Grand Canyon (mile 78-81)

The image shows a geological sample with various minerals labeled:
- Pl (Plagioclase)
- Qtz (Quartz)
- Sil (Silica)
- Grt (Garnet)
- Bt (Biotite)

The scale bar indicates 2 mm.
Grand Canyon (mile 78-81)

Peak conditions:
- Temperature: 705 °C
- Pressure: 0.62 GPa

Peak assemblage:
- Grt-Bt-Sil-Pl-Q

Peak assemblage:
- Temperature: 640 °C
- Pressure: 0.5 GPa

NaKFMASH
Spear et al. (1999)
(sample W3-79-1)
Clear Creek Block (mile 81-87)

- Late Post-D2 Andalusite
- NW
- SE
- 5 cm

- KFMASH
  Spear et al. (1999)
- Peak assemblage
  Grt-Bt-Ms
  St-Pl-Q
- Peak conditions
  600°C, 0.72 GPa
  (sample 13-84.3)

- Temperature (°C)
- Pressure (GPa)
- Grt core
- Grt rim
- early D2
- late Andalusite
- post-D2
Monazite: (LREE) PO₄

Common accessory phase in igneous, metamorphic and sedimentary rocks...

Major REE's: Ce, La, Nd
Minor elements: Y, Si, Ca, Sm, Eu, Gd, Pr

Th : 100’s of ppm → 10’s of wt%
U  : 10’s of ppm → Several wt%
Pb : Very little “common” Pb (ppb → several ppm)
Crazy Basin Pluton, AZ
Reaction-dating

Shaw et al. (2001)

Wing and Ferry (2003)

Foster et al. (2004)

Kohn et al. (2005)

Caddick et al. (2007)

McFarlane, et al. (2005)

Pyle and Spear, 2003
Canadian Shield
Monazite: (LREE) PO$_4$
Syn-kinematic rim: 1901 +/- 12 Ma
(2-σ, MSWD=1.2)

Core:
1915 +/- 16 Ma
(2-σ, MSWD=0.40)

20 μm

ca. 1.9 dextral strain
syn-kinematic grains/rims
ca. 1.93-1.91 cores

Th Mα
m6
Multipoint Background

Fig. 3: Windows used in Probe for EPMA for the setting of multipoint background measurement, and example of result treatment: a) Element properties window; b) Display multipoint background intensity data; c) Overlay wavescan sample on multipoint plot.
Grt-rich felsic granulites
Legs Lake shear zone - Hydrated felsic granulites
Legs Lake shear zone - Hydrated felsic granulites

Retrograde assemblage:
Grt + Bt + Crd + Sil + Pl + Qtz
0.4-0.5 GPa, 550-600 °C

0.5 mm
Anhydrous felsic granulites - P-T pseudosection

No H$_2$O added

Grt Pl Ky Kfs
Grt Pl Sil Kfs
Opx Grt Pl Ky Kfs
Opx Grt Pl Kfs
Opx Grt Sil Kfs
Opx Grt Crd Pl Kfs
Opx Crd Pl Kfs
Qtz present in all fields

Pressure [GPa]

500 600 700 800 900 1000°C

X$_{\text{Mg}}$(Grt) = 0.2
X$_{\text{Ca}}$(Pl) = 0.25

Peak 1.9 Ga
Chipman domain
(mafic dikes)

NCKFMAS
MH$_2$O = 0.0

dry solids
Pseudosection – hydrous felsic granulite

H₂O = 1.0 wt% Qtz in excess
P-T pseudosection for hydrated felsic granulite

Peak 1.9 Ga
Chipman domain (mafic dikes)

Felsic granulite retrograde assemblage
bt crd pl grt sil q
Felsic granulites - 

P-MH2O pseudosection

Stage 1

Stage 2

Stage 3

@ 650 °C
NCKFMASH

Bt Ms Grt Ky V

Bt Grt Ky V

Bt Grt Sta V

Bt Crd Grt Sil V

Bt Crd Grt V

Bt Opx Crd Grt V

Bt Opx Crd Kfs

Bt Opx Crd Grt Kfs

Bt Crd Grt Sil

Bt Opx Crd Kfs

Bt Opx Crd

H2O saturation

Qtz+Pl present in all fields

(1.5 wt\% H2O)
Mn Kα - background

Monazite

S32D-2 Garnet

4 mm
Felsic granulites - Monazite dating results

S32D 2-m7

- Pop 5 1843 ±12 Ma
- Pop 3 2528 ±36 Ma
- Pop 1 2522 ±16 Ma
- Pop 2 2542 ±12 Ma

~gap~

Age [Ma]
# Felsic granulite evolution

<table>
<thead>
<tr>
<th>Major metamorphic and deformation events</th>
<th>Granulite-facies metamorphic event</th>
<th>Granulite-facies metamorphic event</th>
<th>LLsz deformation (amphibolite-facies)</th>
<th>GRsz deformation (lower amphib- to greenschist-facies)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Time scale</strong></td>
<td>2.6-2.5 Ga</td>
<td>1.9 Ga</td>
<td>1.85 Ga</td>
<td>1.80 Ga</td>
</tr>
<tr>
<td><strong>Stage description</strong></td>
<td>Grt-growth, anhydrous peak assemblage</td>
<td>Stage 1 - initial decompression (anhydrous)</td>
<td>Stage 2 - initial H2O infiltration</td>
<td>Stage 3 - continued decompression (hydrated)</td>
</tr>
</tbody>
</table>

**Garnet evolution**

- Garnet (Grt)

**Dominant Retrograde Rxn's**

- Grt + Kfs + H2O -> Bt + Sil
- Grt + Sil + H2O -> Crd

**Monazite growth events**

1. 2. 3. 4. 5. 6.

- Monazite growth events 1-3
- Monazite growth events 4-6
- Monazite growth events 5-6

**Xenotime growth events**

- 1. 2. 3. 4. 5.

**Microprobe analysis**

- Y Lα
- Y Lα
- Y Lα
- Y Lα
- Y Lα

- 20 μm
East Lake Athabasca region - Grease River shear zone
Felsic granulites

Legs Lake shear zone

Grease River shear zone
Grease River shear zone - Syn-kinematic monazite

Rim: $1787 \pm 20$ Ma (n=8)
Core: $\sim 1800$ Ma

50 µm

200 µm
1850-1800 Ma
LIN: PLUNGES AT 15°
ALONG S°40E
DEXTRAL, TOP SIDE DOWN TO EAST, PLUNGE 15°, S40°E

FACING NORTH
Grt => Bt + Pl + Qtz + Y-monazite + HREE monazite

Kspar => Recrystallized Kspar + U-monazite + apatite

Monazite => Apatite + Ca-poor monazite

Decompression, Cooling, Dynamic recrystallization
Xenotime-dating
BP-11-39

BP-12-19

Age (Ma)

1800 1750 1700 1650 1600 1550 1500 1450 1400

U/Th < 1

Xenotime

U/Th > 5

Outer Rim

Inner Rim

Outer Core

Inner Core

Xenotime

U/Th < 1
Starting monazite

The monazite chosen for the experiment was taken from a heavy-mineral sand deposit at Cumuruxatiba, Bahia State, Brazil D.

Moderately rounded, semi-euhedral, relatively transparent, inclusion-free, 100 – 500 mm, amber-colored grains.

The monazite grains were hand-picked out of the heavy mineral sand, crushed to 50 – 150 mm size fragments and then washed in ethanol in an ultrasonic bath.

\[ \text{ThO}_2: 7-8 \text{ wt \%}, \]

\[ \text{UO}_2: 0.5-0.75 \text{ wt\%} \]
**Assemblage:**
monazite, muscovite, albite, amorphous SiO$_2$

**Reagents:**
- CaF$_2$
- Na$_2$Si$_2$O$_5$

**Experimental conditions**
4.5 kbar, 450°C for a Duration: 16 days.

*See: Budzyn (2009)*