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U-Pb isotope systematics on minerals from the gneiss complex at Isukasia, West Greenland

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Abstract

$^{207}Pb/^{204}Pb$ *vs.* $^{206}Pb/^{204}Pb$ results from sphenes from Isua gneisses show a scatter of data points between two isochrons, one at 3560 Ma and the other at 2520 Ma. Similar Pb-Pb plots on apatites from Isua show many data points which are closer to the 3560 Ma reference isochron than Pb-Pb apatite data points from Amîtsoq gneisses and Nûk gneisses in the Godthåbsfjord area. Pb from the Isua gneiss apatite and sphene is more radiogenic than that from Amîtsoq gneisses. In concordia plots of zircons all but one of the Isua data points plot to the right of the Amîtsoq zircon discordia line. Assuming a diffusion Pb loss, the 'oldest' Isua gneiss zircon is about 3700 Ma. U-Pb values for sphenes from the Isua gneisses show discordancy which could be the result of partial or local metamorphic effects between 1500 and 2800 Ma. Comparable values from sphenes from Amîtsoq and Nûk gneisses cluster fairly closely to concordant results about 2500 Ma.

Introduction

The Isua supracrustal belt at Isukasia (Allaart, 1975, 1976; Bridgwater *et al.*, 1976) is enclosed within a multiphase orthogneiss complex (Isua gneisses). The Isua gneisses are considered to be broad chronological equivalents of the Amîtsoq gneisses occurring south and east of Godthaab (Bridgwater & McGregor, 1974). Rb-Sr whole-rock isochron dates on the Isua gneisses of 3620 ± 140 Ma and 3640 ± 60 Ma ($\lambda - {}^{87}Rb = 1.42 \times 10^{-11} y^{-1}$) (Moorbath *et al.*, 1972, 1977) furnish a geochronological correlation with the Amîtsoq gneisses. In addition, Moorbath *et al.* (1975) obtained a Pb-Pb whole-rock isochron date of 3750 ± 120 Ma ($\lambda - {}^{238}U$ & $\lambda - {}^{235}U$ of Jaffey *et al.*, 1971) for the Isua gneisses.

The Isua gneisses are especially interesting not only for their intrusive relationship to the older supracrustal belt, but because the gneisses within the arcuate supracrustal belt (central gneisses) are so little deformed compared with their Amîtsoq gneiss counterparts to the south. Early dykes cutting the Isua gneisses (correlated with the Ameralik dykes cutting the Amîtsoq gneisses) are relatively undeformed sheets striking in linear patterns and indicate absence of the intense post-dyke deformation shown by the Ameralik dykes. In addition, this lack of post-dyke deformation has brought to light predyke intrusive relationships between various phases of the Isua gneiss complex (Nutman *et al.*, 1983). To be able to compare the U-Pb dating of Isua gneiss minerals with that for Amîtsoq gneiss minerals, samples were collected at locations shown in fig. 1. Every sample contained ample zircon and apatite, while most samples also contained sufficient sphene for U-Pb dating.

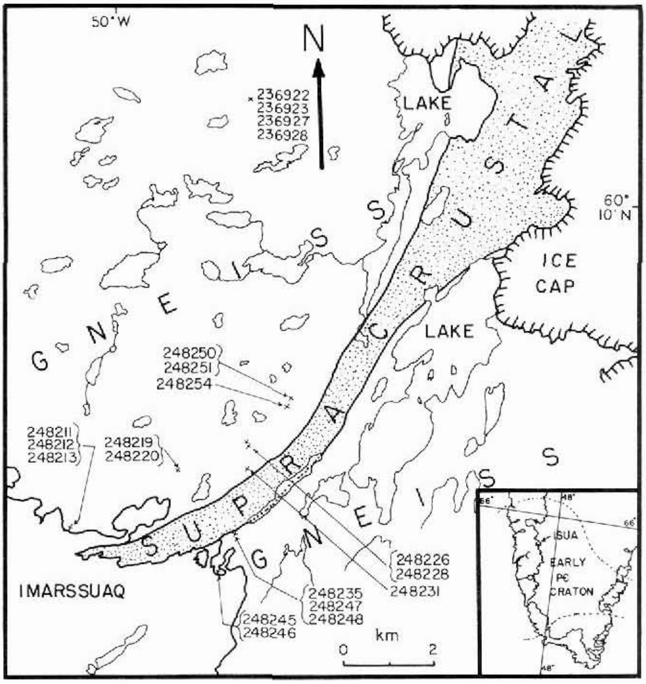

Fig. 1. Geologic sketch map of the eastern Isua supracrustal area. Sample locations of the Isua gneisses.

Analytical methods

Zircon samples were decomposed in teflon pressure bombs using HF and HNO_3 (Krogh, 1973). Sphene was decomposed by HF and HNO_3 in an open teflon beaker, while apatite was simply dissolved in 1:1 HNO_3. After converting the decomposition solutions to HNO_3-solutions, pure $Ba(NO_3)_2$ is added to the solution and a $Ba(NO_3)_2$ precipitation made to separate Pb from U. The Pb is purified on a chloride anion-exchange column. The U is purified on a nitrate anion-exchange column. All isotope runs were made on a Micro-Mass 30 mass spectrometer with automatic on-line data collection and processing. The Pb-blank is 2–3 ng and the U-blank is < 1 ng. The decay constants used are : $\lambda - {}^{238}U = 1.5513 \times 10^{-10} y^{-1}$ and $\lambda - {}^{235}U = 9.8484 \times 10^{-10} y^{-1}$ (Jaffey *et al.,* 1971). A present ratio of ${}^{238}U/{}^{235}U = 137.88$ was used.

Pb-Pb on sphene and apatite

The lead isotope data for sphene and apatite from Isua gneisses is given in Table 1, while some (previously unpublished) comparison data on apatite and sphene from Nûk gneisses is given in Table 2. A ${}^{207}Pb/{}^{204}Pb$ *vs.* ${}^{206}Pb/{}^{204}Pb$ plot for results on sphenes from the Isua gneisses is shown in figure 2, and reveals a scatter of data points between two isochrons, one at 3560 Ma and the other at 2520 Ma. Five of the Isua sphene results plot essentially on the 3560 Ma isochron with the others giving lower nominal Pb-Pb ages, but still older than those for the Amîtsoq gneiss sphenes (Baadsgaard *et al.,* 1976).

Table 1. Measured lead isotope ratios for sphene and apatite from the Isua gneisses

	Pb isotope ratios, measured		
SAMPLE	206/204	207/204	208/204
248231 APATITE	84.32±0.05	30.82±0.03	37.53±0.04
248228 APATITE	117.5±0.4	41.49±0.08	36.60±0.10
248228 APATITE	117.8±0.2	41.52±0.06	36.64±0.06
248226 APATITE	123.24±0.06	42.76±0.02	33.86±0.02
248220 APATITE	198.10±0.08	53.88±0.03	38.99±0.02
248219 APATITE	144.4±0.2	43.49±0.06	35.82±0.05
248212 APATITE	66.40±0.09	22.41±0.04	34.16±0.05
248251 APATITE	100.85±0.06	36.70±0.02	45.23±0.02
248250 APATITE	107.9±0.8	40.30±0.10	43.32±0.14
248248 APATITE	50.51±0.05	20.63±0.02	36.43±0.02
248247 APATITE	68.12±0.05	23.87±0.01	42.30±0.02
248246 APATITE	53.28±0.06	20.48±0.01	33.09±0.01
248245 APATITE	34.54±0.02	17.59±0.01	36.68±0.01
248254 APATITE	75.87±0.12	30.80±0.05	38.45±0.06
248235 APATITE	42.79±0.02	19.56±0.01	35.86±0.01
248219 SPHENE	115.89±0.05	40.54±0.02	35.39±0.01
248219 SPHENE	112.3±0.4	39.59±0.10	35.54±0.12
248220 SPHENE	352.0±0.6	104.26±0.21	46.83±0.09
248220 SPHENE	334.3±0.4	97.18±0.12	45.45±0.07
248228 SPHENE	79.52±0.02	34.16±0.01	32.48±0.01
248228 SPHENE	85.25±0.44	36.06±0.13	32.38±0.12
248231 SPHENE	155.1±0.1	57.74±0.04	42.47±0.03
248231 SPHENE	149.9±0.2	56.62±0.08	42.78±0.06
248235 SPHENE	848.9±7.2	251.0±1.0	144.0±0.9
248235 SPHENE	870.3±2.3	255.7±0.8	146.8±0.3
248250 SPHENE	68.49±0.05	30.39±0.02	33.94±0.02
248250 SPHENE	67.57±0.41	30.36±0.09	34.10±0.06
248254 SPHENE	435.9±0.6	148.5±0.15	60.35±0.08
248246 SPHENE	150.7±0.2	40.69±0.06	36.02±0.05
248226 SPHENE	231.7±0.1	82.09±0.03	37.78±0.03
248251 SPHENE	208.6±0.1	66.80±0.02	40.68±0.02

The errors given are ± *1* σ.

Figure 3 is also a Pb-Pb plot and shows apatite results from the Isua, Amîtsoq and Nûk gneisses plotted together with results on sphenes from each gneiss. While the Pb-Pb data points on sphene and apatite from the Nûk and Amîtsoq gneisses plot close to a 2520 Ma isochron, many data points for apatite from the Isua gneisses give nominally 'older' dates, tending to plot towards the limiting 3560 Ma reference isochron. It is interesting to note that Pb from the apatites and sphenes of the Amîtsoq gneisses is markedly *less* radiogenic than Pb from their counterparts in the Isua gneisses. Also, those Isua gneiss apatite data points which fall close to or on the 2520 Ma isochron line are all for apatites which have *lesser* amounts of radiogenic lead. Further, these same lower age apatites are from gneiss samples (GGU 248235, 248247, 248248, 248245, 248246) which fall *outside* the arcuate supracrustal belt (fig. 1) and which are much more deformed than the central Isua gneisses. At least part of the deformation outside the central gneiss area may be tentatively linked to metamorphism at ~ 2500 Ma. The point labelled A on figure 3 represents the isotopic composition of the least radiogenic lead from feldspar of the Amîtsoq gneiss (Baadsgaard

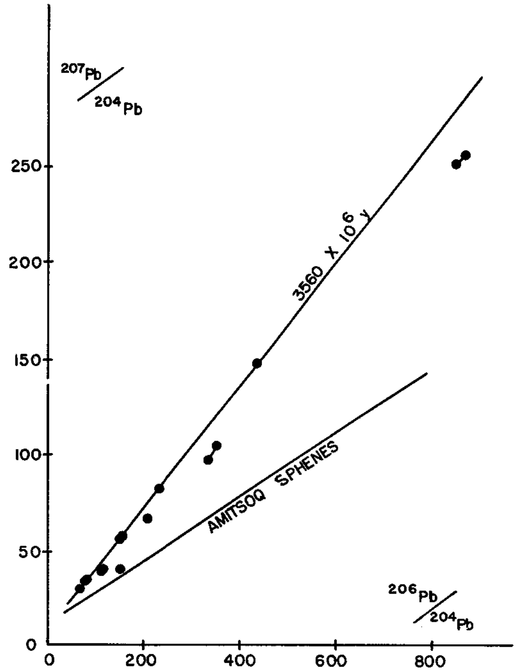

Fig. 2. $^{207}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$ plot for sphenes from the Isua gneisses. There are six duplicate runs, joined by lines where necessary.

Table 2. Measured lead isotope ratios for sphene and apatite from Nûk gneisses at Godthåb townsite (201–) and Bjørneøen (248–)

	Pb isotope ratios, measured		
SAMPLE	206/204	207/204	208/204
201415 APATITE	20.20±0.01	15.20±0.02	34.17±0.03
201416 APATITE	61.05±0.17	21.24±0.01	37.67±0.03
201417 APATITE	40.37±0.20	18.16±0.04	38.76±0.09
201418 APATITE	49.65±0.07	19.34±0.03	35.76±0.05
201420 APATITE	44.50±0.05	19.29±0.05	35.76±0.04
248078 APATITE	47.35±0.16	20.20±0.04	44.49±0.07
248079 APATITE	80.65±0.06	25.51±0.01	38.07±0.02
248081 APATITE	92.08±0.08	26.63±0.02	44.17±0.04
248087 APATITE	78.86±0.04	24.60±0.01	35.36±0.02
248088 APATITE	56.62±0.08	21.25±0.01	38.35±0.02
201418 SPHENE	295.6±1.1	61.19±0.30	70.38±0.33
201417 SPHENE	70.42±0.04	23.77±0.01	64.43±0.03
201416 SPHENE	108.5±0.1	30.10±0.03	76.42±0.07
201415 SPHENE	223.9±0.5	49.45±0.10	59.49±0.10

The errors given are ± 1 σ.

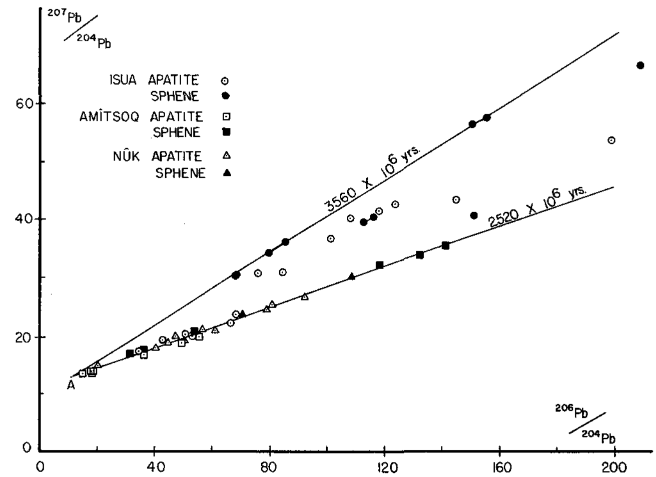

Fig. 3. $^{207}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$ plot of sphenes and apatites from the Nûk, Amîtsoq and Isua gneisses. Points for duplicate runs are joined by a line. Data for the Amîtsoq samples may be found in Baadsgaard *et al.* (1976).

Table 3. U-Pb analytical results for zircons from the Isua gneisses

SAMPLE (All GGU Nos.)	Pb composition, measured 206/204	207/206	208/206	^{238}U, p.p.m.	^{206}Pb, p.p.m.	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$
248247 ZIRCON	16850±750	0.35028±3	0.12991±2	351	207.4	0.6837	32.97
248246 ZIRCON	20850±1550	0.33386±3	0.08423±1	262.8	166.5	0.7321	33.65
236928 ZIRCON	4484±80	0.33534±4	0.08578±2	664	401.3	0.6984	32.08
236927 ZIRCON	581±1	0.34800±2	0.11695±2	608	366.0	0.6960	31.82
236923 ZIRCON	6494±42	0.33018±3	0.12422±1	690	423.0	0.7087	32.12
236922 ZIRCON	5571±102	0.32957±2	0.12105±1	716	433.8	0.7000	31.64
248251 ZIRCON	2495±12	0.31447±6	0.06584±3	968	478.4	0.5708	24.44
248248 ZIRCON	6452±42	0.3275±1	0.11925±2	753	406.5	0.6234	28.02
248226 ZIRCON	28400±1050	0.34319±3	0.08502±2	275.9	174.8	0.7320	34.60
248213 ZIRCON	5319±57	0.31926±1	0.07684±1	743	422.0	0.6565	28.73
248211 ZIRCON	2726±5	0.29760±2	0.07558±1	1878	945.1	0.5813	23.55
248254 ZIRCON	10163±190	0.33732±5	0.09195±2	396	209.0	0.6094	28.27
248250 ZIRCON	9634±139	0.33694±10	0.07591±4	486	309.7	0.7356	34.07
248245 ZIRCON	5179±16	0.32737±5	0.04855±1	493	304.4	0.7129	31.99
248212 ZIRCON	8977±192	0.32201±4	0.06466±1	682	389.1	0.6592	29.18
248235 ZIRCON	1647±5	0.31985±6	0.08837±4	1005	506.6	0.5824	25.20
248231 ZIRCON	1144	0.33956±6	0.1116±1	450	276.0	0.7083	33.04
248228 ZIRCON	20500±1000	0.33757±10	0.07190±2	247	159.2	0.7450	34.63
"Total Sample"							
104-74 microns	11111±320	0.33721±3	0.07063±1	248.3	161.2	0.7501	34.79
74-61 microns	28650±2200	0.33770±4	0.07101±1	244.1	158.2	0.7485	34.82
61-44 microns	30200±1000	0.33782±4	0.07254±1	248.5	160.9	0.7481	34.82
<44 microns	25063±1600	0.33736±5	0.07414±1	259.9	168.0	0.7468	34.70

The errors given are ± 1 σ for the corresponding last digits. The error in the U-Pb ratios is discussed in the text.

et al., 1976), and furnishes a possible approximate common initial lead for the Isua and Amîtsoq gneisses at ~ 3650 Ma.

U-Pb on zircon, sphene and apatite

Table 3 presentes U-Pb data on zircons from the Isua gneisses, while Table 4 gives U-Pb results on Isua gneiss sphenes and apatites plus four U-Pb analyses on sphenes of Nûk gneisses from Godthåb townsite (for comparison). The data from Tables 3 and 4; plus U-Pb data on Amîtsoq zircons (Baadsgaard, 1973), sphenes and apatite (Baaadsgaard *et al.,* 1976); are plotted on a concordia diagram in figure 4.

One zircon sample, GGU 248228, was partly split into four size fractions. U-Pb results for the four size fractions, together with results on the unsieved 'total zircon', are plotted on an enlarged triangular insert on figure 4. Rather than showing strong variable discordance, the data points cluster closely enough to furnish limits on analytical reproducibility of the $^{206}Pb/^{238}U$ and $^{207}Pb/^{235}U$ ratios in the zircons. In the insert in figure 4, A is 0.68% of the average $^{206}Pb/^{238}U$ value and B is 0.55% of the average $^{207}Pb/^{235}U$ value. Since the sieving into size fractions has given rise to some inhomogeneity, it is reasonable to assume an analytical reproducibility of at least ± 0.3% for U/Pb ratios on zircons with $^{206}Pb/^{204}Pb$ ratios > 3000.

There seems to be a slight, but real, difference between the concordia plot data points for

Table 4. U-Pb analytical results for sphenes and apatites from the Isua gneisses and Nûk gneisses at Godthåb townsite

SAMPLE (All GGU Nos.)	Pb composition, measured 206/204	207/206	208/206	^{238}U p.p.m.	^{206}Pb p.p.m.	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$
ISUA GNEISSES							
248251 SPHENE	208.6±1	0.32033±1	0.19503±1	21.85	10.53	0.5568	20.857
248247 SPHENE	1597±800	0.2929±7	0.1600±7	106.8	59.15	0.6401	25.218
248226 SPHENE	231.7±1	0.35430±1	0.16304±1	15.85	9.176	0.6689	28.641
248254 APATITE	75.87±12	0.4060±1	0.5068±3	8.91	4.974	0.6450	23.947
248235 APATITE	42.79±2	0.45702±4	0.8381±2	5.98	2.894	0.5591	15.683
248228 APATITE	117.50±4	0.35311±3	0.31148±5	12.79	7.146	0.6455	23.470
248250 SPHENE	68.49±5	0.4437±1	0.4955±2	3.31	1.856	0.6478	26.017
248235 SPHENE	849±7	0.29563±2	0.16969±4	100.4	56.72	0.6530	25.503
248231 SPHENE	155.1±1	0.37227±6	0.27387±9	18.95	11.849	0.7224	30.636
248228 SPHENE	79.52±2	0.42956±4	0.40843±6	4.18	2.512	0.6943	28.949
248220 SPHENE	352.0±6	0.29620±2	0.13303±2	23.97	10.84	0.5223	19.102
248219 SPHENE	115.89±5	0.34984±1	0.30538±3	6.02	3.066	0.5884	20.831
248254 SPHENE	435.9±6	0.34058±3	0.13845±4	32.39	20.10	0.7170	31.532
248246 SPHENE	150.7±2	0.27005±5	0.23903±9	11.63	5.404	0.5367	14.683
NÛk GNEISSES							
201418 SPHENE	295.6±11	0.2070±1	0.2381±5	33.14	13.08	0.4559	10.453
201417 SPHENE	70.42±4	0.33754±3	0.9150±2	12.12	5.180	0.4939	11.406
201416 SPHENE	108.5±1	0.27745±9	0.7043±5	11.24	4.537	0.4665	10.747
201415 SPHENE	223.9±5	0.22086±6	0.2657±1	15.76	6.563	0.4812	11.102

The errors given are ± 1 σ in the corresponding last digits.

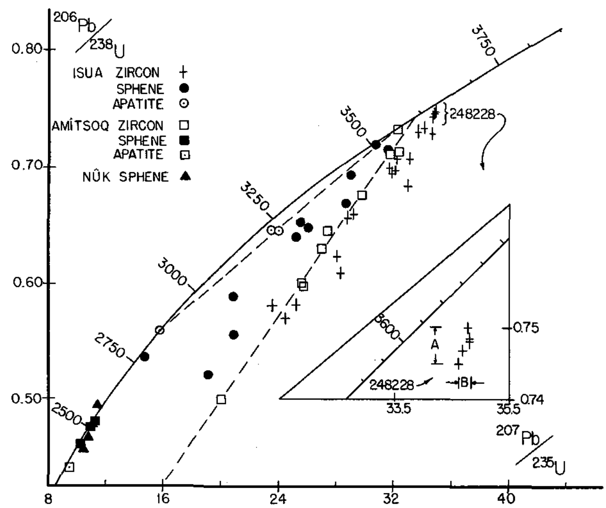

Fig. 4. A concordia plot of U-Pb ratios for zircon, sphenes and apatite from the Nûk, Amîtsoq and Isua gneisses. The data for the Amîtsoq zircons may be found in Baadsgaard (1973) and that for the Amîtsoq sphenes and apatite in Baadsgaard *et al.* (1976).

the Isua and Amîtsoq gneiss zircons. All but one of the Isua gneiss data points plot to the right of the Amîtsoq gneiss zircon discordia line. Assuming a diffusion Pb loss, the 'oldest' Isua gneiss zircon is about 3700 Ma. The scatter of the Isua gneiss zircon data points indicates probable variable metamorphic effects on the zircon ages.

The Isua gneiss zircons with higher U contents are in general more discordant, but the metamorphic effects have not been as strong on the less U-rich zircons. The ~ 3600 Ma discordia-concordia intersection age for the Amîtsoq zircons could well be a metamorphic age, and the more U-rich, slightly older Isua gneiss zircons may not have been so severely affected by this ~ 3600 Ma metamorphism.

U-Pb values for sphene from the Amîtsoq and Nûk gneisses cluster fairly closely to concordant results about 2500 Ma. This is a result of strong metamorphism at the time of formation of the anatectic Qôrqut granite. While it is possible that both the apatite and sphene of the Isua gneisses were completely recrystallized (or formed) at 3500–3600 Ma, post-dyke metamorphism of the central gneisses is not nearly as pervasive as for the Amît-soq gneisses near Godthåb. The concordia plot data in figure 4 indicate secondary metamorphic updating of Isua sphene and apatite, but cannot pin point the time of secondary metamorphism. The scattered discordancy could result from partial and/or local metamorphic effects from 1500 to 2800 Ma ago.

Conclusions

U-Pb dating of sphene and apatite from the Isua central gneisses supports the field observations that post-dyke deformation and metamorphism have been much less than that for the correlative Amîtsoq gneisses near Godthåb. Pb-Pb data on apatites from deformed Isua gneisses within or just outside the arcuate Isua supracrustals indicates a probable metamorphic deformation at about 2500 Ma, but this is only strong enough to completely affect the apatites, not the sphenes. It is difficult to indicate the time of the mild post-dyke metamorphic and resetting effects on sphenes and apatites from the central gneisses. These effects may be very local and sporadic, since widely varying discordance is found. The zircons from the Isua gneisses give slightly older ages than zircons from the Amîtsoq gneisses. This could be a result of less intense pre-dyke ~ 3600 Ma metamorphism. The true original crystallization age of the Isua gneiss zircons is not known, but is likely $\gtrsim$ 3700 Ma.

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