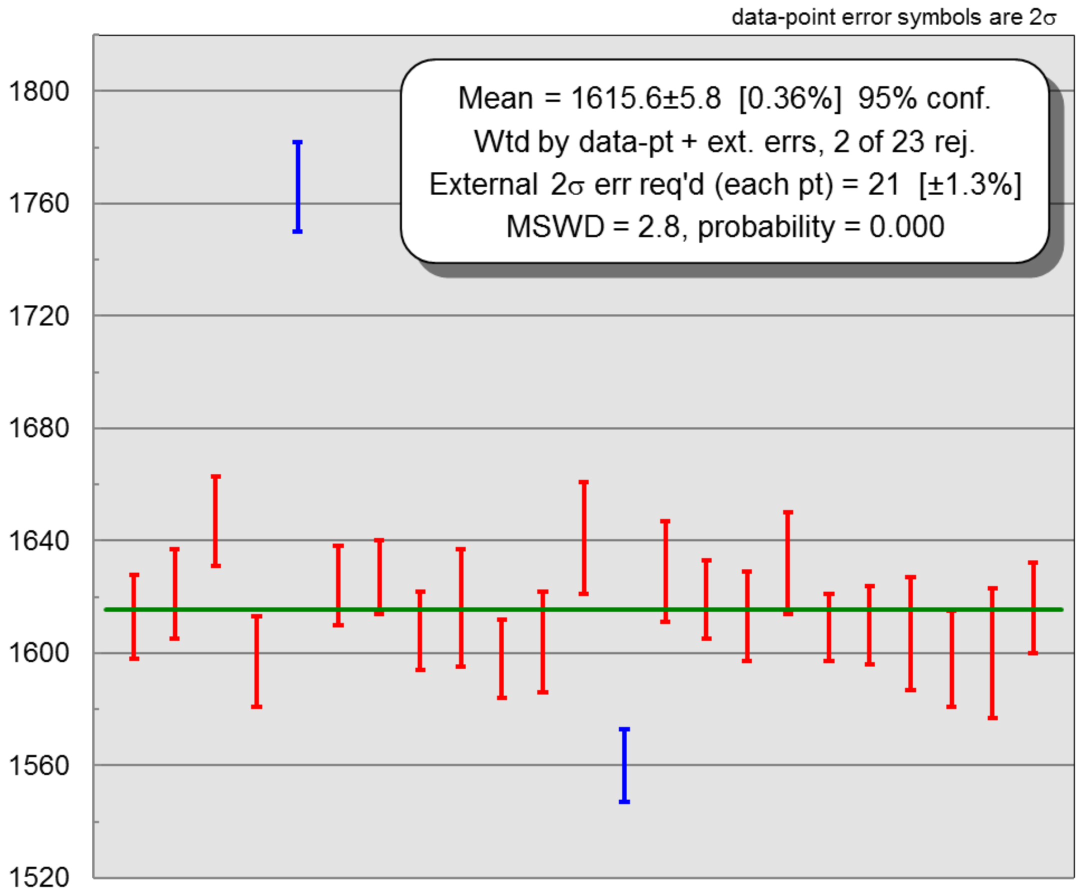


Figure 33: Weighted average Pb-Pb dates for EX096238, with 2 outliers highlighted

1.5.12 EX096246

Lithology: medium to coarse grained calcite-biotite± amphibole rock within feldspathic rock. Contains xenoliths with biotite reaction rims, and forms vein/dyke like structures with alteration selvedges. Zircons visible in biotite due to pleochroic haloes. Otherwise looks like marble. Expected age- if intrusive/alteration should be young or inherited age. If sedimentary in origin should yield detrital spectra

Run	Run1, Run2	Pb207-206 Age	1645.3±3Ma
# Analyses	65	Concordia Age	1646.6±9.5Ma
# Analyses integrated	63	Multiple populations?	Possible 1611±11

Due to the potential for the zircons being detrital, a large number of analyses were undertaken. Of the 63 signals deemed for integration, 11 results had very high uncertainty compared to the rest (Figure 34: TW diagram for EX096246 showing all analyses. Several analyses have uncertainty much higher than the rest, and should be discarded. N=63Figure 34). With these analyses removed (Figure 35), a mostly concordant population is shown with an intercept age of 1646.6±9.5Ma. A weighted average Pb-Pb age (Figure 36) suggest the main population of 1645.3±3Ma, with 7 analyses identified as outliers to this. These outliers do not look like a detrital distribution such as that seen in EX096248. One of these outliers is from a grain with 2 analyses, with the second value returning 1632Ma.

Interestingly, taking the 4 low outliers, and one analyses initially rejected for borderline high uncertainty, plot with good fit on a discordant array of 1611.3±11Ma. Given that textural observations show that this lithology has incorporated wall rock (xenoliths), it is plausible that there is a significant inherited population (the main population shares an age with the QFP), and a much smaller population perhaps related to the emplacement/overprint.

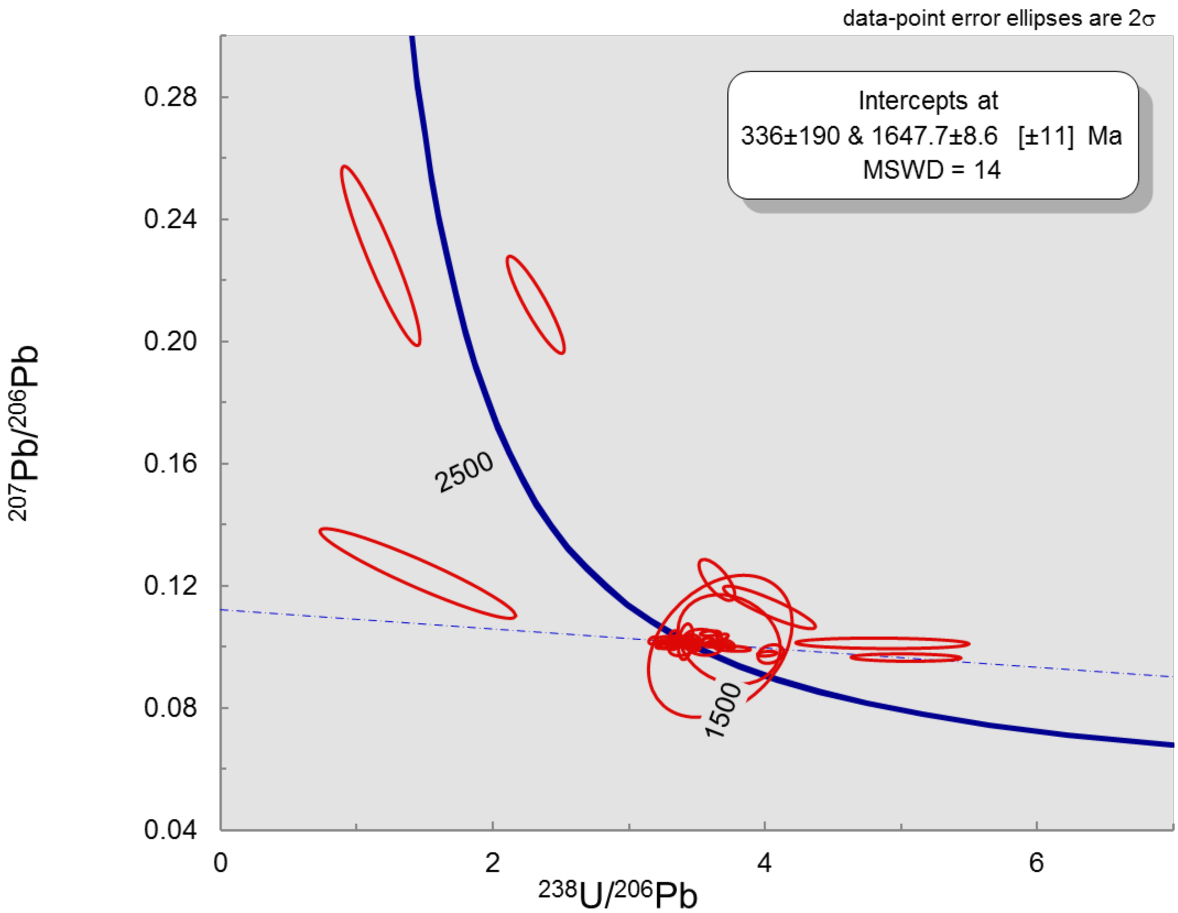


Figure 34: TW diagram for EX096246 showing all analyses. Several analyses have uncertainty much higher than the rest, and should be discarded. N=63

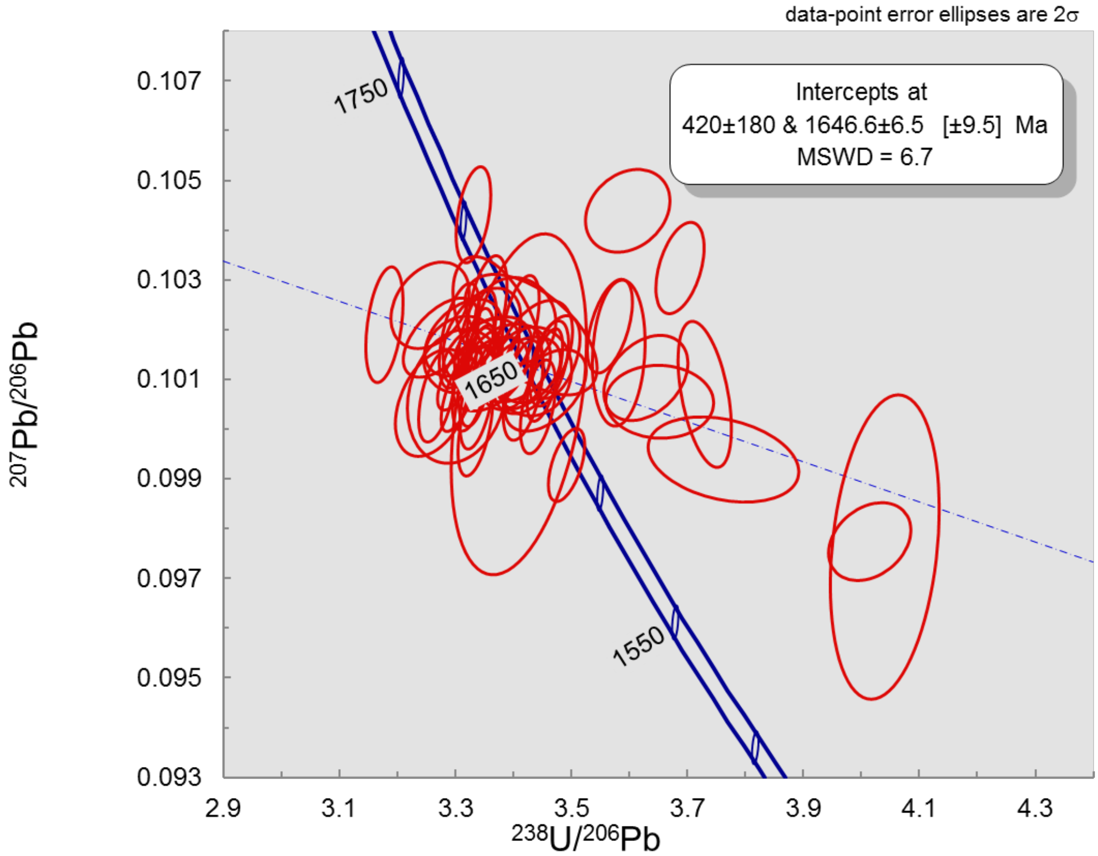


Figure 35: TW Diagram for EX096246 with high uncertainty results removed. A large proportion plot on or near concordance. The discordant analyses do not show a clear array. N=52

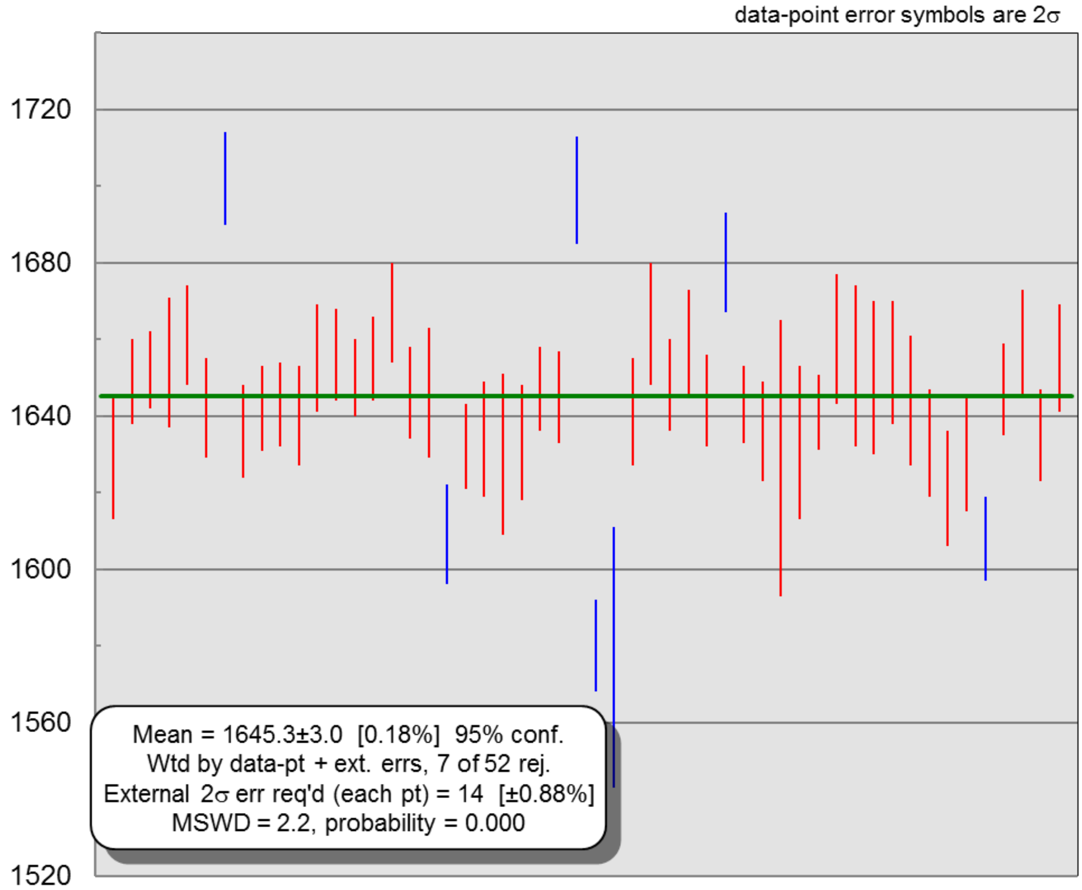


Figure 36: Weighted average for EX09246 with high uncertainty analyses removed. A further 7 analyses were identified as outliers to the main population.

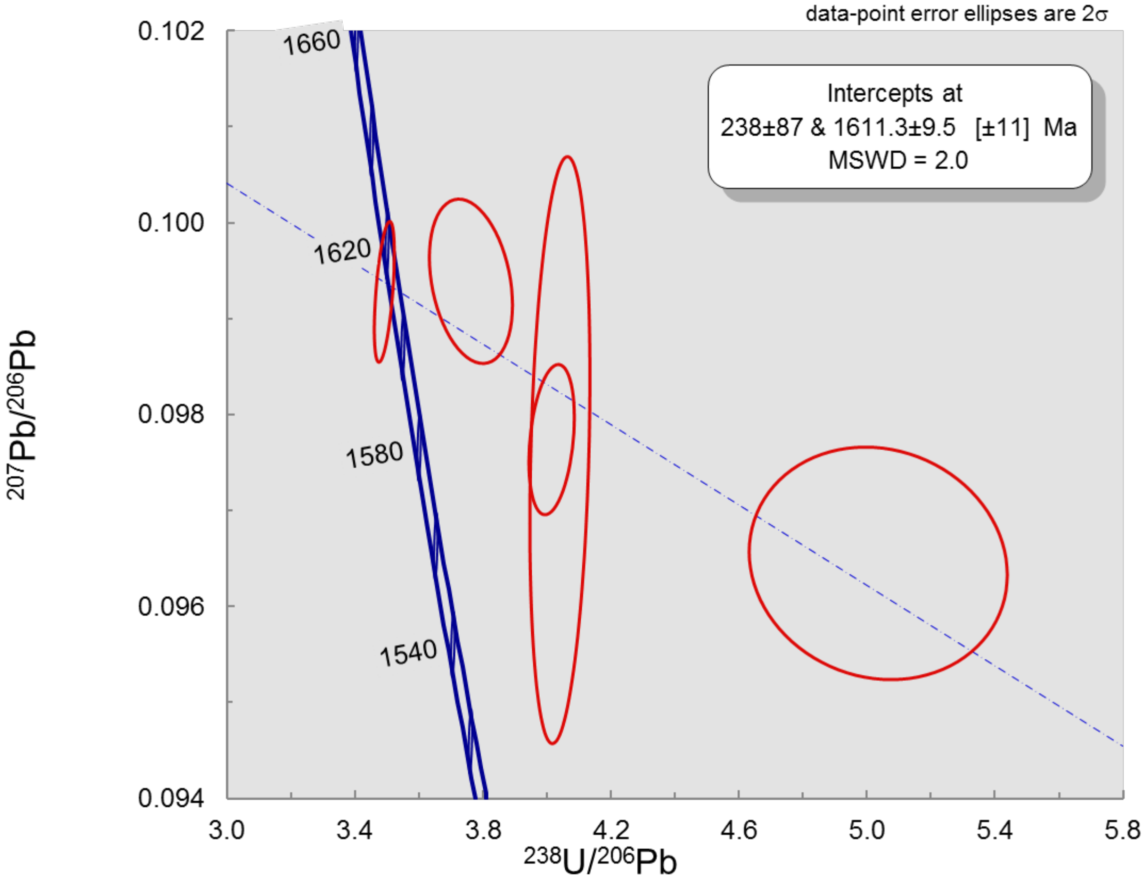


Figure 37: Five analyses considered outliers (young) to the main population of EX096246, which all plot well on a discordant line yielding 1611.3±11Ma

1.5.13 EX096247

Lithology: Biotite-K feldspar ± pyrite rock. Thick dyke/vein of coarse biotite with interstitial/late pyrite. Also, fluorite as blebs at hand sample, and ubiquitous within the biotite in thin section. Zircons seen throughout biotite with pleochroic haloes. Identified as glimmerite

Run	Run3 (20µm)	Pb207-206 Age	
# Analyses	32	Concordia Age	
# Analyses integrated	31	Multiple populations?	complicated

The precision of the analyses is affected by the smaller spot size, however even taking this into consideration, it is difficult to interpret coherent population in the data. There are a large number of U and/or Th rich grains. The data appears similar to EX21980, a granitic pegmatite with high U in the grains and no discernable pattern in the data. Interestingly, both these rocks contain reasonable concentrations of fluorite.

An attempt to pull apart the Pb-Pb data distribution with Gaussian deconvolution suggests peaks at 1430, 1558, 1638, 1776Ma ages. Classifying the zircons by their morphology and CL response did not yield any coherent populations

Closer inspection of Tera Wasserburg diagram suggests 2 possible linear trends in the 'core' of the scatter, which are plotted separately in Figure 41 and Figure 42. The TW and Wetherill diagrams for each population are a weak match within error, with population A (n=10) yielding 1657±19Ma (TW) and 1630±28Ma (W), and population B (n=8) yielding 1616±21Ma (TW) and 1659±62Ma (W). In both populations the lower intercepts of the two diagrams matched within error, with population A showing a Pb loss age of ~150Ma and Population B forming a modern Pb loss trend. The 4 ages yielded by the diagram are close to overlapping errors (Figure 44), with a weighted average of 1637±24Ma, suggesting that the zircons may be a single population with different open system histories (perhaps those encased in K feldspar vs biotite-fluorite?).

This age may be considered sensible, but is of much less reliability than that of other samples due to the amount of interpretation required.

Additionally, 6 of the zircons not included in A or B (pop C), potentially represent another discordant, high Pb loss population (Figure 43). The intercept ages are very imprecise (1506±100Ma on TW, 1567±54Ma on Wetherill), but could indicate either a younger emplacement age (with the main population being inherited), or perhaps a metamorphic/hydrothermal zircon event.

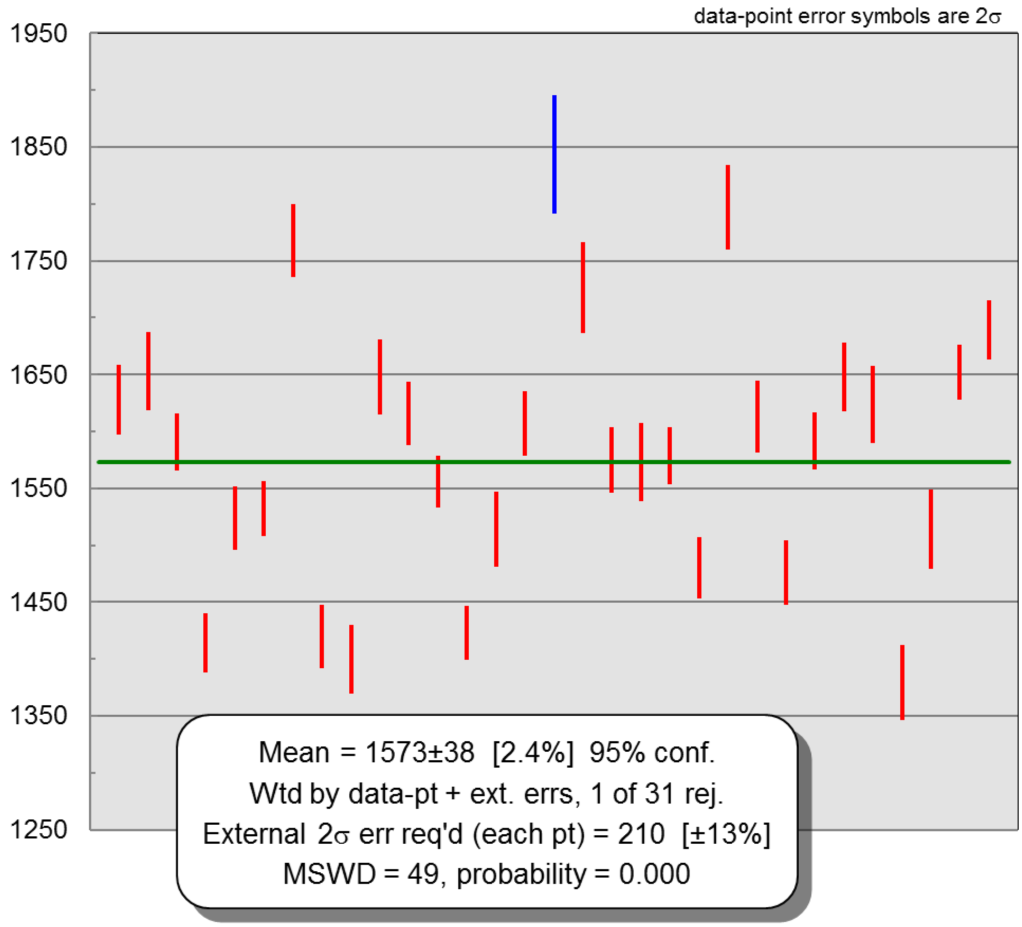


Figure 38: Pb-Pb ages for EX096247, which show a high degree of variability within the sample (order is by analysis sequence)

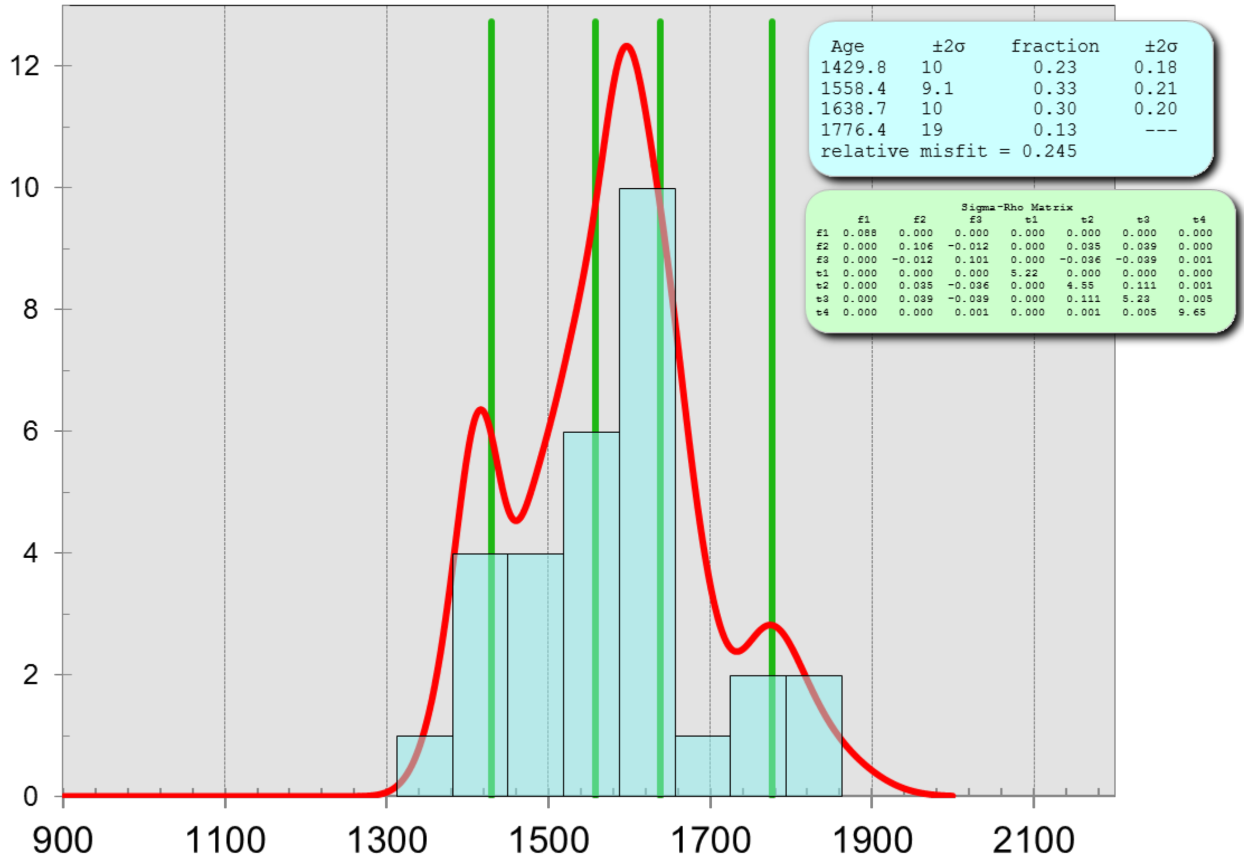


Figure 39: Pb-Pb age distribution with results of semi-automated Gaussian deconvolution (IsoPlot). The results of the deconvolution suggests peaks at approx. 1430, 1559, 1638 and 1776Ma

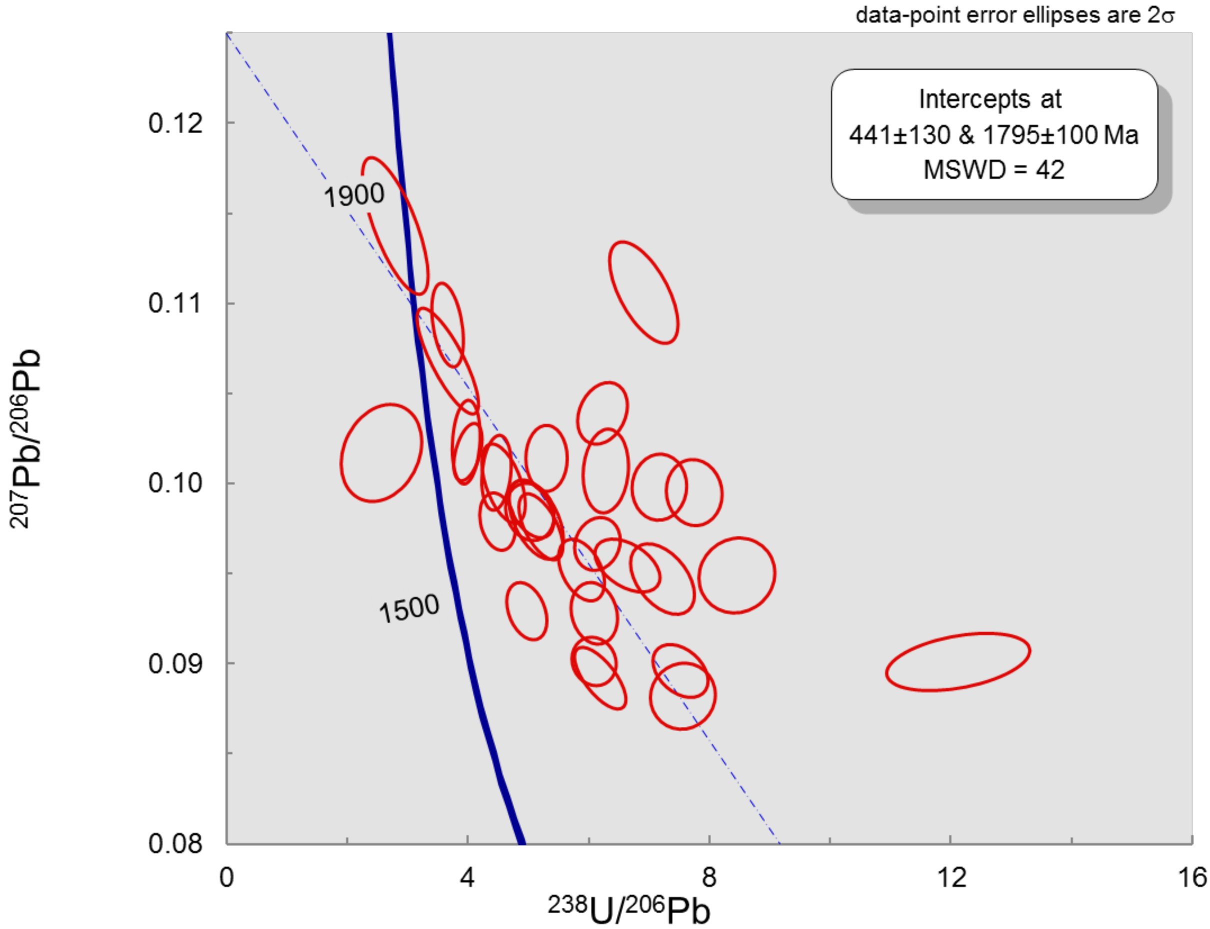


Figure 40: TW diagram for EX096247, all analyses. No clear discordant array is visible, although some subsets may form coherent populations

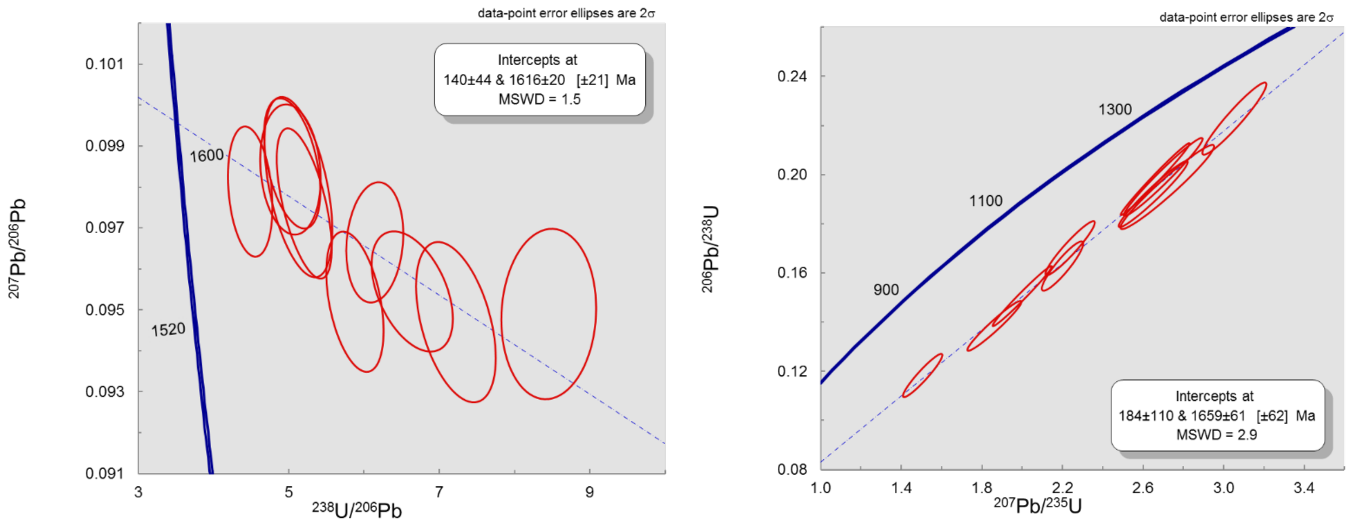


Figure 41: TW diagram (left) and Wetherill diagram (right) of sub population A. The two upper intercept ages are barely within error; however the lower intercepts are very similar n =11

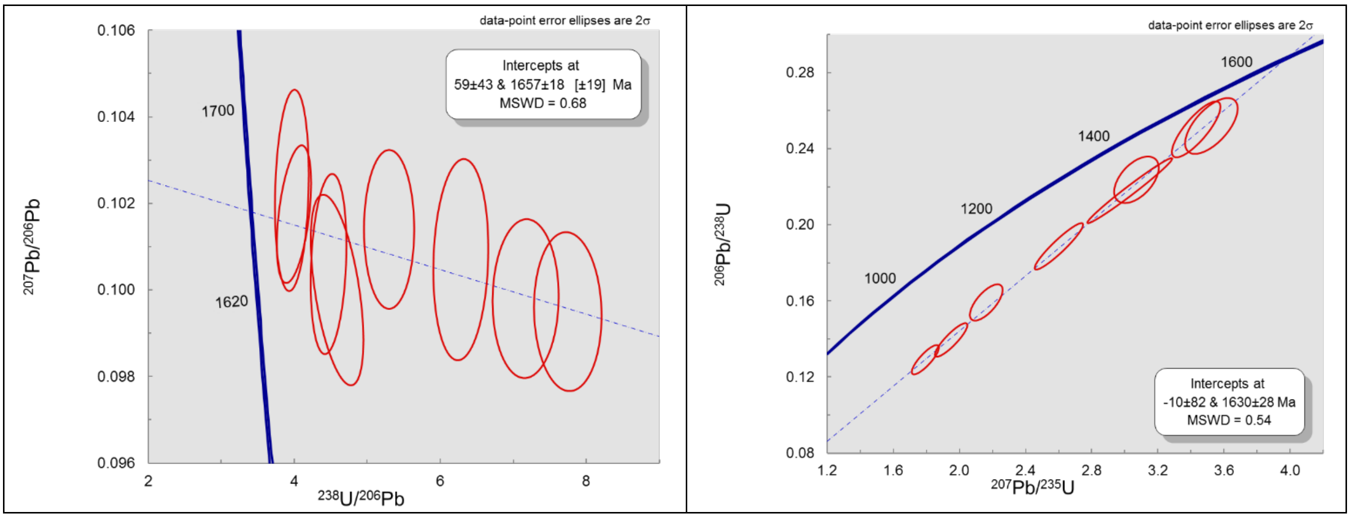


Figure 42: TW diagram (left) and Wetherill diagram (right) of sub population B. The upper intercept ages barely agree within error. Both lower intercept ages are similar, representing modern Pb loss trends. N=8

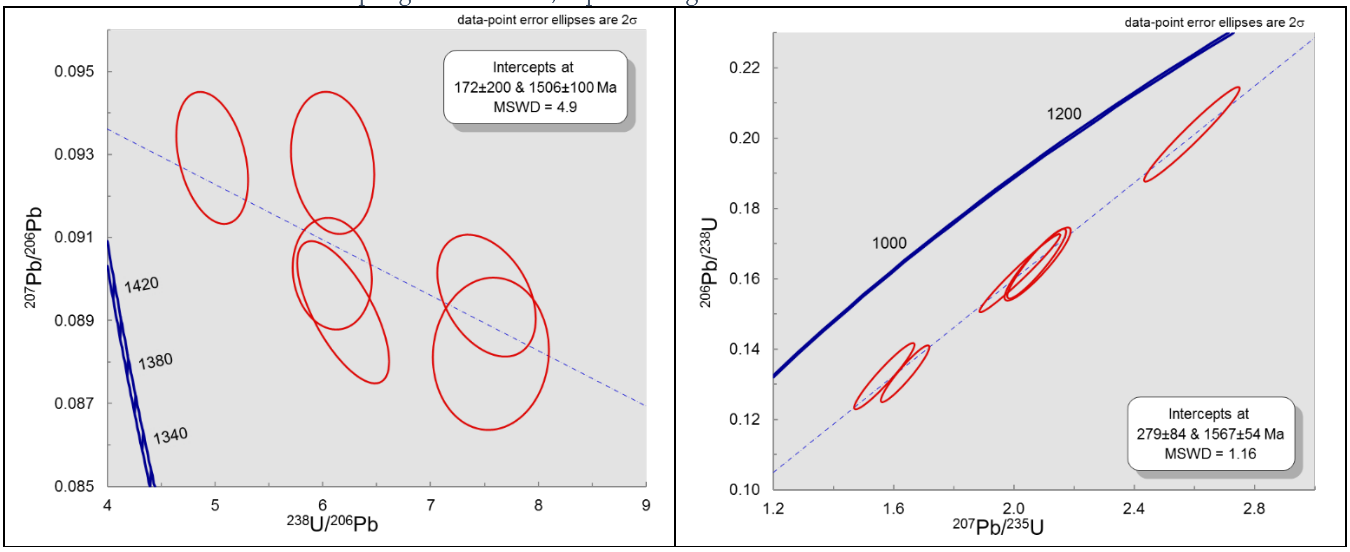


Figure 43: TW diagram (left) and Wetherill diagram (right) of sub population C. The fits are very imprecise and show considerable Pb loss n =6

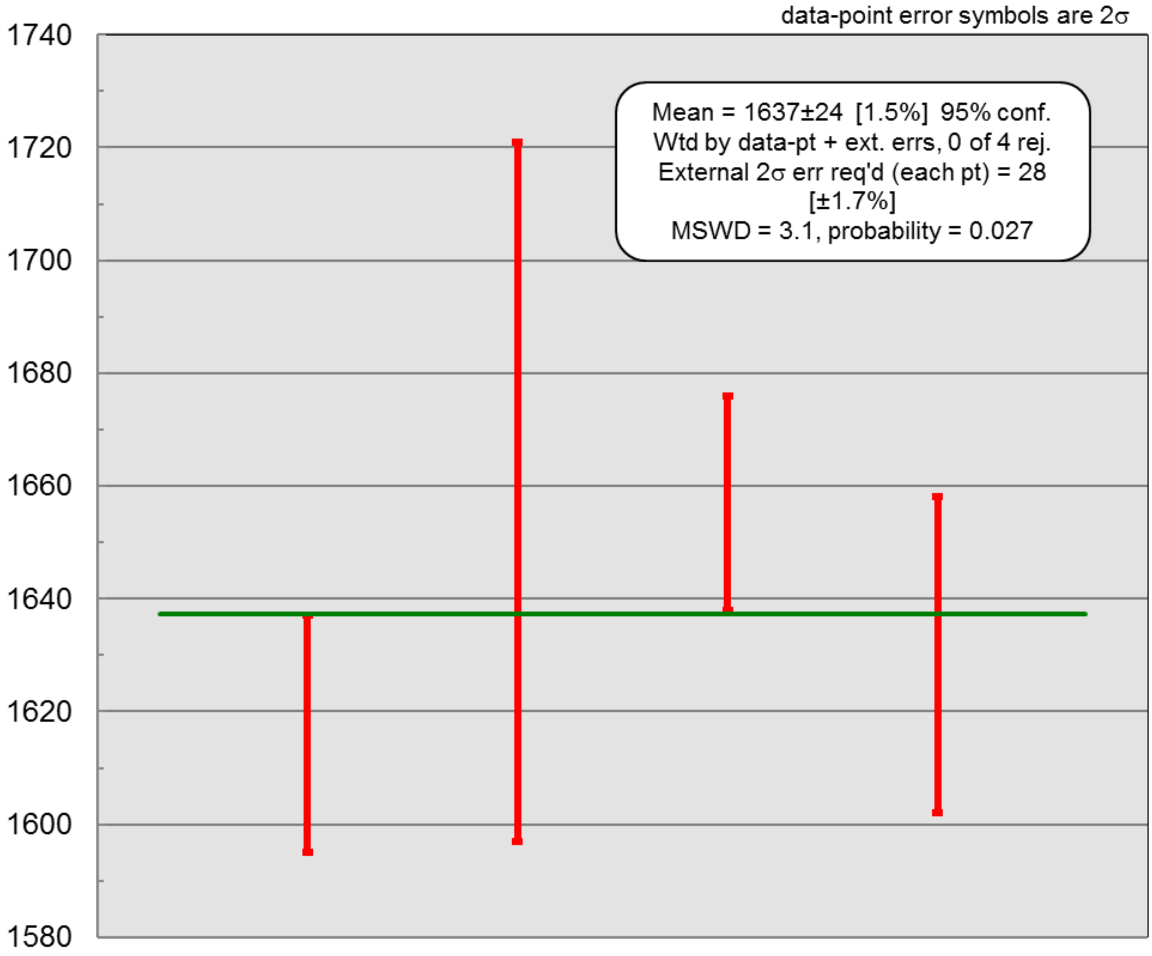


Figure 44: The results of 2 different concordia plots for 2 populations in EX096247. It is possible that the 2 populations share genesis but have experienced different open system behaviors. The weighted average of these ages is 1637±24Ma.

1.5.14 EX096248

Lithology: albite-k feldspar- amphibole ±calcite, epidote, diopside calc silicate. From formation historically placed as Corella formation (~1740Ma). Taken from drillhole TYC015, proximal to faulted contact with Milo/Tommy Creek sediments. Expected age- detrital spectra. True Corella (Mary Kathleen Belt) should lack a 1740Ma spike of Burstall provenance. Doherty and Kuridala equivalents appear to include 1740Ma population but no zircons significantly younger. Is intruded (to the north) by Tommy Creek Microgranite (1650Ma) and therefore should not include detrital grains younger than this (metamorphic ages plausible?)

Run	Run3	Pb207-206 Age	
# Analyses	63	Concordia Age	Max Dep 1747.1±6.3
# Analyses integrated	60	Multiple populations?	Yes

The results of the 60 analyses clearly shows a multi population distribution, as was to be expected for the sedimentary origin. Semi-automated Gaussian deconvolution in IsoPlot suggest 5 possible peaks of 1360, 1625, 1752, 1892, 2440 and 3450Ma (Figure 45).

Inspection of Concordia diagrams (Figure 46) suggest a slightly simpler interpretation, with 3 possible discordant arrays and 3 outlier points. Two of these outliers have close to concordant ages of ~3450Ma, and it is plausible for such old inherited zircons to be present.

Plotting up the apparent discordant arrays yielded reasonable results. Population A (n=11) corresponds to the ~2400Ma peak in the Pb-Pb distribution. The population is a poor fit to a line with an intercept age of 2594±150Ma (TW) or 2572±110Ma (W), however it is likely that these grains are from multiple source populations during this time and may have a complicated open system history (Figure 47).

Population B (n=12) is a considerably tighter fit, yielding 1897±45Ma (TW) and 1891±47Ma (W), and lower intercepts of ~200Ma (Figure 48). This is a reasonable match with the Barramundi Orogen basement ages.

Population CD (n=34) is by far the dominant population, and has a large number of concordant results. The array plots reasonably well on a line with an intercept age of 1768±17Ma (TW) and 1789±21Ma (W) (Figure 49). However, this intercept is older than the oldest concordant age (weighted average age 1747.1±6.3Ma, n=14, Figure 52), and it is possible that there is two sub populations, C and D. These were split on the basis of linear trends in the TW diagram. Population C (n=26) yields a tight fit on a line for 1755.8±10Ma (TW, Figure 50), and population D (n=8) yields 1823±56Ma (Figure 51). This suggests population C is Wonga sourced, with population D perhaps (in error) of Argylla Formation or other early Cover Sequence 2 rocks.

With the interpretation of most analyses falling on one of the above discordant arrays, the apparent younger ages in the Pb-Pb distribution are explained, and the youngest credible population is population C, giving a maximum deposition age of 1747.1±6.3Ma (1755.8±10Ma). This is consistent with this unit being intruded by Tommy Creek Microgranite (~1650Ma) and some of the felsic rocks reported here.

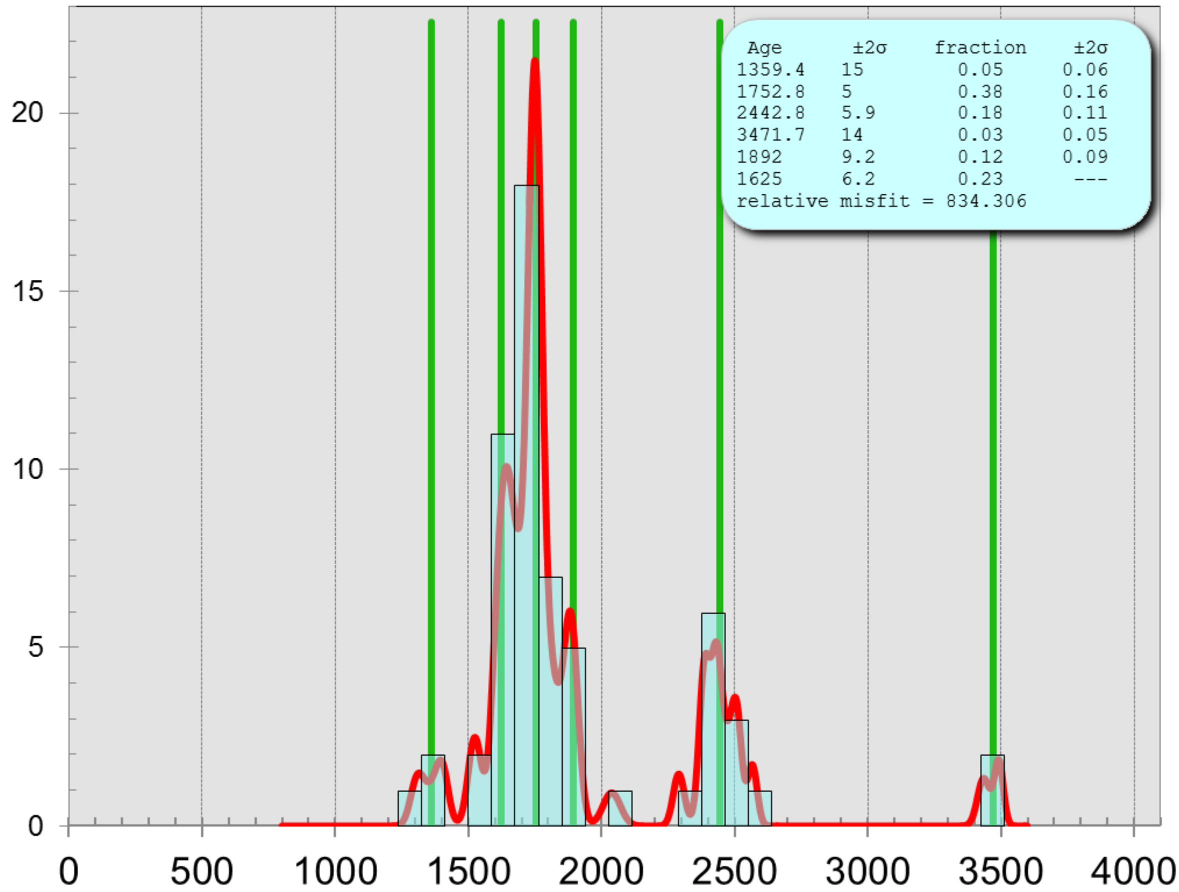


Figure 45: Pb-Pb age distribution with results of Gaussian deconvolution suggest 5 populations

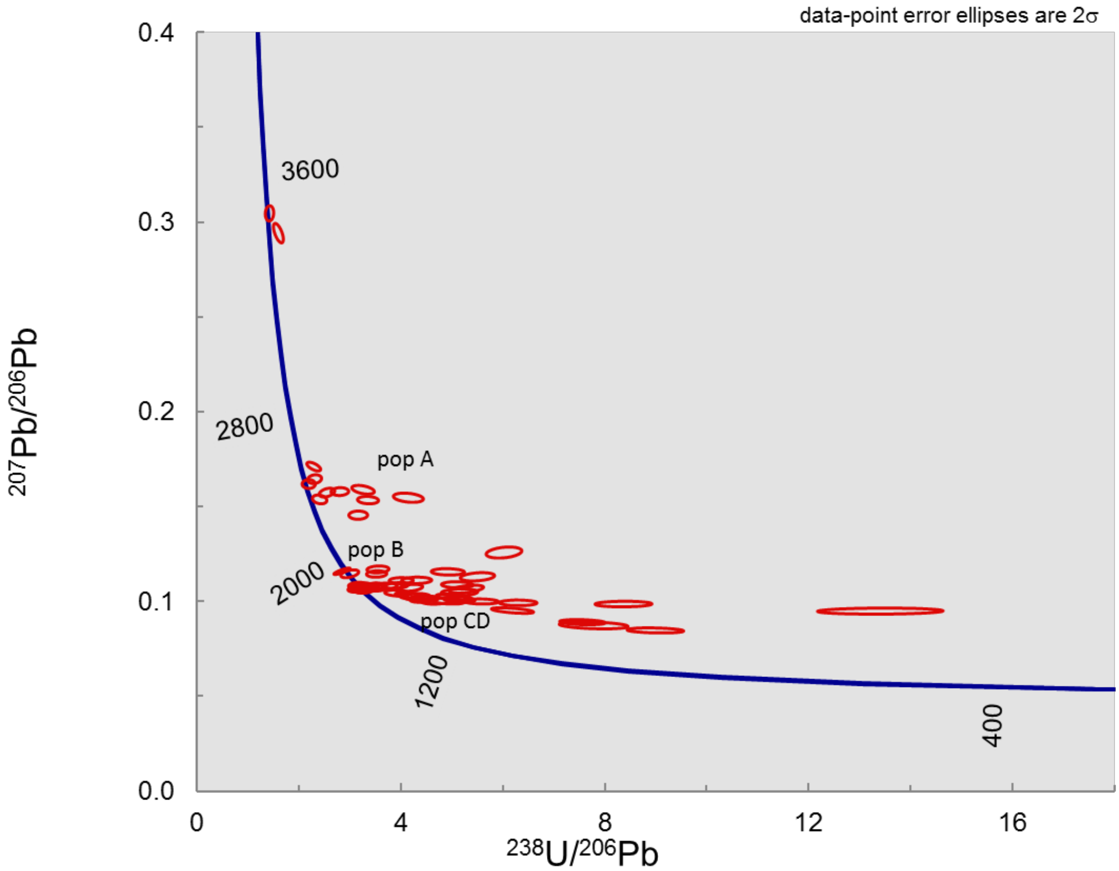


Figure 46: TW diagram of all analyses for EX096248. 3 main populations can be seen in the data, which are subset below

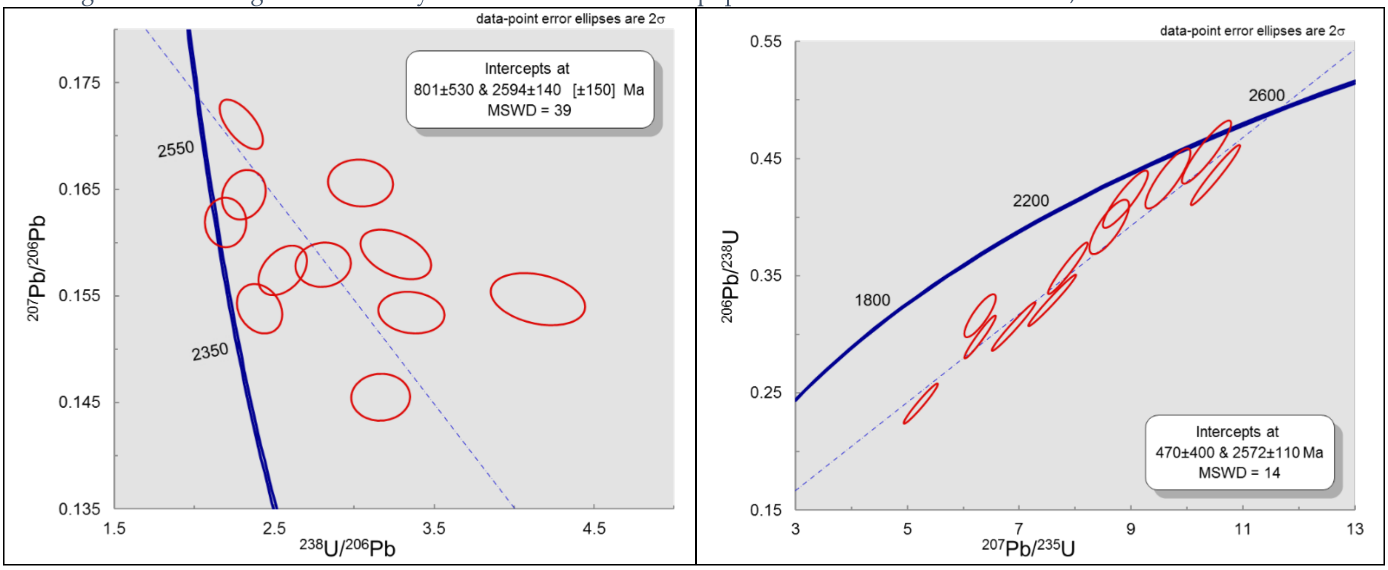


Figure 47: TW diagram (left) and Wetherill diagram (right) of subpopulation A, showing a weak fit to a discordant array of 2594±150Ma and 2572±110Ma

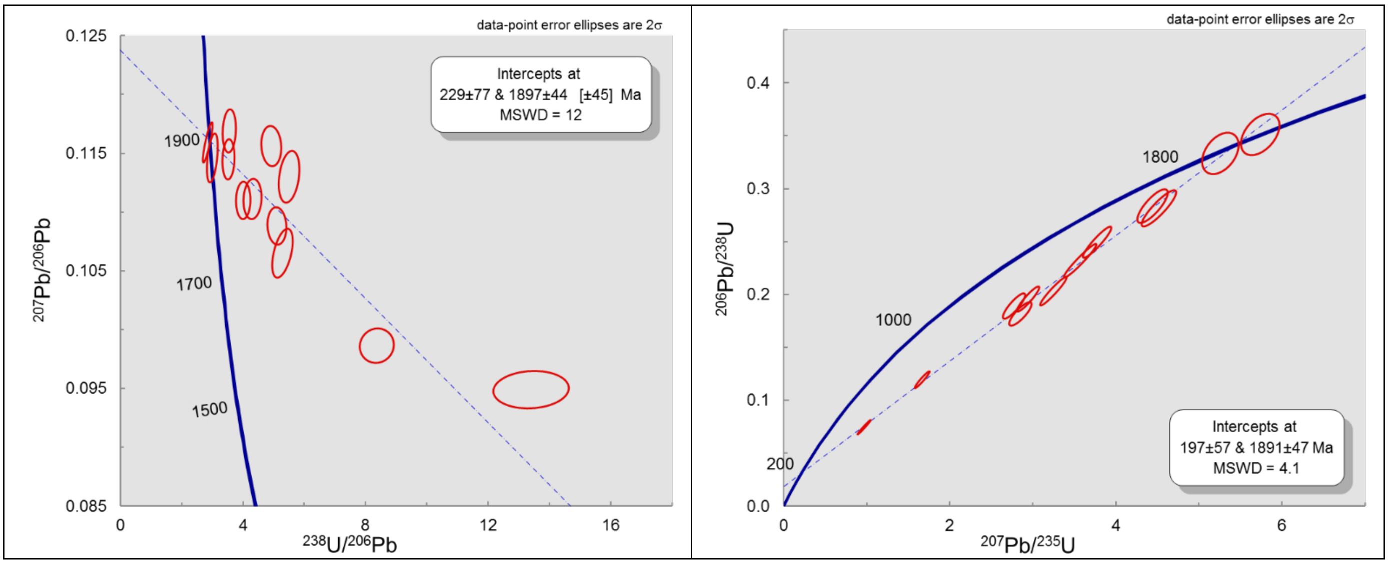


Figure 48: TW diagram (left) and Wetherill diagram (right) of subpopulation B, showing a reasonable fit to a discordant array of 1897±44Ma and 1891±47Ma

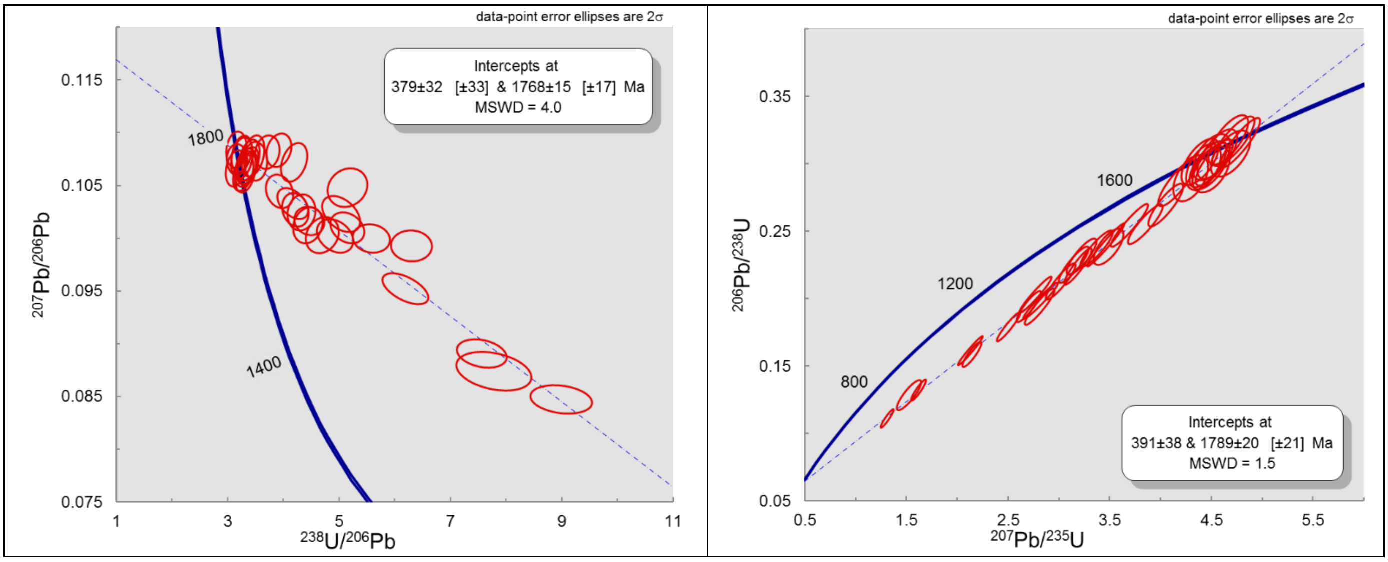


Figure 49:TW diagram (left) and Wetherill diagram (right) of subpopulation CD, showing a reasonable fit to a discordant array of 1768±17Ma and 1789±20Ma. However, this does not agree well with the position of concordant analyses, and it appears that 2 populations may be present.

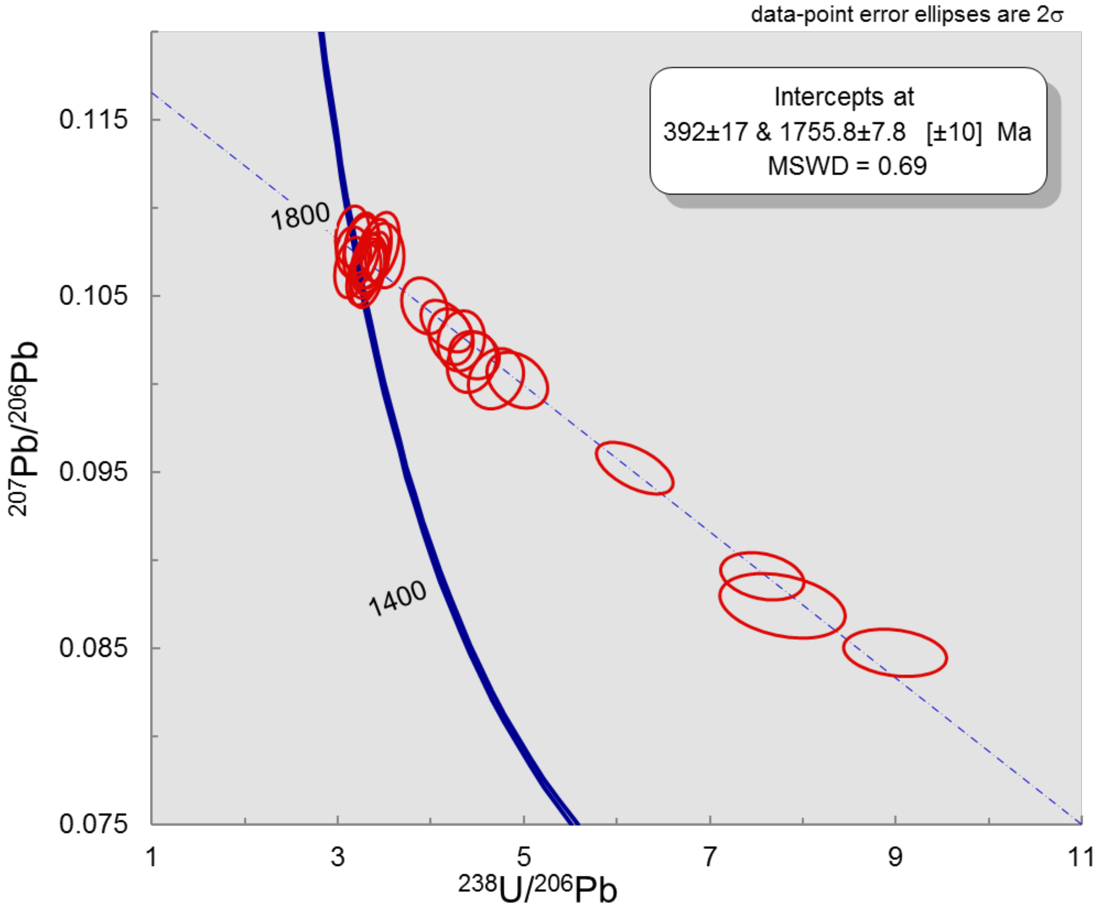


Figure 50: TW diagram of subpopulation C, showing a good fit to a line for 1755.8±10Ma. This population has a high proportion of concordant analyses

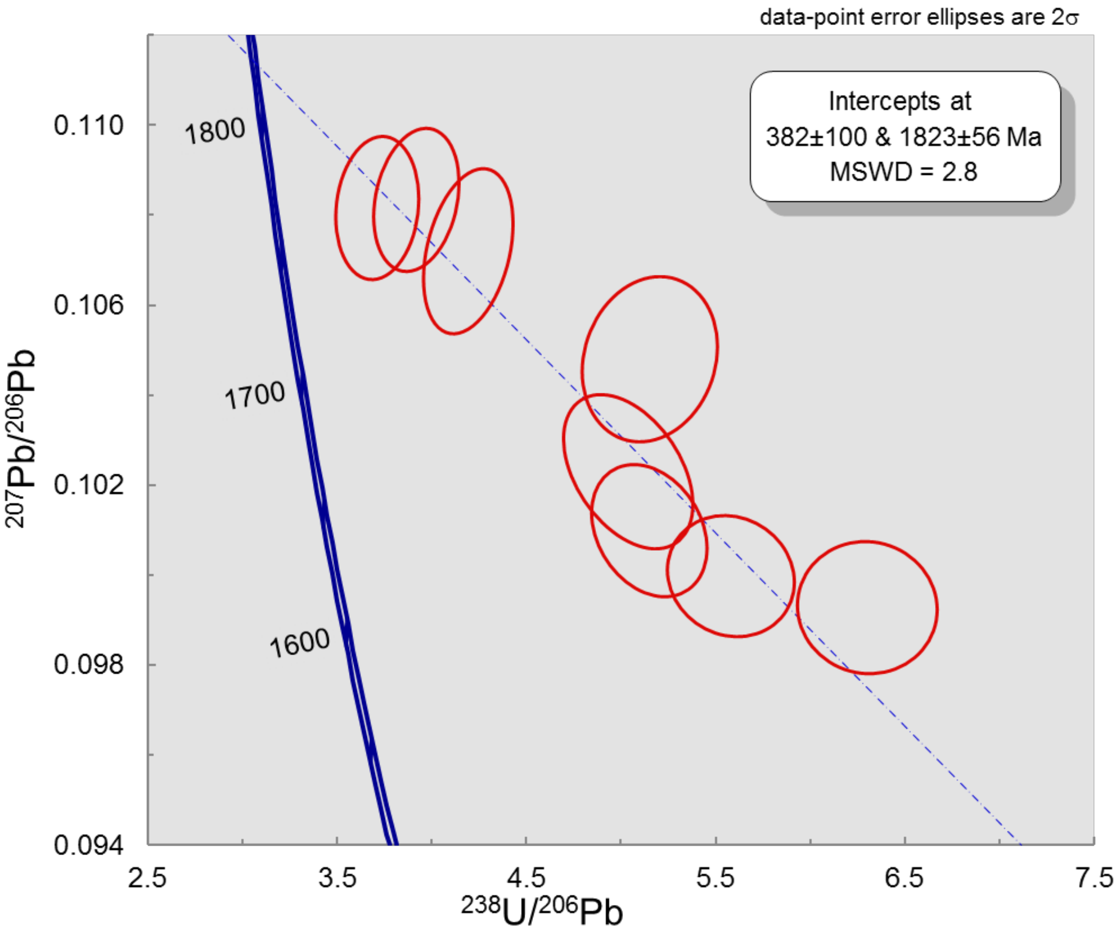


Figure 51: TW diagram of subpopulation D, showing a reasonable fit to a line for 1823±56Ma.

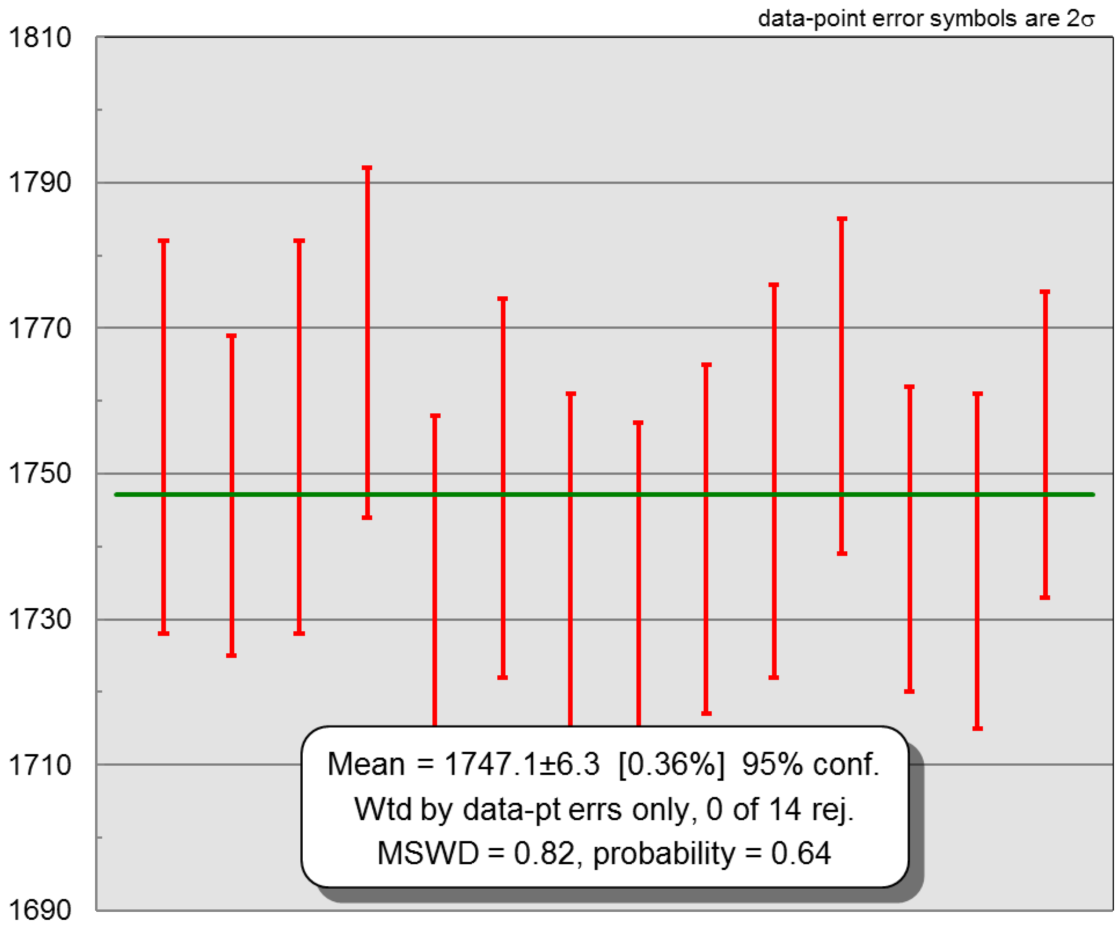


Figure 52: Weighted average Pb-Pb age for concordant analyses in subpopulation C, showing good agreement around 1747.1±6.3Ma

1.5.15 *Accessory or outlier populations*

A number of samples have a small number of results representing outliers or accessory to the main population. These ages were seen across a number of samples and lithology types independently, and are summarized below. Most are individual Pb-Pb ages, unless otherwise stated

Sample	Lithology	1390-1480Ma	1520-1580Ma	1740-1780Ma
EX32127	Massive altered felsic		1-2	
EX32129	QFP	1	5	
EX21973	QFP	1	1	
EX21982	Quartz-Feldspar Biotite	1		
EX096238	Pink microgranite		1	1
EX096247	Glimmerite	4		3

Figure 53: Summary of outlier analyses yielding results common across multiple samples

The repetition of such ages is interesting, and may represent geological events. The 1520-1580Ma bracket is likely to coincide with metamorphism and potentially late metasomatic activity (Williams era).

2 Tommy Creek LA-ICPMS Titanite and Zircon Geochronology, Oct-Nov 2018

2.1 Introduction

Laser Ablation ICPMS analysis at the Advanced Analytical Centre (AAC), James Cook University Townsville, was performed on resin mounted titanite separates from 2 samples, and in-situ (thin section) on 5 samples on the 31st October 2018. Additionally, resin mounted zircons were analysed from 4 samples on the 30th November 2018.

2.2 Samples

The below table outlines the samples that were analysed. A map with their locations and results is in **Error! Reference source not found.**.

Sample ID	Sample Type	Lithology	Grains mounted	Analyses performed
EX22000	Titanite Core (thin Section)	brown pink alteration in strong amph alteration of porphyry/fine felsic		16
EX21959	Titanite Core (thin Section)	Vein qtz and carb with large green amph xtal and large titanite xtal. Wall rock fine-med amph altered qfp. Minor sulphides		20
EX32145	Titanite Core (thin Section)	syenitic pegmatite with large 2-10mm titanite. HB, alkali fd qtz. Late infill siderite, minor py		20
EX32148	Titanite Core (thin Section)	Coarse ?syenite pegmatite with coarse titanite. Some bt veining		20
EX096245	Titanite Core (thin Section)	cc-bt rock with xenolith and biotite reaction rim. Fine titanite alt through xenolith, and within reaction rim bt		20
EX096904	Titanite ¼ Core	very coarse pegmatitic syenite. Amph-fd-bt-tit. Some late qtz	~25	17
EX096909	Titanite ¼ Core	medium to coarse gabbro in large mafic sill	~25	24
EX096250	Zircon Surface	Medium coarse QFP. Phenos mostly qtz to 3mm. Medium to strong linear fabric. Minor pyrite	70+	30
EX096901	Zircon ¼ Core	fine grained mafic (intermineral dyke?) within broader mafic. Apparent truncated sulphide veins but also has sulphide veins	14	19
EX096903	Zircon ¼ Core	coarse amph-kspar rock - syenite? Adjacent to white qtz vein, minor veining present. Coarse titanite	9	6
EX096904	Zircon ¼ Core	very coarse pegmatitic syenite. Amph-fd-bt-tit. Some late qtz	70+	40

Table 2: Table of samples with titanites/ zircons analysed. Polished thins section taken from drill core. ¼ core is material taken directly from drill core by the author

2.3 Methods

Samples were prepared in the Mineral Separation Laboratory at JCU. Samples were crushed using a hydraulic splitter and pulverized with a disc mill.

Pulverised material was sieved into 3 fractions: >500µm, 500µm< x >250µm, and <250µm.

Pulverised material was then treated on a shaker table to remove slimes and concentrate heavy minerals. In general, samples were recycled 2-4 times (mid and heavy fractions), and different sieved fractions were treated separately

The heavy fractions from the shaker table were dried and then magnetic materials were removed using a hand magnet and Frantz isodynamic separator machine with maximum working current of 1.4 amps.

The least magnetic fraction was then treated with hot LST (Lithium polytungstate) density separation.

Target minerals were picked from the heavy fraction and mounted in a resin puck, which was ground and polished to a high finish.

Pucks were imaged with Cathode Luminescence and mineral identification checked with EDS on a Hitachi SU5000 SEM at the AAC.

U-Pb analyses were performed by coupled Laser Ablation and quadrupole Mass Spectroscopy (LA-ICPMS) in the AAC. On the 31st October, 2 samples (EX21959, EX32148) were analyzed with manual laser control, the remaining 5 samples were performed in a 5 hour pre-programmed automated run. On the 30th November, all sample sites were manually controlled

Zircon Standards GJ1 (calibration), FC1 and Temora (check), as well as NIST610 glass. Three spots of each standard were analysed for after brackets of 10 unknowns for zircon standards; NIST glass was analysed at the start, midpoint and end of each run.

Titanite standards MKED1 (calibration) and KHAN (check) as well as NIST 612 glass. Three spots of each standard analysed for after brackets of 10 unknowns for titanite standards; NIST glass was analysed at the start, midpoint and end of each run

The Laser was set to, 5Hz and 2.5J/cm^2 (titanite) or 3J/cm^2 (zircon), with 45s on time and 60s offtime between samples. Titanite samples used a 50µm spot size, except for EX096250, which used 30µm. Zircons were analysed using 30µm spot size, except for EX096250 and 6 spots on EX096904, which were 40µm.

For titanite, the mass spectrometer was set to collect Pb 204, 206, 207, 208, Th 232, U 238, Ca43, Y89, Nb93, Ce140, Hg202 and Si29.

For zircon, the mass spectrometer was set to collect Pb 204, 206, 207, 208, Th 232, U 238, Ti49, Zr91, Si29 and Hg200

Data was reduced using iolite software package (each run independently), with signal integration periods chosen by quality of the Pb 207:206 signal. Data processing and visualization used Isoplot 4.15 add in for excel and ioGAS.

2.4 QAQC

Delays to the titanite analyses were experienced due to poor standard results and high background lead on the 30th October. Lead background lowered to the higher range of acceptable by midday 31st October.

The following includes only results from standards analysed as part of the sample runs

Standard	**Age (Ma)**	**Uncertainty (2σ)**
GJ1	608.5	±0.4
FC1	1099	±0.6
Temora2	417	
MKED1	1521.02	±0.55
KHAN	522.2	±2.2

The data collected on the 31st October shows a marked increase in analysis uncertainty (precision) between the shift from manual control to robotic control. The source of this imprecision is unclear. The sample cell was removed and a thin section swapped at this time as well.

2.4.1 MKED1 (31/10/18)

The MKED1 standard was used as the calibration standard for titanite, with a total of 48 analyses

2.4.2 KHAN (31/10/18)

Khan was used as a check standard for titanite, with a total of 48 analyses. The results for the 50μm spot size is slightly discordant, has a relatively high MSWD, and is outside the expected age of 520Ma. The 30μm spot size has 2 groupings resulting in a larger spread. The age is within error of expected.

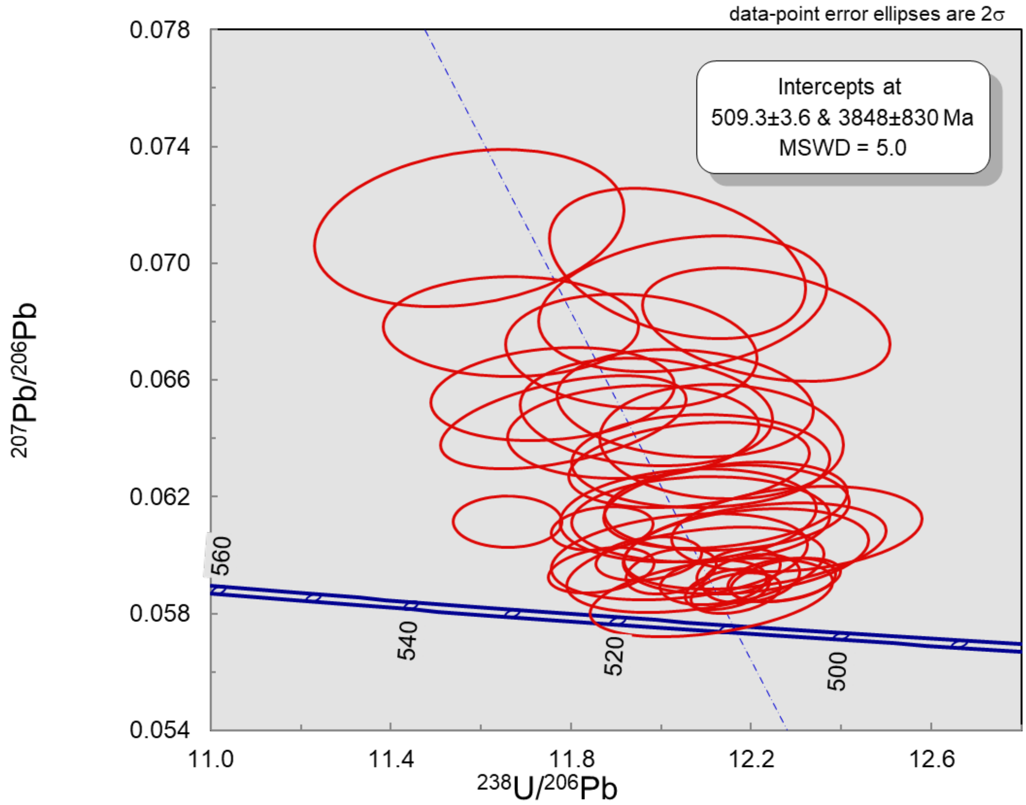


Figure 54: Tera Wasserburg plot of results for KHAN at 50μm spot size

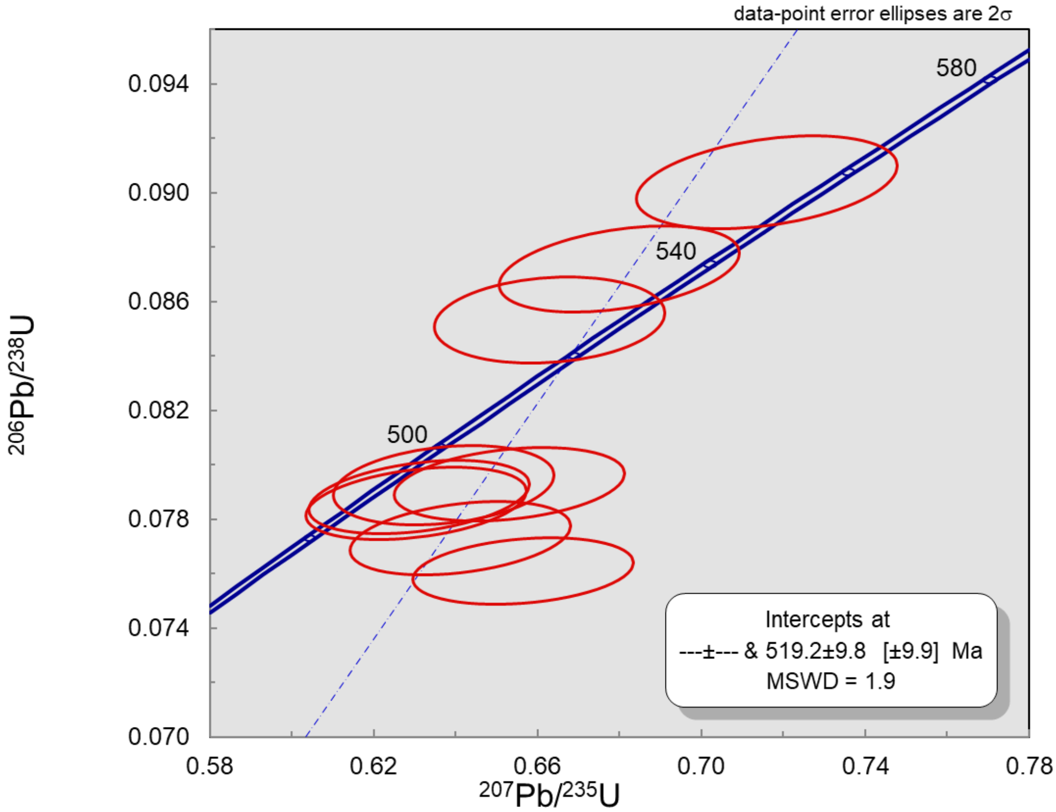


Figure 55: Tera Wasserburg plot of results for KHAN using 30μm spot size

2.4.3 GJ1 (30/11/18)

The GJ1 standard was used as the calibration standard for zircon, with a total of 33 analyses

2.4.4 FC1 (30/11/18)

FC1 was used as a check standard for zircon, with a total of 20 analyses. There are several erratic analyses that are outside the Concordia. The concordant analyses are slightly older than the expected value.

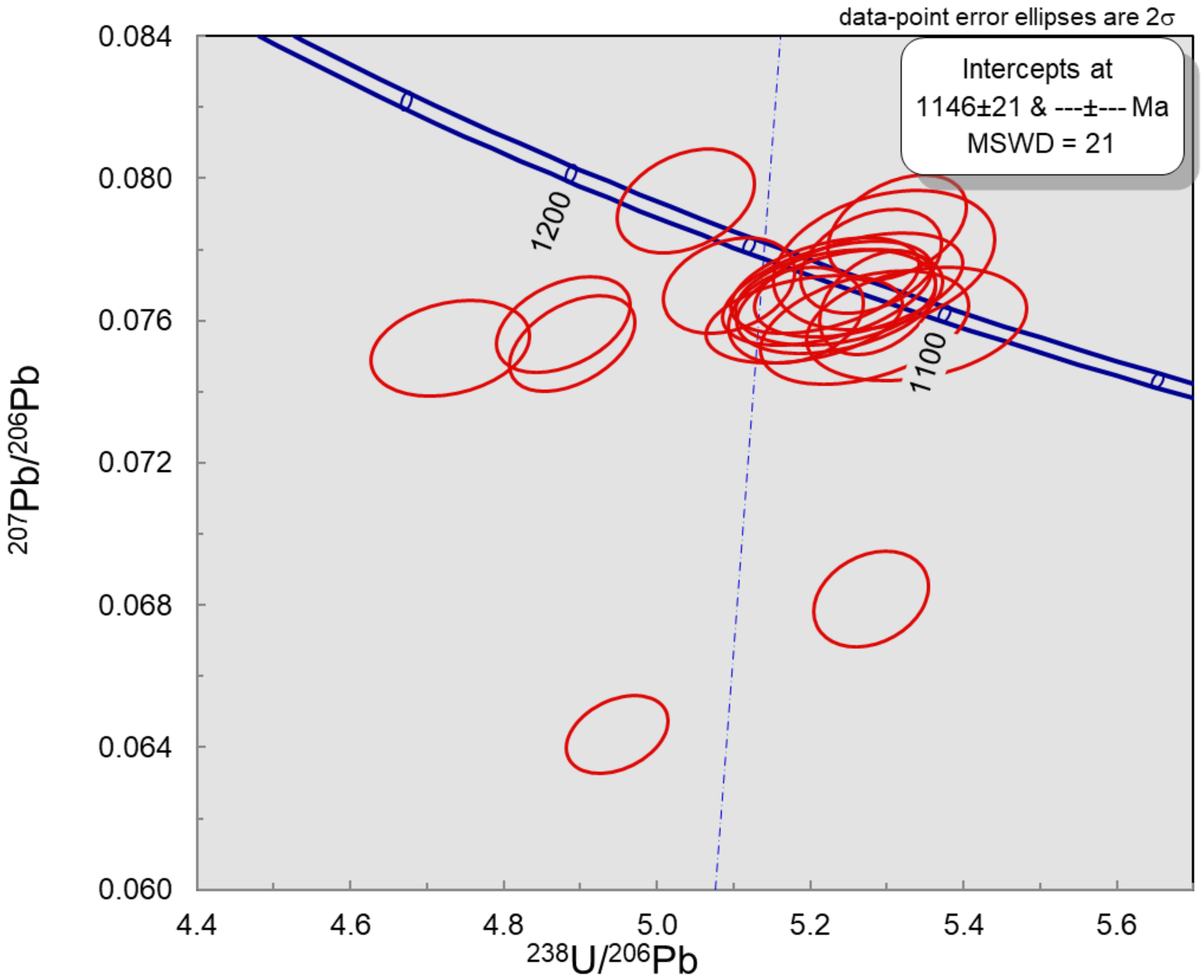


Figure 56: TW diagram for check standard FC1

2.4.5 Temora2 (30/11/18)

Temora was used as a check standard for zircon, with a total of 21 analyses. There was also some scatter in this data, with one bracket of 3 analyses (TEM06-08) being problematic. When the 4 outliers are removed, the determined age is just within error of the expected age

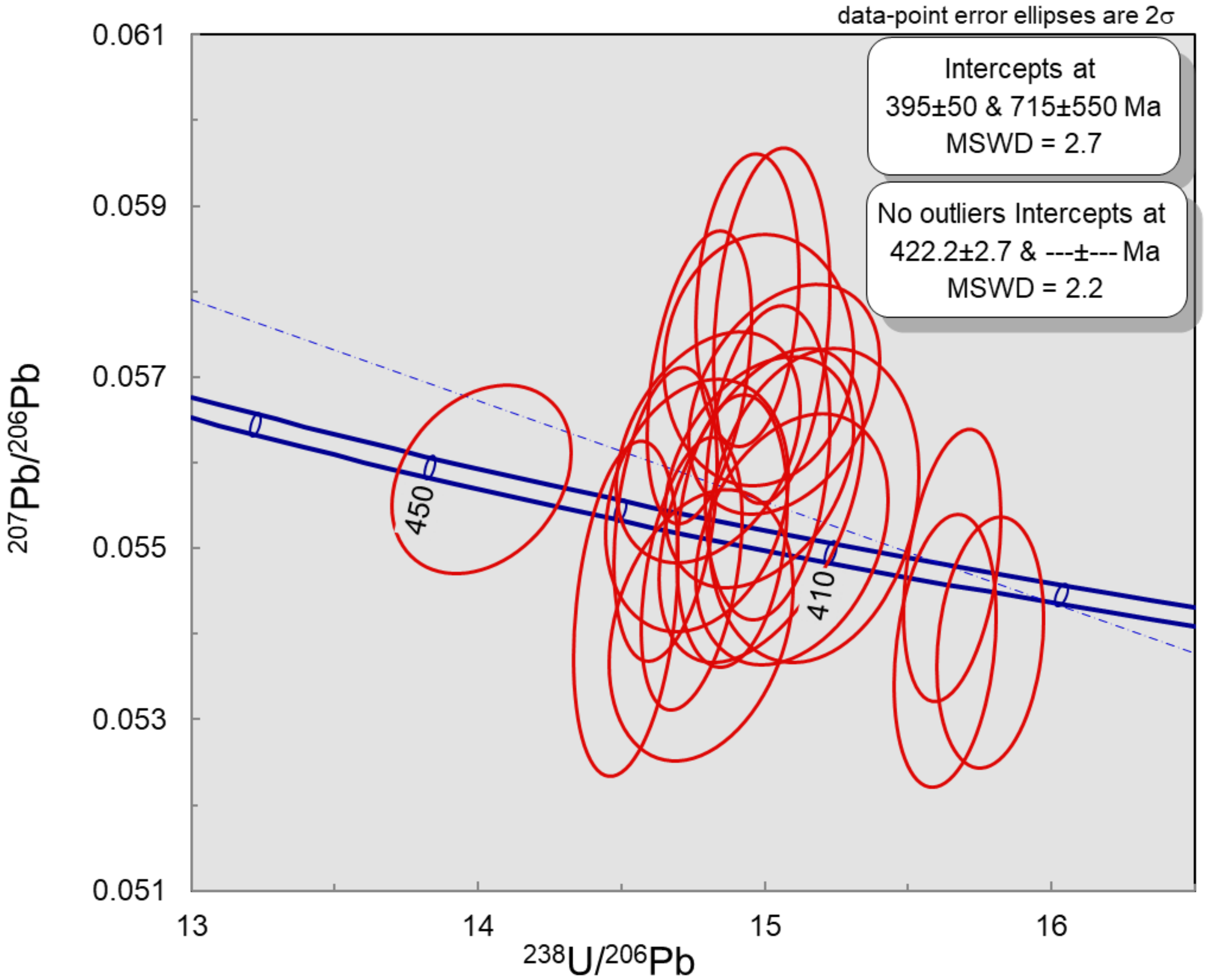


Figure 57: TW diagram for check standard Temora1

2.5 Results-Titanite

The titanite results in general appear to have a considerable scatter, despite most samples comprising only 1-3 crystals (exceptions EX096245, EX096909).

2.5.1 EX21959

Lithology: Large titanite crystal in vein of amphibole, pyroxene, feldspar and carbonate. Vein cuts through QFP.

Run	Run1 31/10	Pb207-206 Age	
# Analyses	20	Concordia Age	1573.7±6.1
# Analyses integrated	20	Multiple populations?	

This set of analyses contains a roughly half concordant results, with the remainder siting reasonably well on 1 array. The 1573.7±6.1Ma age suggests this vein formed around the likely time of peak metamorphism.

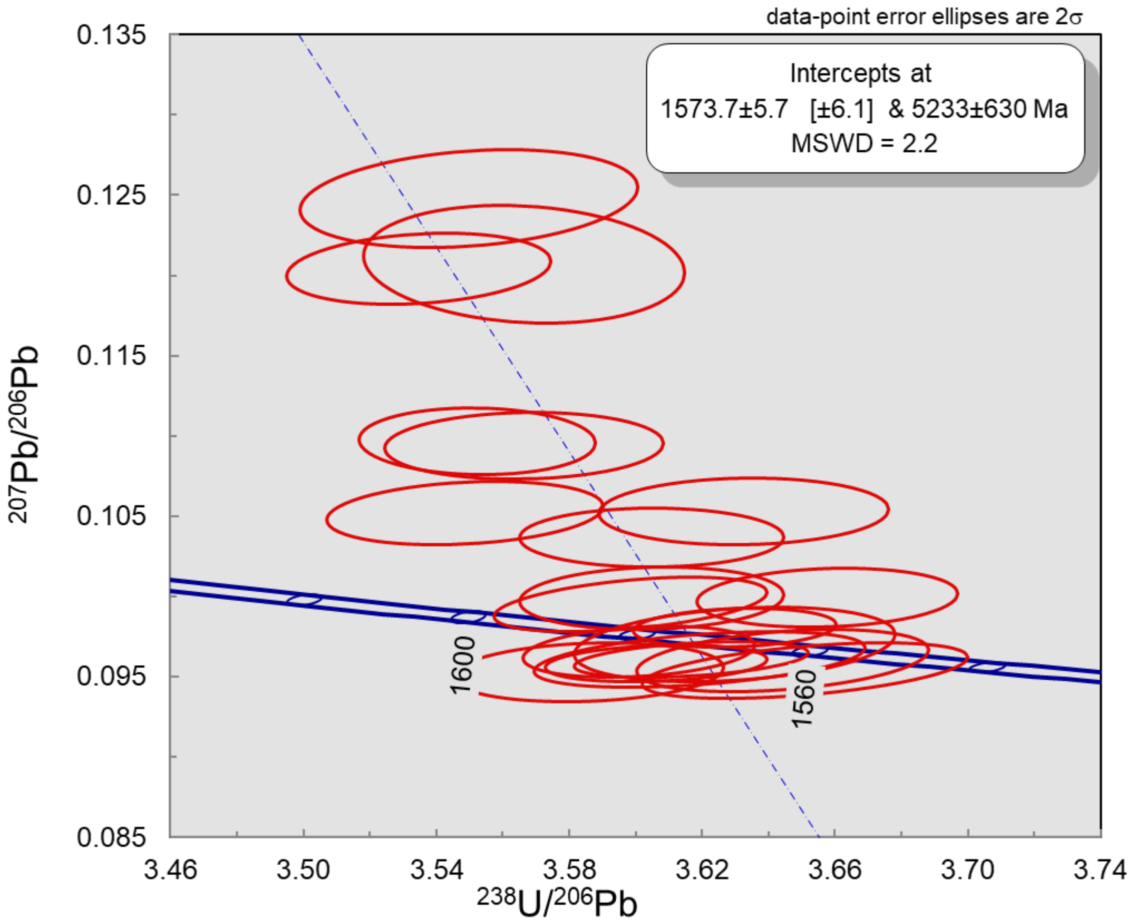


Figure 58: TW diagram for EX21959, all analyses. Approximately half are concordant within error, with the remaining appearing to form a single discordant array. N=20

2.5.2 EX22000

Lithology: Titanite alteration in QFP, with coarser grain size on either side of a fracture, much finer in ground mass.

Run	Run2 31/10	Pb207-206 Age	
# Analyses	16	Concordia Age	1525±26 (n=15)
# Analyses integrated	16	Multiple populations?	

Analyses only targeted larger grains associate with the fracture. There are no concordant analyses, however most fall reasonably well on a single array. Removing the one outlier considerably improves the Concordia age

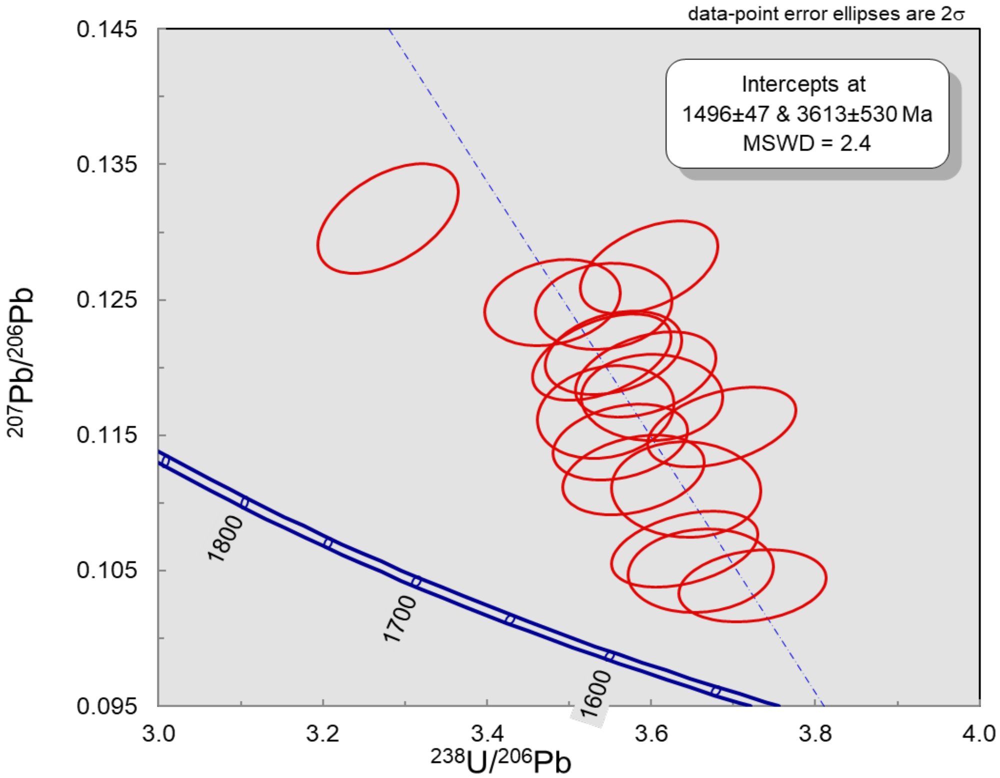


Figure 59: TW diagram for EX22000, all analyses. N=16

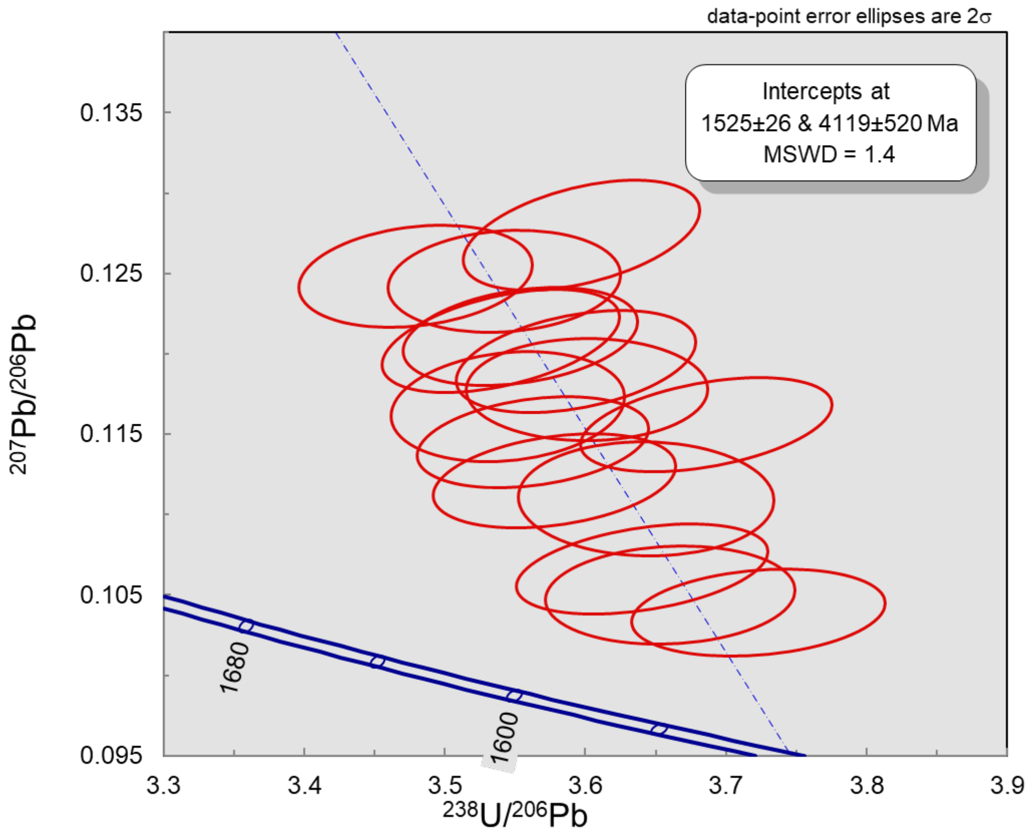


Figure 60: TW diagram for EX22000, with 1 outlier removed, significantly improving the fitted concordia. N=15

2.5.3 EX32145

Lithology: Very large titanite crystal within coarse ?syenite (amphibole-kspar-biotite) pegmatite

Run	Run2 31/10	Pb207-206 Age	
# Analyses	20	Concordia Age	1560±10 (subset)
# Analyses integrated	20	Multiple populations?	

This set of analyses includes a cluster of concordant results, with two trends, one discordant, and a second following the concordia (slightly reversely discordant). Regression of the entire dataset yeilds a poor result, however removing the outlying values leaves a reasonable set of concordant results with a discordant array. These outlying values do not appear to have any relationship to trace element chemistry or backscatter response regions

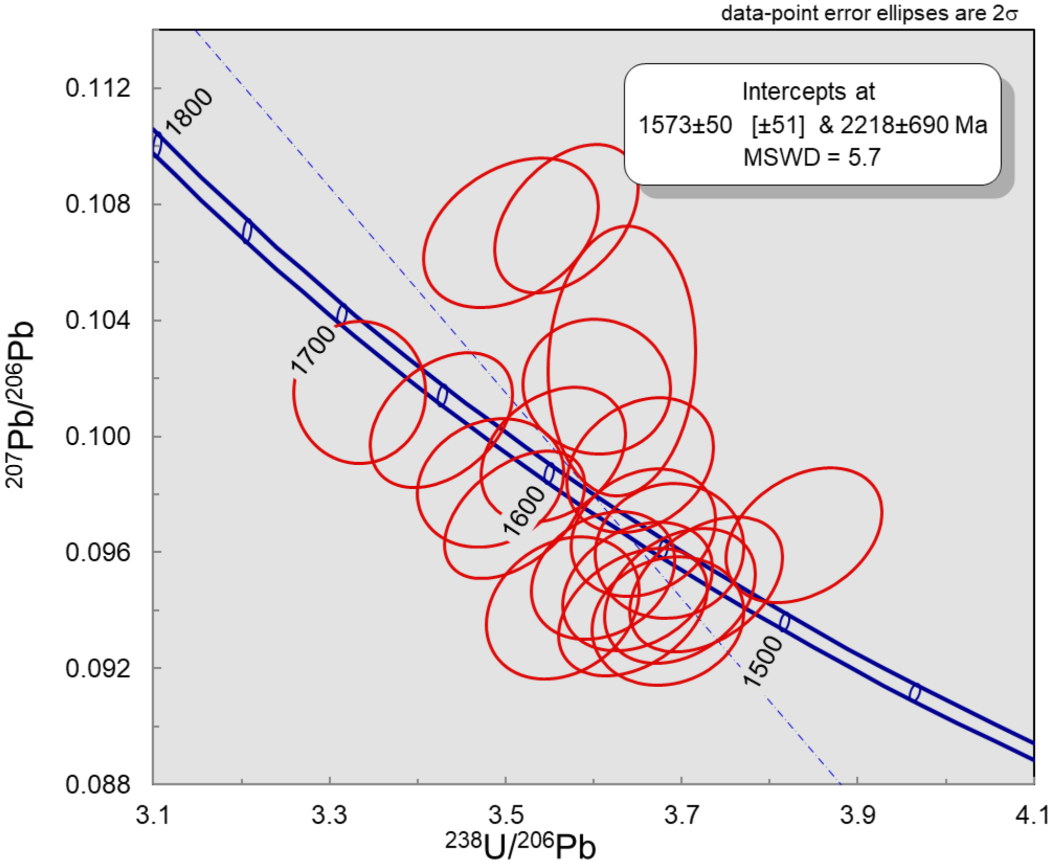


Figure 61: TW diagram for EX32145, all analyses. a spread of results along the concordia can be seen along with the main concordant-discordant array. N=20

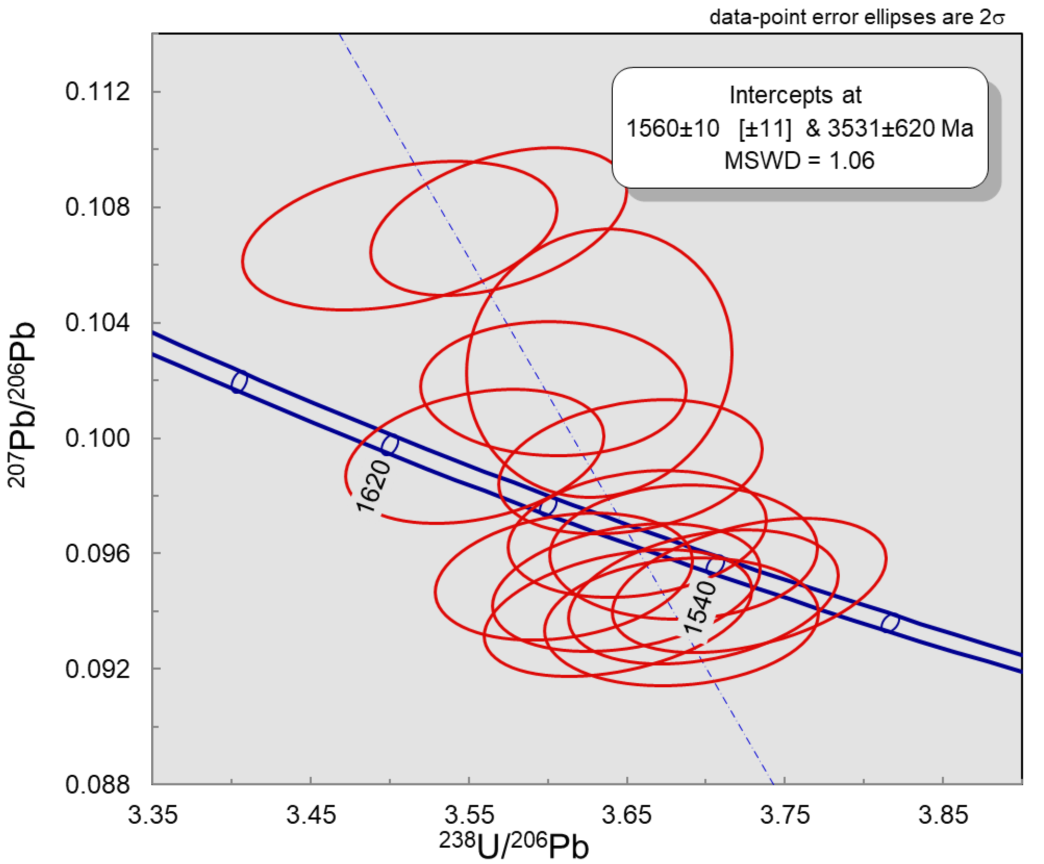


Figure 62: TW diagram for EX32145 after removing outlying results, significantly improving fit. N=14

2.5.4 EX32148

Lithology: Very large titanite crystal within coarse ?syenite (amphibole-kspar-biotite) pegmatite

Run	Run1 31/10	Pb207-206 Age	
# Analyses	20	Concordia Age	1524±9.3
# Analyses integrated	19	Multiple populations?	

This set forms a relatively coherent concordant-discordant array with a reasonable fit. A single outlier was removed, with this analysis also being adjacent to the one analysis rejected at the integration stage.

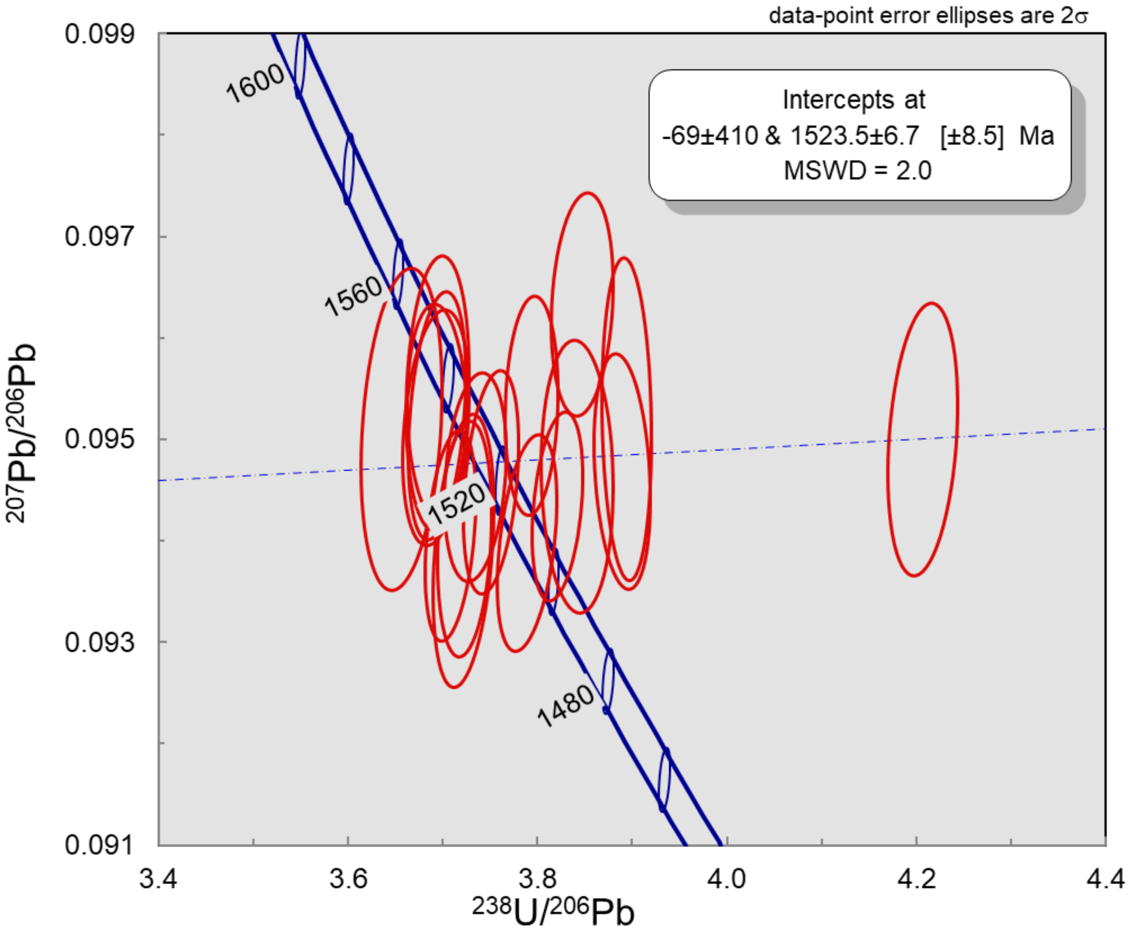


Figure 63: TW diagram for EX32148, with 1 outlier removed. This outlier was shot adjacent to an analysis that was rejected at the integration stage. N=18

2.5.5 EX096245

Lithology: fine titanite alteration of QFP clast/xenolith within carbonate-biotite rock. Grains also within biotite reaction rim

Run	Run3 31/10	Pb207-206 Age	
# Analyses	20	Concordia Age	1528±30 (subset)
# Analyses integrated	20	Multiple populations?	

This dataset was collected with a smaller spot size (30µm) in an attempt to analyse the small disseminated alteration grains. Several the spots may cross the grain boundaries, however no obvious signs of extraneous material was seen in the raw signal.

All spots are discordant, with what appears to be one main array and a number of scattered results. There is no obvious coherence in the trace element data relating to these analyses. Isolating the central array (n=13) yields a moderately successful regression giving 1528±30Ma

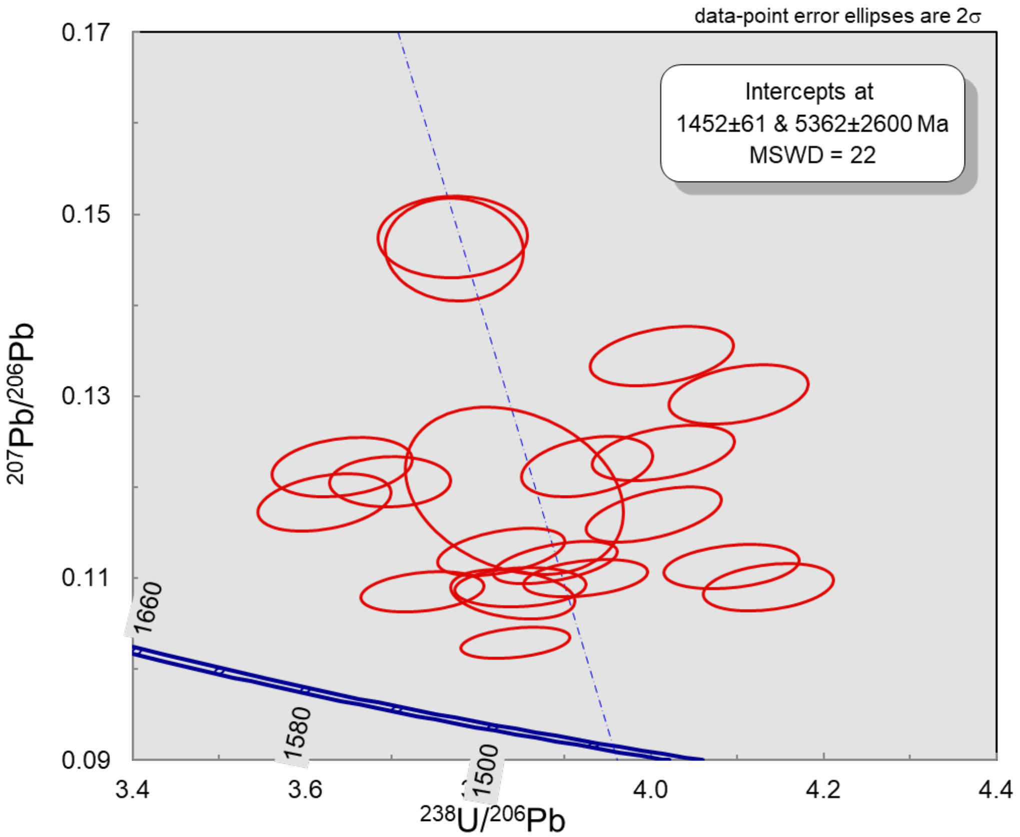


Figure 64: TW diagram for EX096245, all analyses

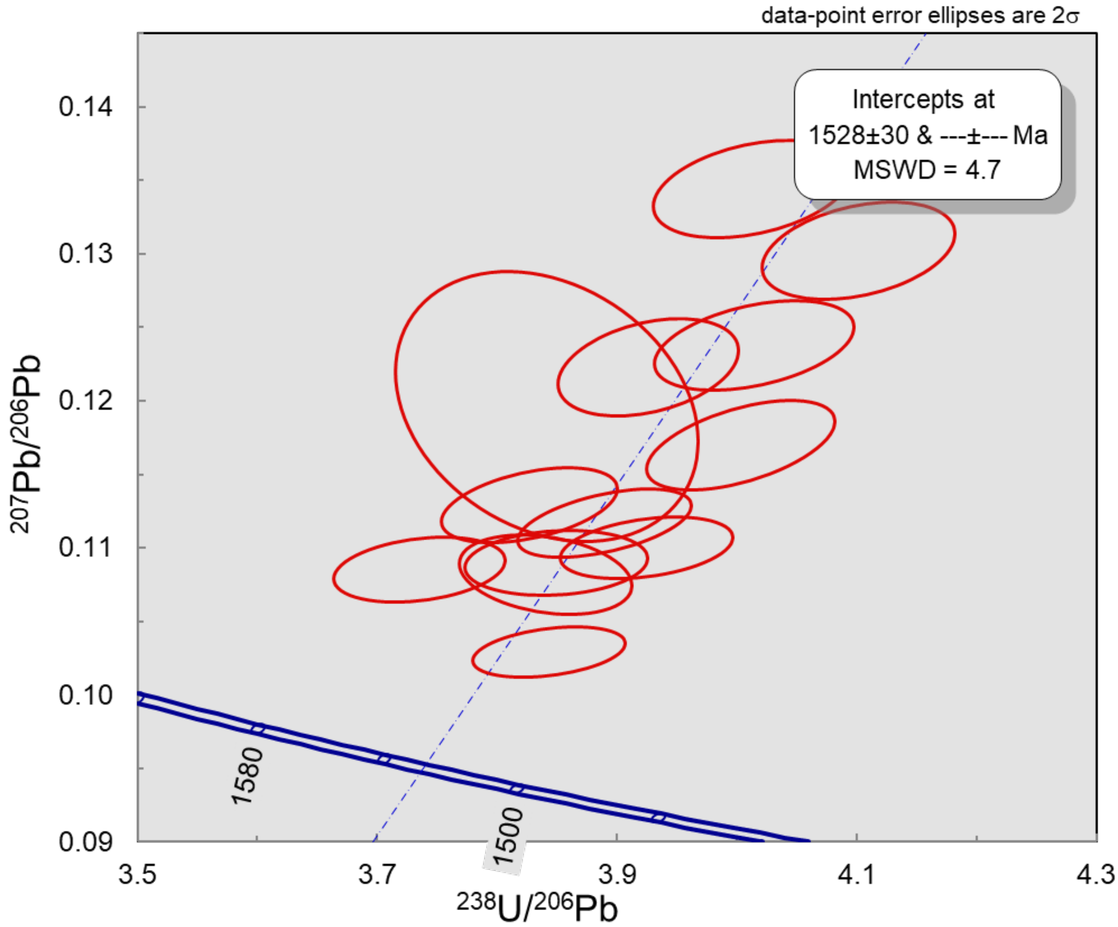


Figure 65: TW diagram for EX096245, with results outside the main trend excluded, yielding a moderate fit. N=13

2.5.6 EX096904

Lithology: small grains/fragments from coarse ?syenite pegmatite (resin mount)

Run	Run2 31/10	Pb207-206 Age	
# Analyses	17	Concordia Age	1554±8.9
# Analyses integrated	17	Multiple populations?	

This set is well clustered with concordant analyses along with a short discordant array on both sides of the Concordia. Unlike most of the titanite analyses presented here, these are from numerous small grains taken from a crushed sample. This sample is drawn from the same drill core intersection as EX32148. There is no evidence for a younger (~1525 Ma) population to match the EX32148 result

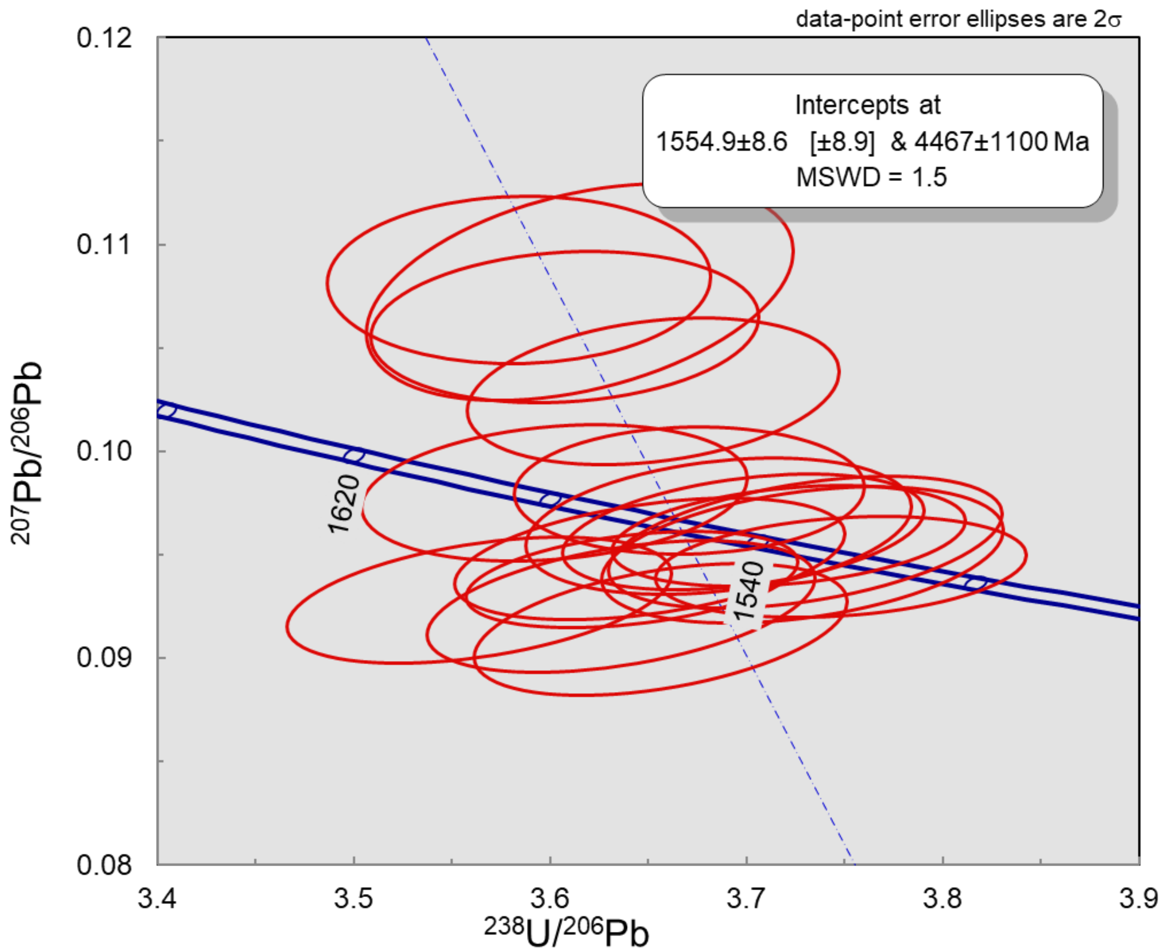


Figure 66: TW diagram for EX096904, all analyses. N=17

2.5.7 EX096909

Lithology: Coarse hornblende-feldspar gabbro.

Run	Run2 31/10	Pb207-206 Age	
# Analyses	24	Concordia Age	1597±28
# Analyses integrated	24	Multiple populations?	

A very discordant set of analyses, but reasonably well distributed along a single array, giving am intercept age of 1597±28. These analyses are taken from multiple small grains. This is probably some form or metamorphic age, however given the ~1618 Ma age for the host schist, it puts a reasonably small window for emplacement. It is also an interesting age for metamorphism, which is usually placed at ~1575 Ma (Foster and Rubenach 2006), and a later event at ~1525-1510 Ma. This later event also appears to be where most other titanite ages from the region fall, e.g. Mary Kathleen (Spandler et al. 2016).

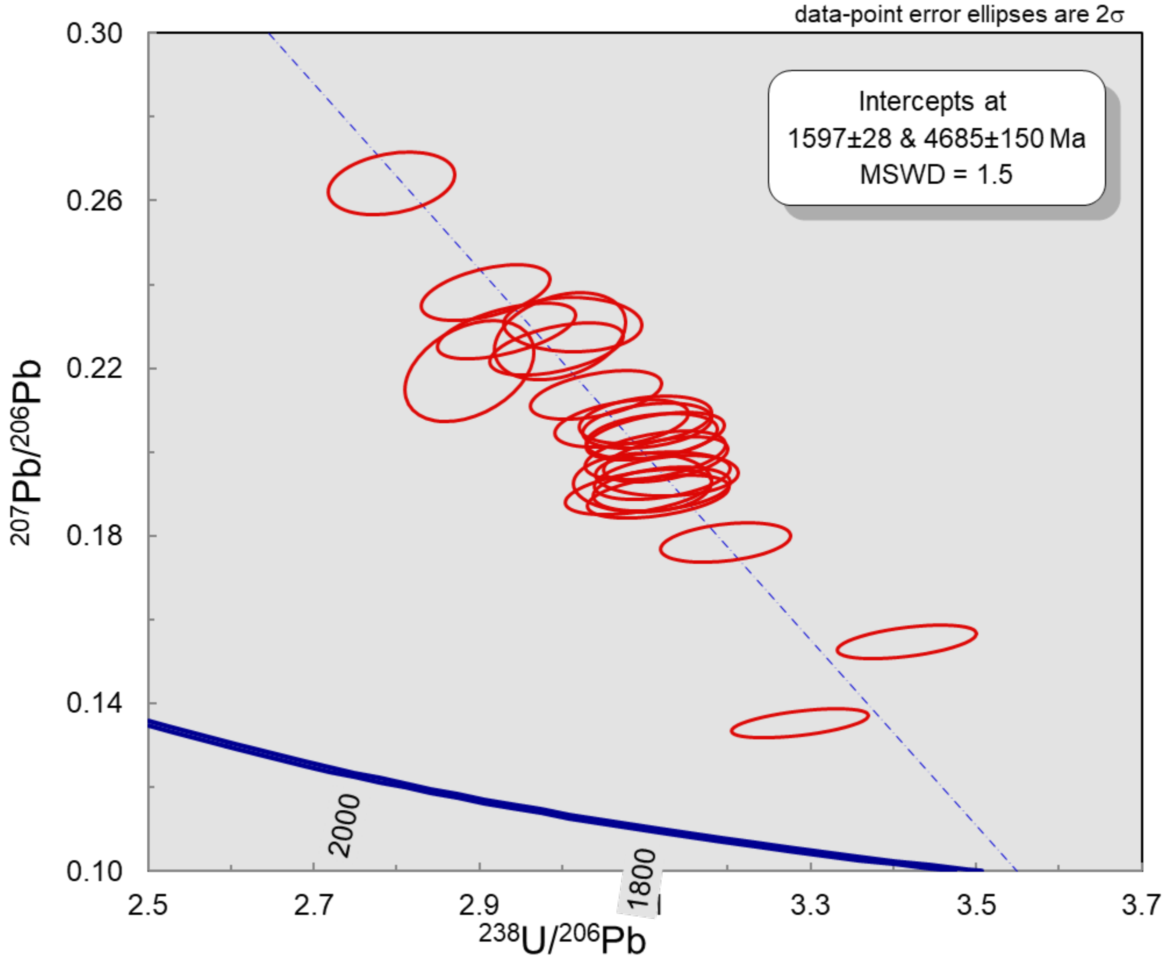


Figure 67: TW diagram for EX096909, all analyses. N=24

2.6 Results- Zircon

2.6.1 EX096250

Lithology: Medium to coarse quartz feldspar porphyry (QFP), phenocrysts mostly quartz to 3mm. Medium to strong linear fabric, minor pyrite. Intrudes calcsilicates, contact with Milo beds probably faulted.

Run	Run1 30/11	Pb207-206 Age	
# Analyses	30	Concordia Age	1612±15 (Subset n=11)
# Analyses integrated	30	Multiple populations?	

Compared to the quartz feldspar porphyries analysed previously, the data is quite scattered. A sub population of mostly concordant results (n=11) yields a result of 1612±15 Ma. Initially it was assumed this would be a similar age to the northern porphyries (~1642 Ma), however it does have a distinct composition and texture. Interestingly, it also appears to be different to the other two samples of felsic rocks that yielded similar ages in the first round of analyses.

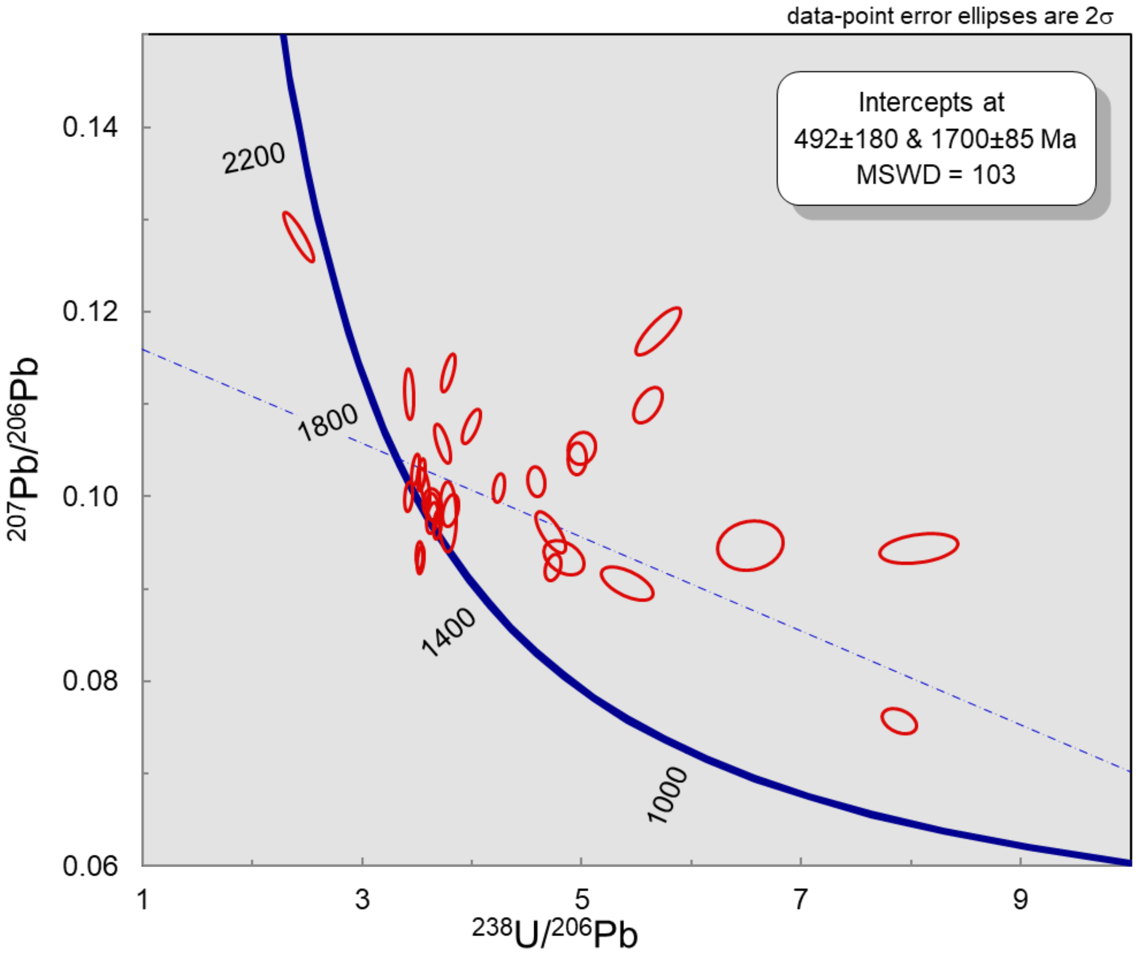


Figure 68: TW diagram for EX096250, all analyses

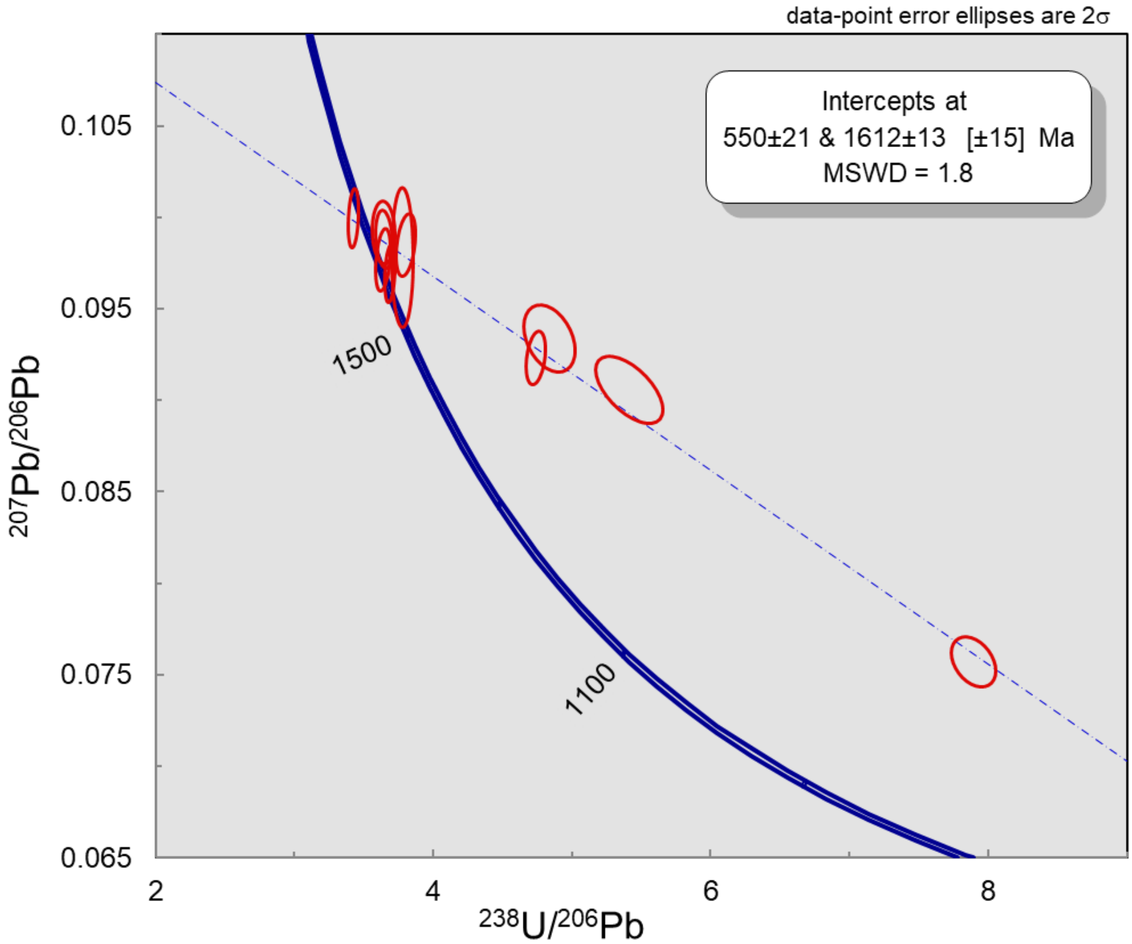


Figure 69: TW diagram for a mostly concordant sub population from EX096250 (n=11)

2.6.2 EX096901

Lithology: Fine grained mafic (basalt) within broader mafic intersection within graphitic schist. At one end of interval appears to truncate sulphide veins, however this may be from a later shear.

Run	Run1 30/11	Pb207-206 Age	
# Analyses	19	Concordia Age	1617.8±10
# Analyses integrated	19	Multiple populations?	

A good, coherent mostly concordant trend with a single outlier, suggesting a single population of zircons on a modern lead loss trend. Removing the outlier significantly improves the precision of the calculated age.

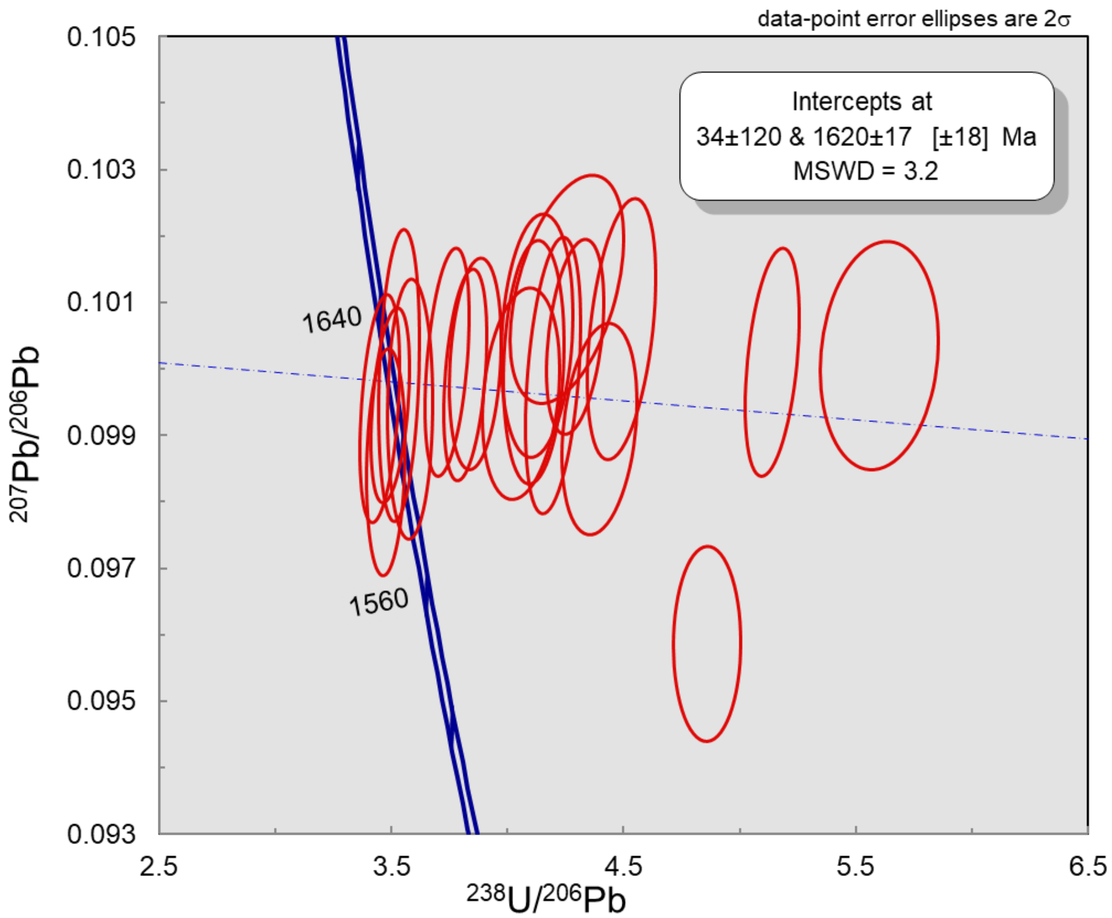


Figure 70: TW diagram for EX096901. A single outlier is present for an otherwise coherent array.

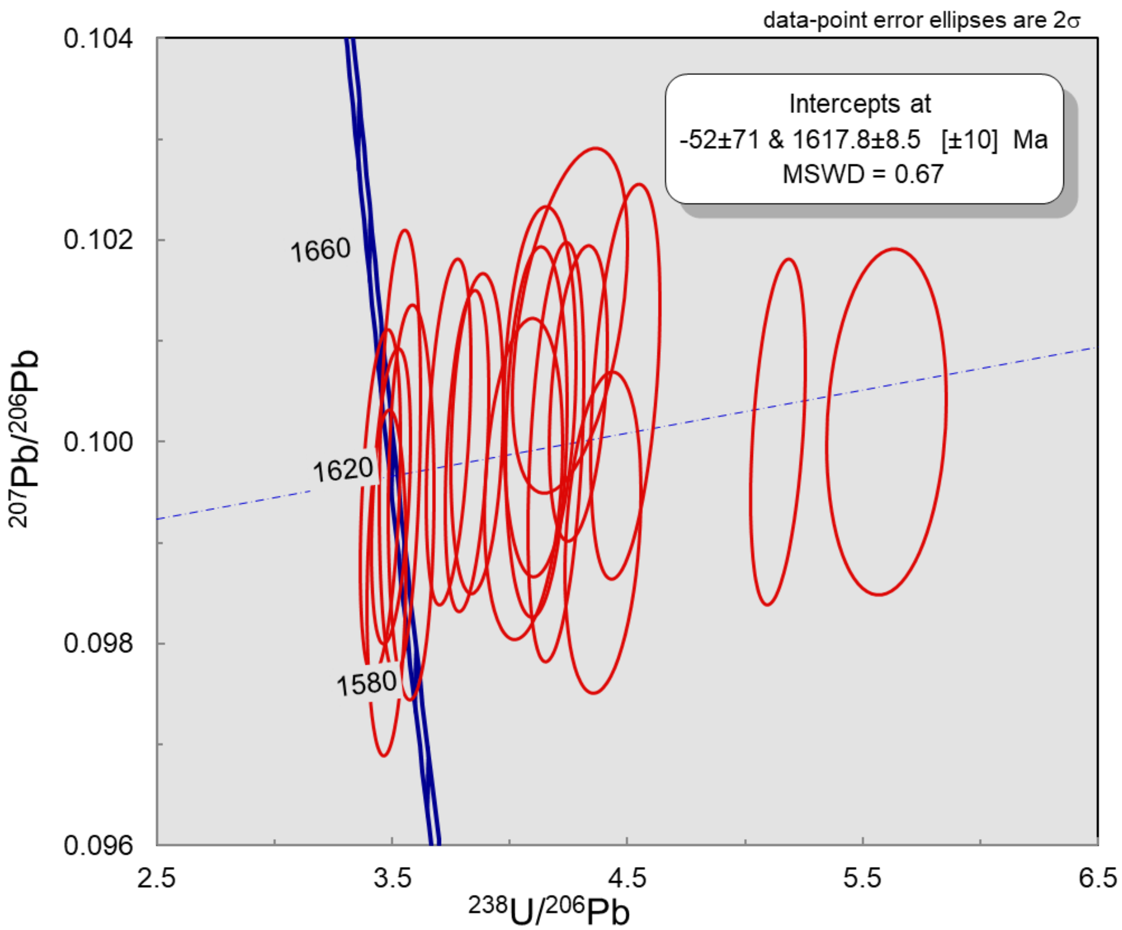


Figure 71: TW diagram for EX096901 with outlier removed.

2.6.3 EX096903

Lithology: Coarse amphibole-k feldspar rock, thought to be syenite, with very coarse titanite. Adjacent to white quartz vein.

Run	Run1 30/11	Pb207-206 Age	
# Analyses	6	Concordia Age	none
# Analyses integrated	5	Multiple populations?	

The small number of analyses do not form a coherent array, and there are no concordant results.

2.6.4 EX096904 (and EX096903)

Lithology: very coarse "syenitic" pegmatite with very large amphibole, k feldspar, biotite and titanite.

Run	Run1 30/11	Pb207-206 Age	
# Analyses	40	Concordia Age	complicated
# Analyses integrated	36	Multiple populations?	1614±12 (n=6) 1695±13 (n=8)

This is a very complicated set of results, including a large number of poor analyses that were rejected at data reduction stage, and a number of those processed have significant error. Given the same source unit, the 5 analyses from EX096903 were included. Inspection of the TW diagrams has led to the identification of some populations which may have meaningful ages (neither include analyses from EX096903). The first (population E) has 6 results forming an array yielding 1614 ±12 Ma, while population F (n=8) yields 1695±13 Ma. Both have reasonably similar lower intercepts.

These ages are a little troublesome given the interpreted intrusive field relations and other geochronology suggesting the host rocks age of ~1620Ma. Population E can possibly be fit into this framework, as a very near surface intrusion, however this does not match the very coarse grained texture. Petrographically, most of the zircons were found within the coarse grained perthitic K feldspars. Population F is even more difficult to reconcile, as this is far older than the apparent age of the host rock, including the felsic rocks at the base of the sequence (~ 1660 Ma). It is also unlikely this has been confused with the Corella Formation calc silicates, which show multiple source populations older than ~1747 Ma.

It is clear from the minimal number of analyses forming apparent usable data from these samples (14 out of 46 total) that something is causing problems in the U/Pb system. This lithology contains visible fluorite, which was noted in other problematic samples in the June batch (pegmatite, glimmerite). Another possibility is the presence of common lead, causing apparent older ages. Indeed, several the analyses rejected at integration stage was due to spikes or zones of Pb204.

Finally, these zircons have been extracted from the same intervals as EX32145, EX32148 and the EX096904 Titanite samples. These titanites yielded 1560, 1524 and 1554 respectively. It is possible that these represent metamorphic and/or alteration ages

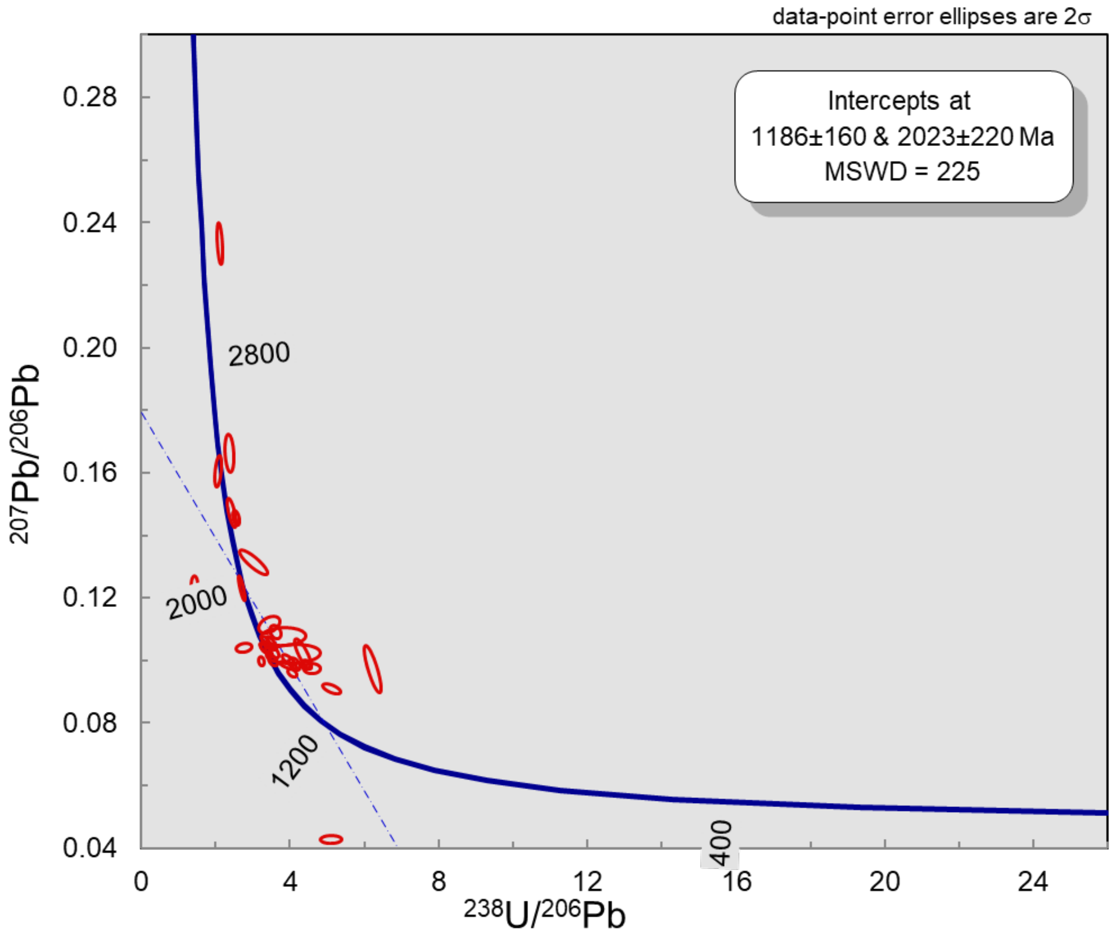


Figure 72: TW diagram of all analyses, EX096903, EX096904

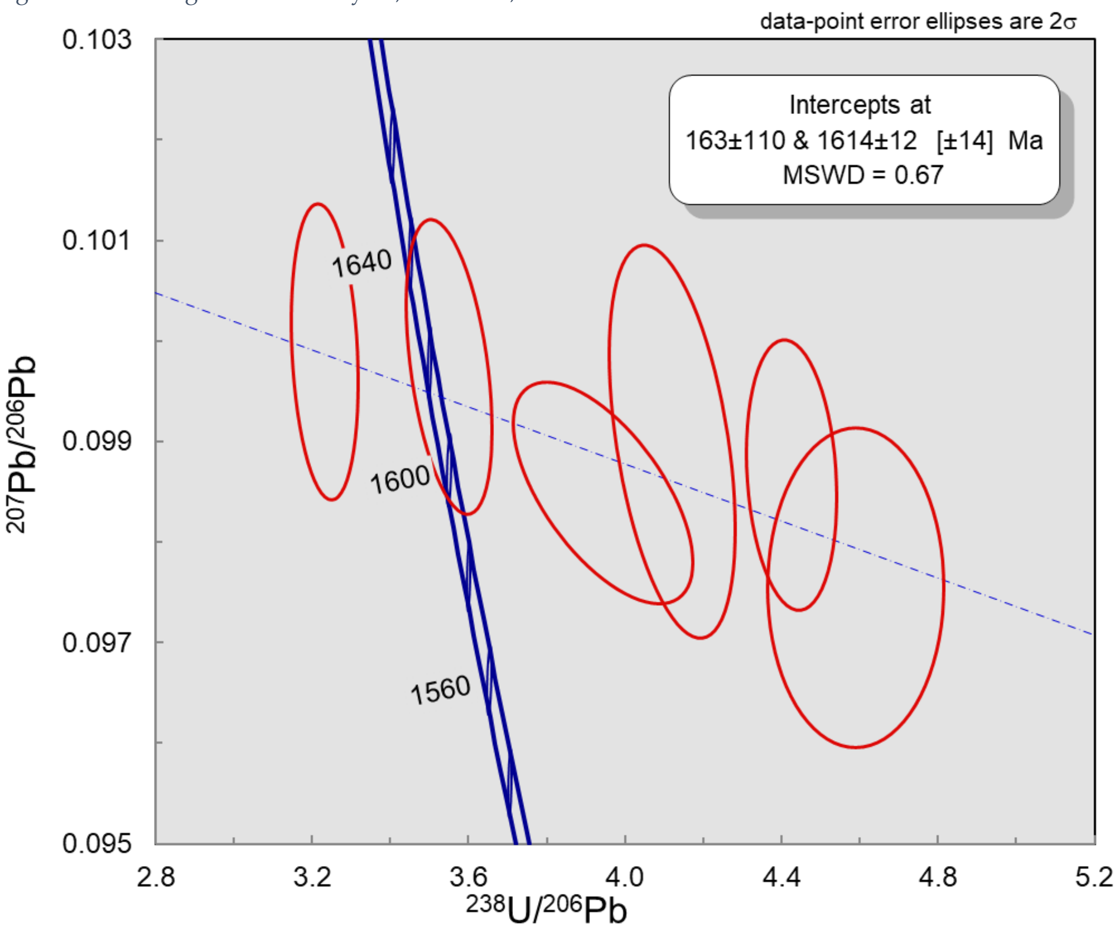


Figure 73: TW Diagram for EX096904 subpopulation E (n=6)

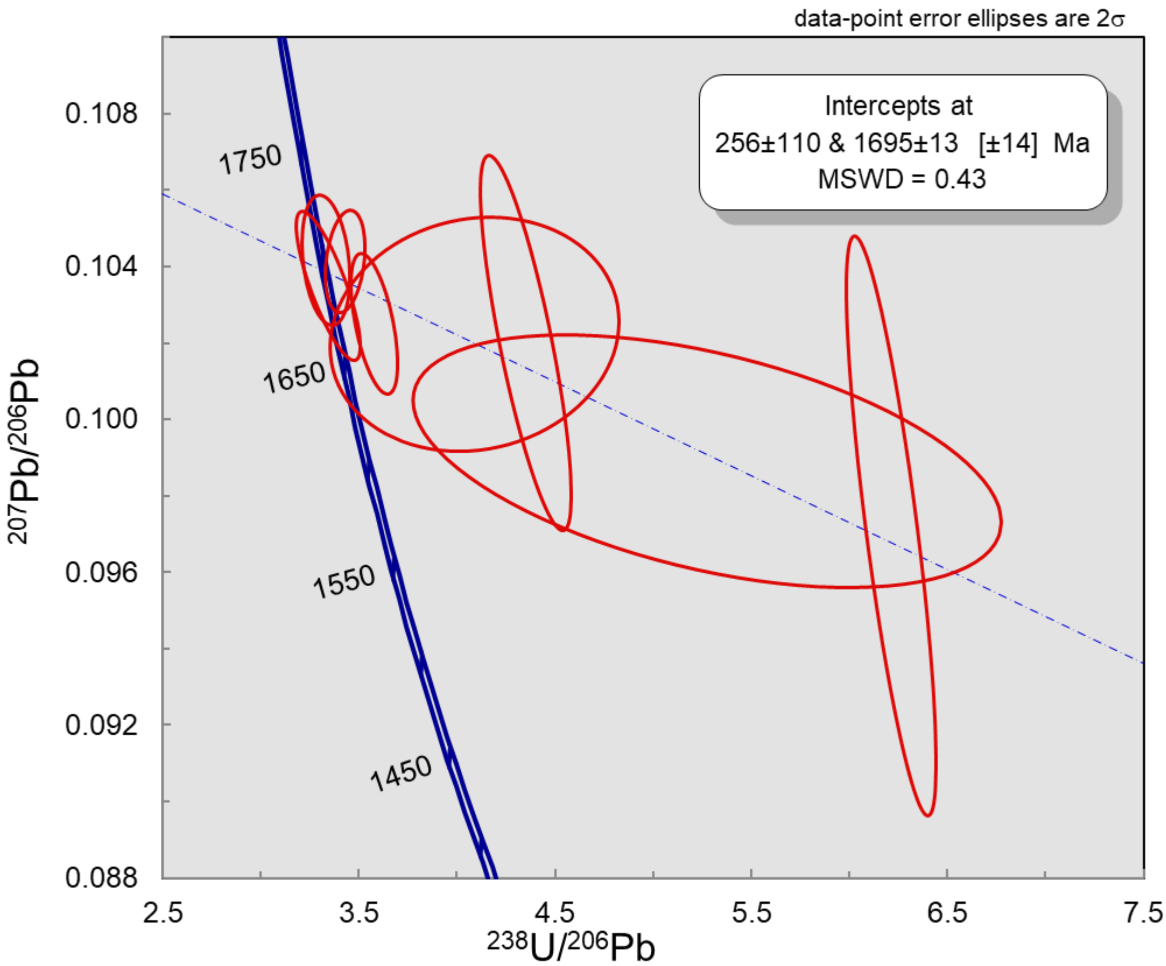


Figure 74: TW diagram for EX096904, subpopulation F. (n=8)

3 Tommy Creek LA-ICPMS Zircon Geochronology, June 2019

3.1 Introduction

Laser Ablation ICPMS analysis at the Advanced Analytical Centre (AAC), James Cook University Townsville, was performed on resin mounted zircon separates from 5 samples, on the 26th June 2019.

The below table outlines the samples that were analysed. A map with their locations and results is in **Error! Reference source not found.**.

Sample ID	Sample Type	Lithology	Grains mounted	Analyses performed
EX32136	Surface	QFP- pyritic quartz feldspar porphyry	~50	28
EX096246	¼ Core	Carbonate-biotite rock with xenoliths. Further analysis of grains not used in June 2018	~100 (65 prior analyses)	35
EX096916	Surface	dark porphyritic rock thought to be volcanic just below base of graphitic schist	>100	31
EX096917	Surface	Muscovite schist with graphitic unit	90-100	55
EX096919	surface	Foliated feldspar porphyry	>100	48

Table 3: Table of samples with zircons analysed. Polished thins section taken from drill core. ¼ core is material taken directly from drill core by the author

3.2 Methods

Samples were prepared in the Mineral Separation Laboratory at JCU. Samples were crushed using a hydraulic splitter and pulverized with a disc mill.

Pulverised material was sieved into 3 fractions: >500µm, 500µm< x >250µm, and <250µm.

Pulverised material was then treated on a shaker table to remove slimes and concentrate heavy minerals. In general, samples were recycled 2-4 times (mid and heavy fractions), and different sieved fractions were treated separately

The heavy fractions from the shaker table were dried and then magnetic materials were removed using a hand magnet and Frantz isodynamic separator machine with maximum working current of 1.4 amps.

The least magnetic fraction was then treated with hot LST (Lithium polytungstate) density separation.

Target minerals were picked from the heavy fraction and mounted in a resin puck, which was ground and polished to a high finish.

Pucks were imaged with Cathode Luminescence and mineral identification checked with EDS on a Hitachi SU5000 SEM at the AAC.

U-Pb analyses were performed by coupled Laser Ablation and quadrupole Mass Spectroscopy (LA-ICPMS) in the AAC.

Zircon Standards GJ1 (calibration), FC1 and 91500 (check), as well as NIST610 glass. Two spots of each standard were analysed for after brackets of 10 unknowns for zircon standards; NIST glass was analysed at the start, midpoint and end of each run.

The Laser was set to, 5Hz and 2.5J/cm^2, with 45s on time and 60s offtime between samples. Zircons were analysed using 30µm spot size, For zircon, the mass spectrometer was set to collect Pb 204, 206, 207, 208, Th 232, U 238, Ti49, Zr91, Si29 and Hg200, as well as Y89, Ce 140, Hf179 on short dwell times.

Data was reduced using iolite software package, with signal integration periods chosen by quality of the Pb 207:206 signal. Data processing and visualization used Isoplot 4.15 add in for excel and ioGAS.

3.3 QAQC

Standard	Expected Age (Ma)	Uncertainty (2σ)	Pb-Pb	U238 Pb206	Concordia Age
GJ1	608.5	±0.4			
FC1	1099	±0.6	1088.2±7.5	1103.9±5.8	1097.6±6.8
91500	1065		1033±13	1056.1±2.9	1057.5±2.8

3.3.1 GJ1

The GJ1 standard was used as the calibration standard for zircon, with a total of 40 analyses

3.3.2 FC1

FC1 was used as a check standard for zircon, with a total of 40 analyses. There are a number of erratic analyses, these are thought to be potential edge effects from small grains. The concordant analyses are within error of the expected value, however the Pb-Pb age is slightly low.

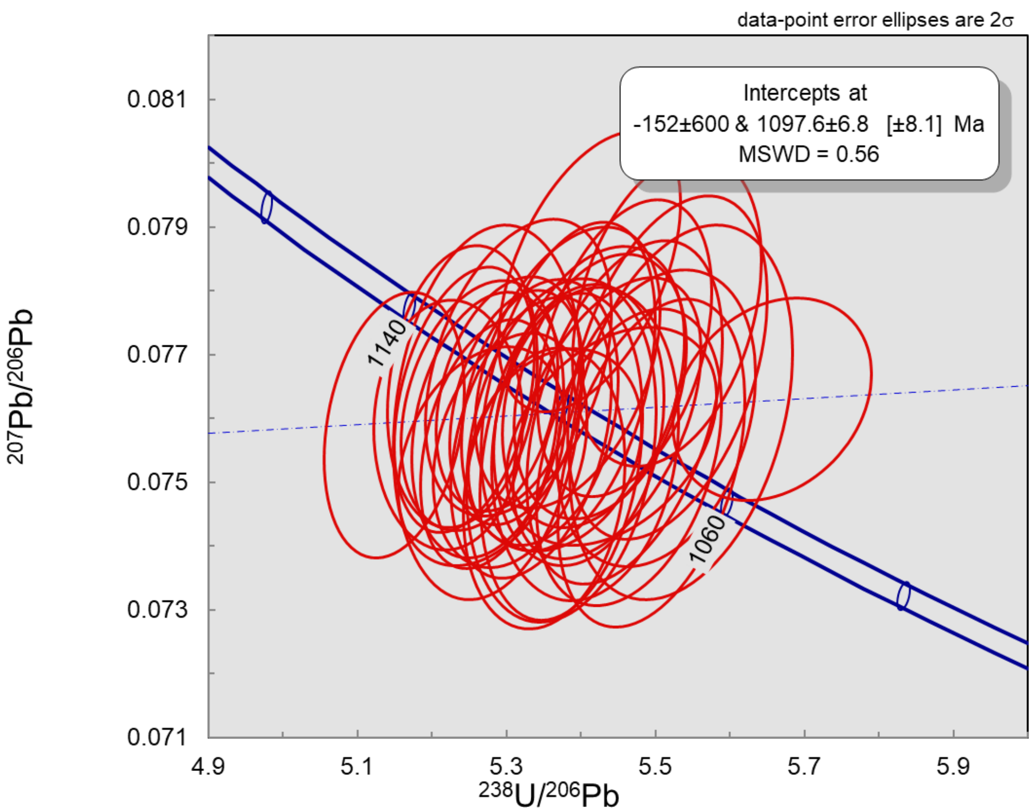


Figure 75: TW diagram for check standard FC1. Erratic results removed

3.3.3 91500

91500 was used as a check standard for zircon, with a total of 40 analyses. Results are generally good, with only 1 marginally discordant result, yielding and age just lower than expected (1057±3 Ma). The Pb Pb age is significantly low, at 1033±13 Ma.

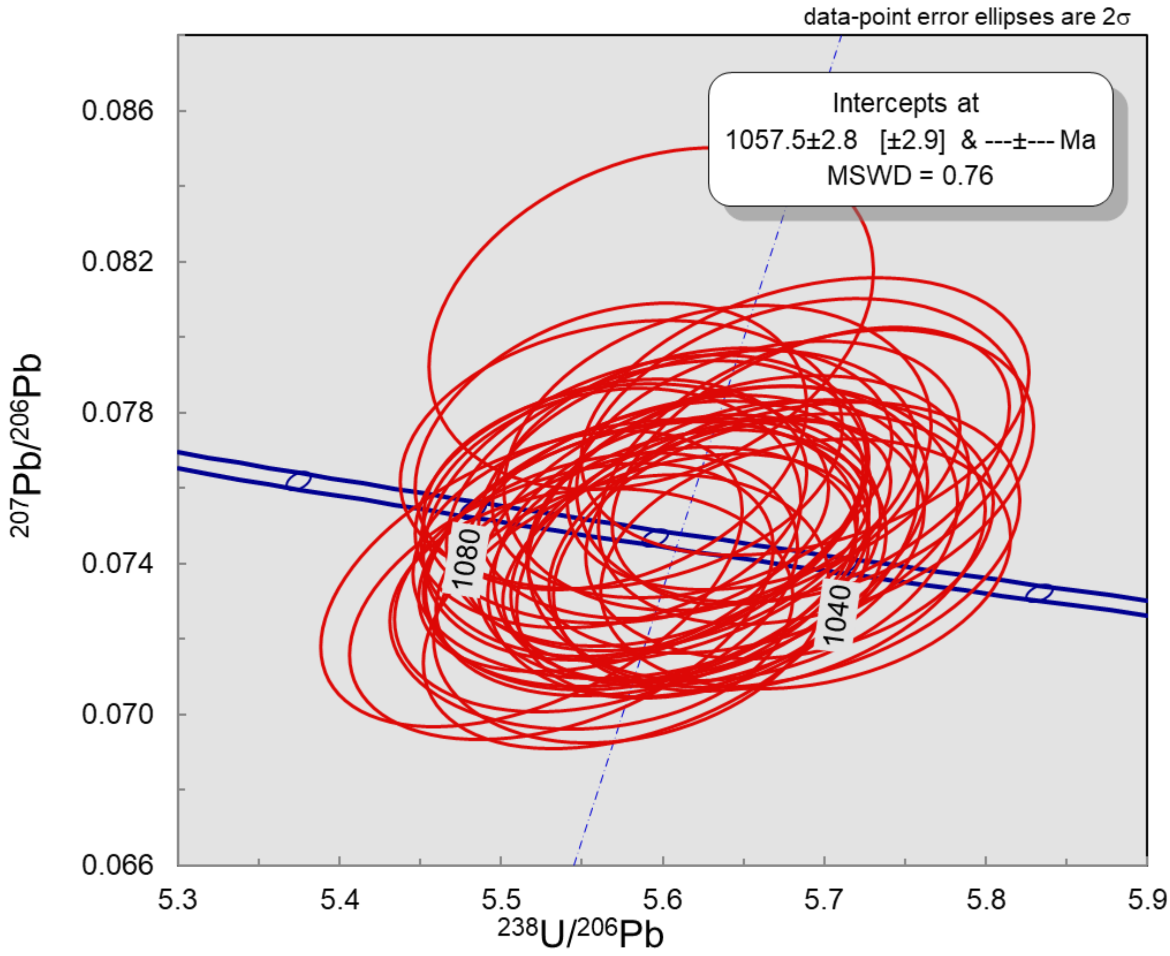


Figure 76: TW diagram for check standard 91500

3.4 Results

3.4.1 EX32136

Lithology: Medium to coarse quartz feldspar porphyry (QFP), phenocrysts mostly to 3mm. Medium to strong linear fabric, moderate pyrite.

Run	Run 26/06	Pb207-206 Age	
# Analyses	28	Concordia Age	1638.7±11 Ma
# Analyses integrated	28	Multiple populations?	

The data contains both concordant or close to concordant analyses, as well as a long trend of Pb loss(Figure 77). Concentrating on the near concordant data (n=17) yields a 1638.7±11 Ma age on a Tera Wasserburg plot (Figure 78). This agrees well with other samples from the QFP unit of 1642±10 Ma and 1641.2±7.6 Ma.

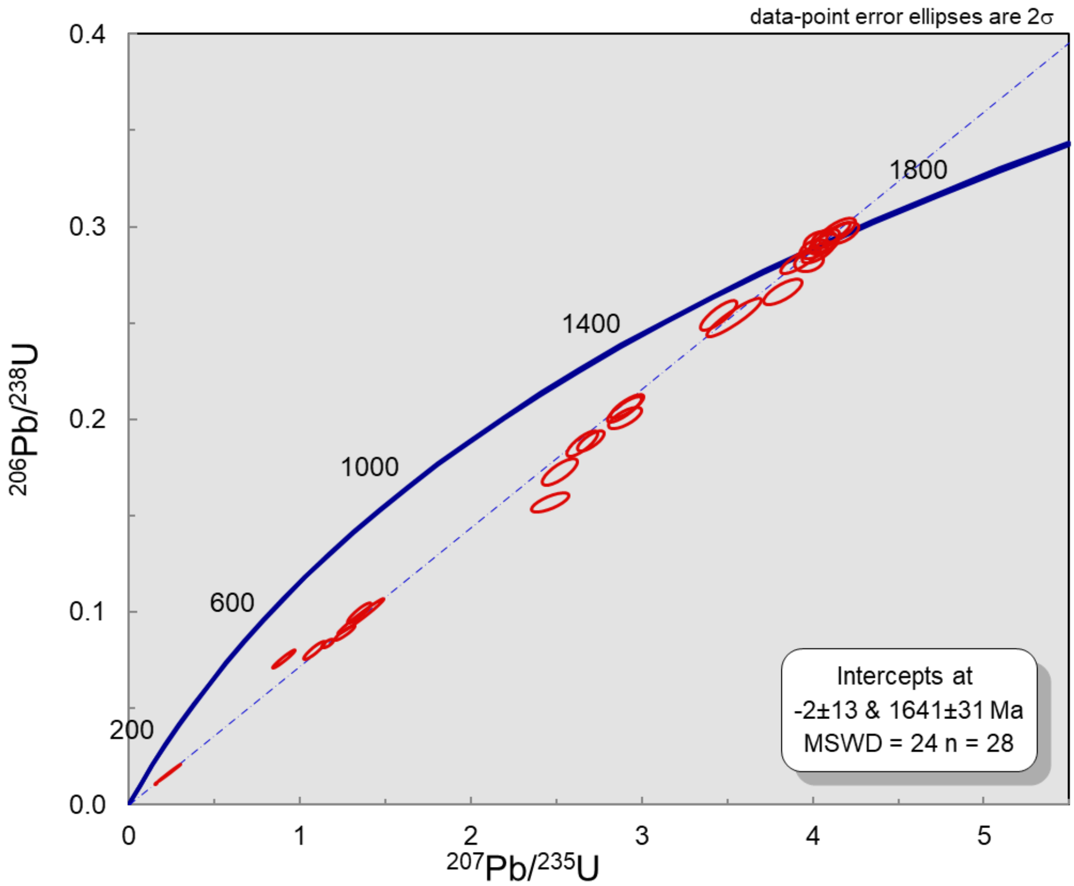


Figure 77: Wetherill diagram of all analyses for EX32136, showing concordant data and a long trend of Pb loss

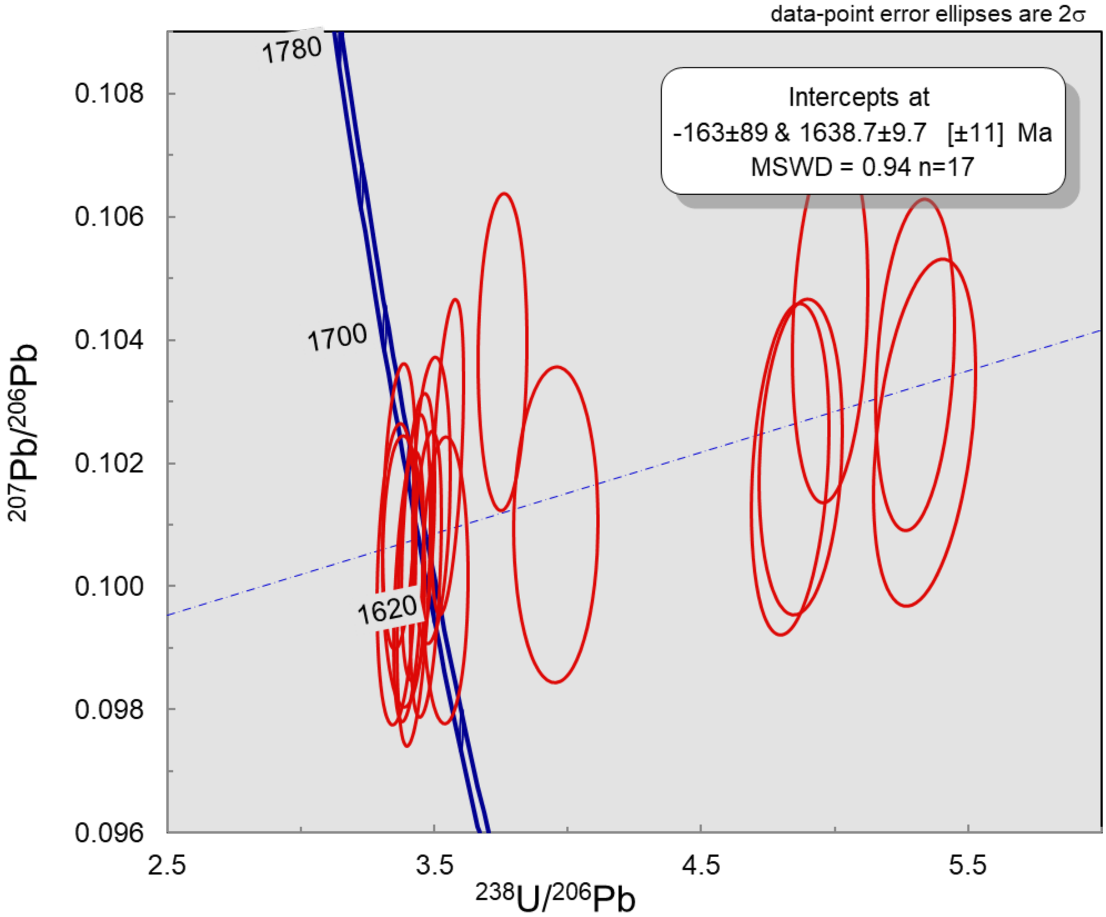


Figure 78: TW diagram of near concordant analyses from EX32136

3.4.2 EX096246

Lithology: medium to coarse grained calcite-biotite± amphibole rock within feldspathic rock. Contains xenoliths with biotite reaction rims, and forms vein/dyke like structures with alteration selvedges. Zircons visible in biotite due to pleochroic haloes. Otherwise looks like marble. This sample was analysed in June 2018. Analyses here represent grains not used in 2018

Run	Run1 26/06	Pb207-206 Age	
# Analyses	35	Concordia Age	1646.0±8.2
# Analyses integrated	34	Multiple populations?	

A mostly coherent population near the Concordia, with a bias towards negative. No huge outliers like that seen in the first round of analyses, A single concordant outlier exist with a U- Pb ages of 1590±16 and 1600±25. This outlier fits reasonably with the population of 4 outliers in the first run (June 2018).

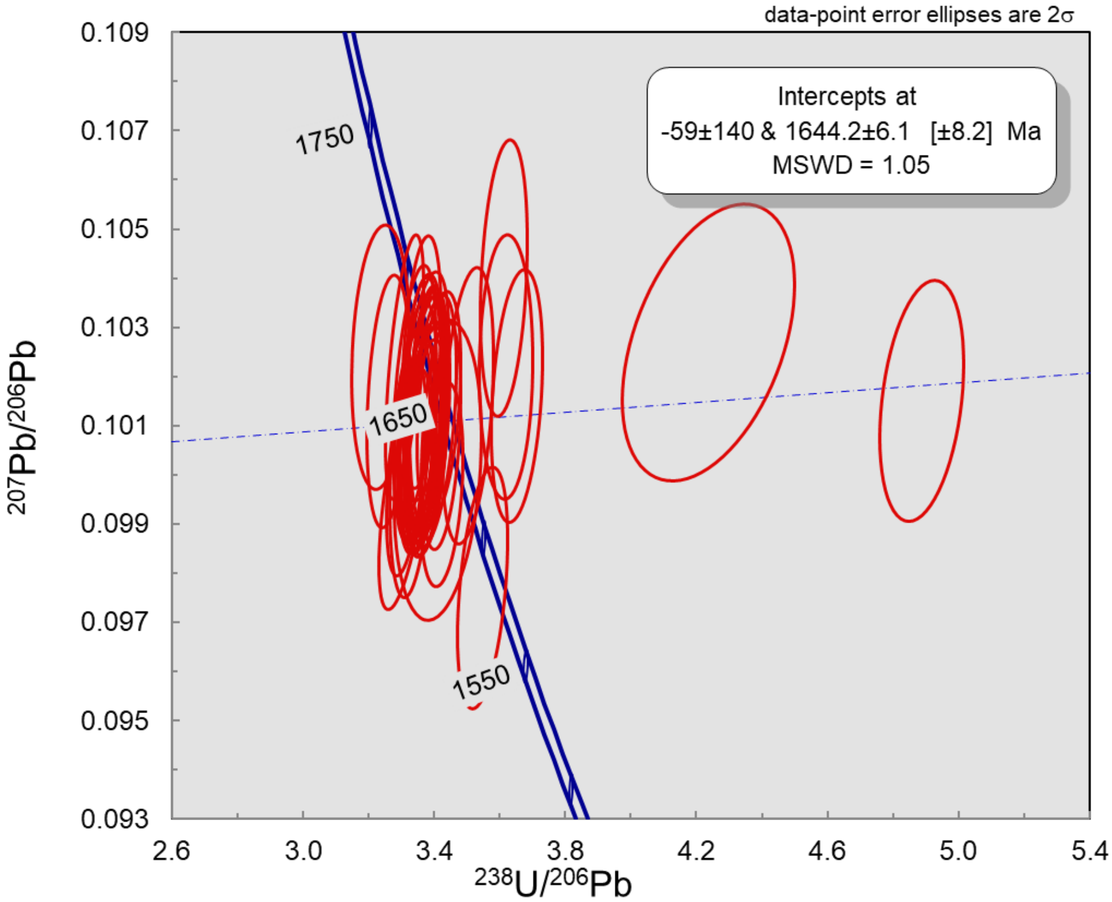


Figure 79: TW diagram of All analyses from EX096246 in the June 2019 dataset. One low concordant outlier can be seen, removing this yields an age of 1646±8.2 Ma

Run	Combined	Pb207-206 Age	
# Analyses	100	Concordia Age	1646.7±6.6 (n=76)
# Analyses integrated	97	Multiple populations?	1613±13 Ma (n=5)

Combining both datasets collected (June 2018, June 2019) yields a dataset with 76 near concordant ages resulting in 1646.7±6.6 Ma. This age is within error of the 3 Quartz Feldspar Porphyry samples. Given the carbonate intrudes the QFP, the interval has xenoliths of QFP, and the Zr assay for this interval is higher than in other examples of this unit, it is highly probable that this is inheritance. Interestingly, these zircons show much less evidence for Pb loss than the QFP samples.

The second population of 5 analyses yields a 1613±13Ma age with 2 concordant results.

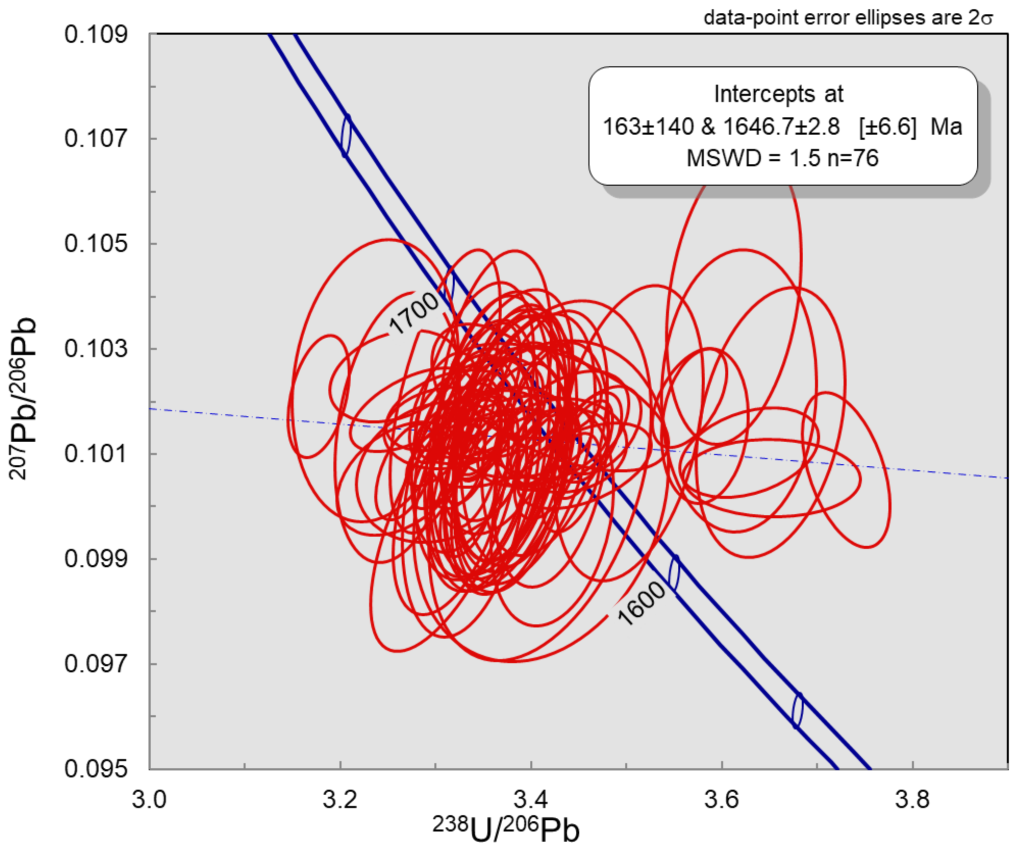


Figure 80: TW diagram of the main concordant population from all analyses of EX096246.

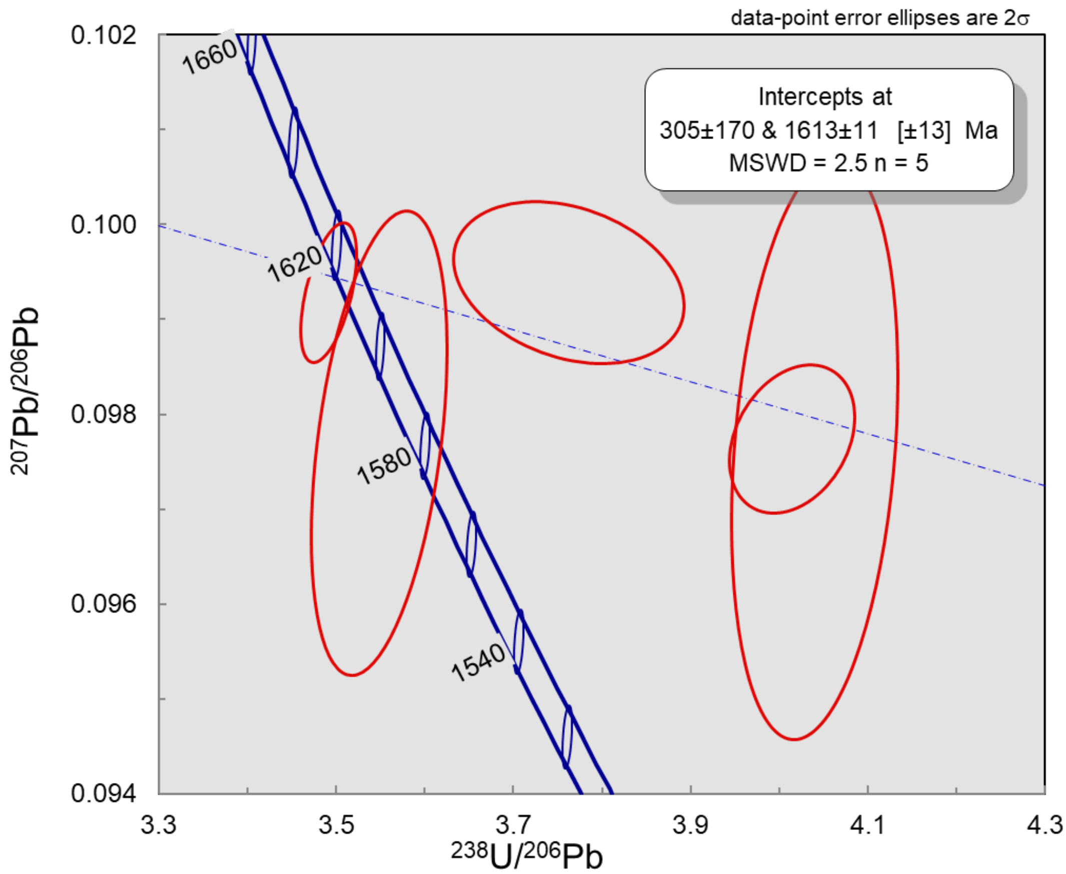


Figure 81: TW diagram of 5 outlier results from EX096246 that may form a population of younger zircons

3.4.3 EX096916

Lithology: Dark porphyritic rock thought to be volcanic just below base of graphitic schist.

Run	Run1 26/06	Pb207-206 Age	
# Analyses	31	Concordia Age	1616±12 Ma
# Analyses integrated	31	Multiple populations?	

This data shows a mainly concordant population with several outliers (some of these we noted as borderline at data reduction). The concordant population has a slight trend along the Concordia. With outliers removed, the remaining population (n=23) gives an age of 1615±12 Ma. This is very similar to an age determined by the GSQ for a very similar looking rock type in the Milo Basin to the south (1615±5 Ma). This age was interpreted to be volcanic deposition, partly due to its uniform zircon morphology, U/Th and single population. Field relationships and petrography are also consistent with this interpretation. EX096916 also has field relationships and petrography consistent with volcanic protolith, although a high level intrusive is also plausible. The U/Th is also consistent between grains, and is comparable to that of the GSQ sample. This age is also seen in sample EX096901, which is a mafic rock in stratiform bodies within the graphite schist (1617.8±10 Ma)

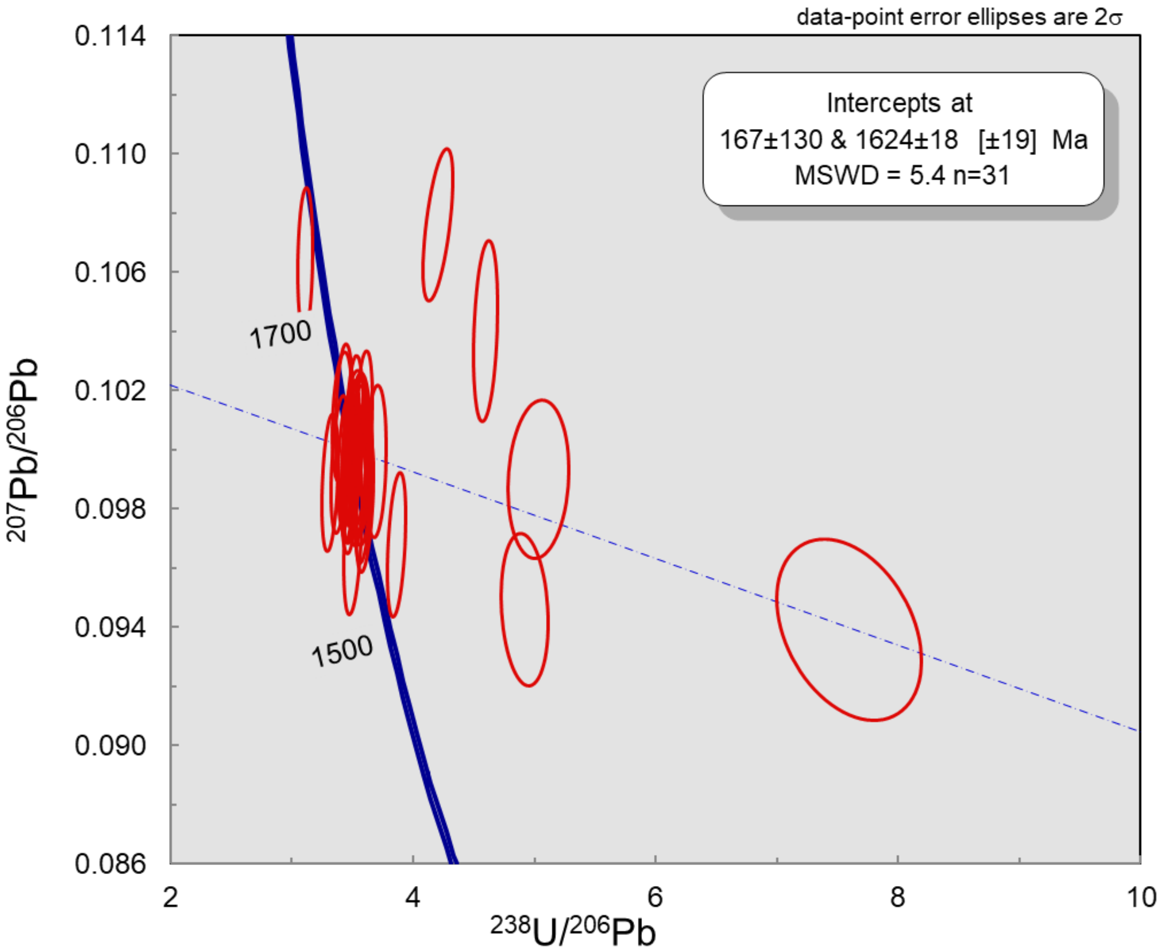


Figure 82: TW diagram of all analyses for EX096916

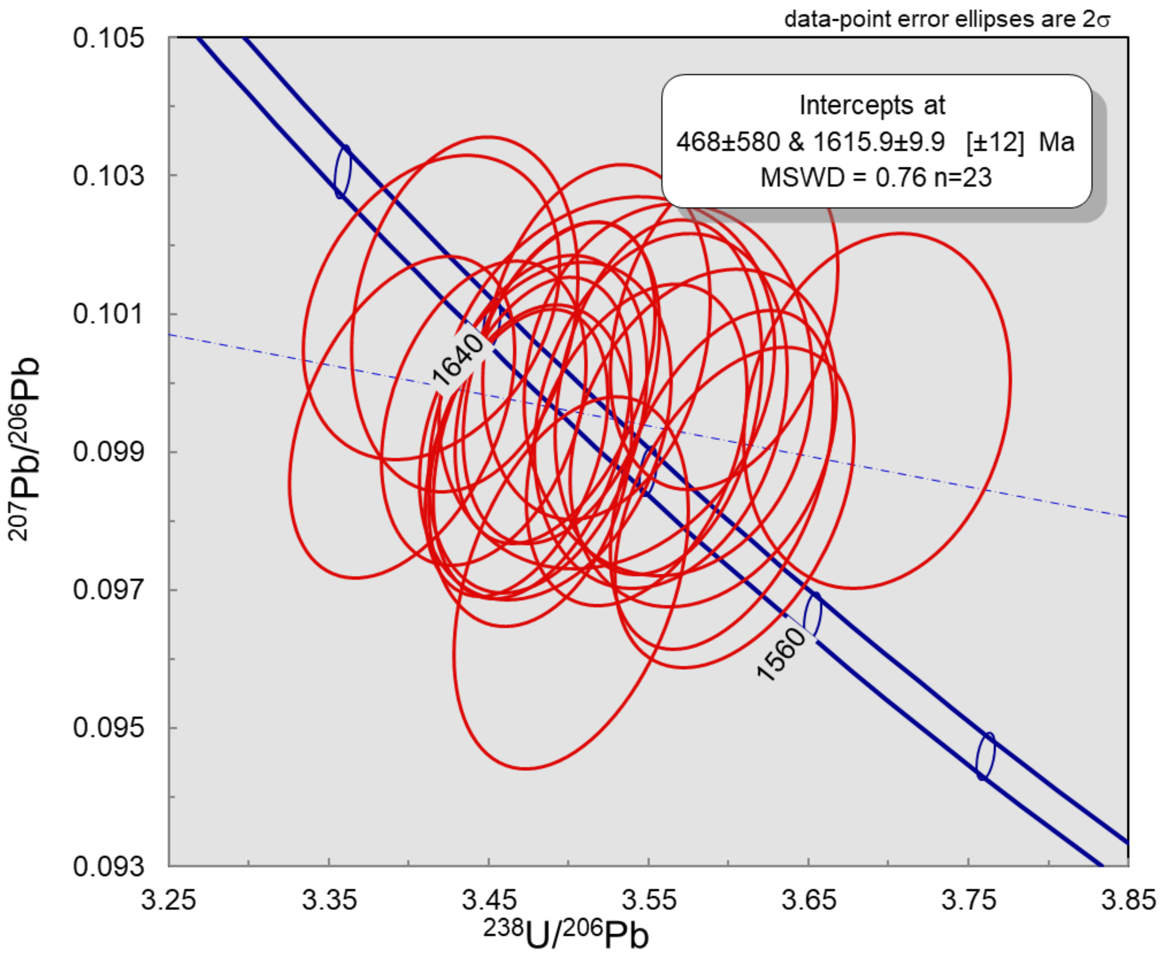


Figure 83: TW diagram for EX096916 with outliers removed.

3.4.4 EX096917

Lithology: Sandy muscovite schist adjacent to fine garnet bearing volcanic within graphitic schist package

Run	Run1 26/06	Pb207-206 Age	
# Analyses	55	Concordia Age	1639.6±11
# Analyses integrated	55	Multiple populations?	

This set of 55 analyses shows a main concordant population with a long trend of Pb loss, as well as 3 discordant outliers that may indicate rare older detrital material. Trimming out these outliers, and the samples with high Pb loss, yields an age of 1649.6±11 Ma. This is probably best interpreted as a maximum depositional age, although if this material is dominantly volcanic in origin it may represent a deposition age. The lack of substantial additional populations, and a coherent U/Th ratio, suggest the zircons are mostly from a single source. This age is also very similar to that of the QFP

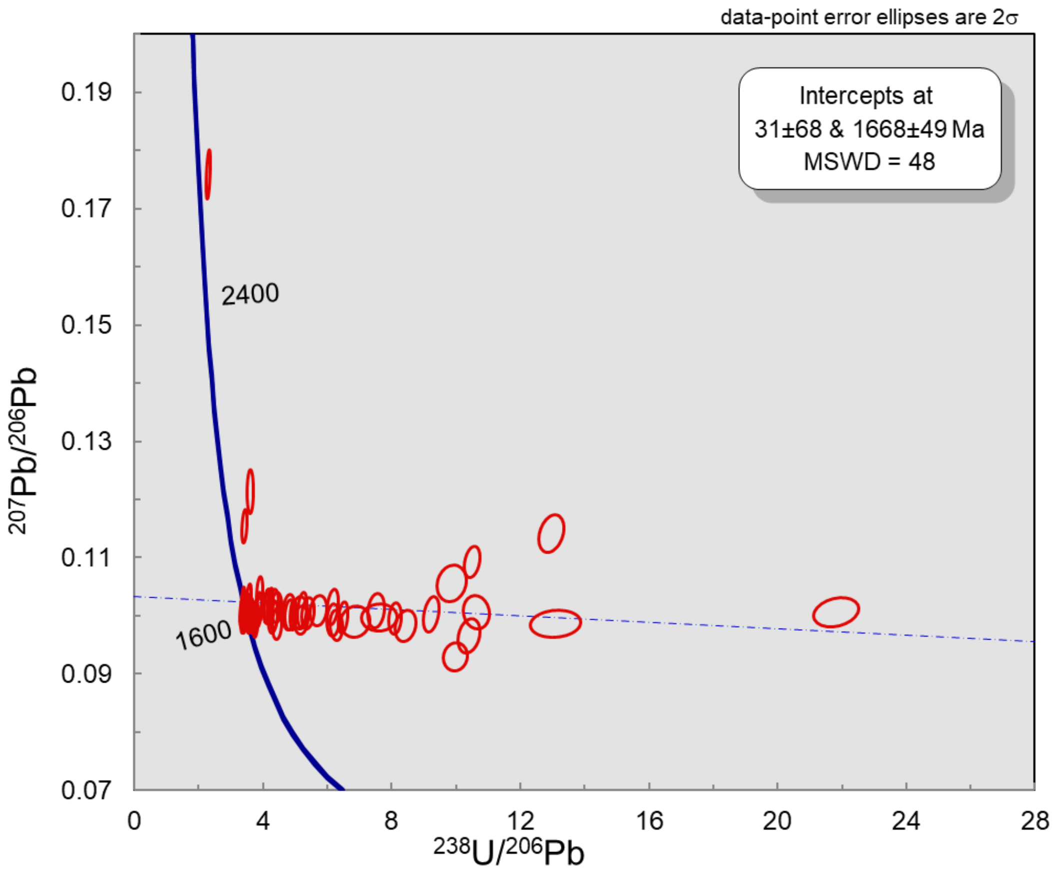


Figure 84: TW diagram of all analyses from EX096917 (n=55). One main population is visible with a long Pb loss trend. 3 discordant results lie outside this population, and may represent rare grains of detrital material

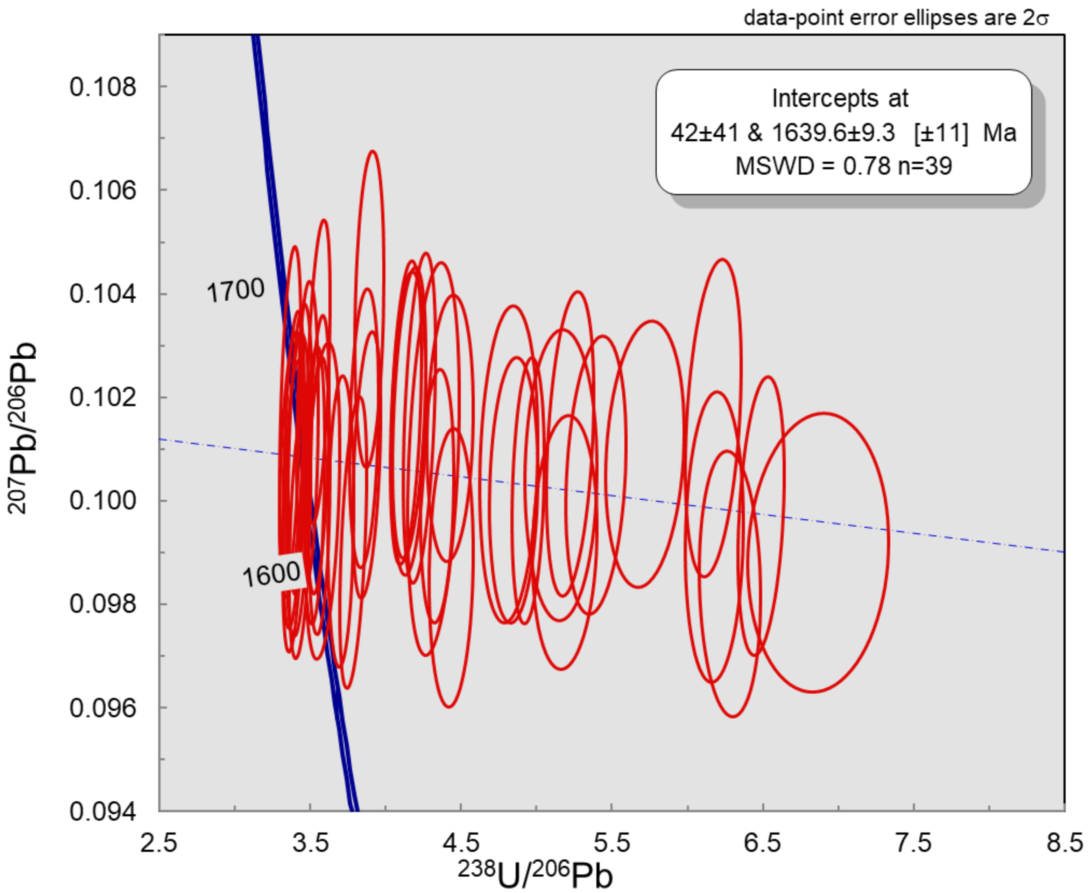


Figure 85: TW diagram for EX096917 with outliers and extreme Pb loss results removed. This gives a coherent population of concordant results and Pb loss trend, yielding an age of 1639.6±11Ma

3.4.5 EX096919

Lithology: Porphyritic schist with strong lineation/foliation. Protolith likely QFP or QP

Run	Run1 26/06	Pb207-206 Age	1610±8.3
# Analyses	48	Concordia Age	1615±13
# Analyses integrated	47	Multiple populations?	

This dataset forms a long Pb loss trend, without a dominant concordant population. Error and scatter increase with increasing 238U/206Pb. A trimmed set (n=22) with the high Pb loss analyses removed yields a Concordia intercept of 1615±14 Ma (lower intercept 6±55 Ma). There is no evidence of secondary/detrital populations. The sampled unit is adjacent to that of EX096250 (1612±15 Ma), and probably represents the same magmatic event. The foliation and muscovite development is likely associated with high strain associated with the nearby mylonite zone.

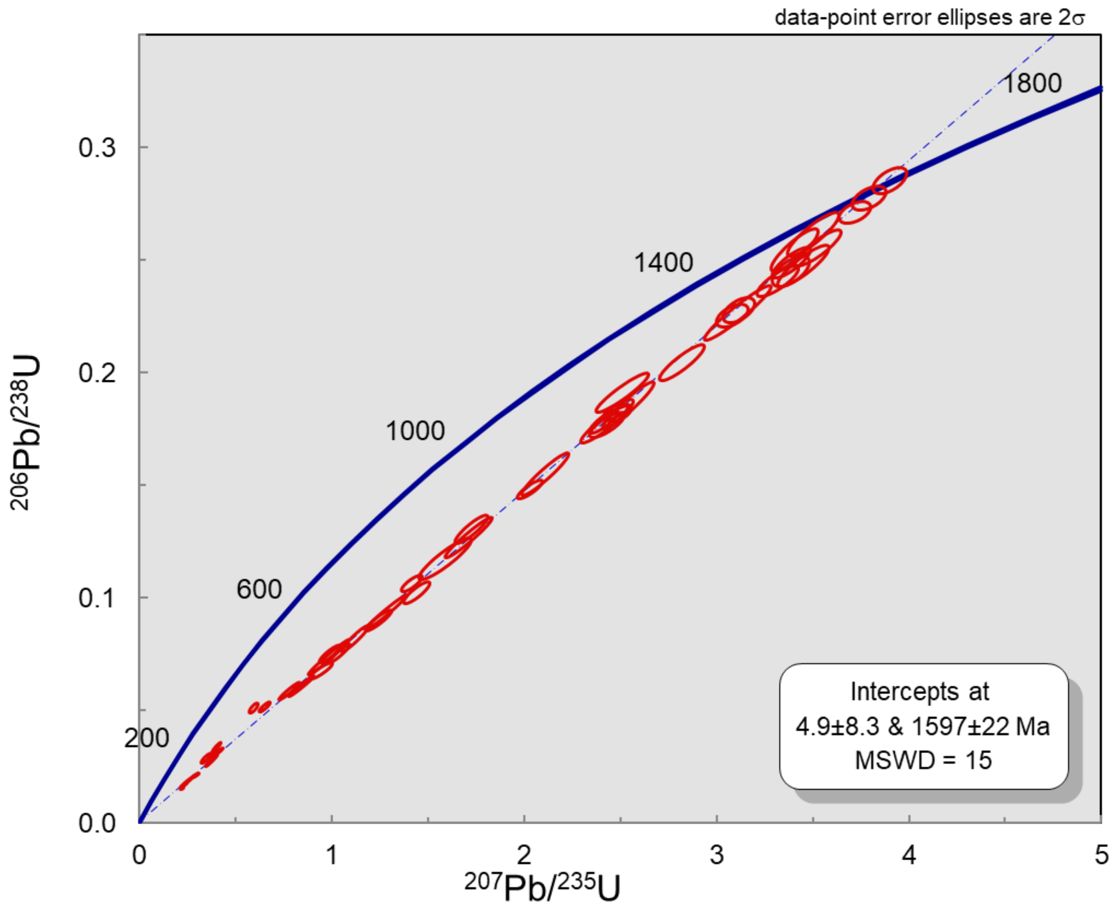


Figure 86: Wetherill diagram of EX096919 for all analyses. This shows a long lead loss trend

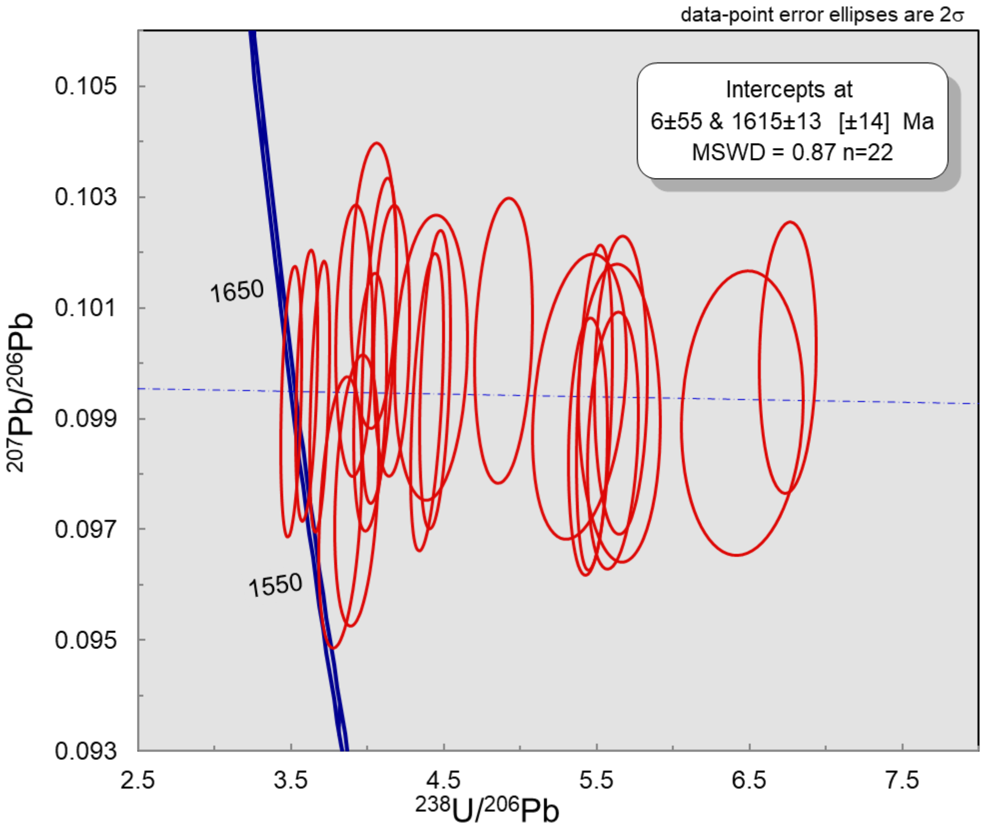


Figure 87: TW diagram of EX096919 with analyses showing extreme Pb loss removed.

4 Tommy Creek LA-ICPMS Zircon Geochronology, August 2019

4.1 Introduction

Laser Ablation ICPMS analysis at the Advanced Analytical Centre (AAC), James Cook University Townsville, was performed on resin mounted zircon separates from 9 samples, on the 13th and 15th August 2019.

The below table outlines the samples that were analysed. A map with their locations and results is in **Error! Reference source not found.**.

Sample ID	Sample Type	Lithology	Grains mounted	Analyses performed
EX096904	¼ Core	very coarse pegmatitic syenite. Amph-fd-bt-tit. Some late qtz	>60	60
EX096923	¼ Core	med coarse bt-amph marble with minor pyrite. Some shale interbeds/fragments	~10	11
EX096925	¼ Core	fine-med bt marble with pyx-amph pblasts	~60	63
EX096927	¼ Core	med carbonate-pyx-amph-spinel-mt rock, possible lamproite. A bit weathered/oxidised	~10	15
EX096928	¼ Core	fine-med bt marble with mottled appearance. Interesting reaction/bx on contacts below and above	~50	27
EX096929	¼ Core	coarse bt-cc-amph rock. Bt reaction rims on contact, some amph	~40	49
EX096930	¼ Core	Fine bt-amph carbonate rock. Xenoliths with reaction rims, but not in sampled interval	~25	26
EX096931	¼ Core	Fine-med bt marble with shaley interbeds and fragments	>50	60
EX096932	¼ Core	Vein Bt-cc rock +amph. Reactions on contact	~15	47

Table 4: Table of samples with zircons analysed. Polished thins section taken from drill core. ¼ core is material taken directly from drill core by the author

4.2 Methods

Samples were prepared in the Mineral Separation Laboratory at JCU. Samples were crushed using a hydraulic splitter and pulverized with a disc mill.

Pulverised material was sieved into 3 fractions: >500µm, 500µm< x >250µm, and <250µm.

Pulverised material was then treated on a shaker table to remove slimes and concentrate heavy minerals. In general, samples were recycled 2-4 times (mid and heavy fractions), and different sieved fractions were treated separately

The heavy fractions from the shaker table were dried and then magnetic materials were removed using a hand magnet and Frantz isodynamic separator machine with maximum working current of 1.4 amps.

The least magnetic fraction was then treated with hot LST (Lithium polytungstate) density separation.

Target minerals were picked from the heavy fraction and mounted in a resin puck, which was ground and polished to a high finish.

Pucks were imaged with Cathode Luminescence and mineral identification checked with EDS on a Hitachi SU5000 SEM at the AAC.

U-Pb analyses were performed by coupled Laser Ablation and quadrupole Mass Spectroscopy (LA-ICPMS) in the AAC.

Zircon Standards GJ1 (calibration), FC1, Mud Tank and 91500 (check), as well as NIST610 glass. Two spots of each standard were analysed for after brackets of 10 unknowns for zircon standards; NIST glass was analysed at the start, midpoint and end of each run.

The Laser was set to, 5Hz and 2.5J/cm^2, with 45s on time and 60s offtime between samples. Zircons were analysed using 30µm spot size, For zircon, the mass spectrometer was set to collect Pb 204, 206, 207, 208, Th 232, U 238, Ti49, Zr91, Si29 and Hg200, as well as Y89, Ce 140, Hf179 on short dwell times.

Data was reduced using iolite software package, with signal integration periods chosen by quality of the Pb 207:206 signal. Data processing and visualization used Isoplot 4.15 add in for excel and ioGAS.

4.3 QAQC

Standard	**Expected Age (Ma)**	**Uncertainty (2σ)**	**Pb-Pb**	**U238 Pb206**	**Concordia Age**
GJ1	608.5	±0.4			
FC1	1099	±0.6			
91500	1065		1029±11		1062±3
Mud Tank	732	±5			728.9±4.7

4.3.1 GJ1

The GJ1 standard was used as the calibration standard for zircon, with a total of 88 analyses

4.3.2 FC1

FC1 was used as a check standard for zircon on the 15th August, with a total of 20 analyses. The performance of this standard was low, and some analyses were not even zircon. It is thought that the puck used is of low quality, with very small fragments and non zircon fragments

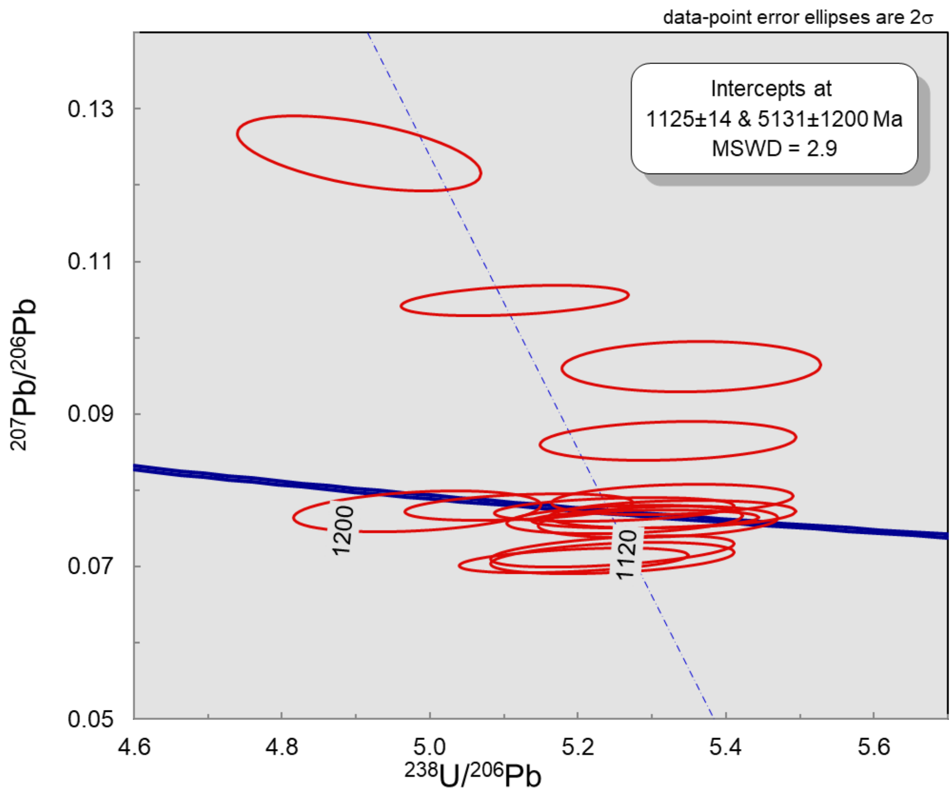


Figure 88: TW diagram for check standard FC1. Some analyses were not able to be processed sensibly or were not zircon, and have been removed

4.3.3 91500

91500 was used as a check standard for zircon, with a total of 89 analyses. For the run on August 13th the results are generally good, with only 1 marginally discordant result, yielding an age within error of expected (1062±3 Ma). The Pb Pb age is significantly low, at 1029±11 Ma. Performance on the 15th with 15 analyses was not as good, but still acceptable with a result of 1072±6 Ma.

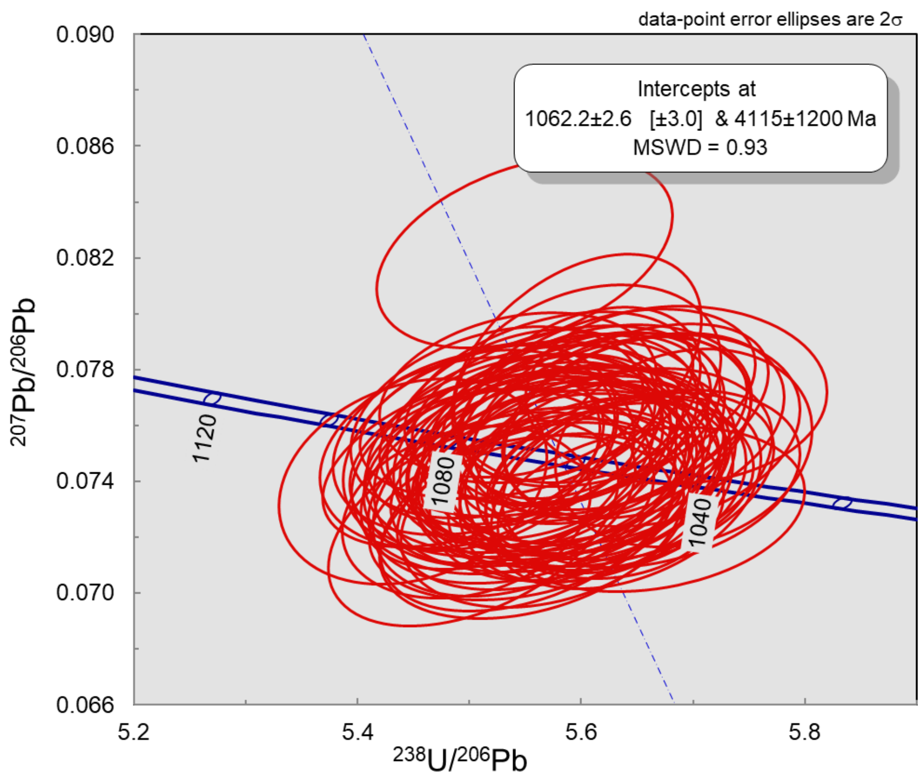


Figure 89: TW diagram for check standard 91500

4.3.4 Mud Tank

Mud Tank was used as a check standard for zircon, with a total of 36 analyses, on August 13th run (it was intended that FC1 be used, but the puck was misidentified in the sample holder). The results are good, with one discordant result, yielding an age within error of expected (728±4.8 Ma). The Pb Pb age is significantly low, at 631±49 Ma.

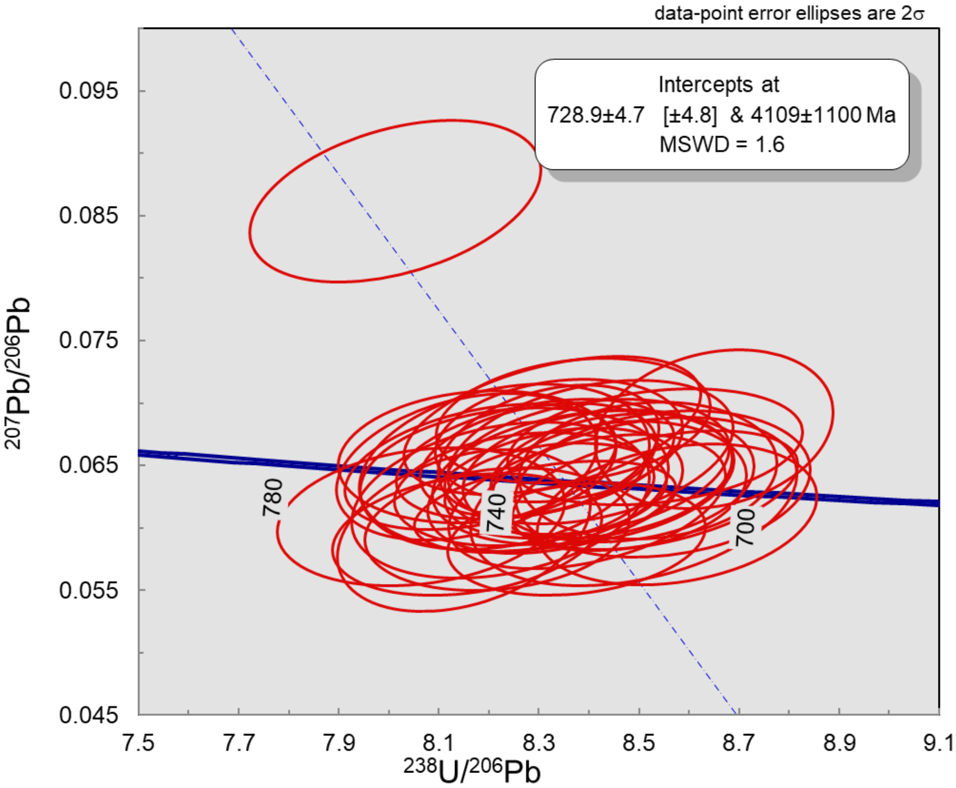


Figure 90: TW plot of standard Mud Tank

4.4 Results

4.4.1 EX096904

Lithology: very coarse pegmatitic syenite. Amph-fd-bt-tit. Some late qtz

Run	Run1 130819	Pb207-206 Age	
# Analyses	60	Concordia Age	
# Analyses integrated	53	Multiple populations?	1616±21, 1725±15, 1822±22

This is a second attempt at analyzing zircons from this sample. Like the first, the data is quite erratic and scattered although there was no extreme reverse discordance. Concordant results are spread between 1550 and 2700 Ma.

The data from this batch was combined with that from nov 2018 to form a single dataset of 94 analyses. An attempt to pull apart trend in the main data cluster (n=56) was attempted, with 3 possible Pb loss trends identified. These populations yielded ages of 1822±22 Ma, 1725±15 Ma and 1616±21 Ma. A further 9 concordant results are not part of these populations with ages of ~1900-2700 Ma.

It is difficult to interpret what this dataset means. The spread of concordant ages suggest some form of inheritance is likely. The textural, geochemical, and field relationships of this lithology are indicative of an intrusive rock, which the youngest population of zircons is consistent with. The 1616 Ma age is seen in several other intrusive (felsic) phases in the area. The ~1725 Ma age is also one that is commonly seen in samples from the area, usually as part of a multi population dataset.

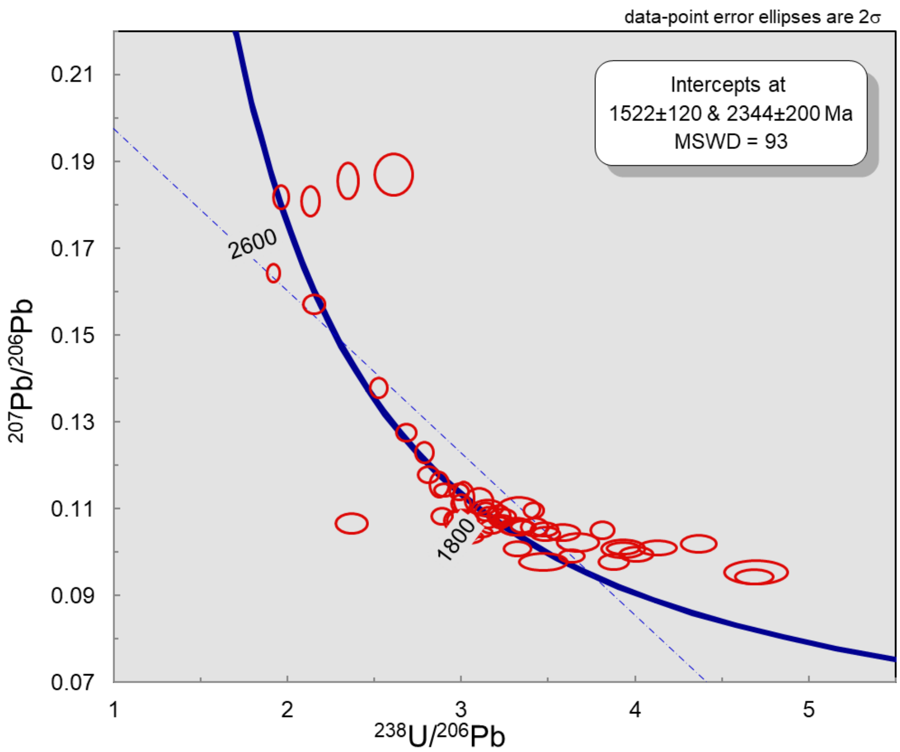


Figure 91: TW diagram of all analyses for EX096904 from this run of analyses

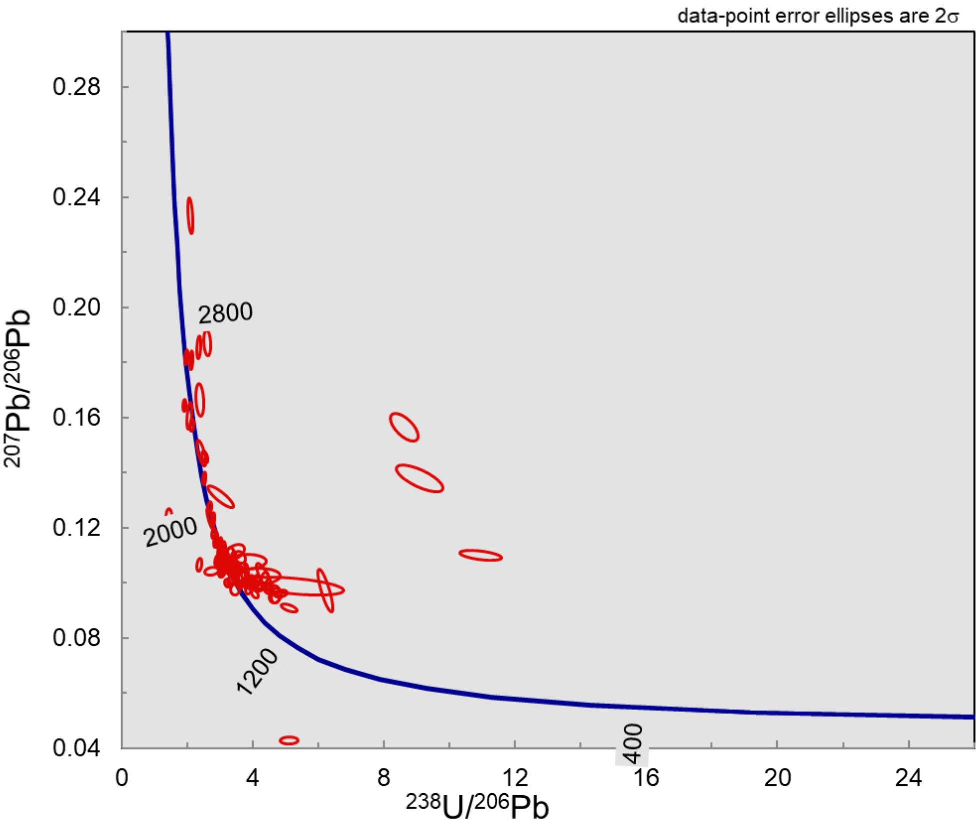


Figure 92: TW diagram the combined EX096904 dataset. Some extremely low Pb-Pb samples plot below the Concordia and are not visible.

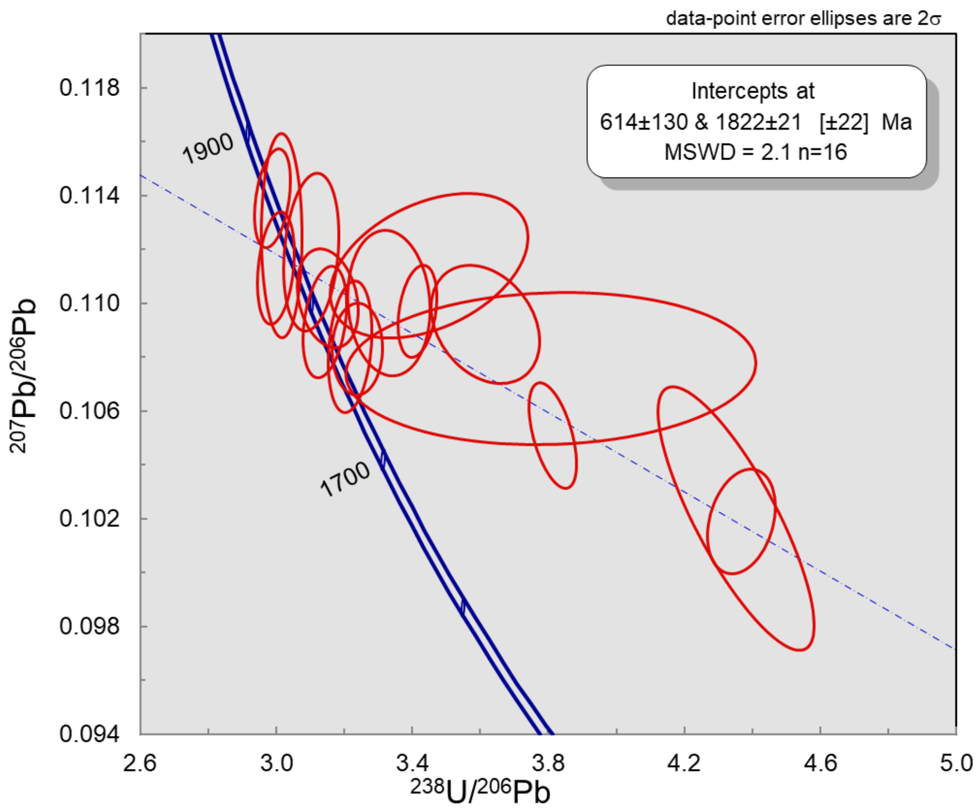


Figure 93: TW diagram of population A from EX096904

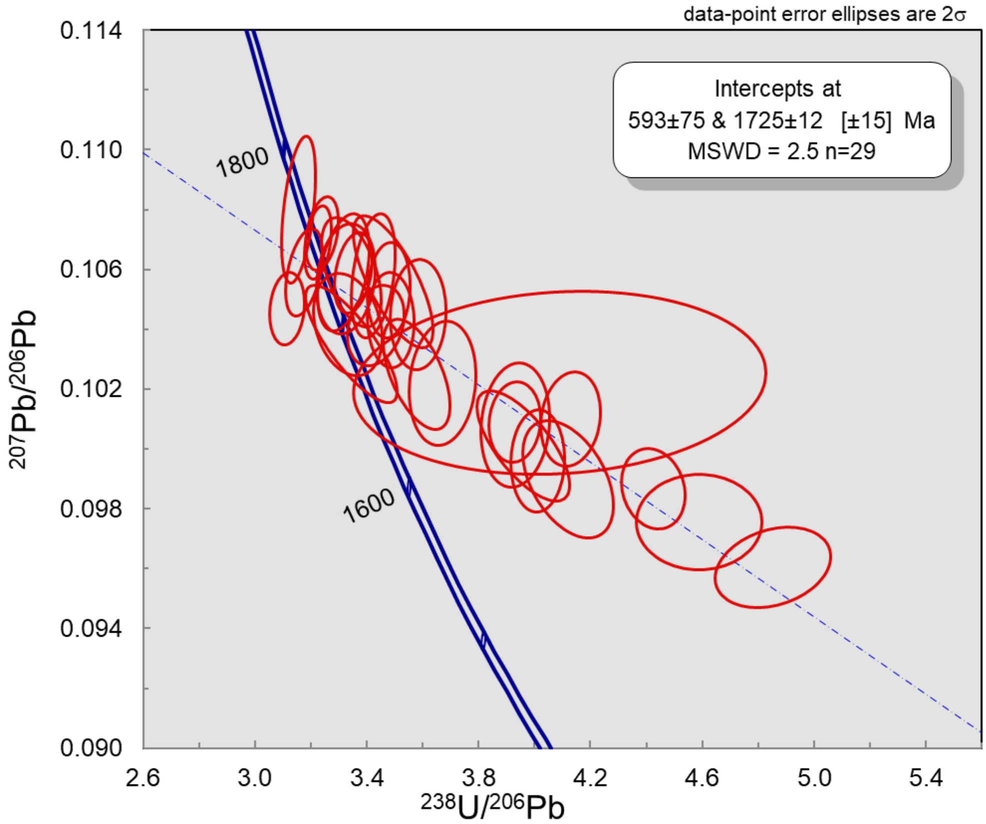


Figure 94:TW diagram of population B from EX096904

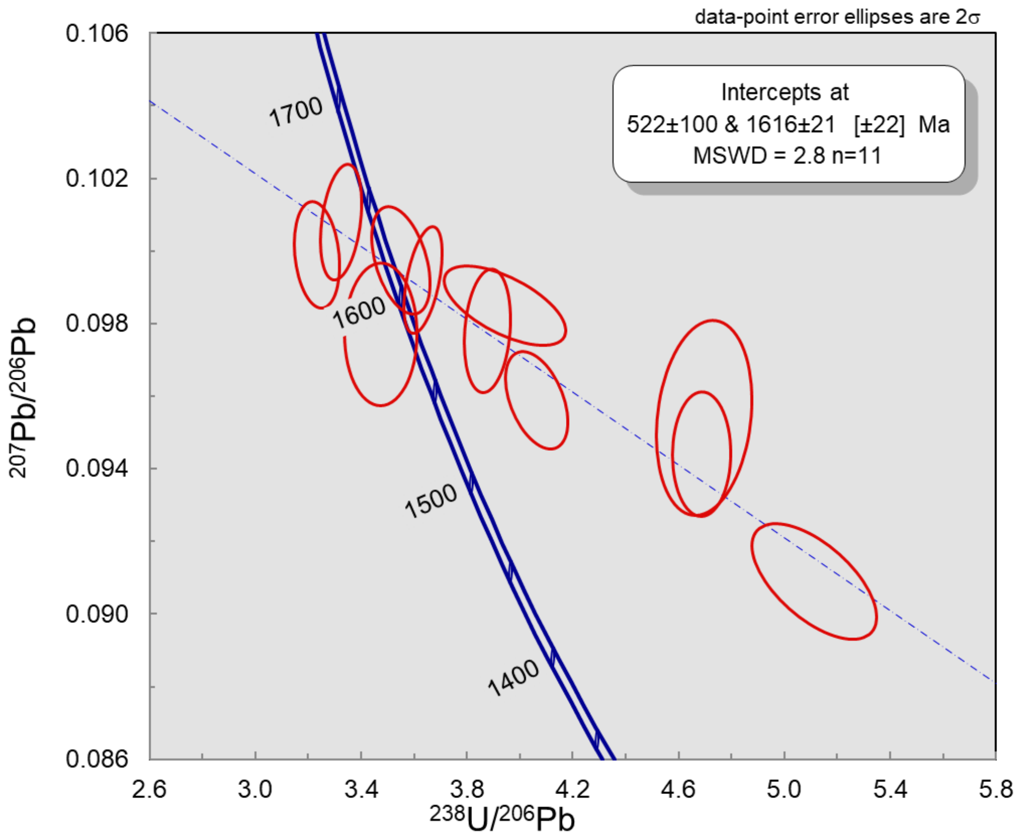


Figure 95: TW of population C from EX096904

4.4.2 EX096923

Lithology: med coarse bt-amph marble with minor pyrite. Some shale interbeds/fragments

Run	Run2 150819	Pb207-206 Age	
# Analyses	11	Concordia Age	
# Analyses integrated	9	Multiple populations?	

The results from this sample show a high degree of scatter, although most are/near concordant. The limited number of grains identified do not allow a meaningful density spectra, however there is a suggestion that there are multiple populations consistent with a sedimentary origin

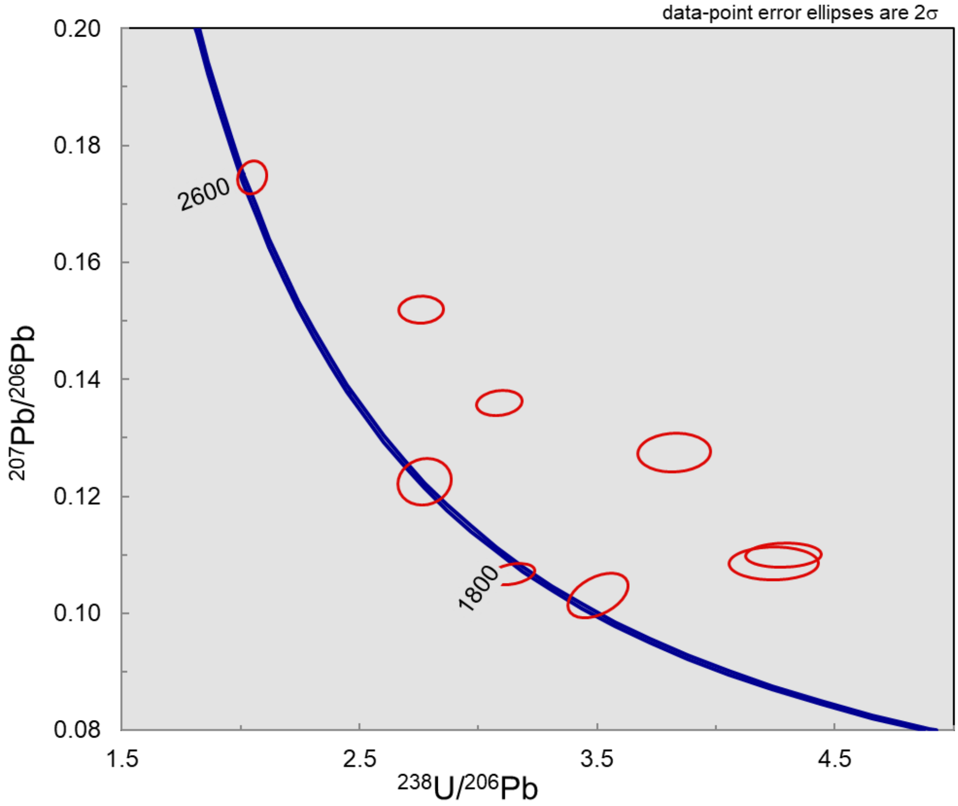


Figure 96: TW diagram of all analyses of EX096923.

4.4.3 EX096925

Lithology: fine-med bt marble with pyx-amph pblasts

Run	Run1 130819	Pb207-206 Age	
# Analyses	63	Concordia Age	1647.4±11
# Analyses integrated	62	Multiple populations?	

EX096925 shows a single population of mostly concordant results. Some reverse discordance is also evident. The 48 concordant results yeild an age of 1647.4±11 Ma, which is essentially identical to that including the discordant results (1646.4±11 Ma).

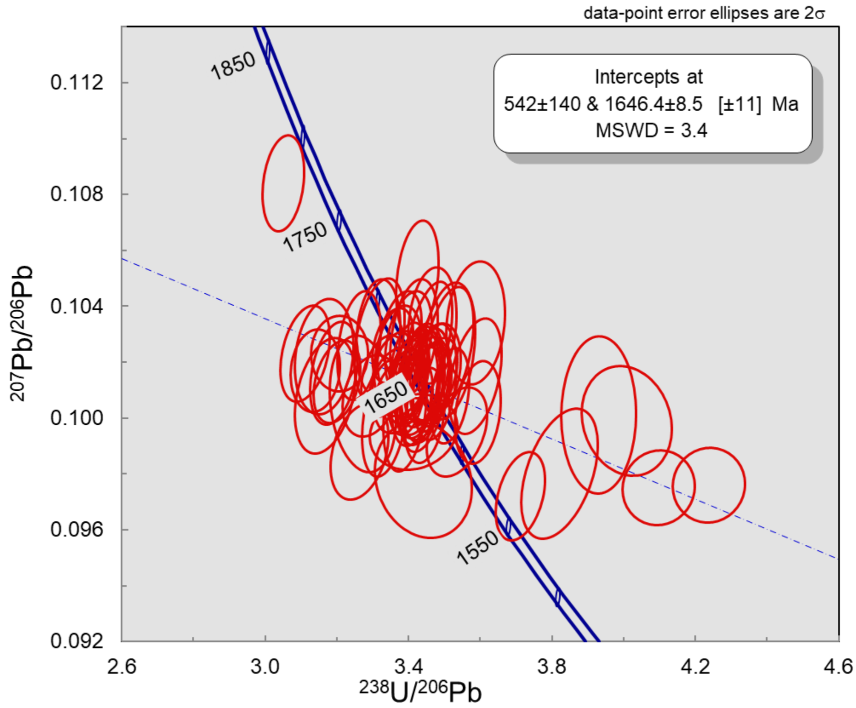


Figure 97: TW diagram of all analyses for EX096925

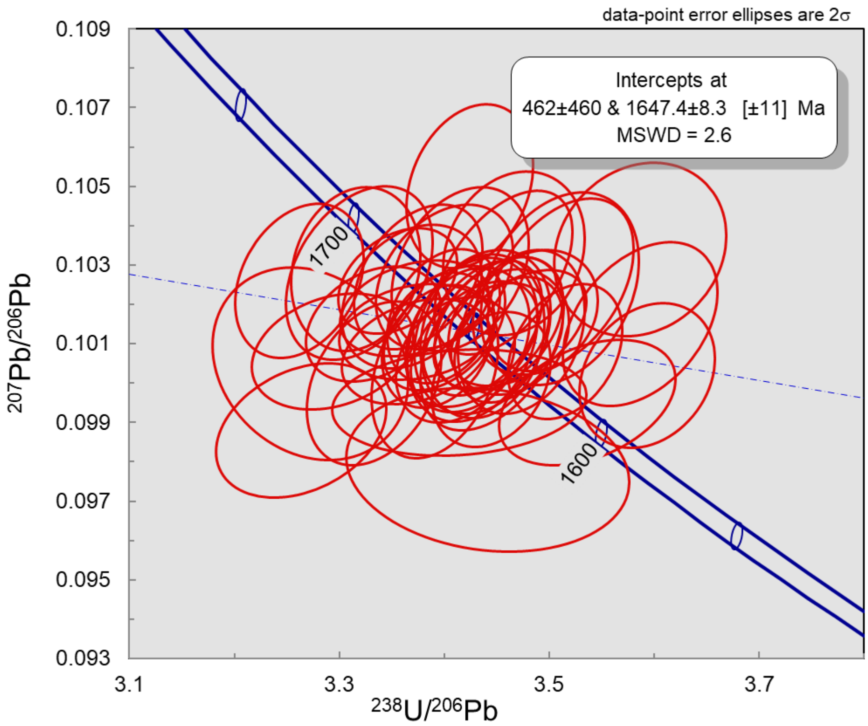


Figure 98: TW diagram for EX096925 showing only the main concordant results. n=48

4.4.4 EX096927

Lithology: med carbonate-pyx-amph-spinel-mt rock, possible lamproite. A bit weathered/oxidised

Run	Run2 150819	Pb207-206 Age	
# Analyses	15	Concordia Age	1722±75 (poor)
# Analyses integrated	14	Multiple populations?	

The data for EX096927 has a high degree of scatter and apparent Pb loss. Removing the extremely discordant results yields a very rough Concordia age of 1722±75 Ma. There is no tight cluster of concordant results to give this any sort of confidence

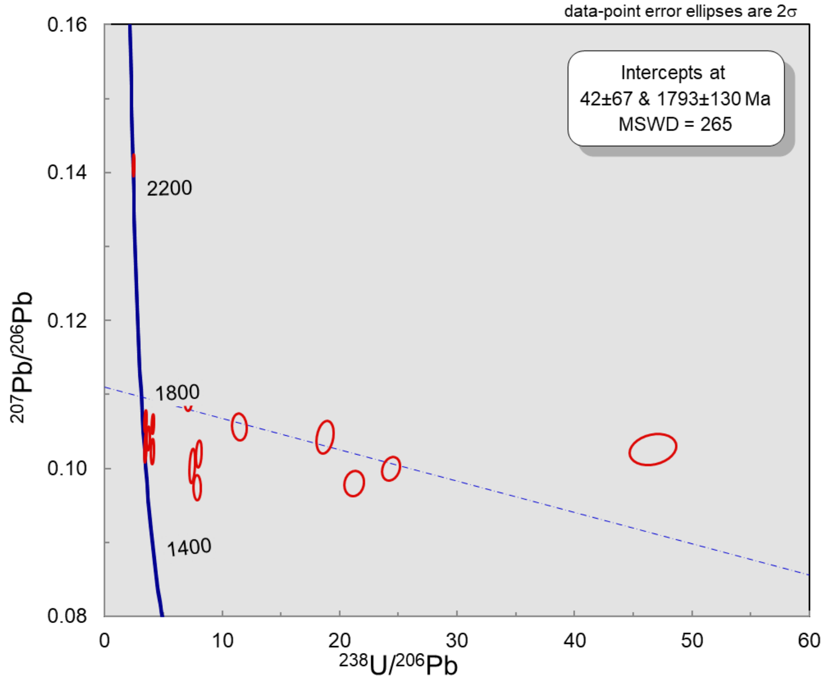


Figure 99: TW diagram of all analyses from EX096927

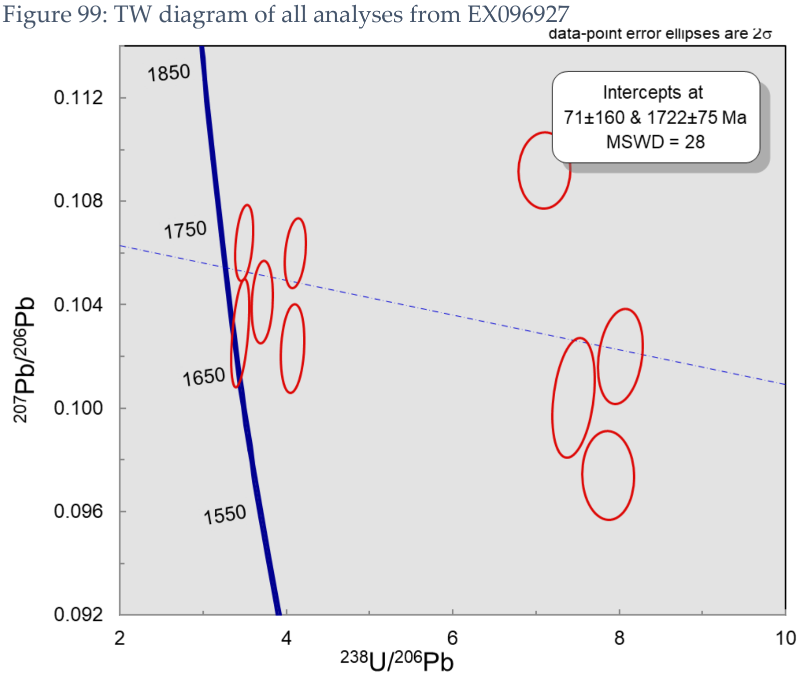


Figure 100: TW diagram of EX096927 with analyses showing extreme Pb loss removed.

4.4.5 EX096928

Lithology: fine-med bt marble with mottled appearance. Interesting reaction/bx on contacts below and above

Run	Run1 130819	Pb207-206 Age	
# Analyses	27	Concordia Age	1642±16 Ma
# Analyses integrated	27	Multiple populations?	

A main population of 22 concordant results is present, with 5 mostly discordant results that do not appear related to the main population. The concordant population yields and age of 1642±16 Ma

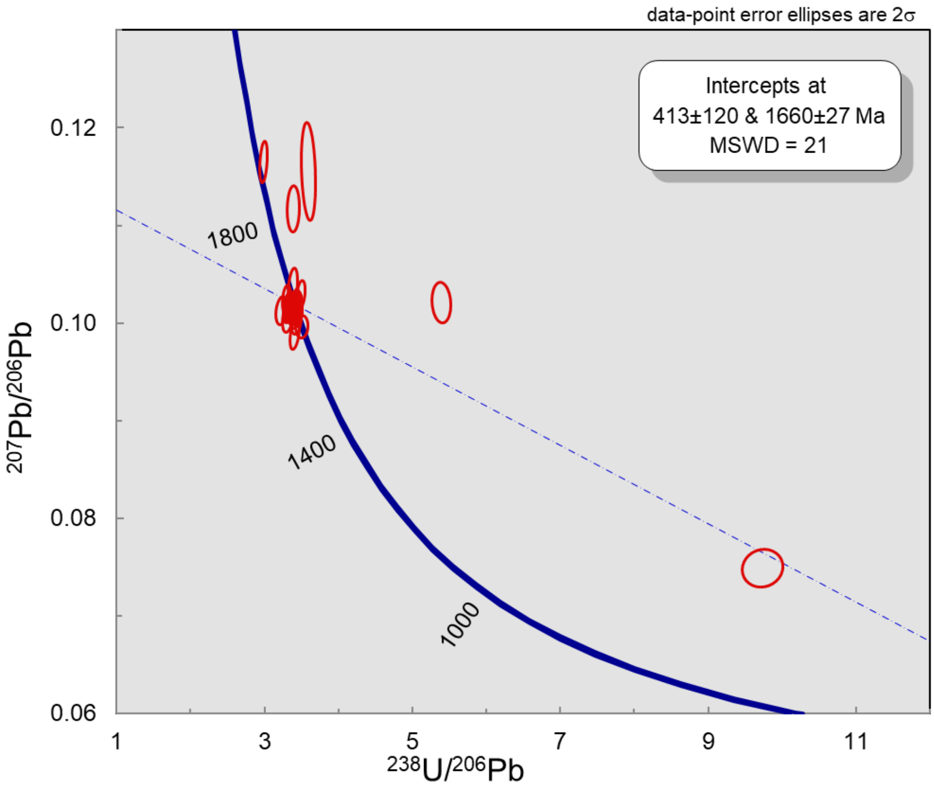


Figure 101: TW diagram of all analyses from EX096928 (n=27). One main population is visible. 5 discordant results lie outside this population, and do not appear related to the main population

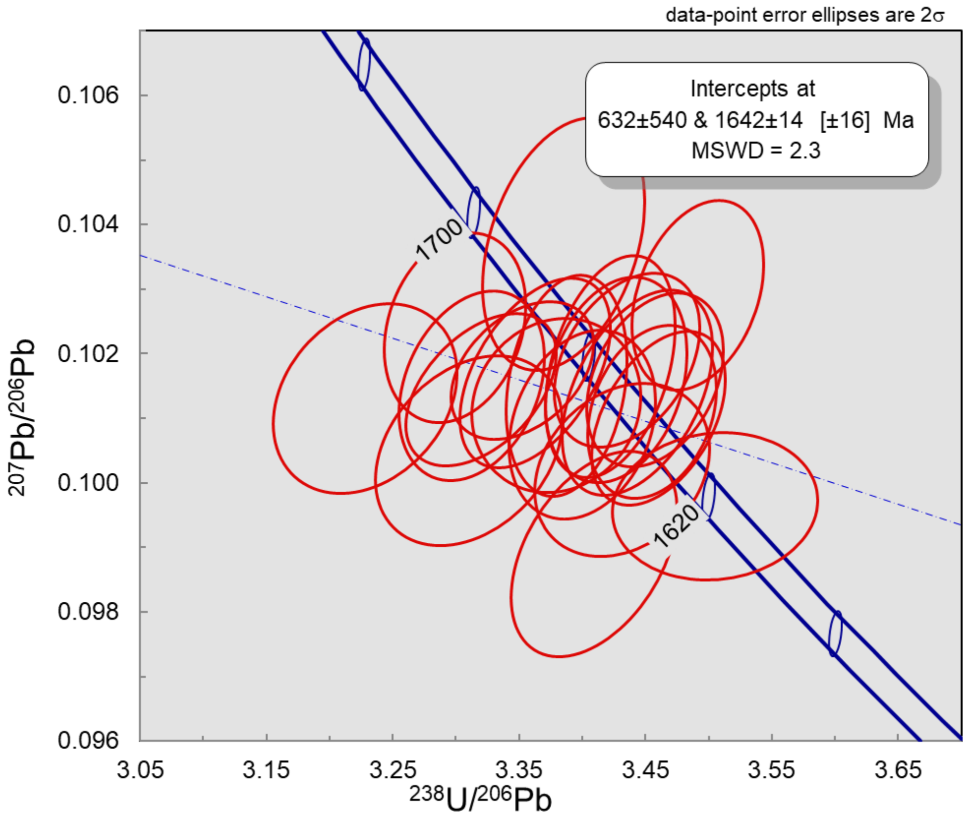


Figure 102: TW diagram for EX096928 showing the main concordant population (n=22), yielding an age of 1642±16 Ma

4.4.6 EX096929

Lithology: coarse bt-cc-amph rock. Bt reaction rims on contact, some amph

Run	Run1 130819	Pb207-206 Age	
# Analyses	49	Concordia Age	1655.3±9.4 Ma
# Analyses integrated	48	Multiple populations?	

EX096929 has a population of 38 concordant results, which yield an age of 1655.3±13 Ma. Two other clusters of discordant results are present, one of which is possibly from common Pb, plus a significantly discordant outlier result. The apparently younger grouping is interesting, but attempts fit a curve are very sensitive to the lower intercept. Using an intercept similar to those yielded in the concordant population suggest an age in the vicinity of 1600 Ma (1599±34), which is similar to the small population in EX096246. However, very little confidence can be placed on this interpretation

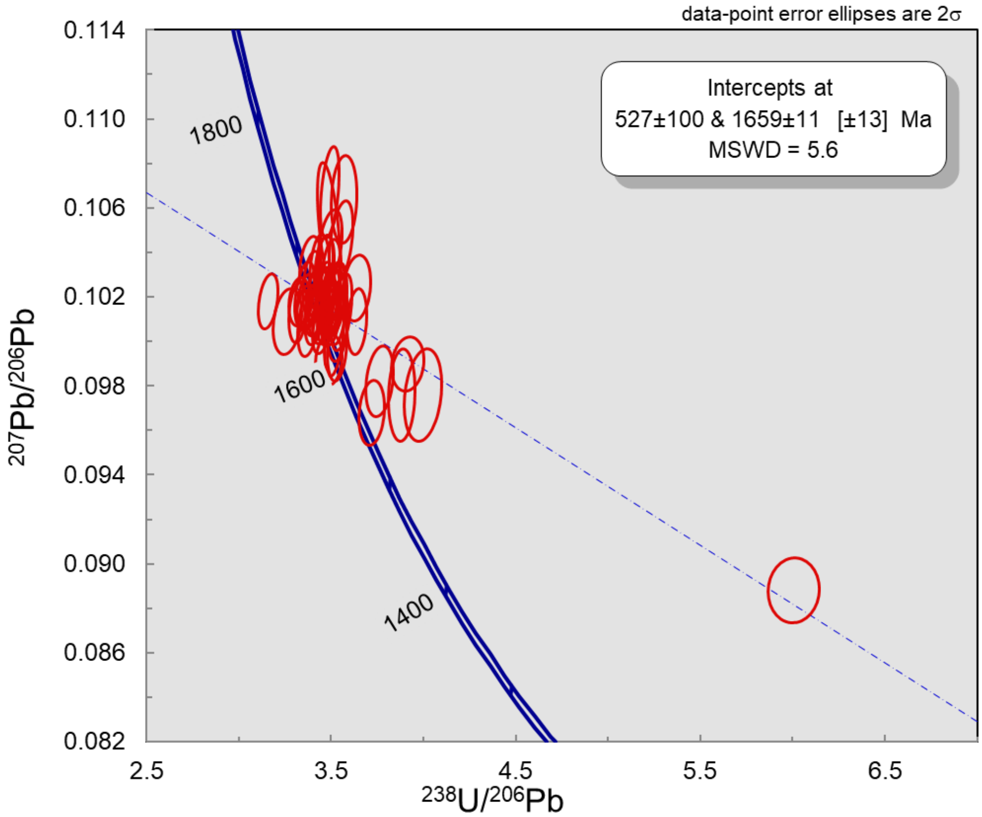


Figure 103: TW diagram showing all analyses for EX096929

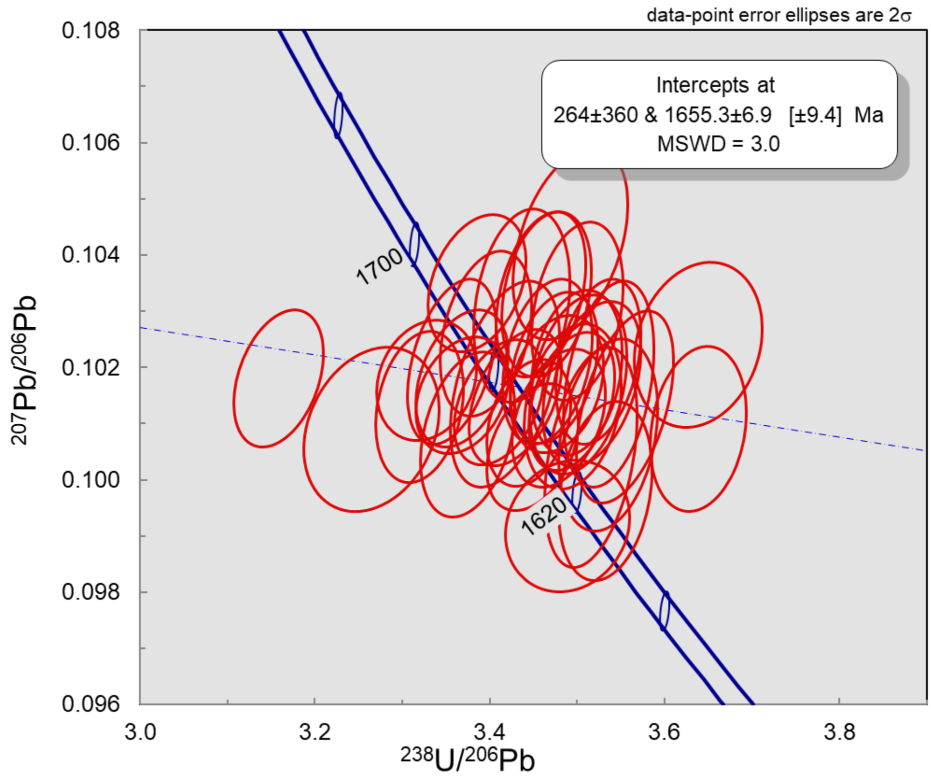


Figure 104: TW diagram of the main concordant population for EX096929

4.4.7 EX096930

Lithology: Fine bt-amph carbonate rock. Xenoliths with reaction rims, but not in sampled interval

Run	Run1 130819	Pb207-206 Age	1644.7±9 Ma 1728±39Ma
# Analyses	26	Concordia Age	
# Analyses integrated	25	Multiple populations?	

The interpretation of data from EX096930 is not clear, with a main population of largely reversely discordant results. Regression fitting of all those (only the outliers removed) yields an intercept age of 1635±45Ma. It seems reasonable that there are 2 populations, with Gaussian deconvolution of the Pb-Pb age suggesting 1649.7±7.3Ma and 1720.8±14Ma. The reverse discordance will influence these results. Further trimming out of discordant results yields two populations (n=9, n=4) with Pb-Pb ages of 1644.7±9 Ma and 1728±39 Ma

The two populations could be interpreted as either inheritance or sedimentary in origin. The host rock contains xenoliths of wall rock, pointing to a reasonable host for inheritance. The sedimentary origin may be problematic, as this sequence containing the 'marble' (as it would then be interpreted) is intruded by the ~1645Ma QFP

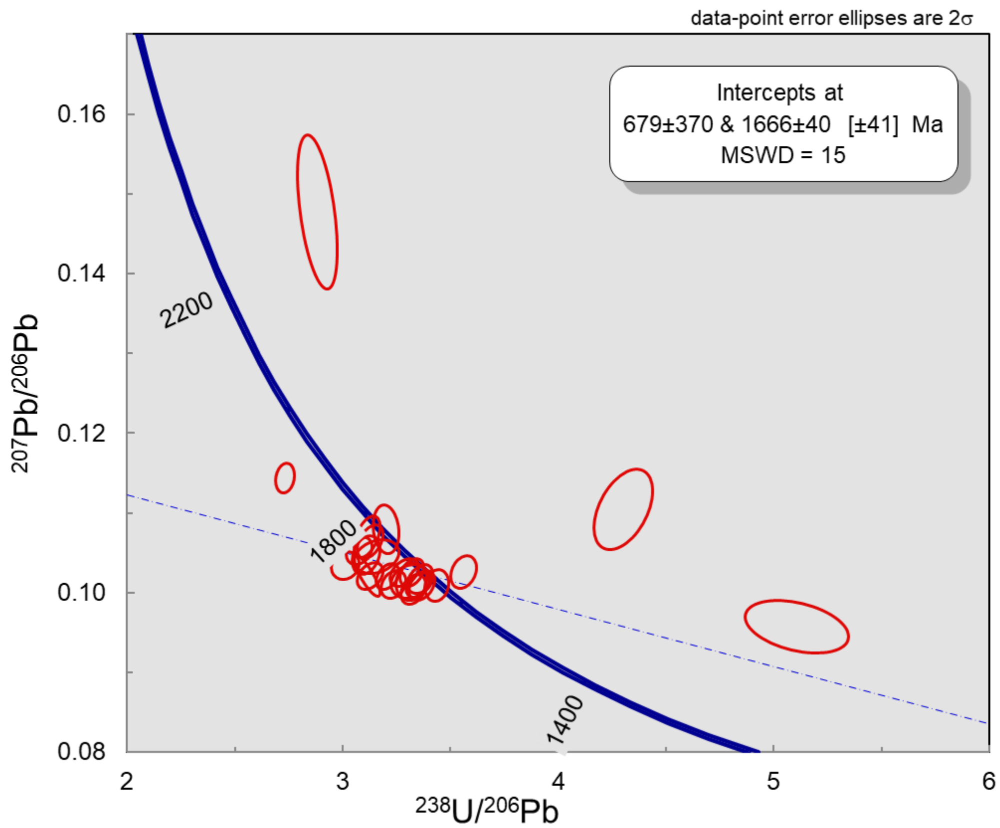


Figure 105: Tera Wasserburg diagram for all analyses from EX096930. The main cluster of data is reversely discordant. Four analyses are considered outliers.

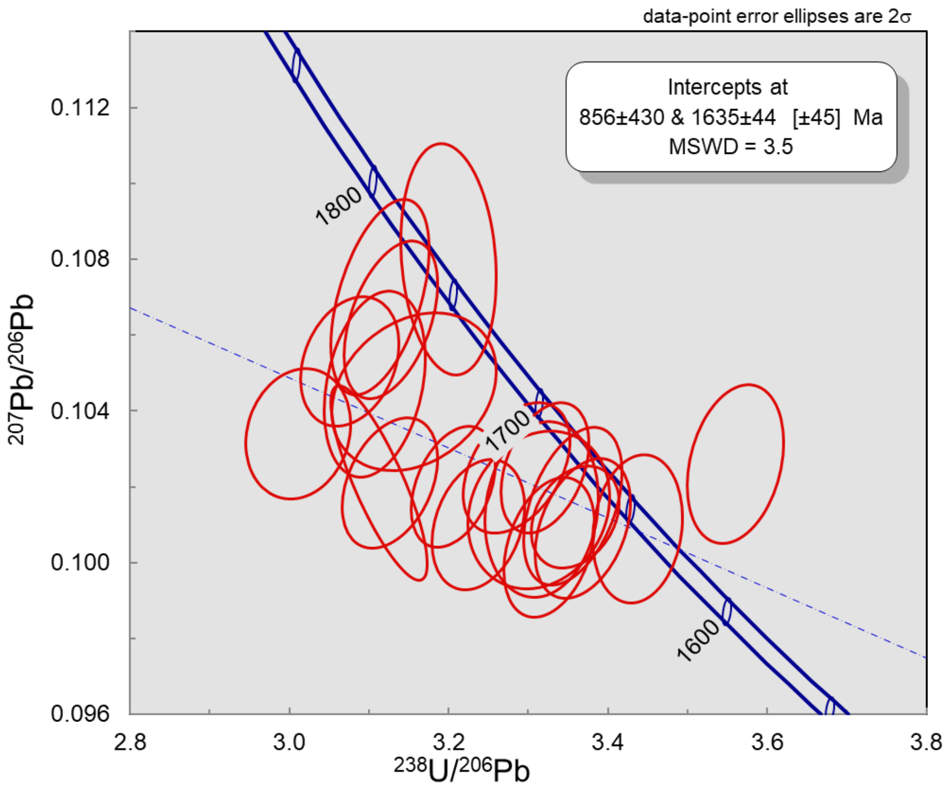


Figure 106: Tera Wasserburg diagram for EX096930 with outliers removed. Treating all as one population yields a concordia age of 1635±45Ma, however a 2-population interpretation may be more appropriate

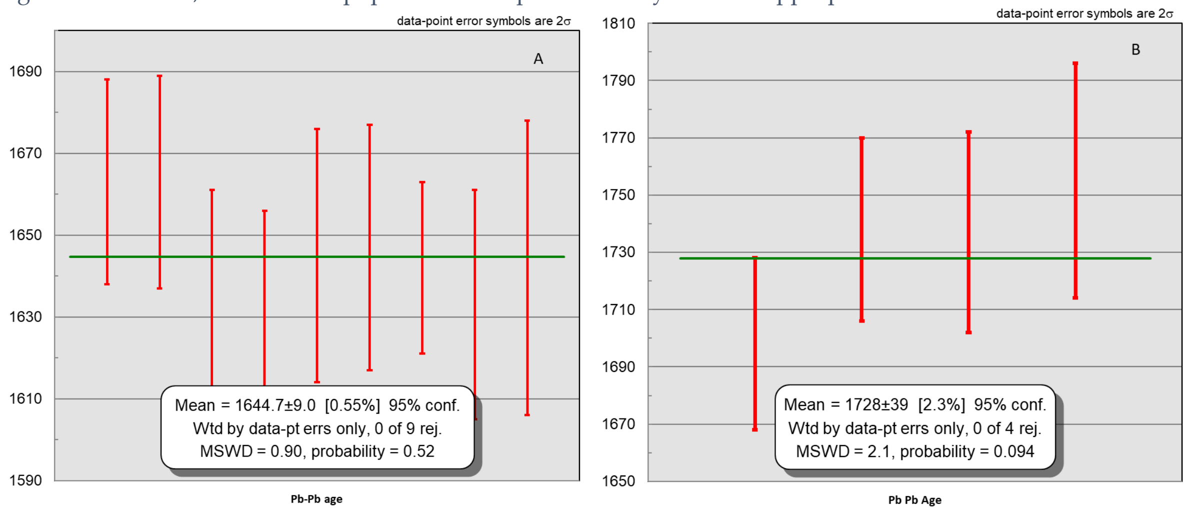


Figure 107: Pb-Pb age weighted average for two concordant populations.

4.4.8 EX096931

Lithology: Fine-med bt marble with shaley interbeds and fragments

Run	Run1 130819	Pb207-206 Age	
# Analyses	60	Concordia Age	
# Analyses integrated	60	Multiple populations? (Gaussian deconvolution)	1651.5±5.1 (A), 1720±21 (B), 1834-2012 Ma ,2631Ma (singletons)

The results for EX096931 appear to include multiple populations of concordant or near concordant analyses, with one outlier/extreme Pb loss. Gaussian deconvolution was done on the 52 concordant analyses, suggesting 4 populations at 1657.3±5, 1752.4±12, 1984±19 and 2631±25. The concordant data was also inspected in ioGAS using probability plots and histograms, with two main sub populations identified, plus the concordant singletons. Weighted average Pb-Pb ages for these subpopulations are 1651.5±5.1 Ma and 1720±21 Ma. The remaining concordant results plot between 1834-2012 Ma, and a result at 2630 Ma

These ages could be seen as consistent with sources of pre-Barramundi basement (singletons), Burstall/Corella (~1720 Ma). Population A is interesting, as this is an age that has been commonly occurring within study area. It is possible that is a shared source with the Lower Milo (Tommy) Beds (previously dated EX32127 1658±9Ma, however this is also within error of the interpreted intrusive ages of the QFP, and within error of the dominant ages represented in the other carbonate rocks of this sample batch.

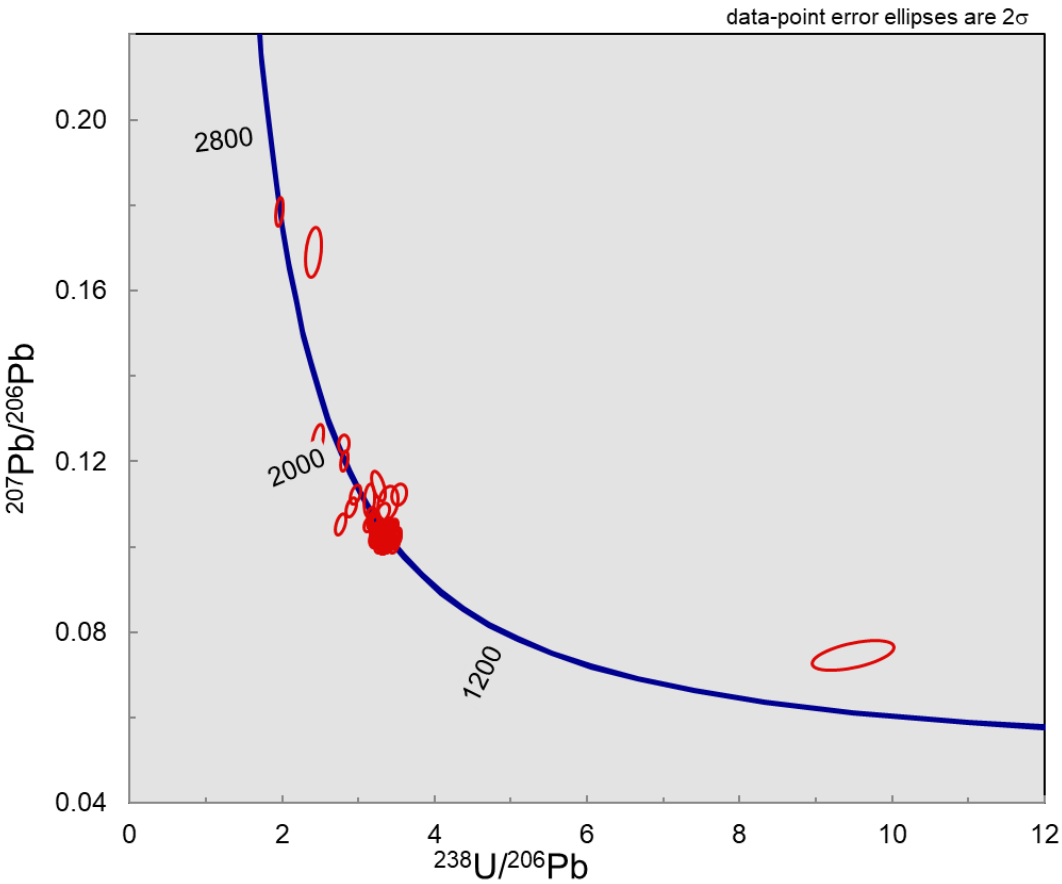


Figure 108: TW diagram for all analyses from EX096931. N = 60

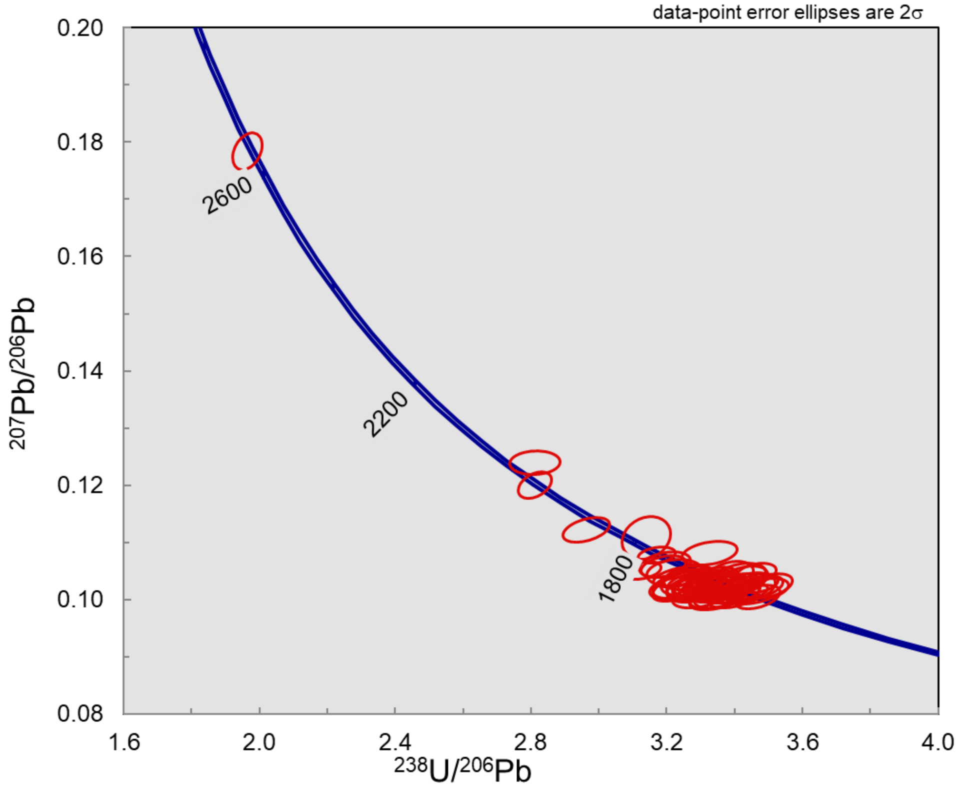


Figure 109: TW diagram of concordant results from EX096931. N=52

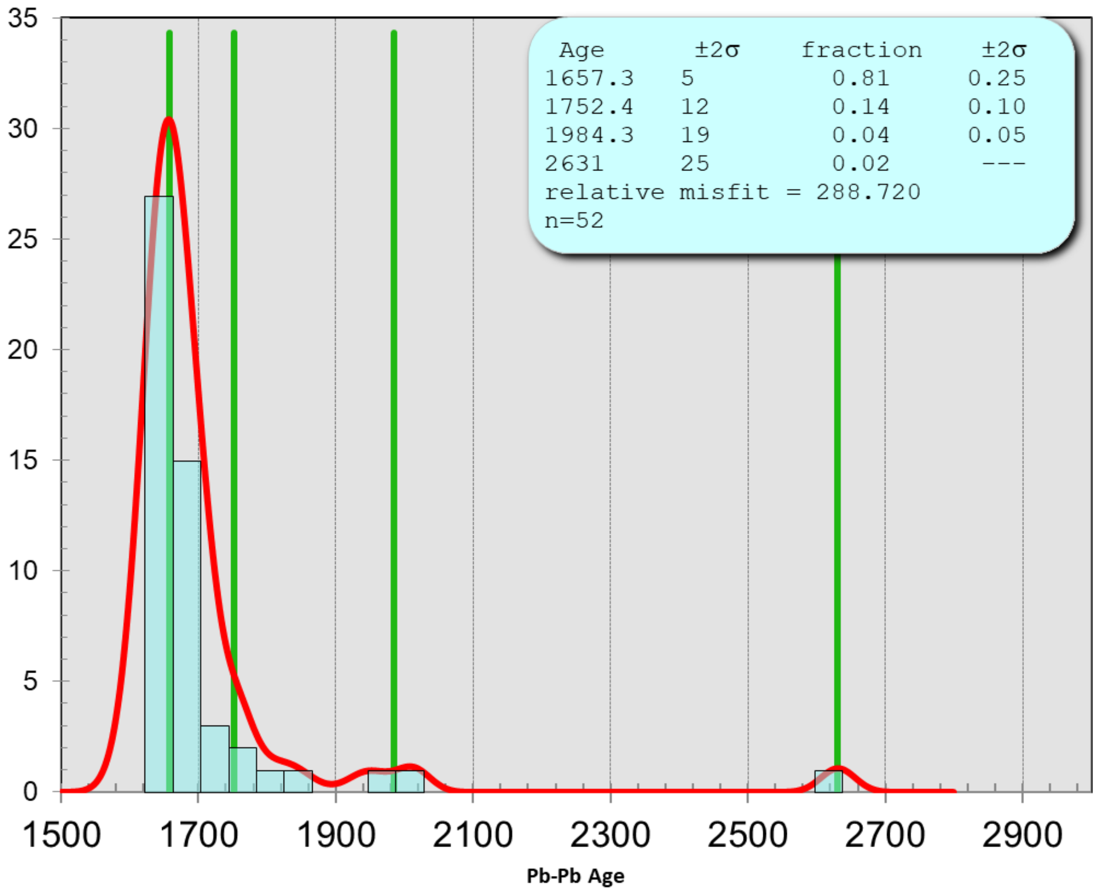


Figure 110: Pb-Pb spectra and gaussian deconvolution for concordant analyses from EX096931. n=52

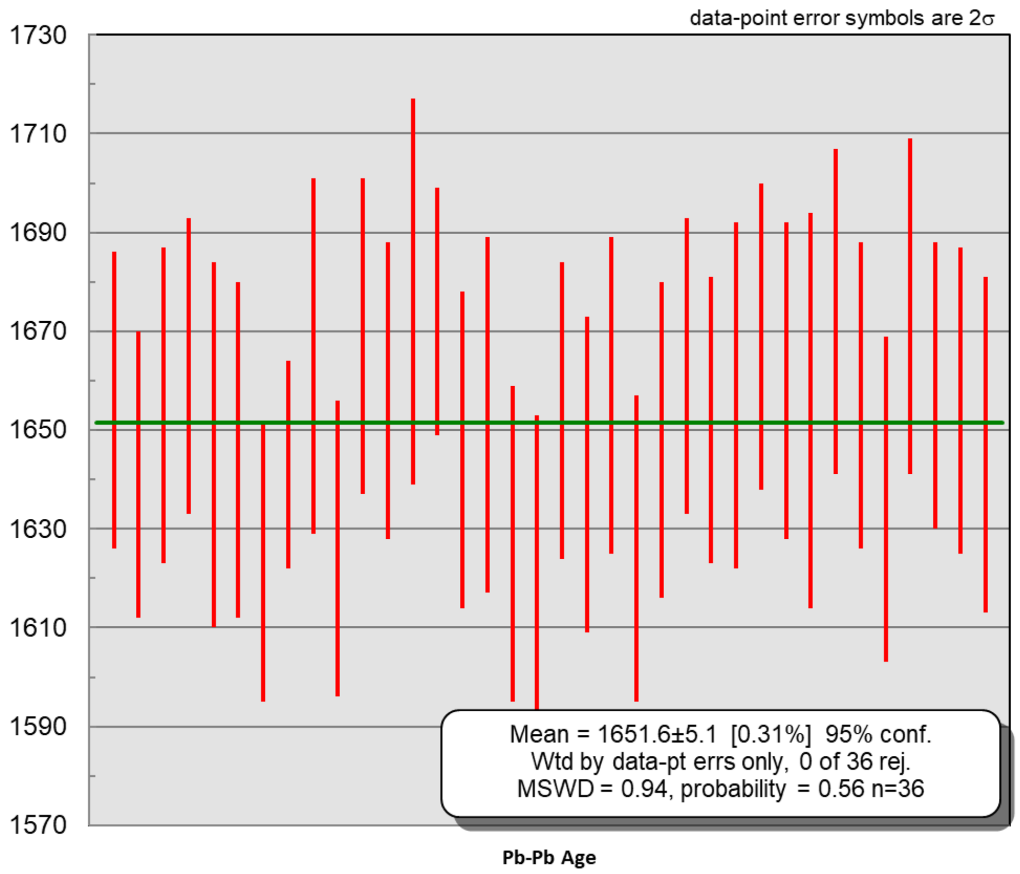


Figure 111: Weighted average Pb Pb age for the largest sub population (A) from EX096931

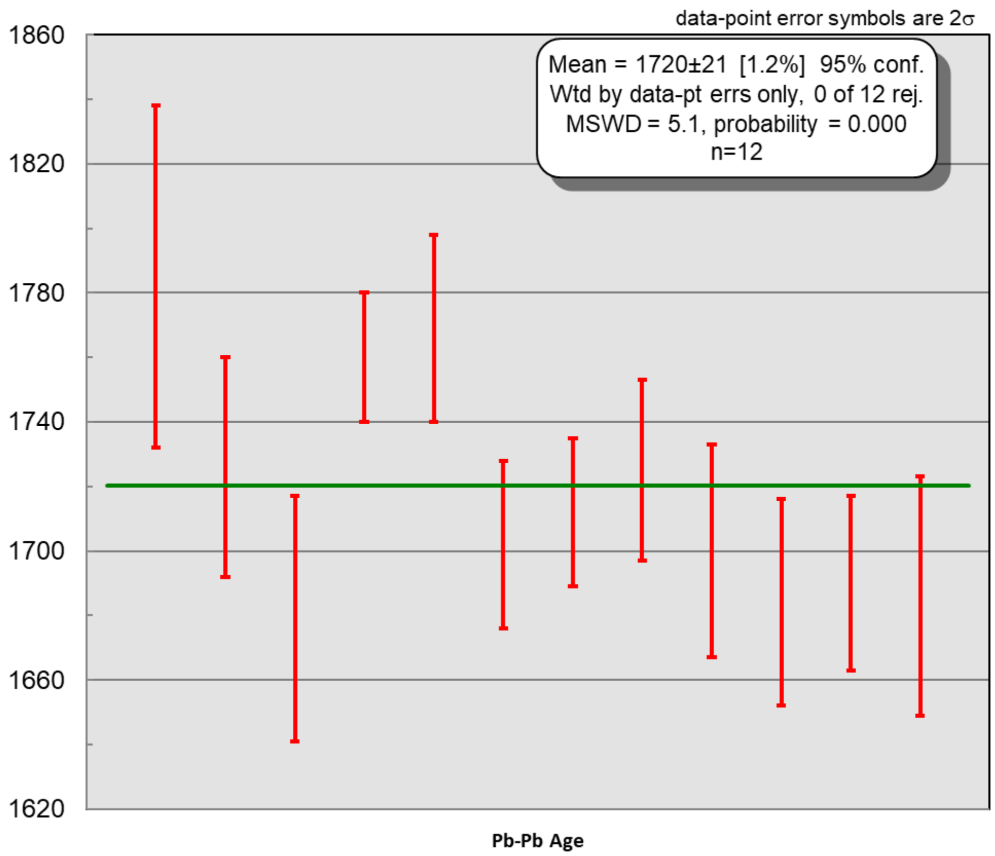


Figure 112: Weighted average Pb Pb age for subpopulation B from EX096931

4.4.9 EX096932

Lithology: Vein Bt-cc rock +amph. Reactions on contact

Run	Run1 130819	Pb207-206 Age	
# Analyses	47	Concordia Age	
# Analyses integrated	45	Multiple populations?	1725±17 Ma, 1850-2700Ma

Although initially interpreted as a vein, the analyses from EX096932 show several populations that may be more consistent with a detrital source. A considerable spread is present in the data. Only 25 results are concordant, and Gaussian deconvolution is not clear in identifying populations. Inspection on probability plots and histograms in ioGAS suggest 3 populations can be identified. The largest (n=9) returns a reasonable weighted average Pb-Pb age of 1725±17 Ma. The remaining two populations are considerably less precise, centering around 1970 Ma and 2710 Ma.

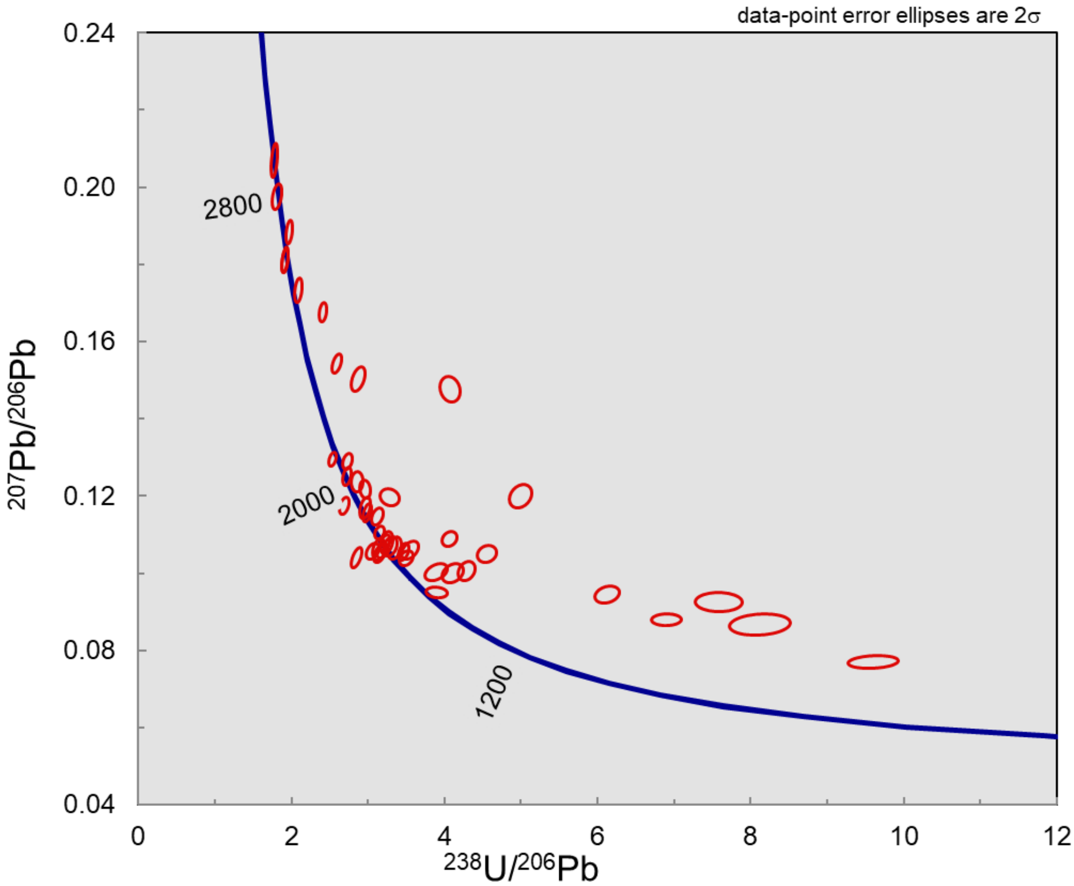


Figure 113: TW diagram showing all analyses from EX096932

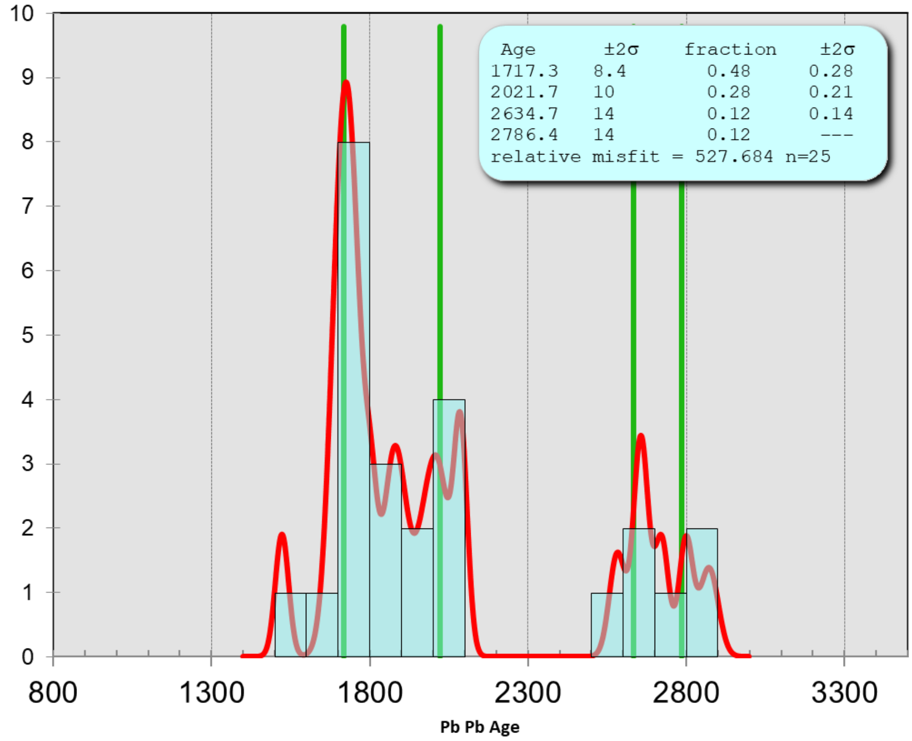


Figure 114: Gaussian deconvolution of Pb-Pb age distribution for concordant results. n=25

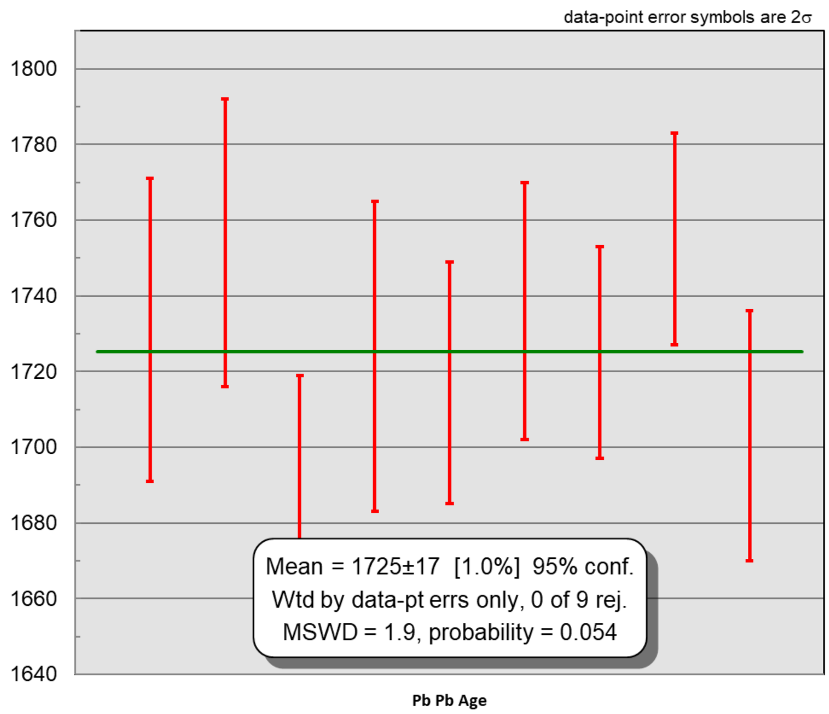


Figure 115: Weighted average Pb-Pb age for a coherent population of concordant results. N=9