Impact cratering as a planetary process:

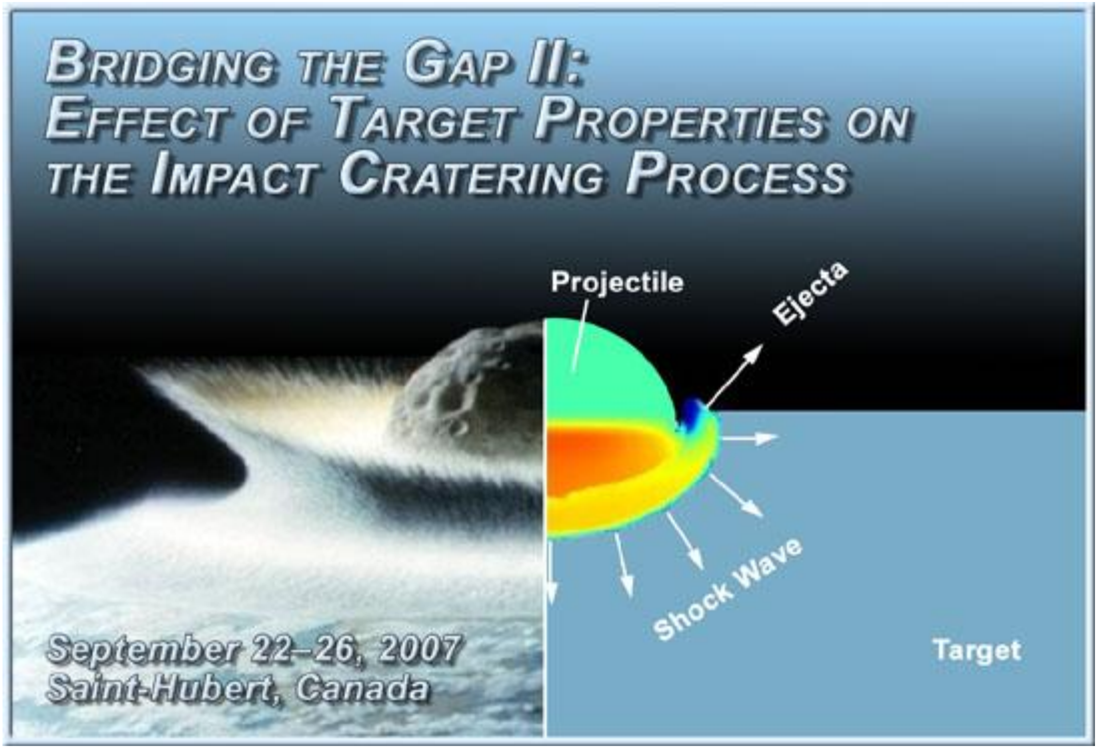
Information from impact glasses

G. Giuli

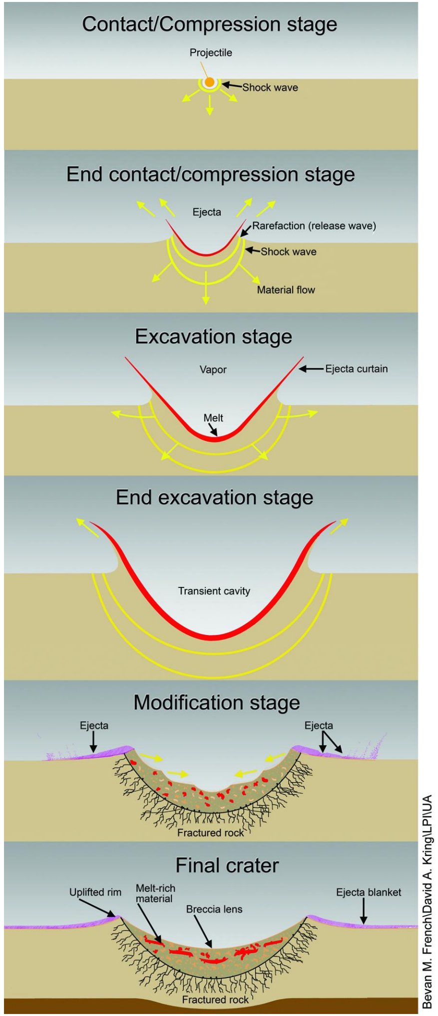
Scuola d … cnologie- sez … Università di Can…

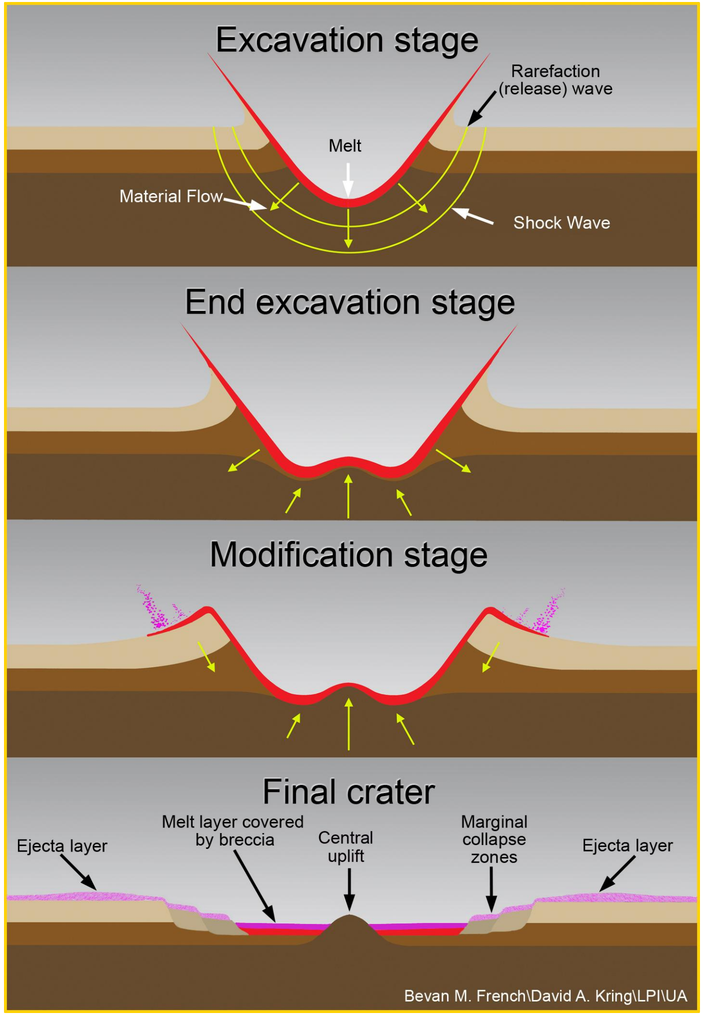



SST PhD National days, l'Aquila, 07/06/2024



https://www.lpi.usra.edu/lpi/contribution_docs/LPI-001360.pdf





https://clrn.uwo.ca/clrn-research/impact-crater-formation-and-morphology/

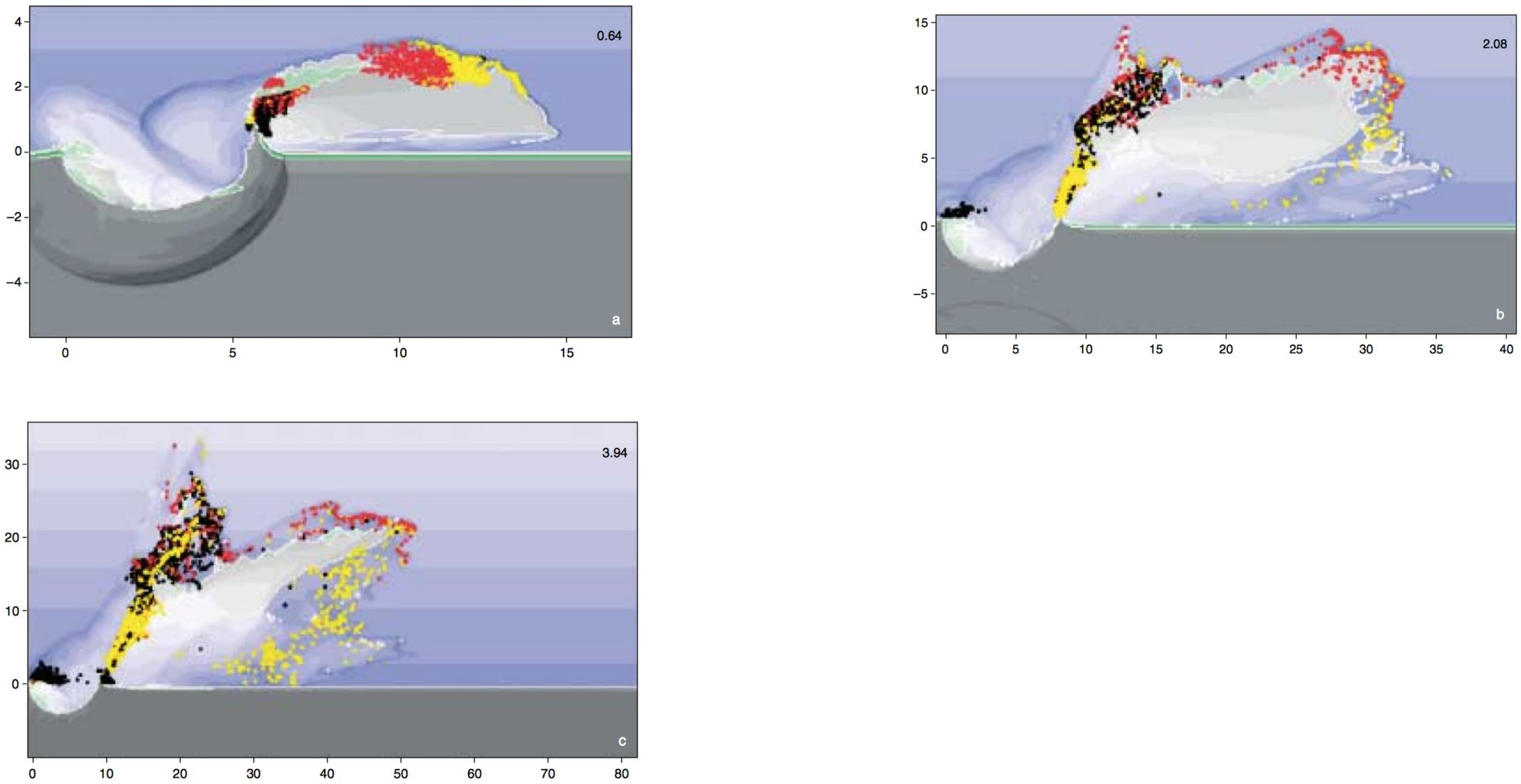
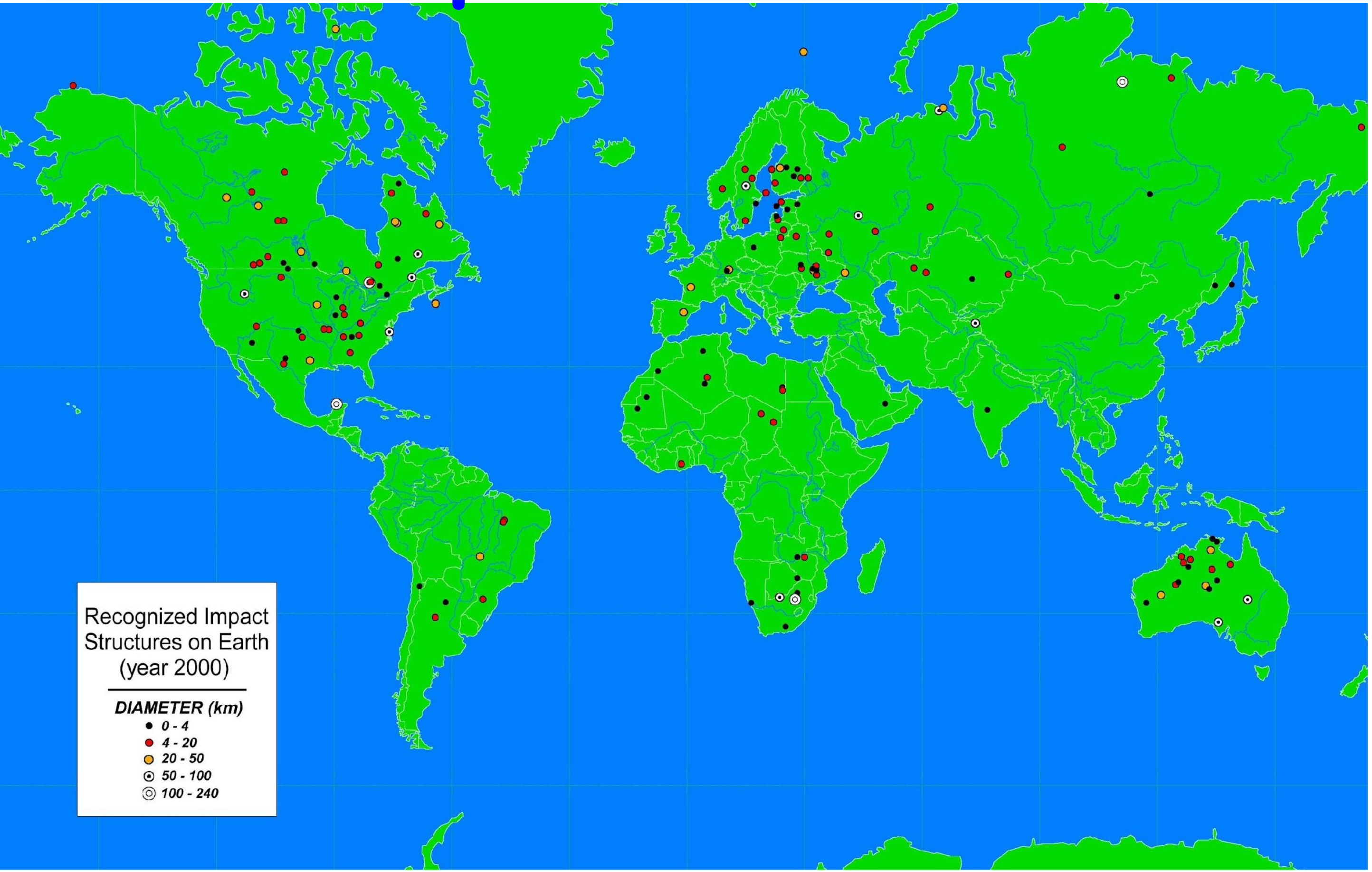


Figure 3. Tektite ejection model results for a 30° impact and impact speed of 20 km/s at a) 0.6 sec, b) 2 sec, and c) 3.9 sec. after the impact. ● – molten upper layer material (possible tektites); ● – molten target materials (not tektites); ● – solid target material.

Ejection model

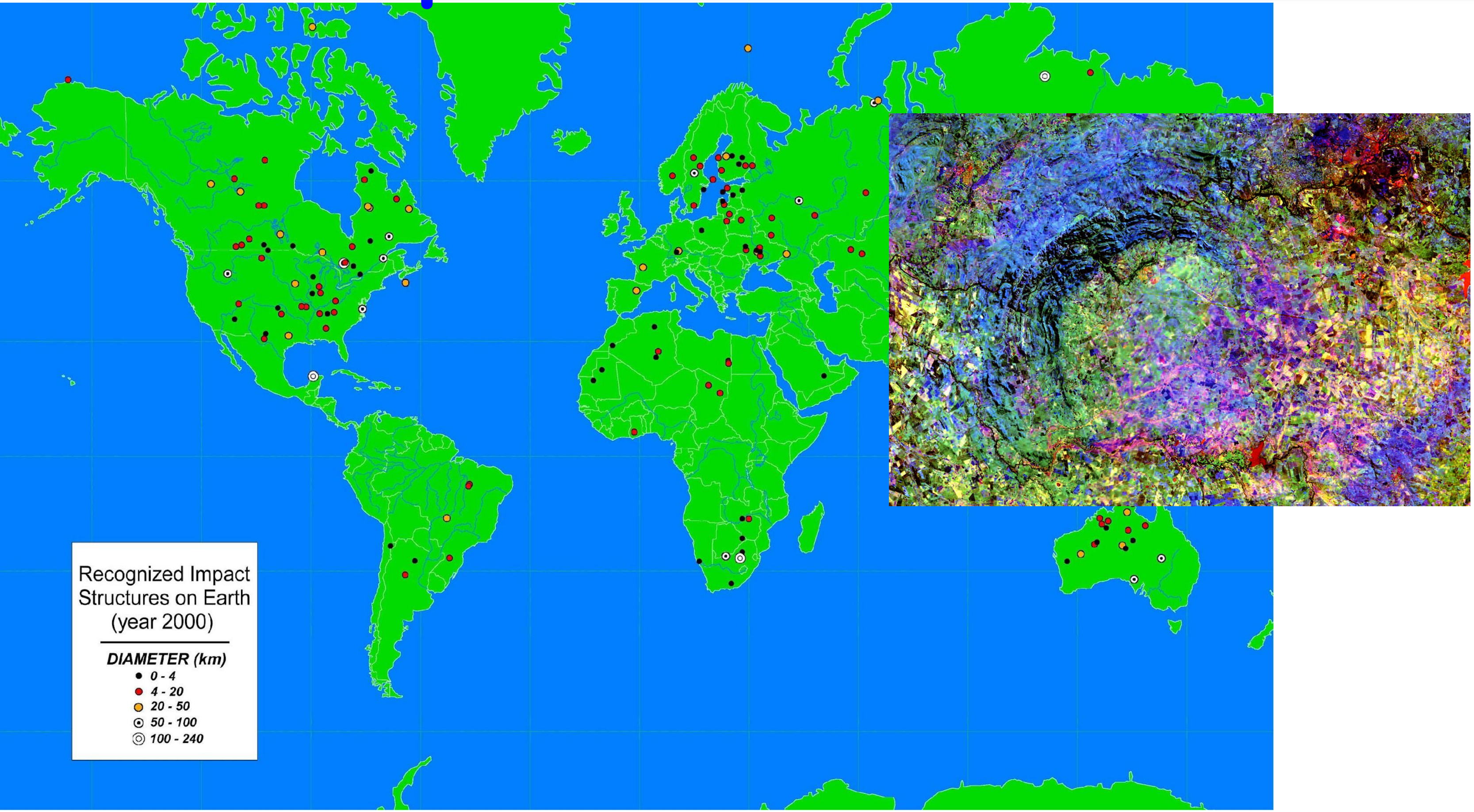
Stoffler, Artemieva, Pierazzo (2002) M&PS, **37**, 1893-1907

Impact crater distribution



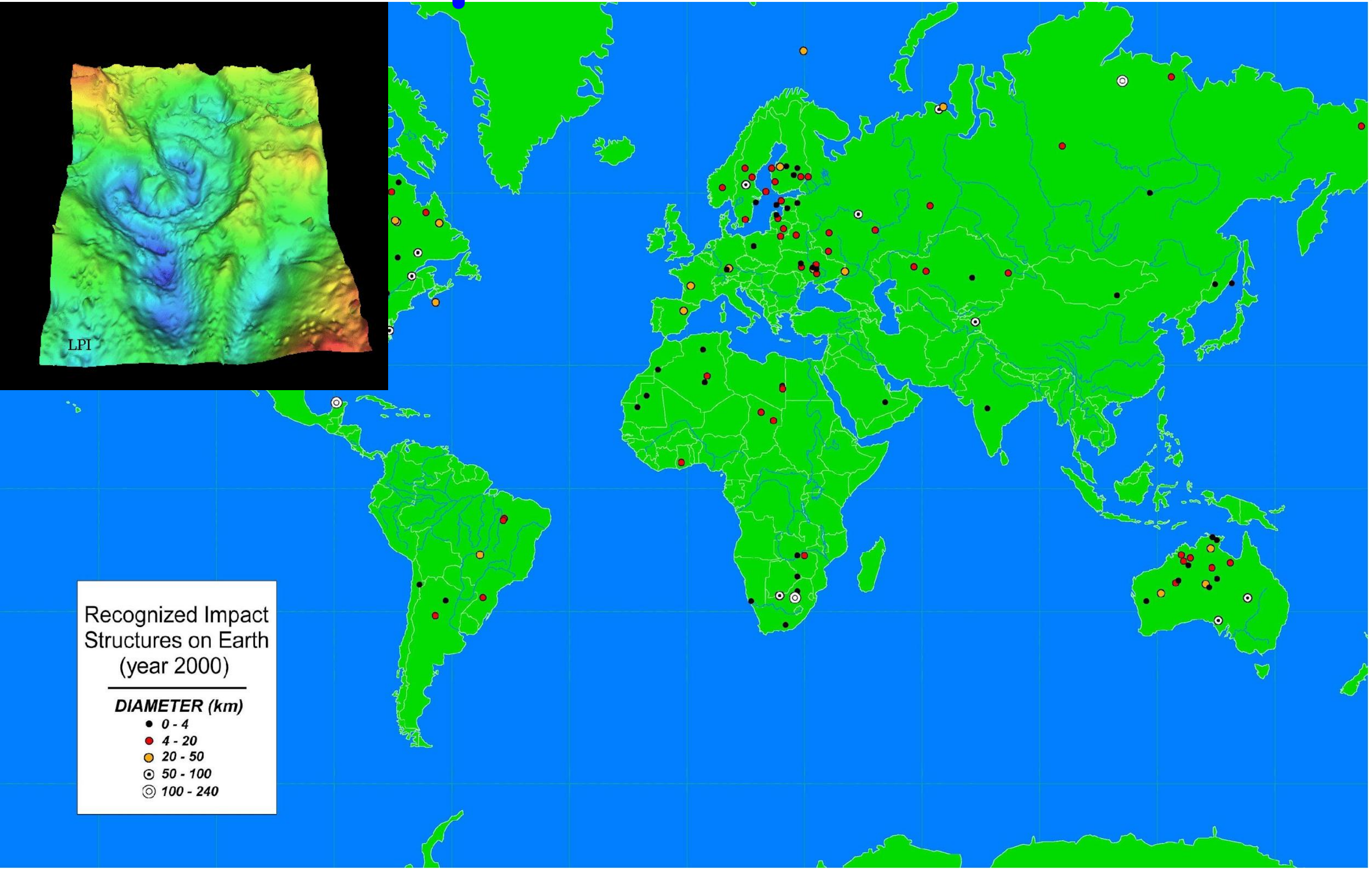
http://www.lpi.usra.edu/publications/slidesets/craters/ compiled by C. Koeberl and V.L. Sharpton

Impact crater distribution



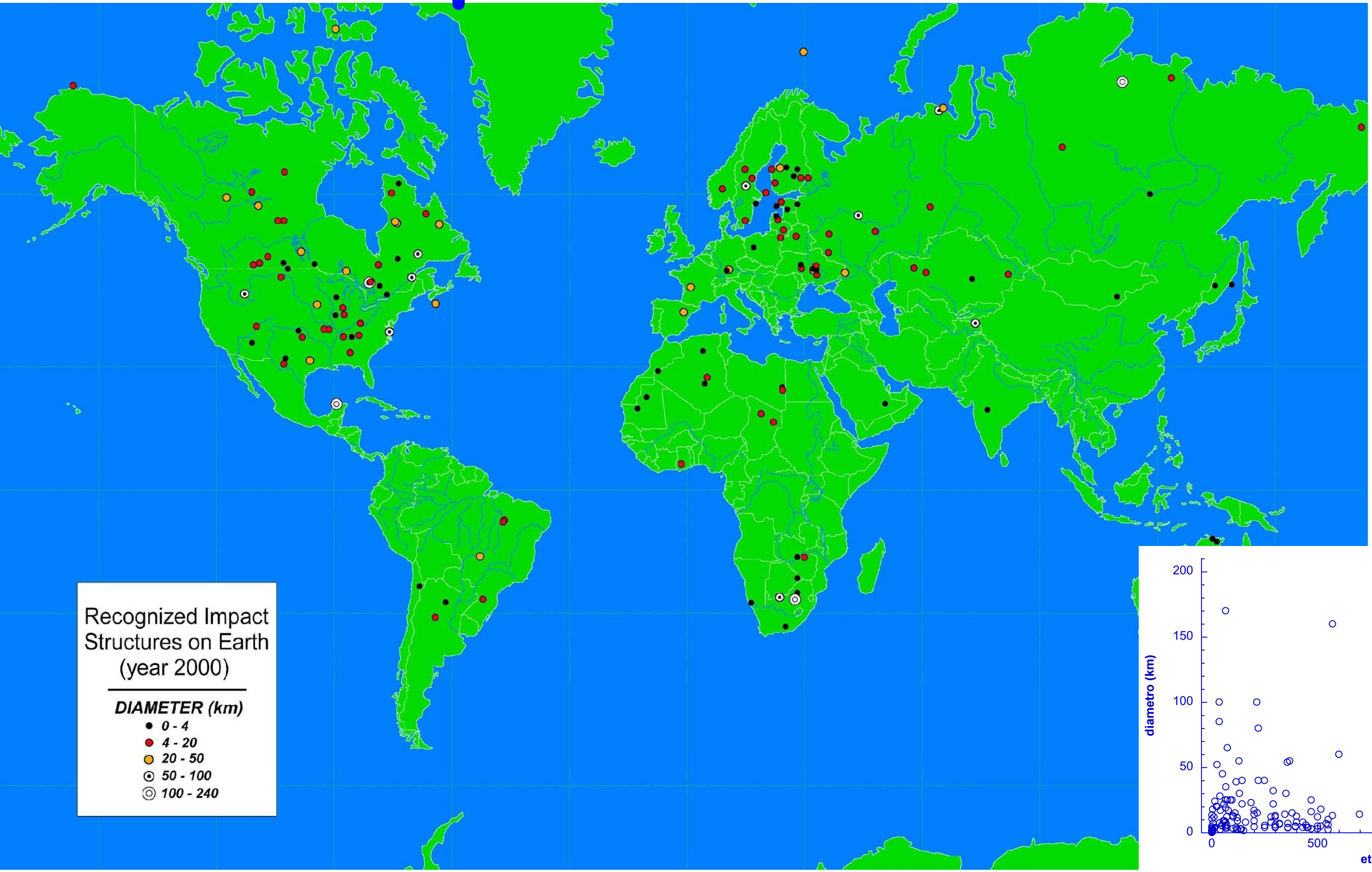
http://www.lpi.usra.edu/publications/slidesets/craters/ compiled by C. Koeberl and V.L. Sharpton

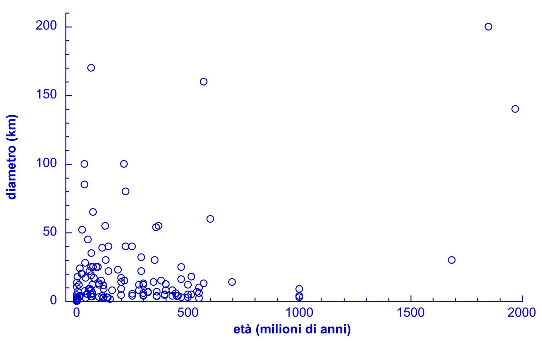
Impact crater distribution



http://www.lpi.usra.edu/publications/slidesets/craters/ compiled by C. Koeberl and V.L. Sharpton

Impact crater distribution





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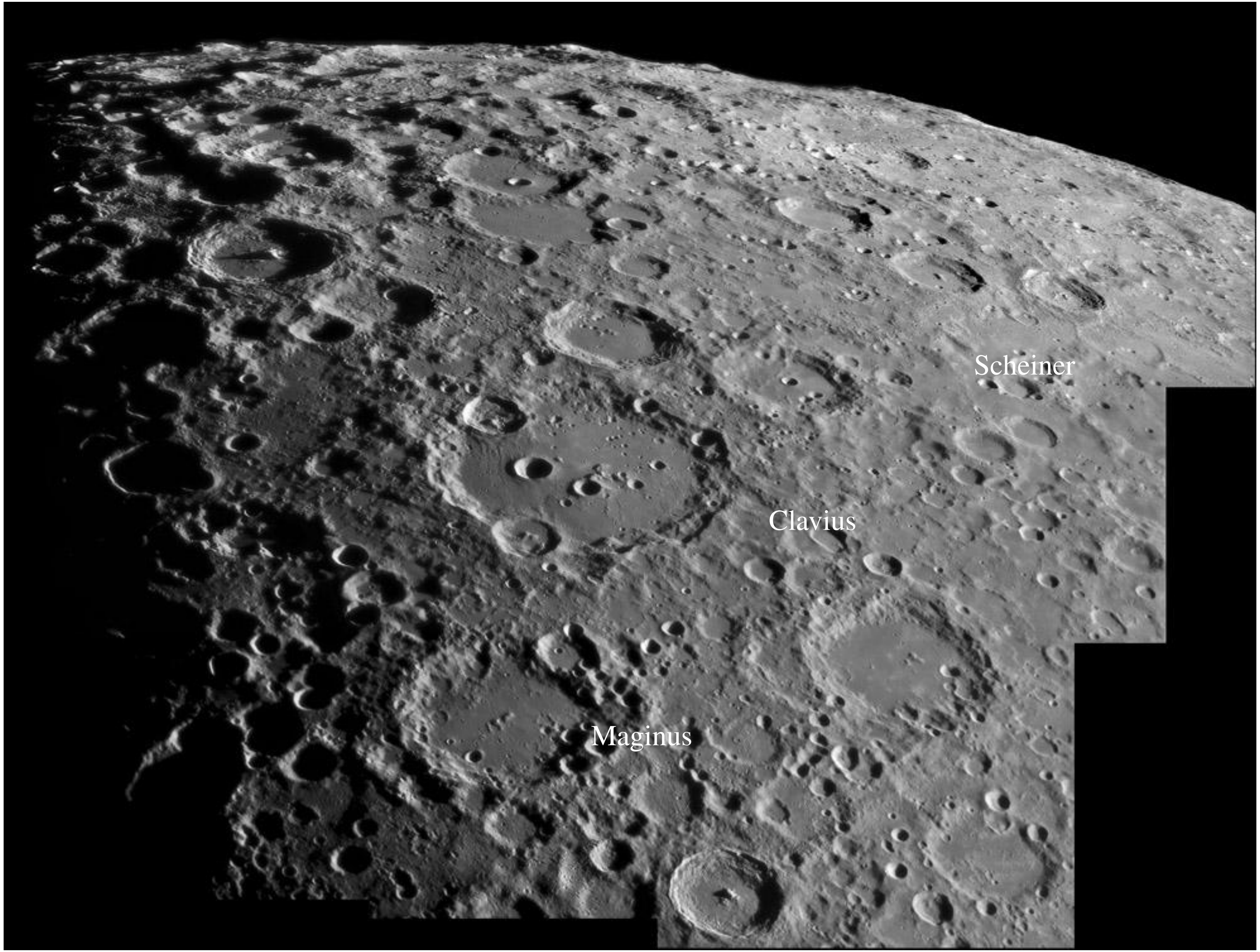
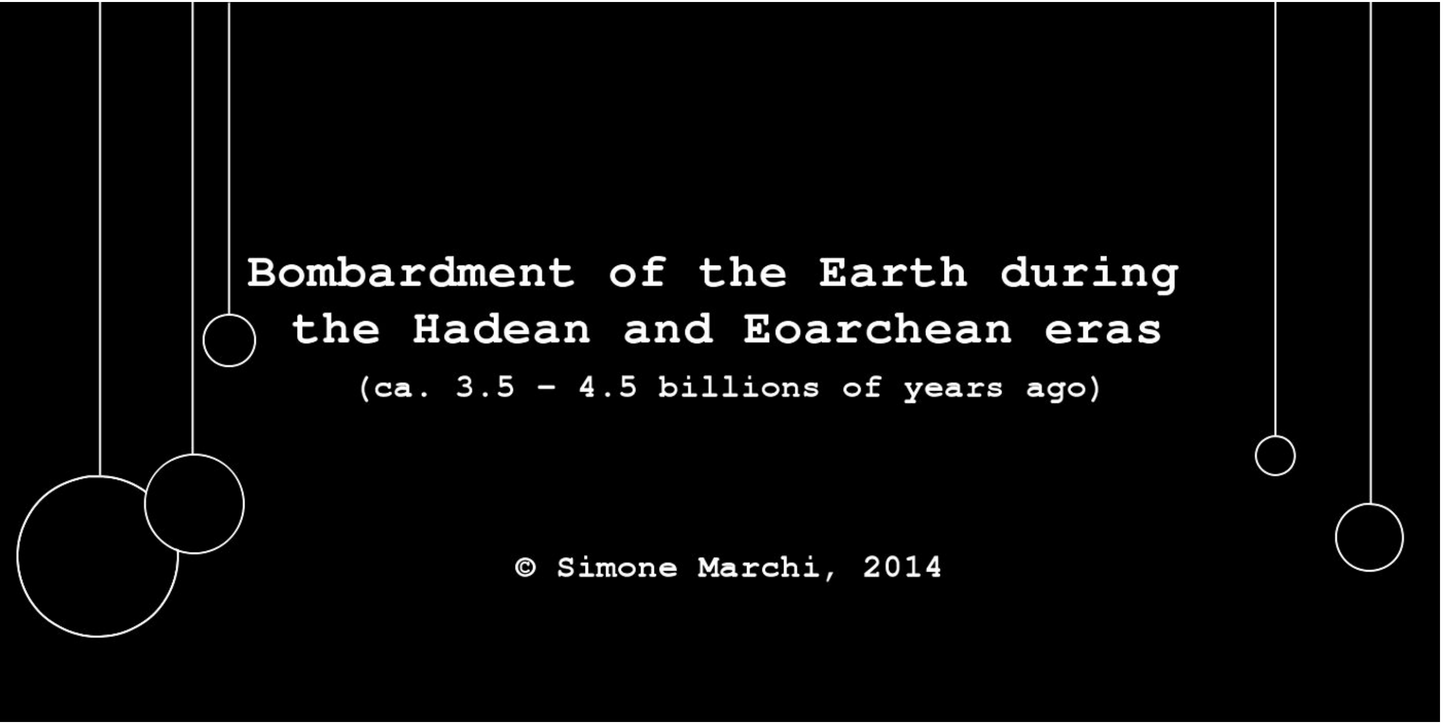


Scheiner
Clavius
Maginus



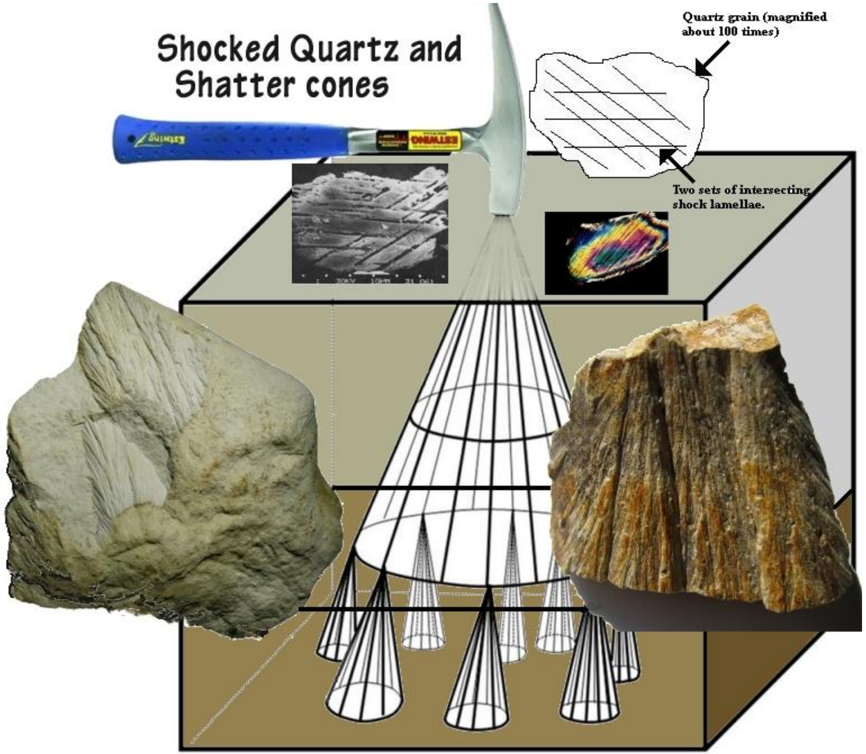
http://www.lpi.usra.edu/nlsi/HadeanEarth/ © Simone Marchi

S. Marchi, W. F. Bottke, L. T. Elkins-Tanton, M. Bierhaus, K. Wuennemann, A. Morbidelli, and D. A. Kring (2014), *Nature* 511, pp. 578–582

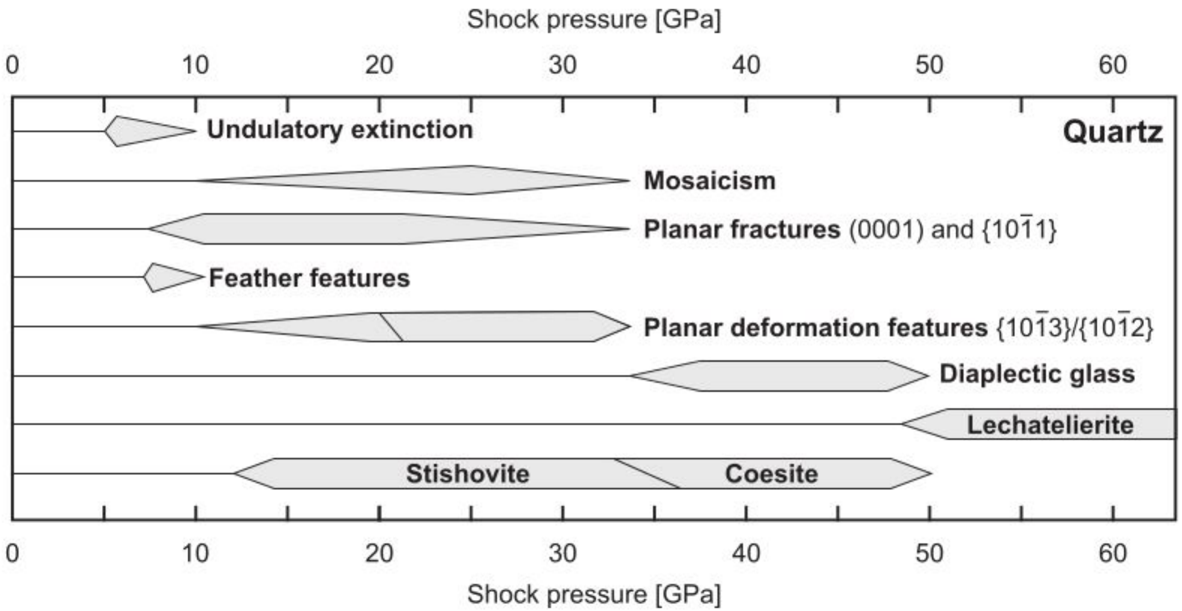
Megascopic features

Shatter cones from the Ries crater (D)

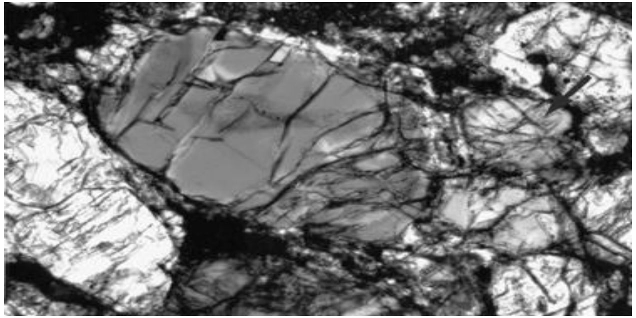
Megascopic features



Microscopic features



-Undulose extinction



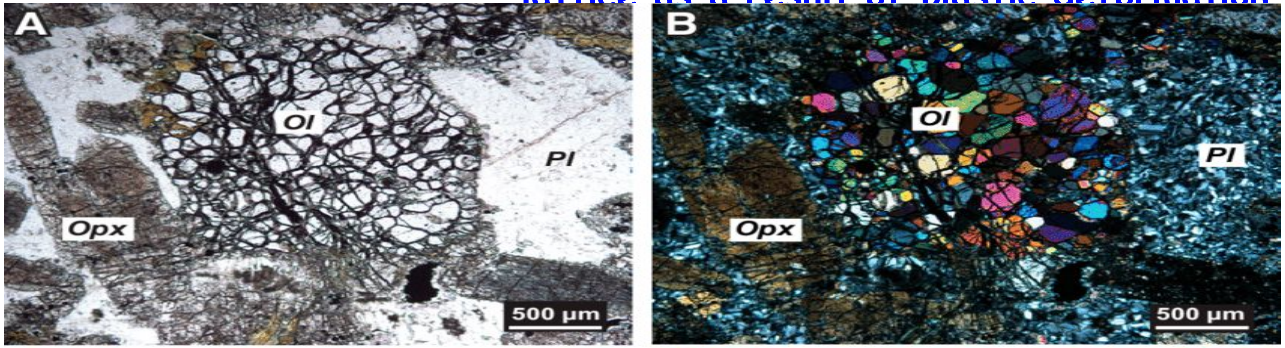
Olivine showing weak undulose extinction In the framville chondrite (H6).

A crystal showing undulose extinction has somewhat non-uniform extinction caused by slight-to-moderate misorientation of the crystal lattice as a result of Plastic deformation.

-Mosaicism

Olivine showing weak undulose extinction In the framville chondrite (H6).

A crystal showing mosaic extinction has patchy extinction caused by moderate-to-large misorientation of the crystal lattice as a result of plastic deformation.



-Planar Deformation Features

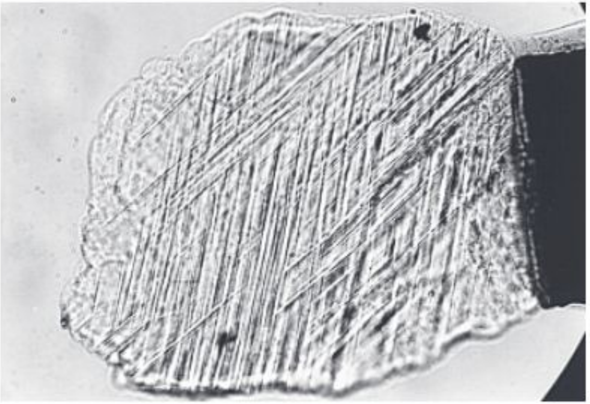


Fig. 4.17. Quartz; multiple PDFs, fresh. Small quartz grain (0.20 mm long) from K/T boundary ejecta layer, showing two prominent sets of fresh (undecorated) PDFs. (Small dots with halos are artifacts.) Specimen from Starkville South, a few kilometers south of Trinidad, Colorado. Photograph courtesy of G. A. Izett. Spindle stage mount (plane-polarized light).

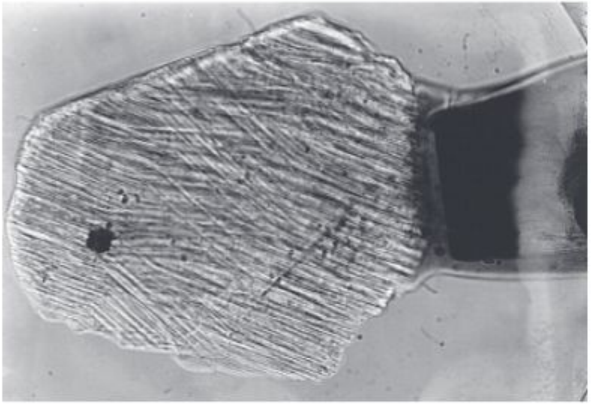
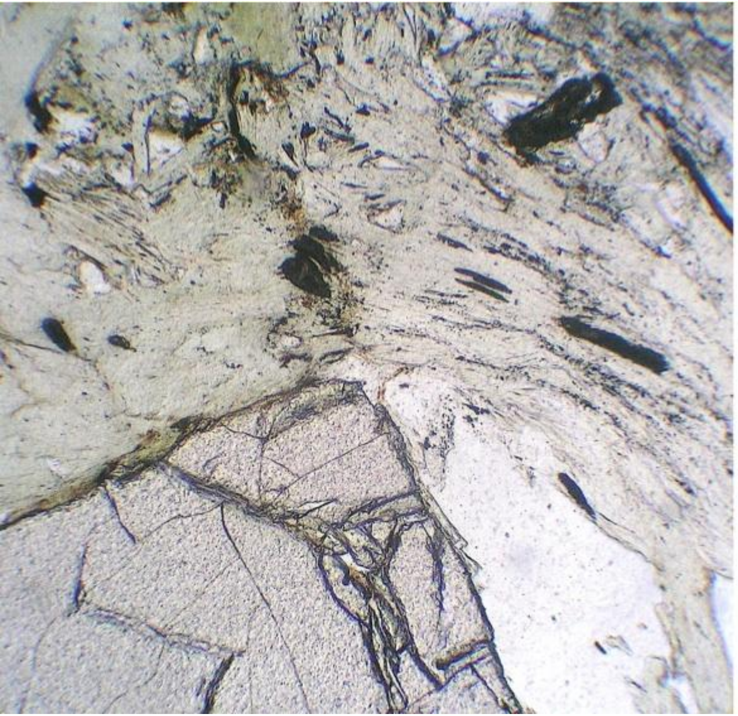
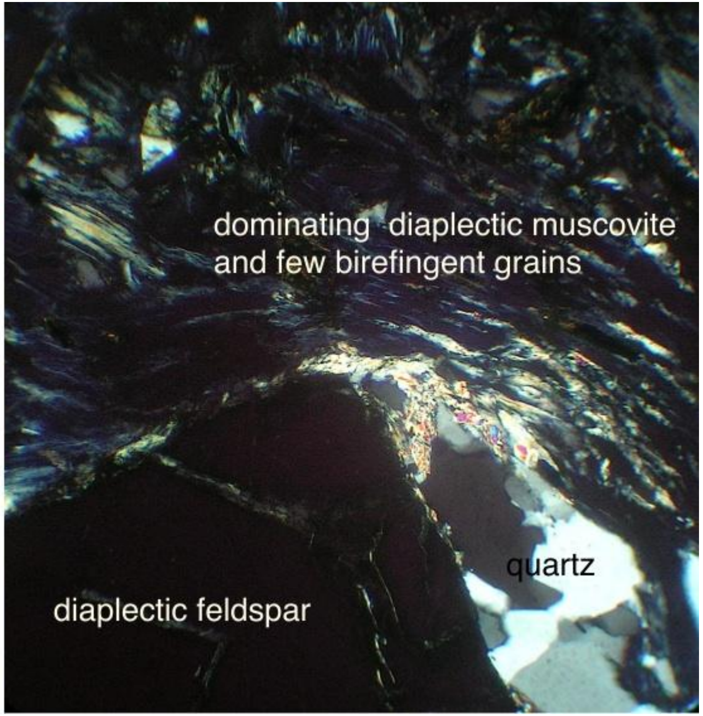


Fig. 4.18. Quartz; multiple PDFs, fresh. Small quartz grain (0.36 mm long) from K/T boundary ejecta layer, containing one opaque inclusion and multiple (3–5?) prominent sets of fresh (undecorated) PDFs. Specimen from Clear Creek North, a few kilometers south of Trinidad, Colorado. Photograph courtesy of G. A. Izett. Spindle stage mount (plane-polarized light).

-Diaplectic glass





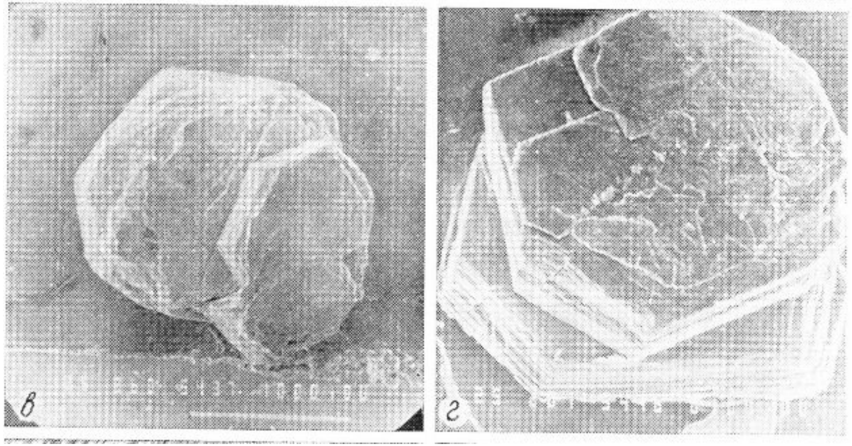
The passage of a shock wave can cause a solid-state amorphization

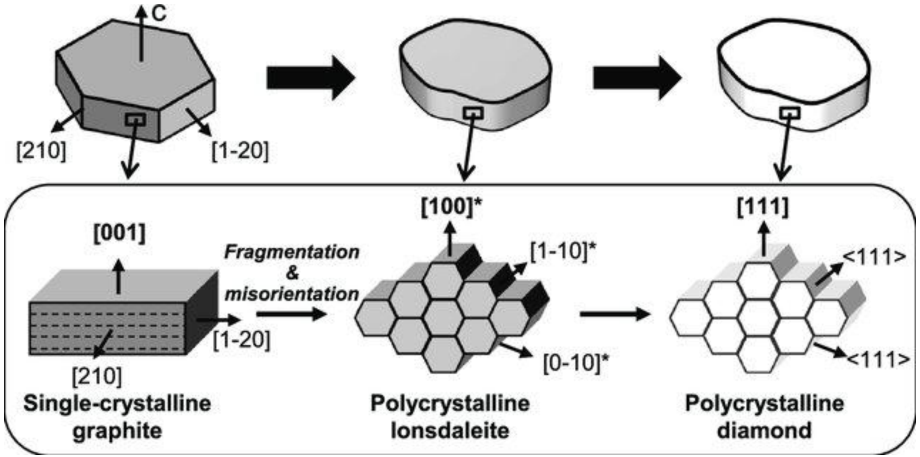
No melting features (flow) observed

Pre-existing fractures and cleavages can be preserved

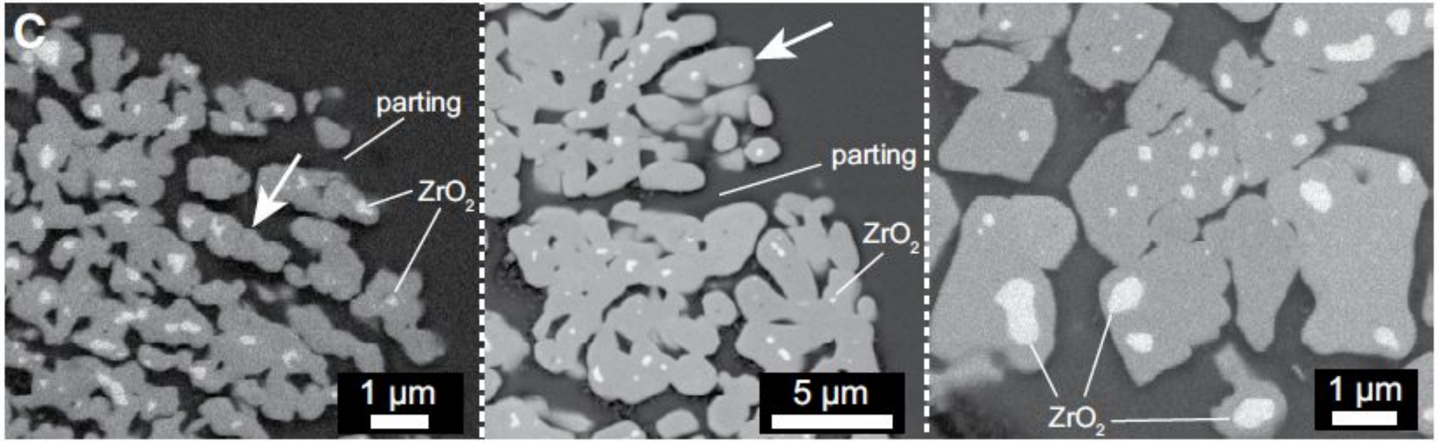
-Polimorphic transformation

Diamond paramorph on graphite





-Thermal decomposition



The heat produced by the passage of a shock wave can trigger a thermal decomposition

e.g. $ZrSiO_4 \longrightarrow ZrO_2 + SiO_2$ @ 1673 °C
typical also of fulgurites

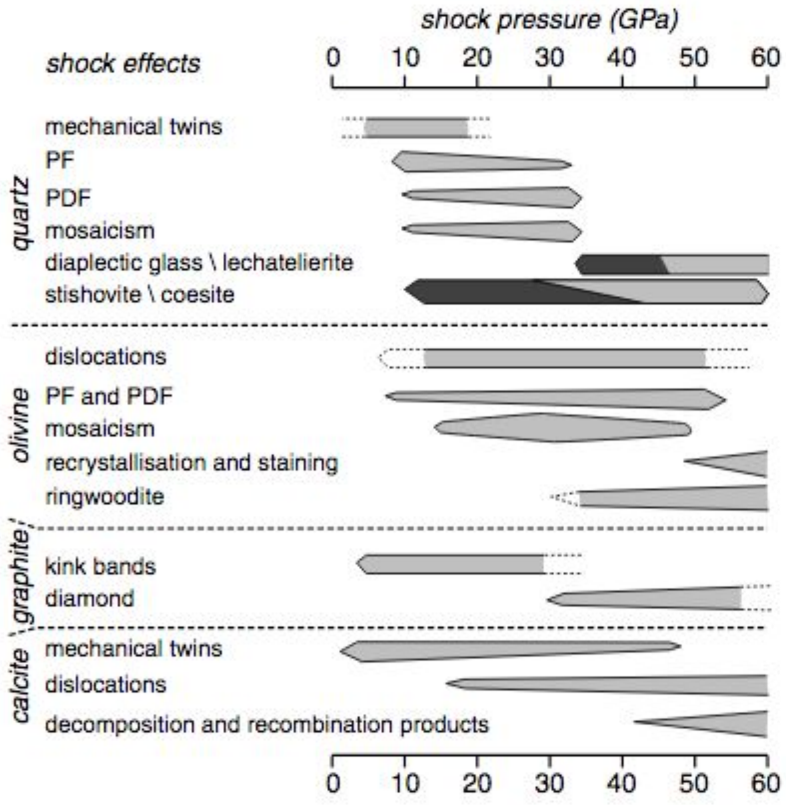
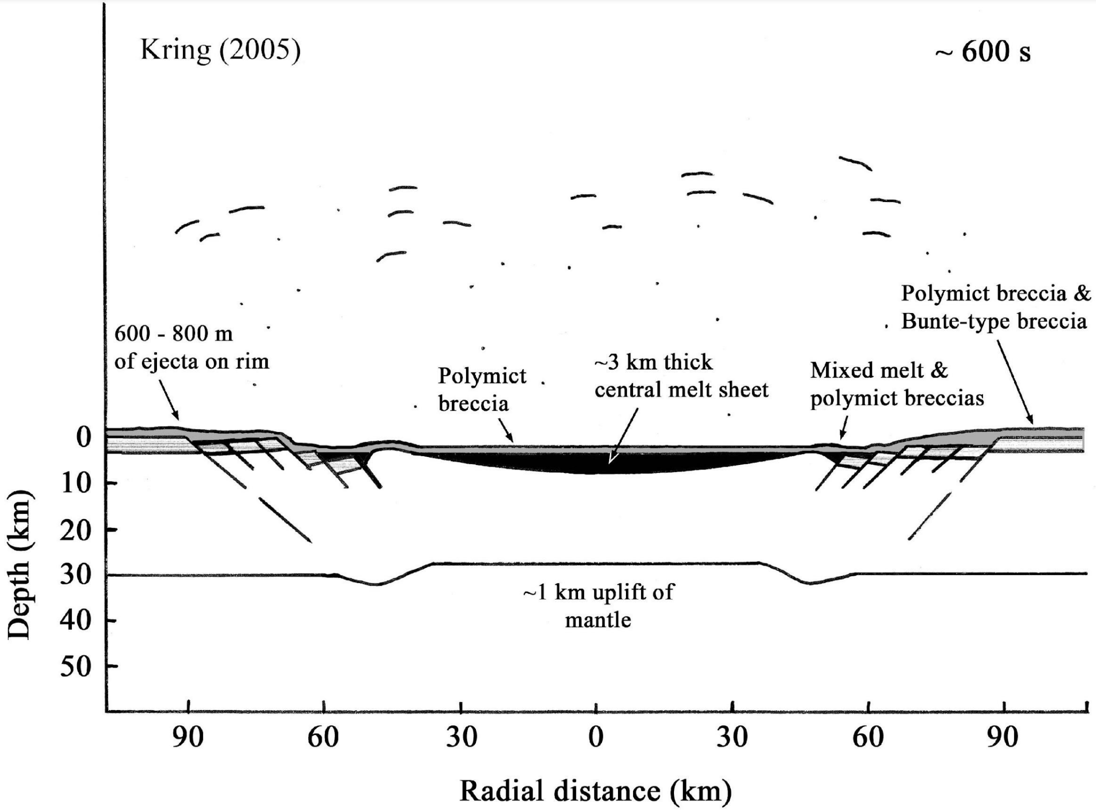


Fig. 6. Compilation of the pressure intervals over which certain shock effects are formed in quartz, olivine, graphite and calcite (modified after Stöffler and Langenhorst 1994 and Langenhorst and Deutsch 1998). The diagram is based on shock experiments with non-porous samples.

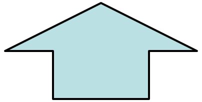
IMPACT MELT BODIES



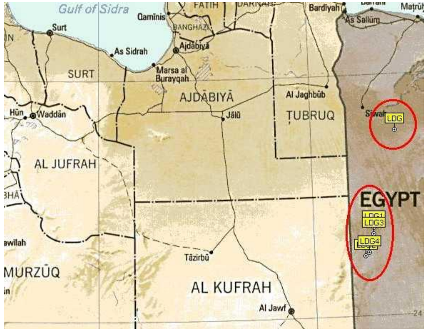
Impact melting can profoundly affect crust evolution in the early stages of planet formation

IMPACT MELT EVOLUTION?

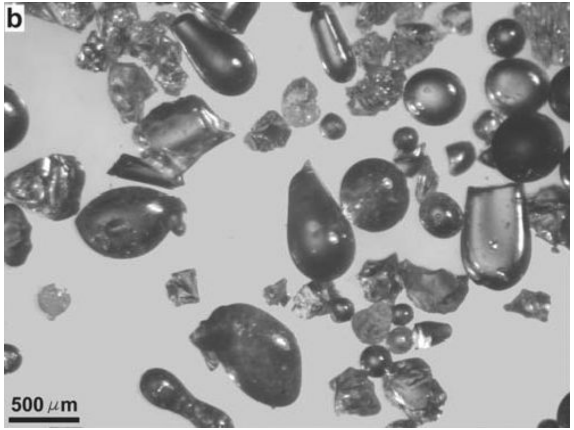
- MELT PHYSICAL PROPERTIES evolution:
- DENSITY
- VISCOSITY



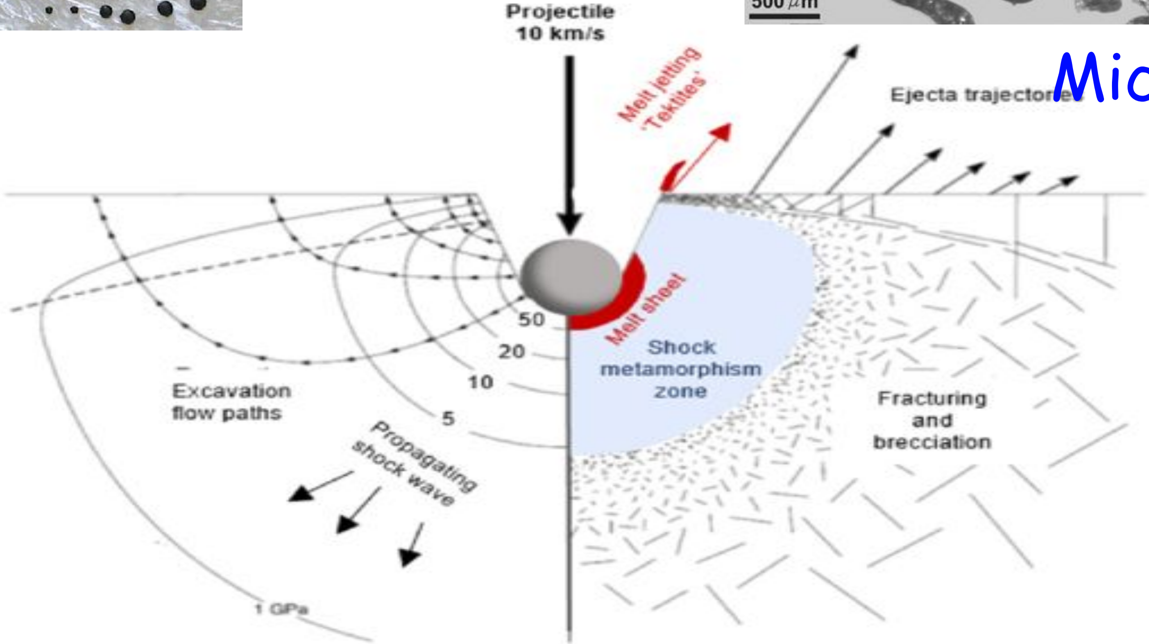
- Melt composition, P, T
- Redox conditions [$Fe^{3+}/(Fe^{2+} + Fe^{3+})$];
- Water content.


Gulf of Sidra
Qaminis
Surt
As Sidrah
Ajdabiya
Marsa al Burayqah
SURT
AJDABIYA
Al Jaghbub
TUBRUQ
Jalu
Hun
Waddan
Bardiyah
As Sallum
Matruh
Siwah
LDG
AL JUFRAH
EGYPT
LDG1
LDG3
LDG4
Tazirbu
MURZUQ
AL KUFRAH
Al Jawf

Tektites

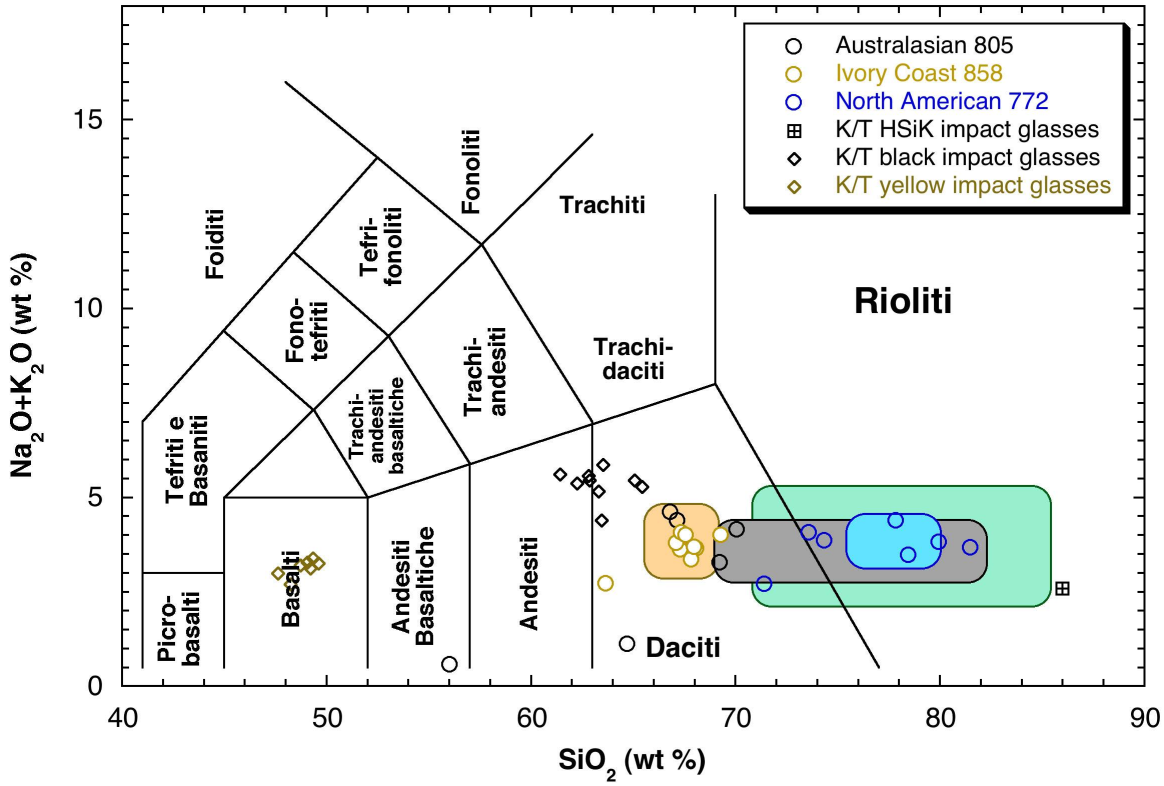


Microtektites

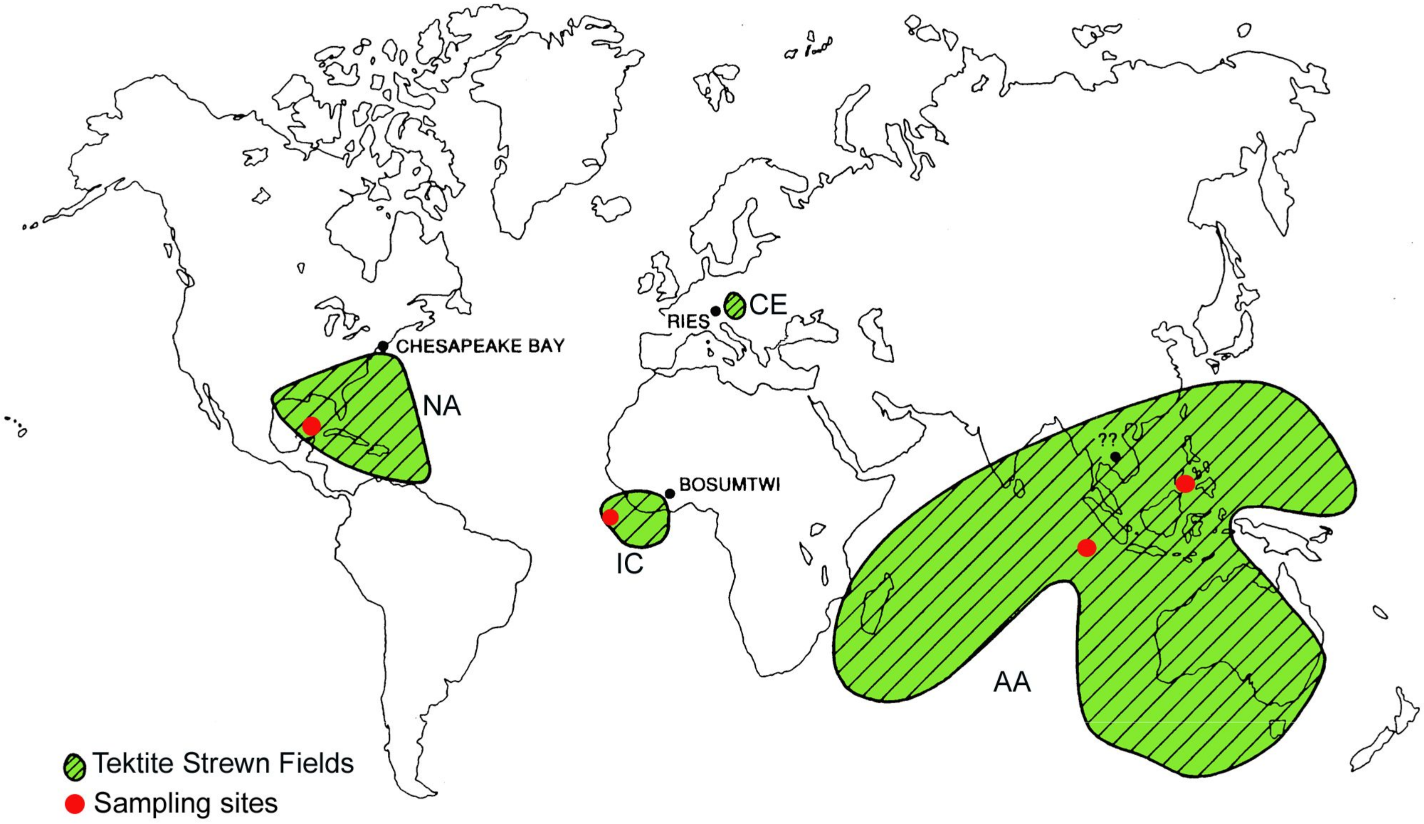


Belza, J. & Goderis, Steven & Vanhaecke, Frank & Claeys, Philippe. (2012). Spatially resolved geochemistry of K-Pg impact spherules. Geochimica et Cosmochimica Acta. 788-

Microtektite and impact glass composition



Tektites



CE
RIES
CHESAPEAKE BAY
NA
BOSUMTWI
IC
??
AA
Tektite Strewn Fields
Sampling sites

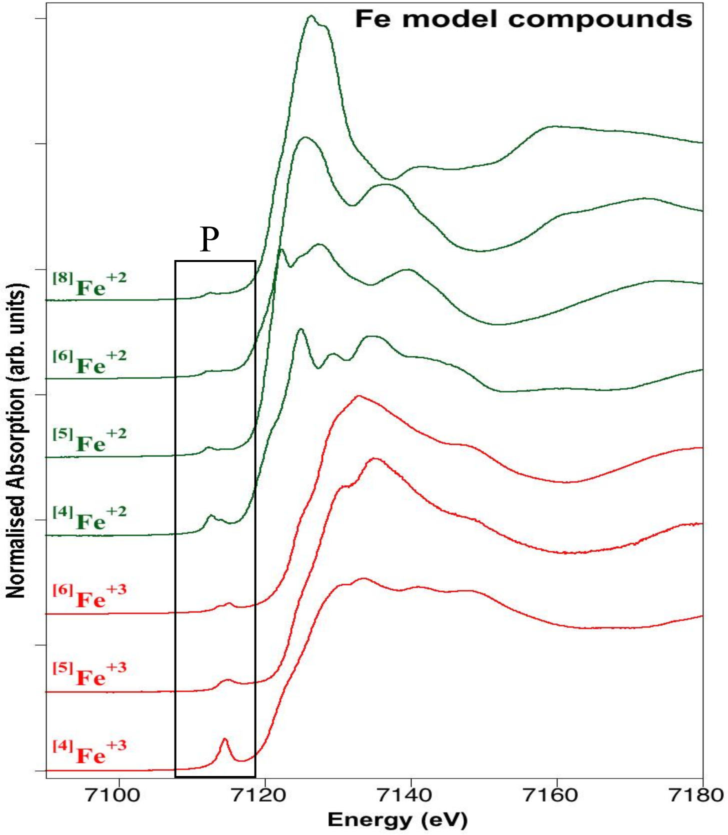
Effect of impact cratering on the planetary crust?

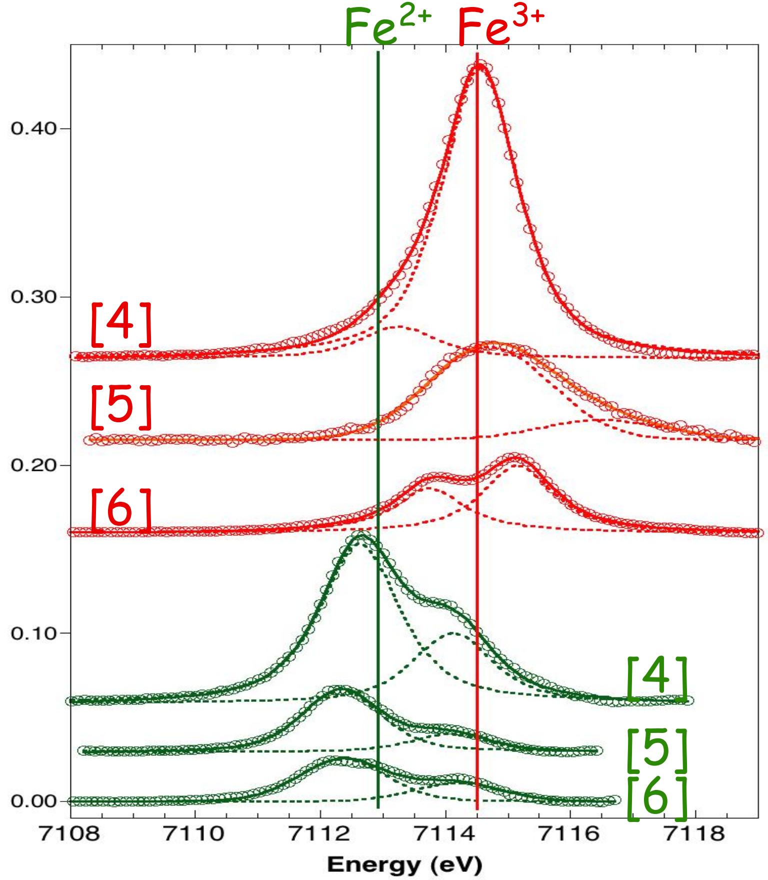
- Effect of impact cratering on melt:
  - melt redox: $Fe^{3+}/(Fe^{2+} + Fe^{3+})$;
  - melt water content.

- Transport processes of melt droplets

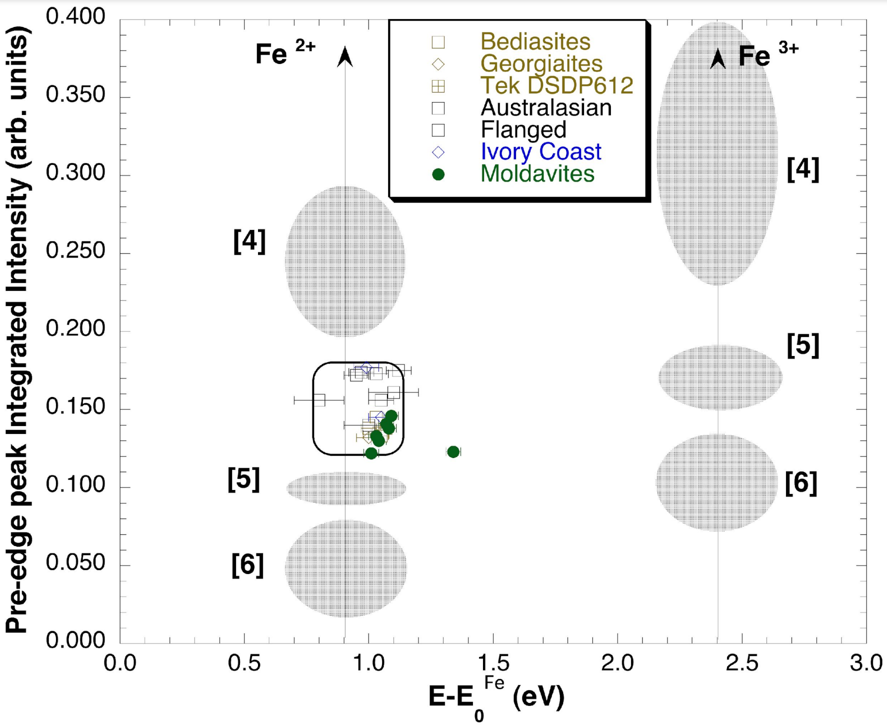
Analytical technique

Element selective technique able to analyse Fe redox also in diluted/small samples





Tektites



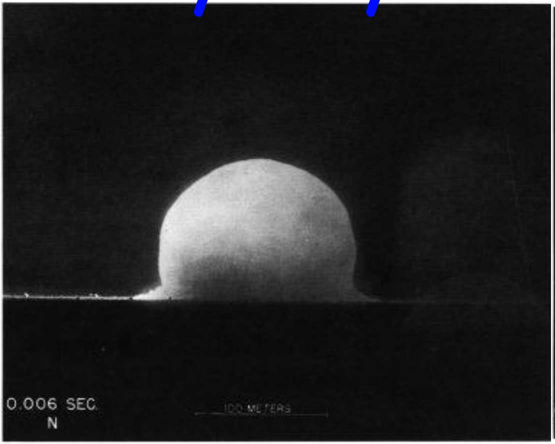
$Fe^{3+}/(Fe^{2+} + Fe^{3+}) \approx 0.05 \div 0.15$ (±0.03). Rarely up to 0.2

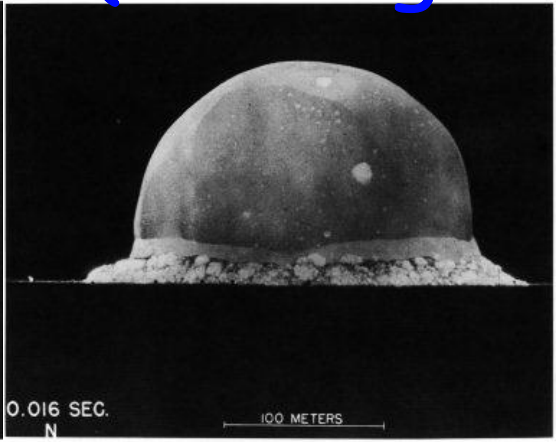
G. Giuli, G. Pratesi, E. Paris, C. Cipriani (2002) *Geochimica et Cosmochimica Acta*, **66**, 4347-4353.

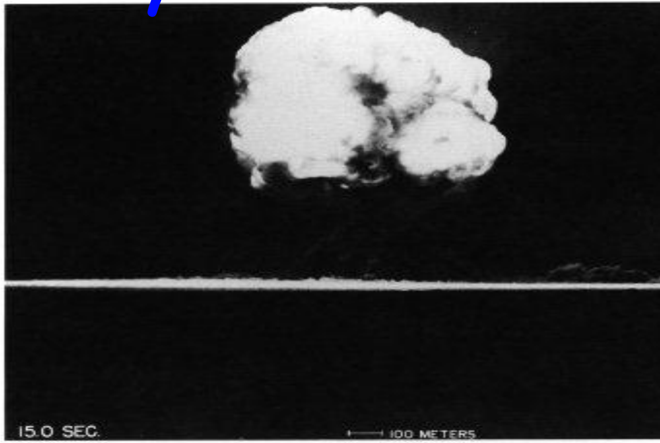
G. Giuli, G. Pratesi, S.G. Eeckhout, C. Koeberl, E. Paris, (2010a) *Geological Society of America Special Paper*, 465, 653-660.

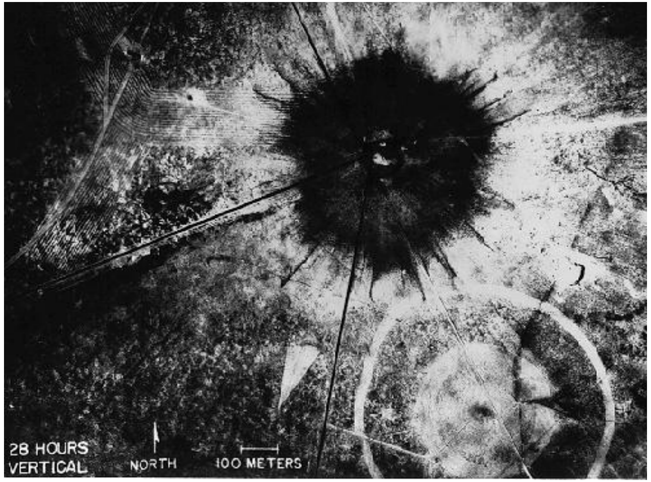
G. Giuli, S.G. Eeckhout, M.R. Cicconi, C. Koeberl, G. Pratesi, E. Paris, (2010b) *Geological Society of America Special Paper*, 465, 645-651.

Trynity site (Alamogordo) July 16 1945

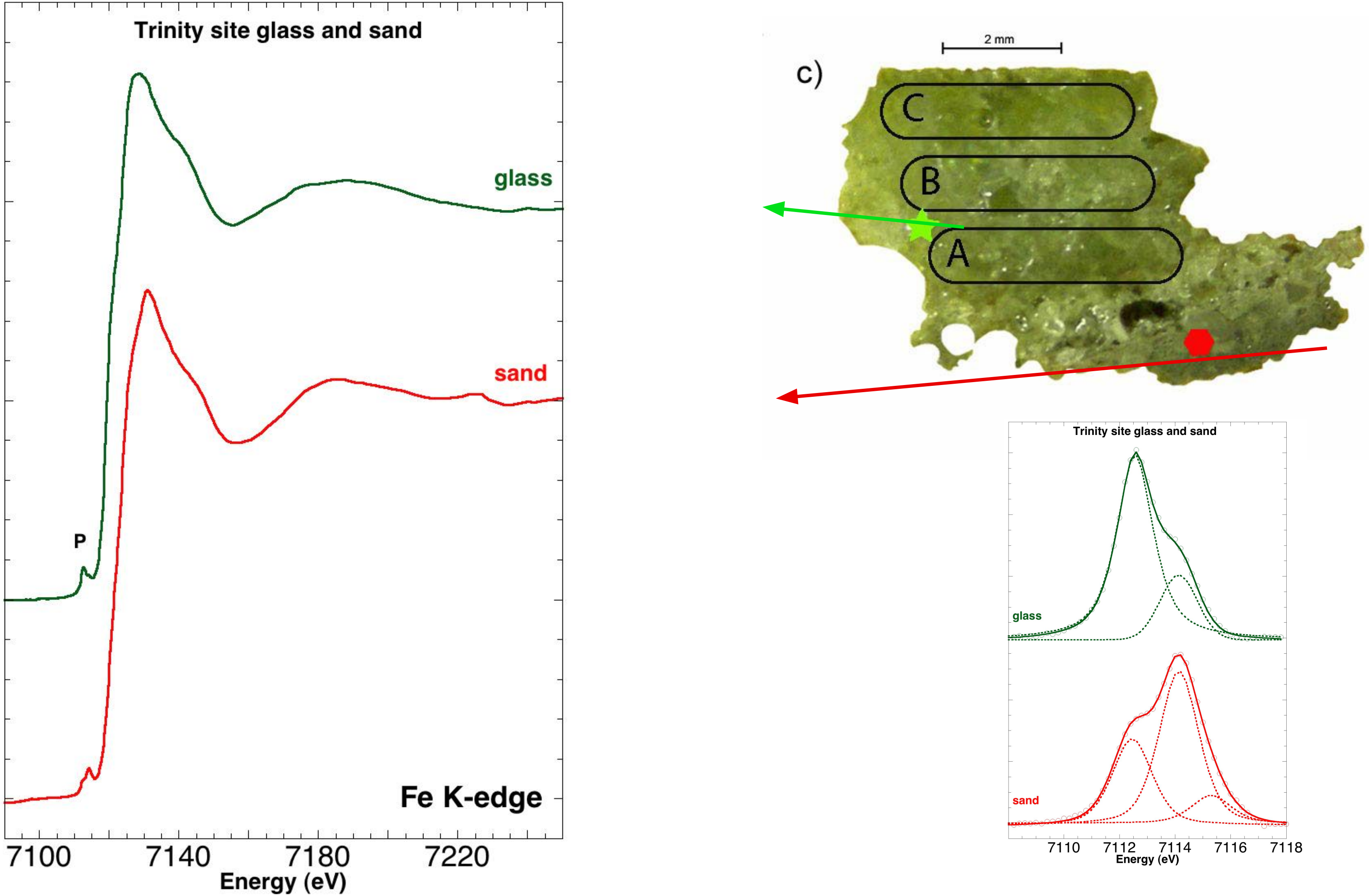




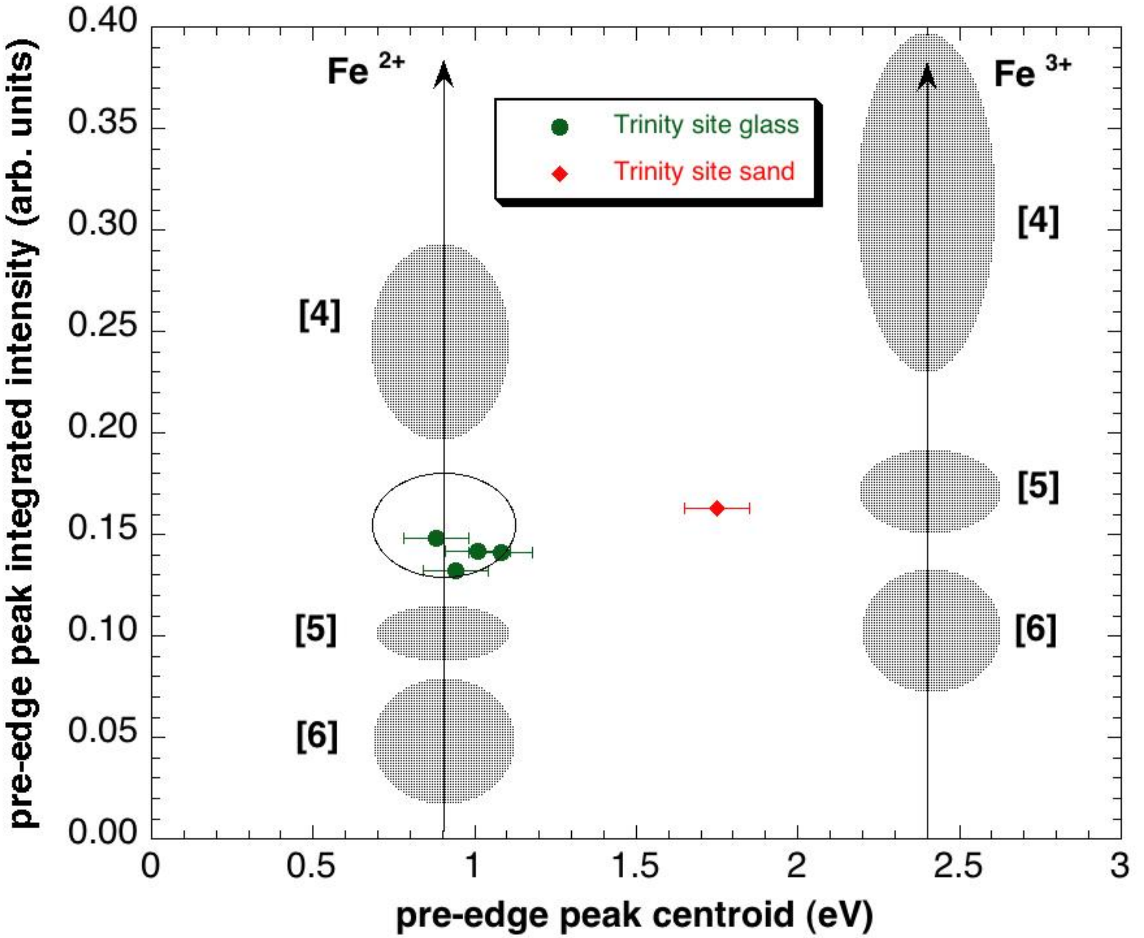




Source: http://www.nucleararchive.com/Photos/Trinity/image8.shtml



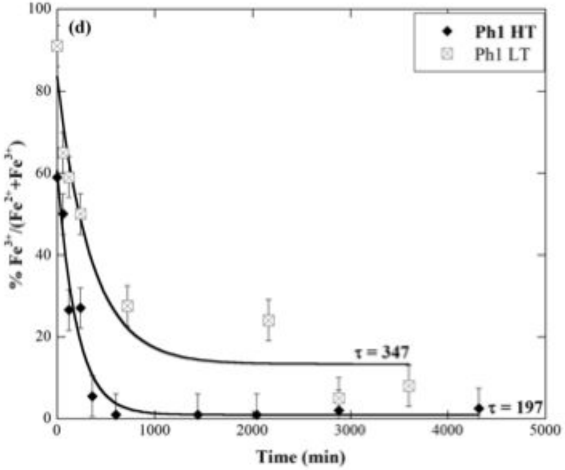
Trinity site glass and sand
glass
sand
P
Fe K-edge
7100
7140
7180
7220
Energy (eV)
2 mm
c)
C
B
A
Trinity site glass and sand
glass
sand
7110
7112
7114
7116
7118
Energy (eV)

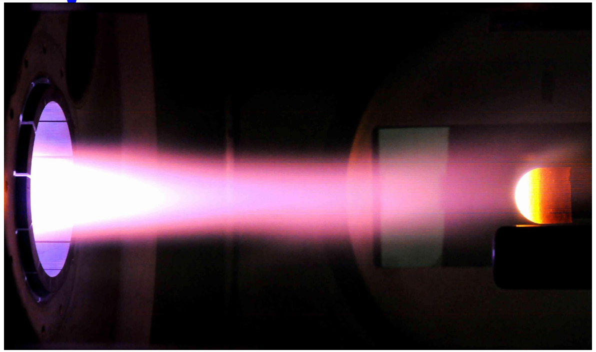


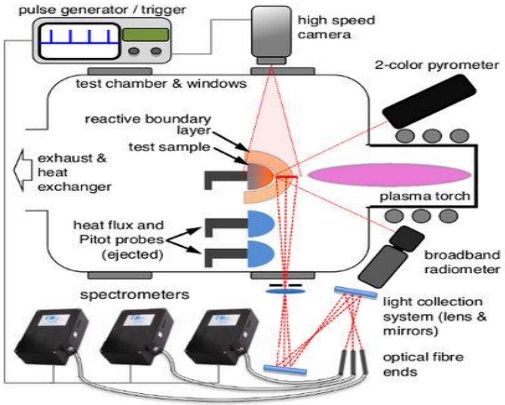
-Massive reduction in molten rock from the first atomic bomb test (Alamogordo, USA)

G. Giuli, G. Pratesi, S.G. Eeckhout, C. Koeberl, E. Paris, (2010) *Geological Society of America Special Paper* **465**, 653-660.

A matter of speed





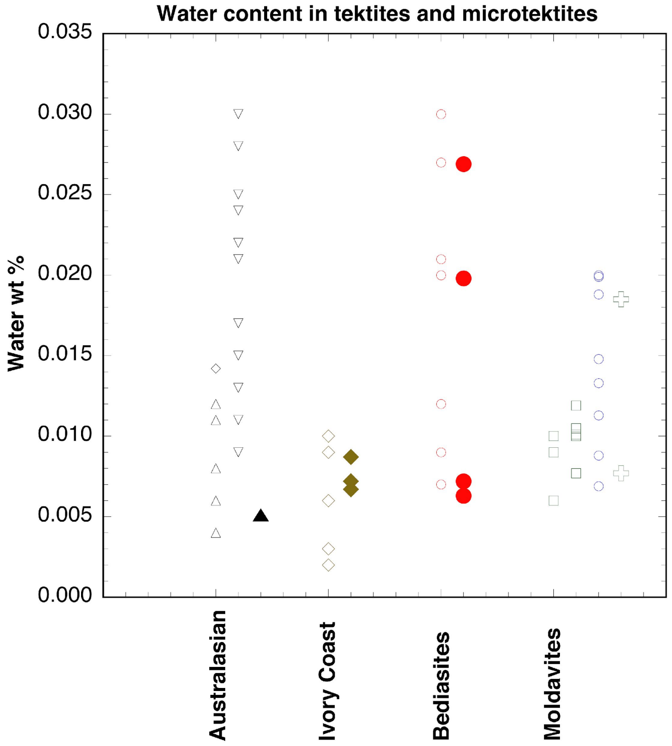


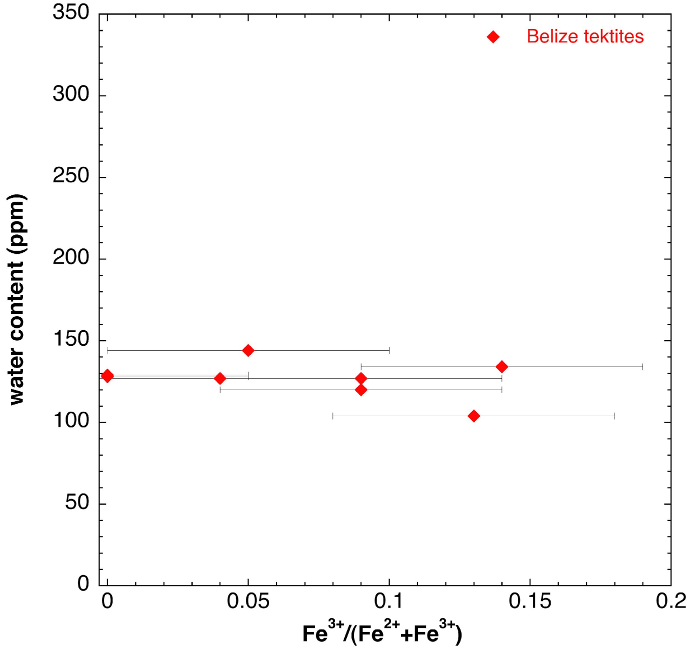
Magnien, V., et al. (2006) Journal of Nuclear Materials, 352, 190–195.
Magnien, V., et al. (2008) Geochimica et Cosmochimica Acta, 72, 2157–2168.
Cicconi et al. (2015) Amer. Mineral, 100, 1610-1619
Cicconi et al. (2015) Amer. Mineral, 100, 1013-1016

$Fe^{3+}/(Fe^{2+}+Fe^{3+})$ 0.11-0.17 ±0.05

Pittarello et al. (2019) Icarus 331, 170-178

Water content





Beran A., and Koeberl, C. (1997) Meteoritics & Planetary Science, 32, 211-216
Gilchrist J., Thorpe A.N., and Senftle F.E. (1969) Journal of Geophysical Research, 74, 1475-1483.
Giuli G., Cicconi M. R., Eeckhout S. G., Koeberl C., Glass B. P., Pratesi G., Cestelli-Guidi M., and Paris E. (2013). *Am. Mineral. 98, 1930-1937*
Giuli G., Cicconi M. R., Eeckhout S. G., Koeberl C., Glass B. P., Pratesi G., Cestelli-Guidi M., Carroll MR and Paris E. (2013). *Acta Minerl Petr.. **6**, 777*
Giuli, G., Cicconi, M.R., Stabile, P., Trapananti, A., Pratesi, G., Cestelli-Guidi, M., Koeberl, C., (2014). LPI Contribution, **1777**, .2322.

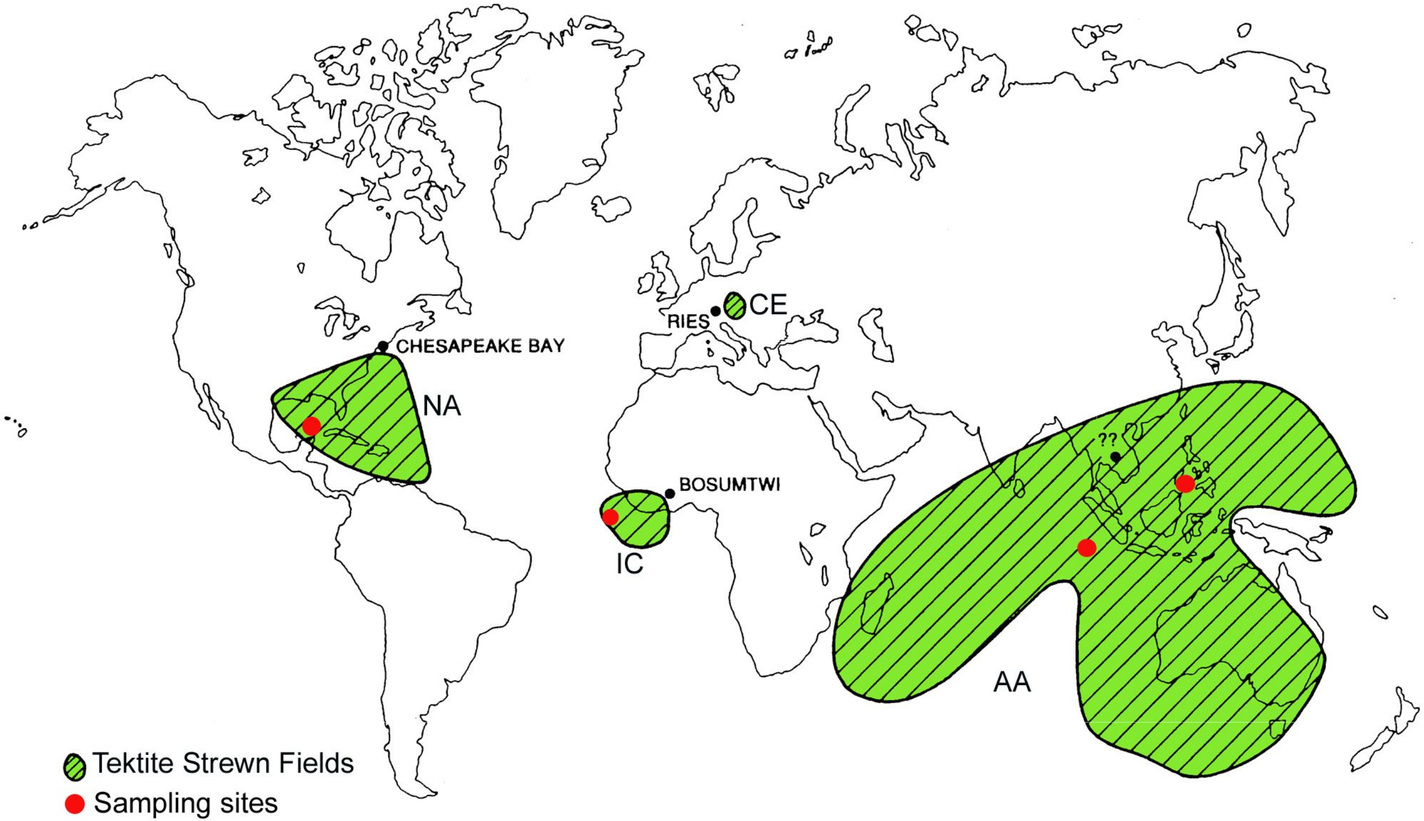
Tektites:

-tektites have been homogeneously reduced from a presumably a wide range of Fe oxidation state in the target rock down to almost exclusively divalent.

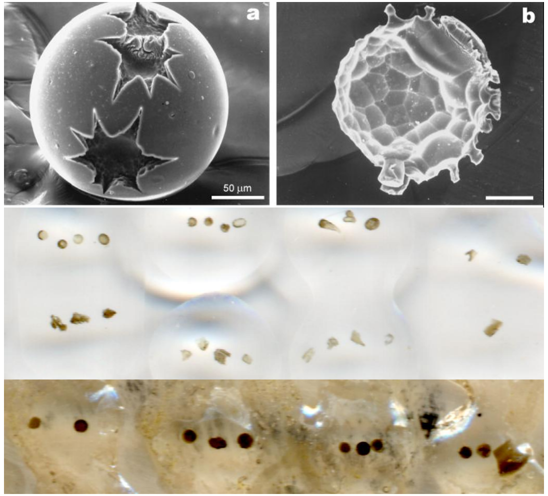
-No significant variations have been found according to impact age, target rock composition.

-G. Giuli, G. Pratesi, E. Paris, C. Cipriani (2002) *Geochimica et Cosmochimica Acta*, **66**, 4347-4353.
-G. Giuli, G. Pratesi, S.G. Eeckhout, C. Koeberl, E. Paris, (2010a) Large Meteorite Impacts and Planetary Evolution: *Geological Society of America Special Paper*, 465, 653-660.
-Giuli, G., Cicconi, M.R., Stabile, P., Trapananti, A., Pratesi, G., Cestelli-Guidi, M., Koeberl, C., (2014). LPI Contribution, **1777**, .2322.

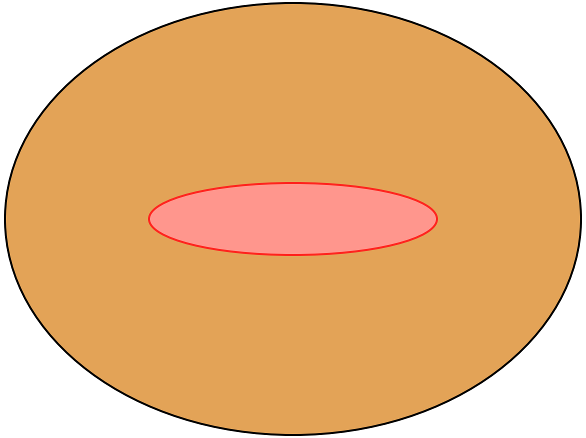
Microtektites



Microtektites



X-ray Beam



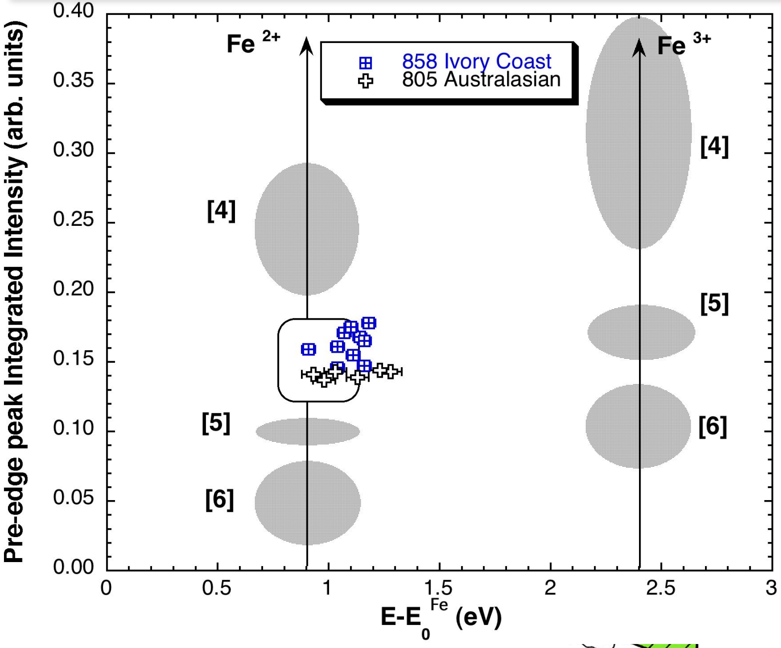
400-800 µm
Polished surfaces

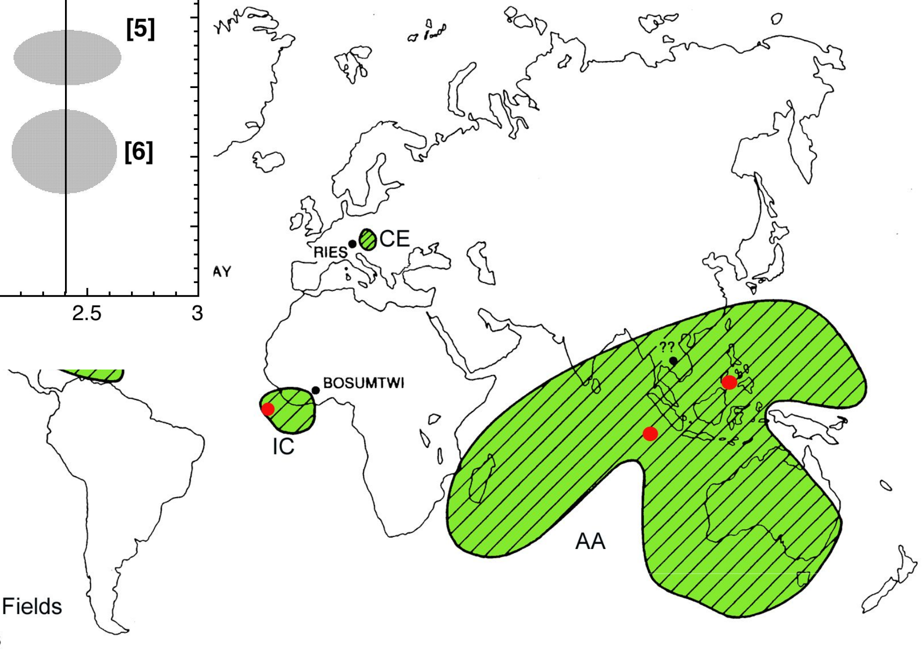
Microprobe mount

50 x 120 µm

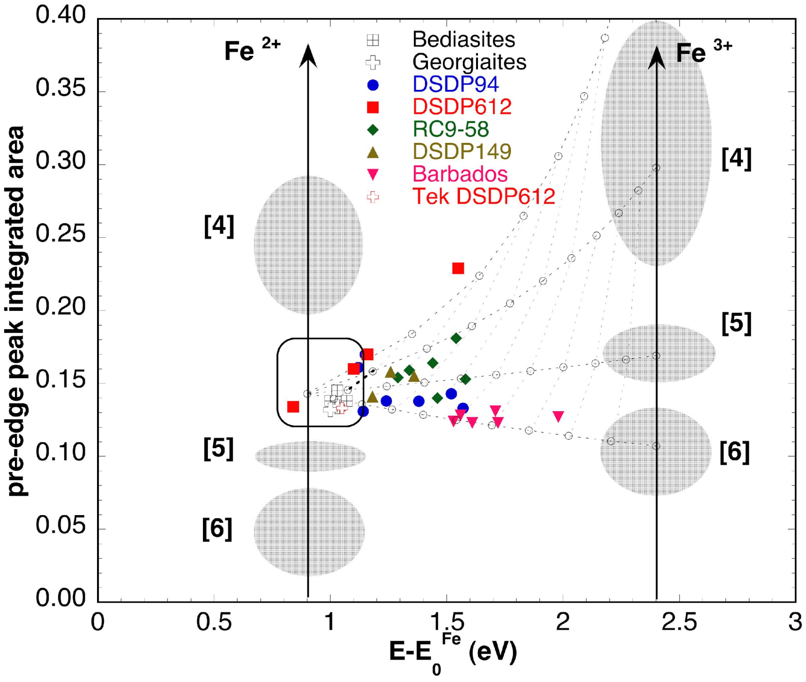
Sample at 45° from beam

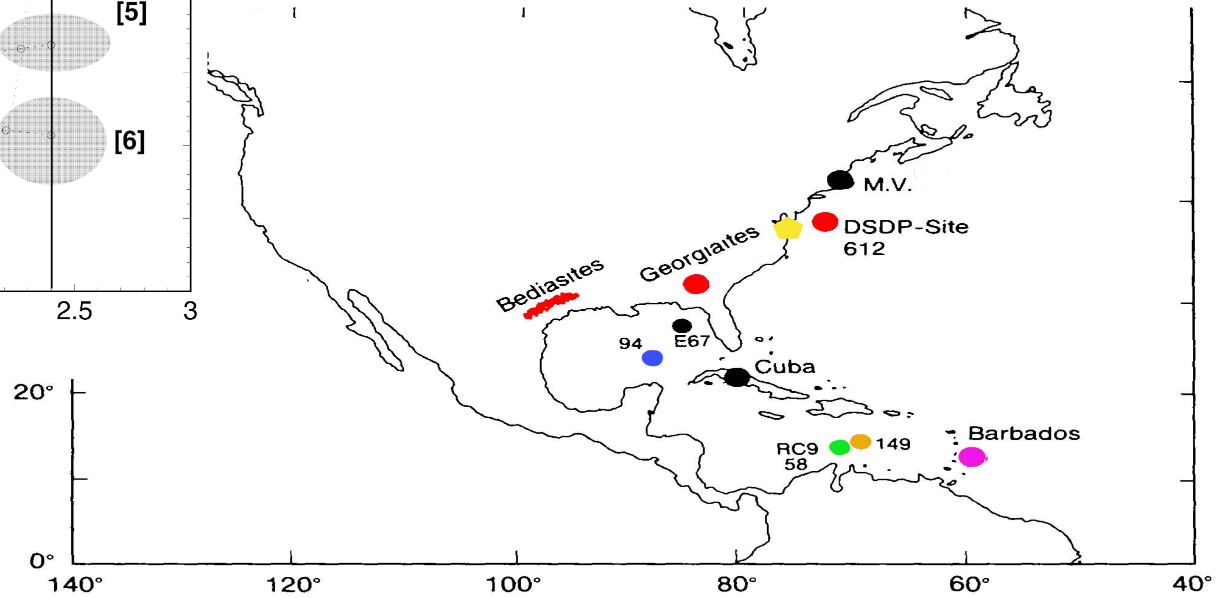
IC - AA Microtektites

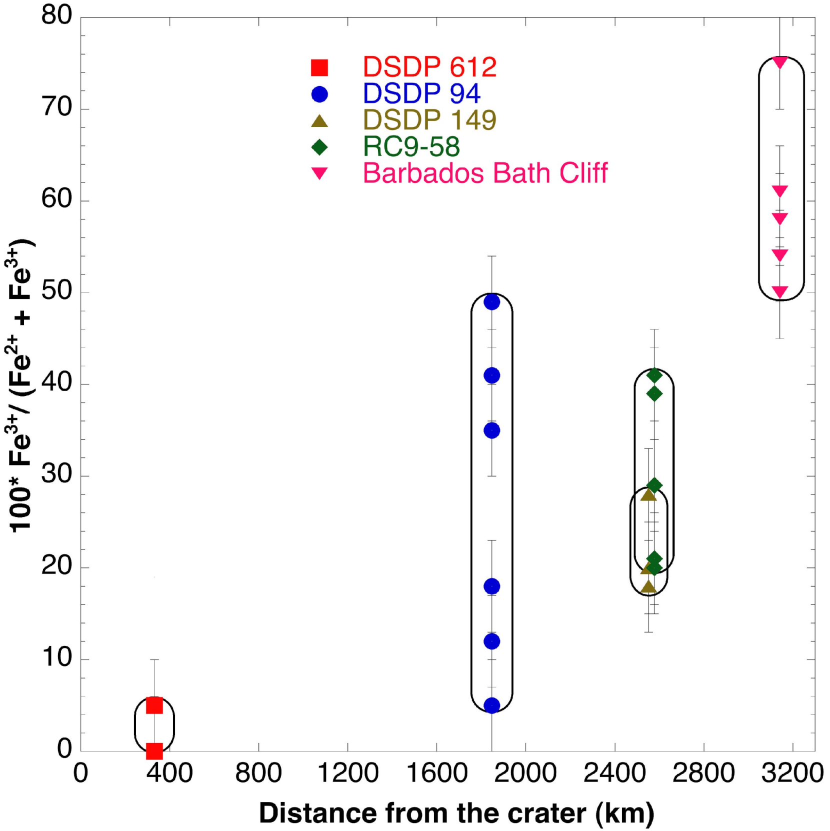




NA Microtektites







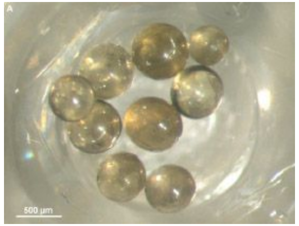
Distance from crater →

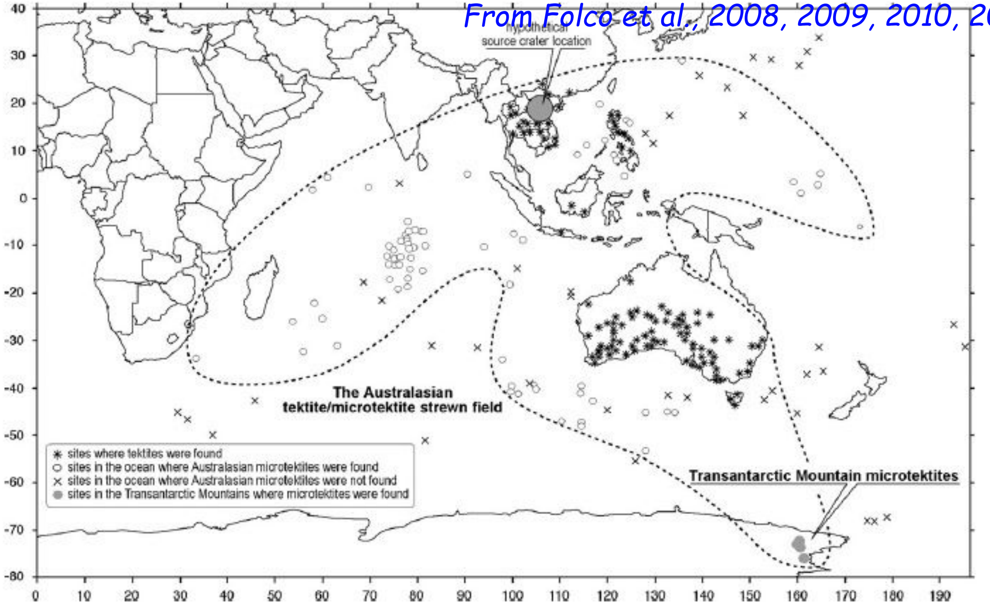
G. **Giuli**, S.G. Eeckhout, M.R. Cicconi, C. Koeberl, B.P. Glass, G. Pratesi, E. Paris, (2012) *GCA* (submitted)

TAM Australasian Microtektites

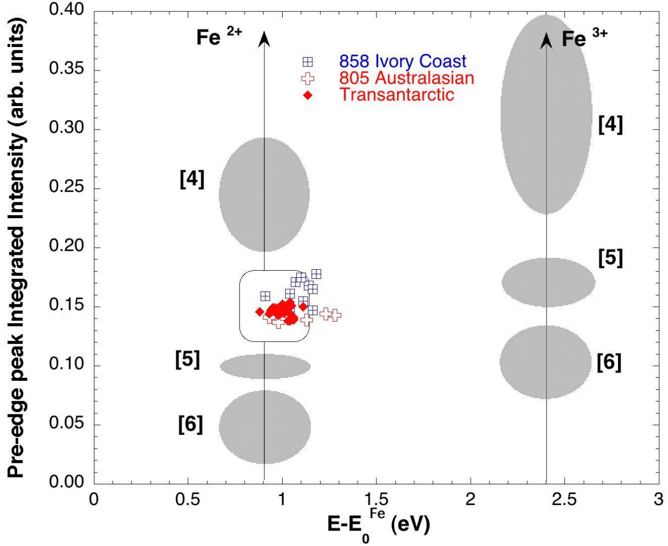
Comparable chemistry
Same age
Volatilisation trend vs. distance from crater

From Folco et al., 2008, 2009, 2010, 2011





TAM Australasian Microtektites



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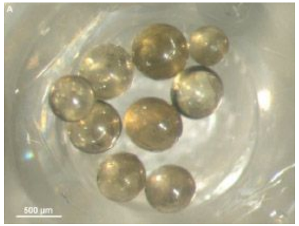
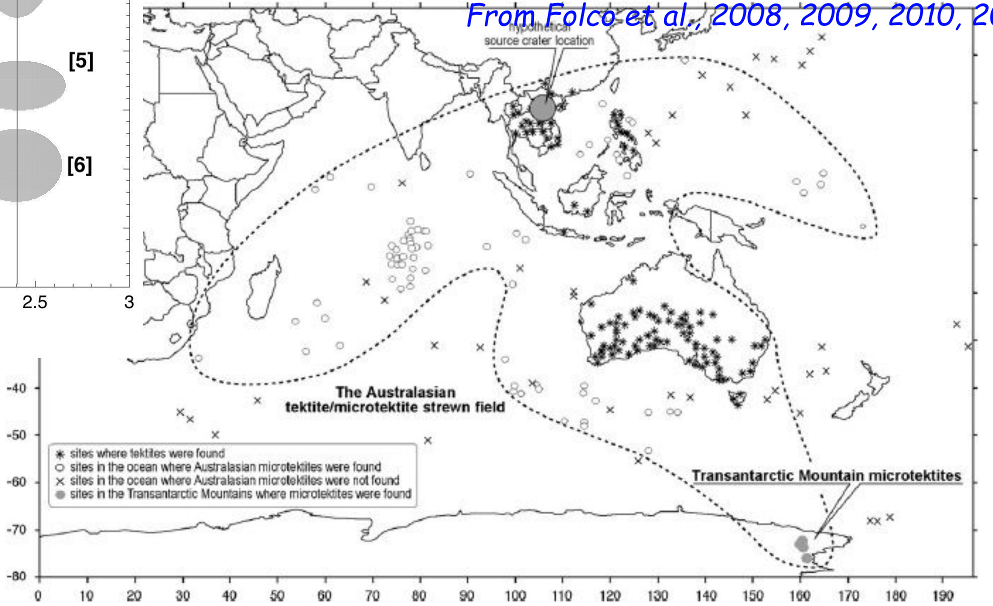




Same Fe redox ratio as AU microtektites

No oxidation during flight

Microtektites

-

- In **Australasian** and **Ivory Coast** microtektites Fe is essentially divalent

- In **North-American** microtektites $Fe^{3+}/(Fe^{2+} + Fe^{3+})$ ratio ranges from 0 to 50% (correlation with distance)

- Possible differences in the formation/transport mechanisms with tektites?

Dellen (Sweden)

-rhyolite impact melt rocks (90-140 My old)

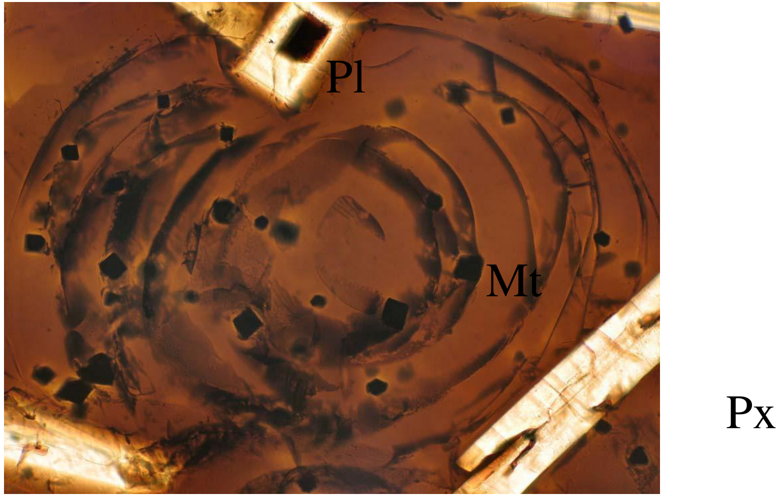
- ≈200-500 m thickness of impact melt body

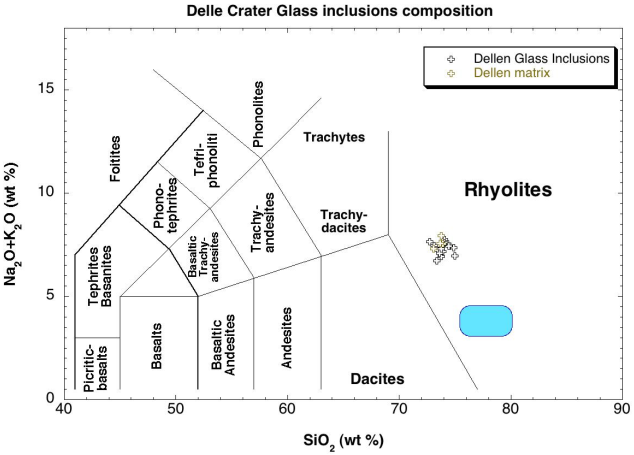
- glacially eroded

- melt evolution?

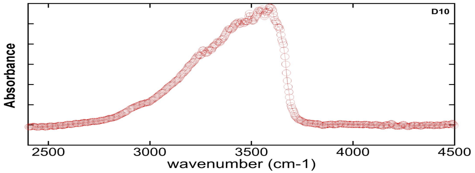
Henkel et al., 1992, Tectonophysics, 216, 31-40;
Deutch et al., 1992, Tectonophysics, 216, 205-218; Mark et al., 2014

Dellen impact melt (Sweden)

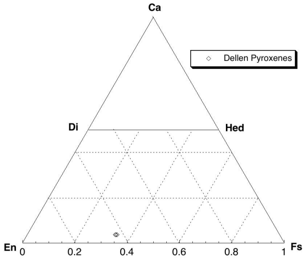


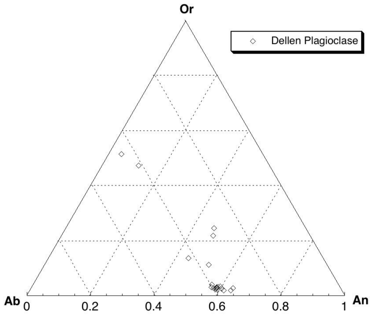


- water = 1.47 ± 0.3 wt%



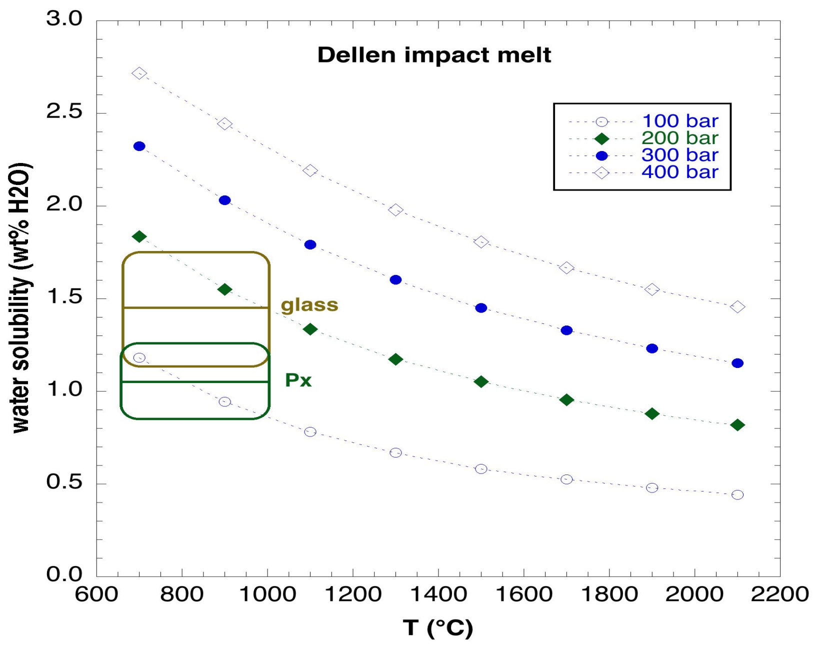
- P, T ?
- origin ?

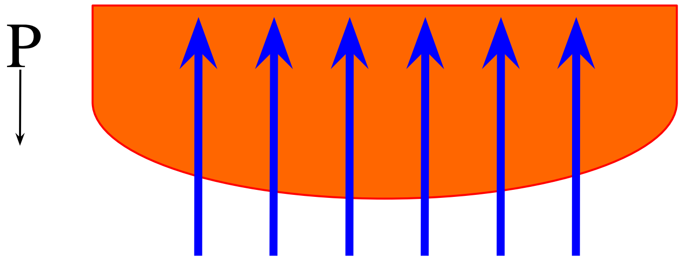




Magma water content from pyroxene/glass

Using the partition coefficient of Tenner et al (2009) we calculated a value of 1.04 ± 0.21 wt% of H_2O^T for the melt in equilibrium with pyroxene.





Water from fractured rock
Flows through the melt

H_2O solubility calculated according to Papale (1999) model; viscosity according to GRD (2006) model

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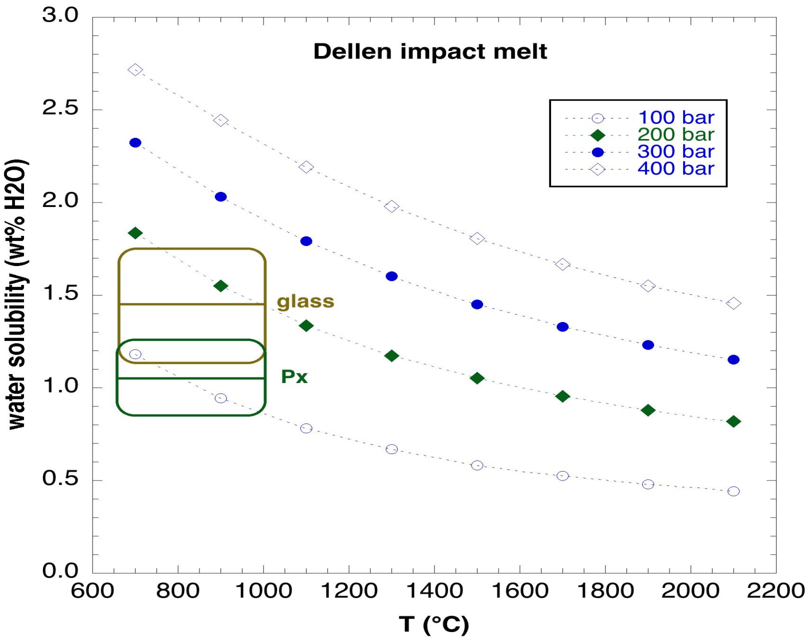
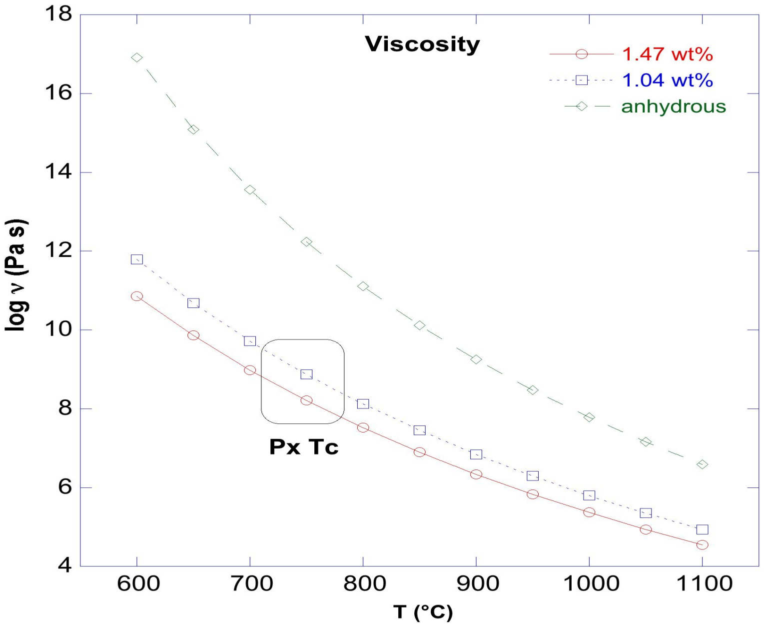




H_2O solubility calculated according to Papale (1999) model; viscosity according to GRD (2006) model

Dellen impact melt (Sweden)

- Dellen rhyolitic glass contains 1.47 ± 0.3 wt% water
- OH content of pyroxenes = 98 ppm OH

  Resulting in melt water content of 1.04 wt% ± 0.21

- we interpret this water to originate from volatiles released by the shocked basement, diffusing through the impact melt
- water content of impact melt is essential in order to correctly model melt viscosity, density, and evolution

Conclusions

- impact cratering is a geologic process which has been very intense in the first billion y
- affect planetary surfaces both morphologically and chemically
- Impact melt formation can potentially affect crustal evolution
- water content of impact melt is essential in order to correctly model melt viscosity, density, and evolution
- Important implications to model the role of impact melts on water mobilization in planetary crusts

Thank you for your attention!

Carancas, Perú, 2007

Thanks to:

G. Pratesi, M. Corazza, C. Cipriani, E. Paris, C. Koeberl, S. G. Eeckhout, M.R. Cicconi, M.R. Carroll, B. Glass, P. Stabile, M. Cestelli Guidi, L. Folco, R. Skala, L. Dzikova, M. Trnka, S. Caporali, F. Arzilli, W. Marinucci, K-U Hess, D.B. Dingwell, S. Nazzareni

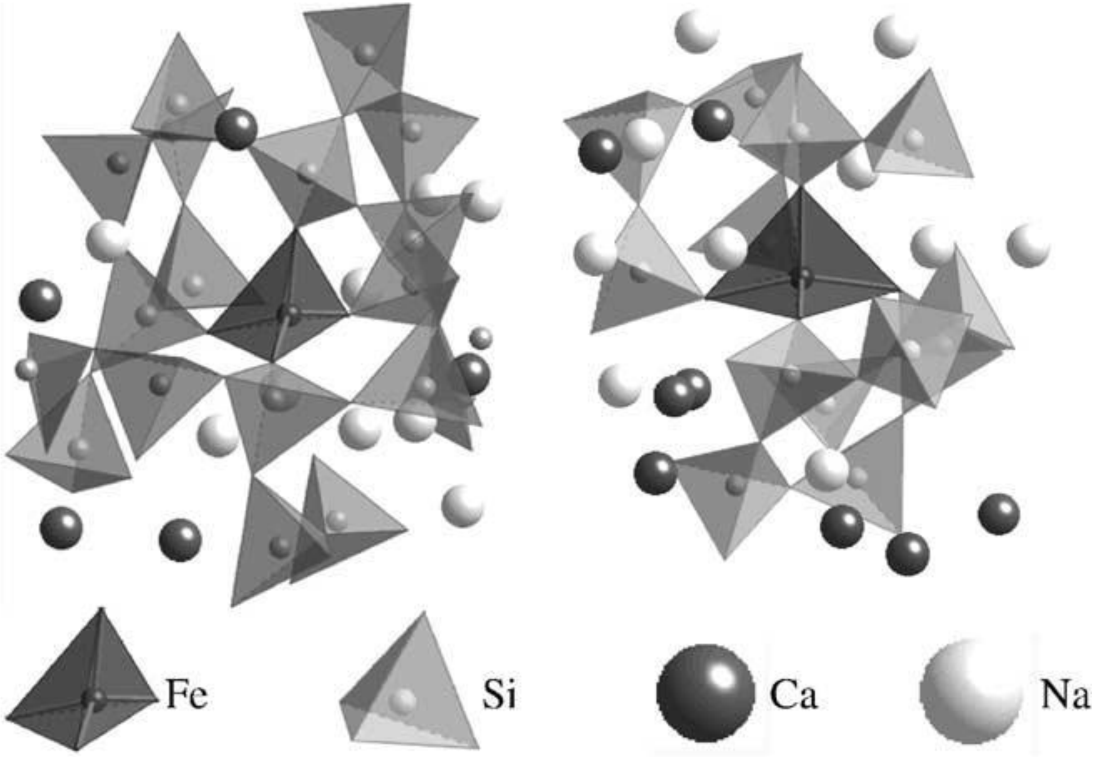
B. Glass
Uwe Reimold
Philippe Claeys

discussions

Museo Storia Naturale Firenze
NHM Vienna
Museo Nazionale dell'Antartide (Siena)
DSDP

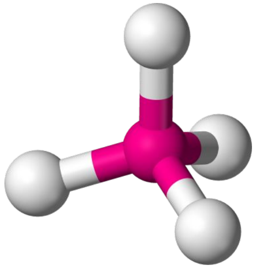
samples

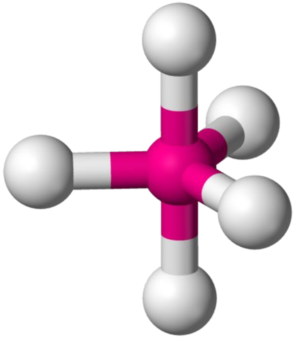
Structure of silicate glasses



From Farges et al, 2006, JNCS

Structure of silicate glasses





Fe^{2+}

[4]

<Fe-O>~2.00 Å

[5]

<Fe-O>~2.07 Å

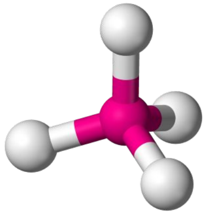
Fe^{3+}

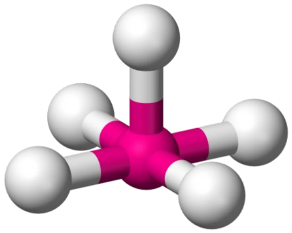
[4]

<Fe-O>~1.85 Å

[5]

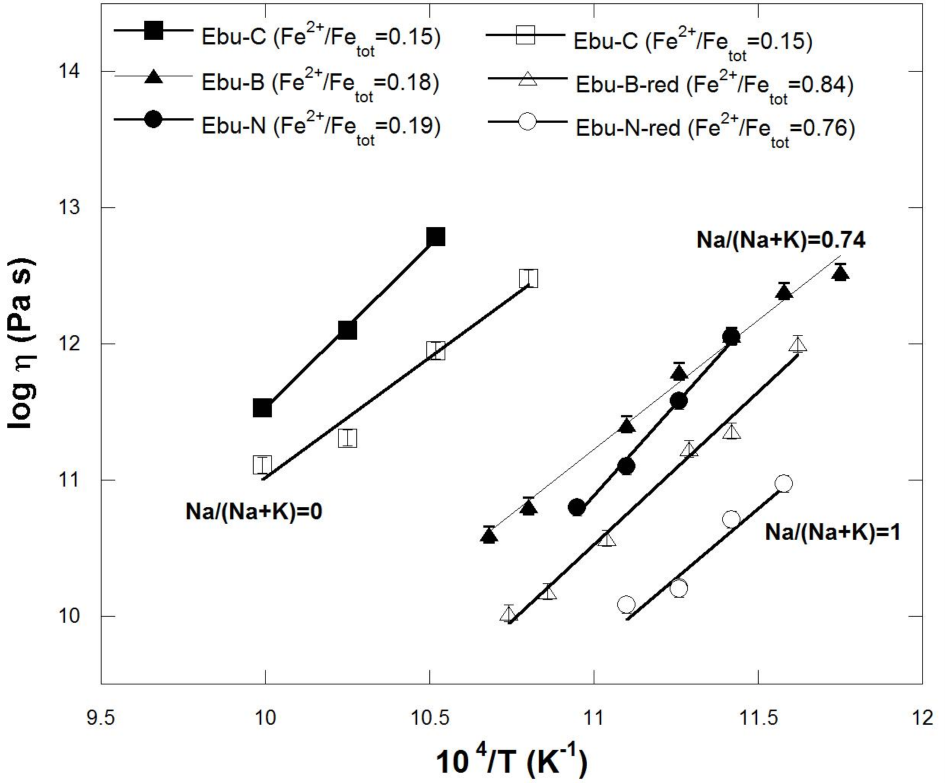
<Fe-O>~1.94 Å





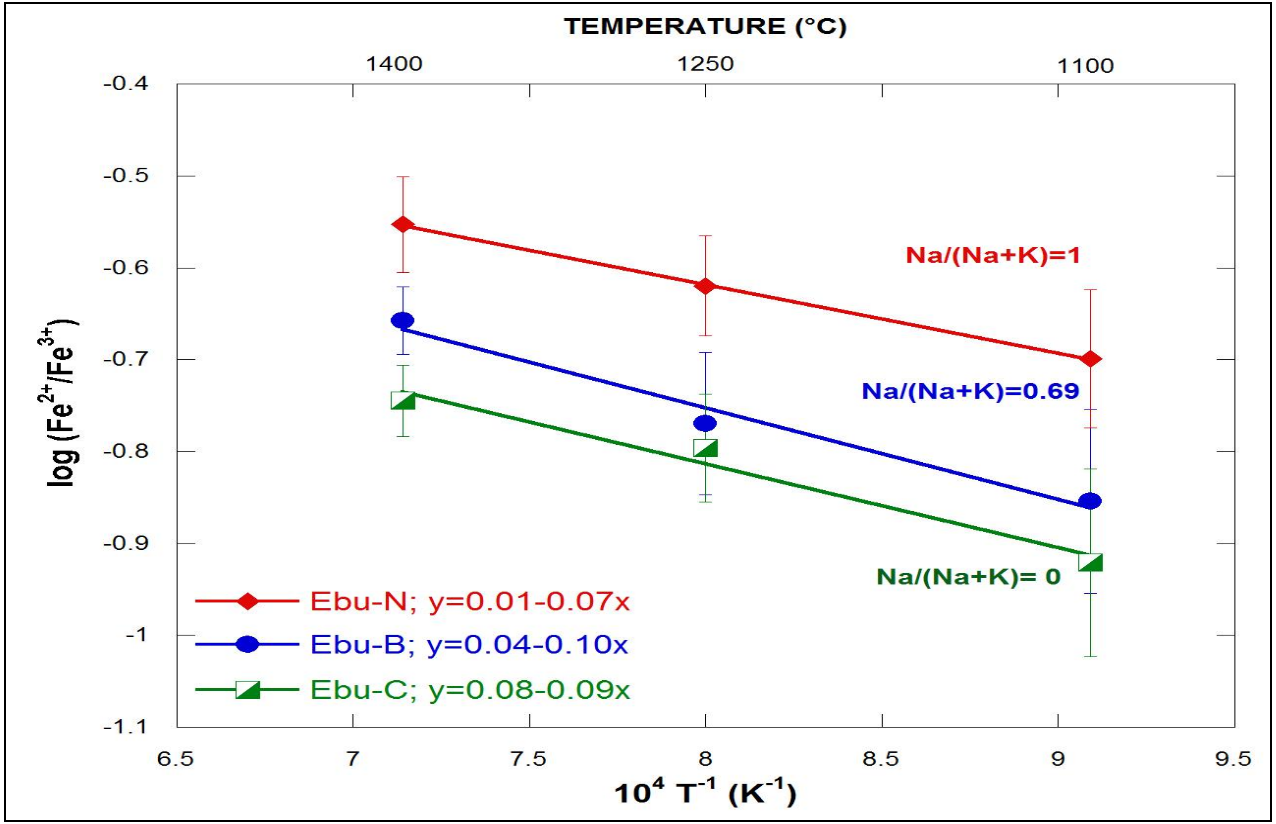
Density, compressibility, bond strength, polymerization

Alkalis and iron redox influence on viscosity



Stabile, Webb. Knipping, Behrens, Paris, Giuli, (2016) Chemical Geology, 442, 73-82

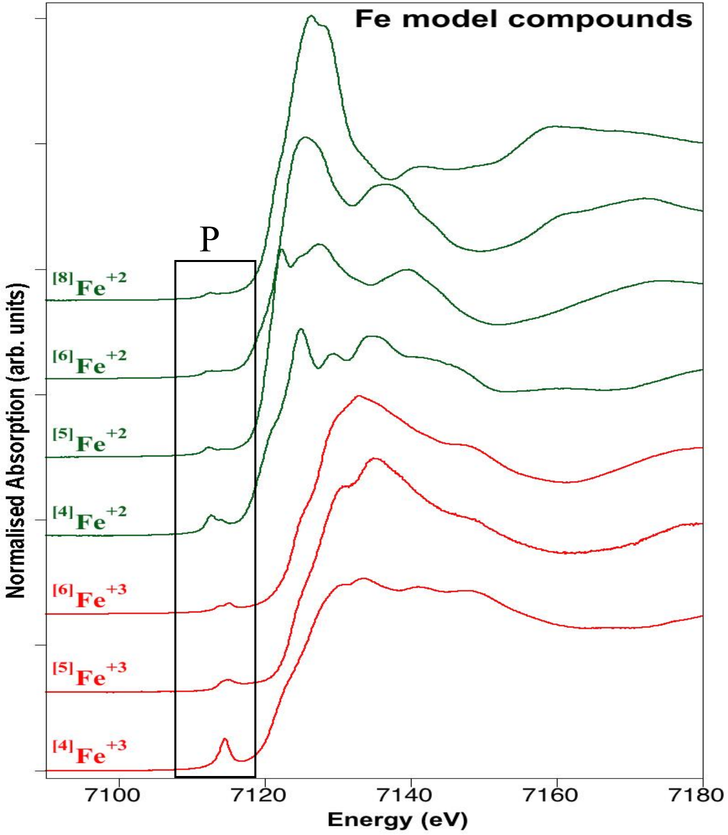
T and alkali influence on Fe redox

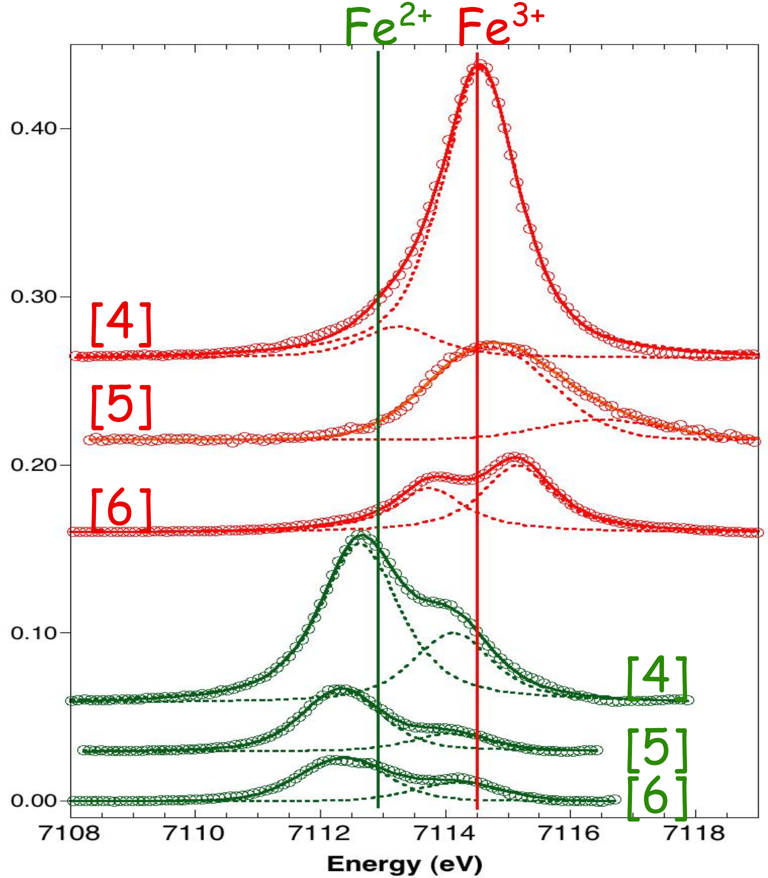


Stabile, Giuli, Cicconi, Paris, Trapananti, Behrens (2016) J. Non-Cryst. Solids, 478, 65-74

Analytical technique

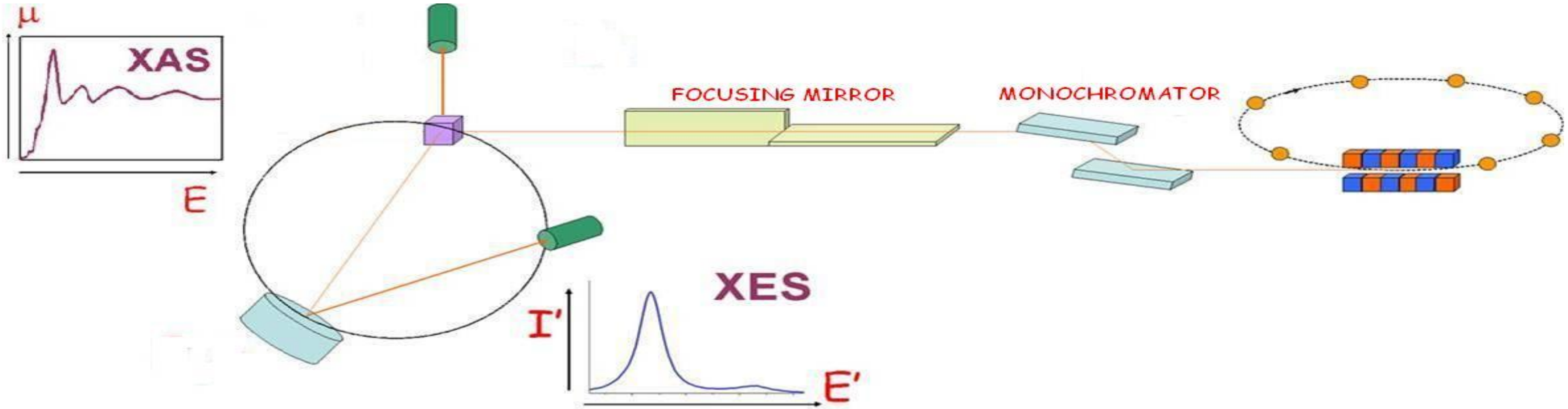
Element selective technique able to analyse Fe redox also in diluted/small samples



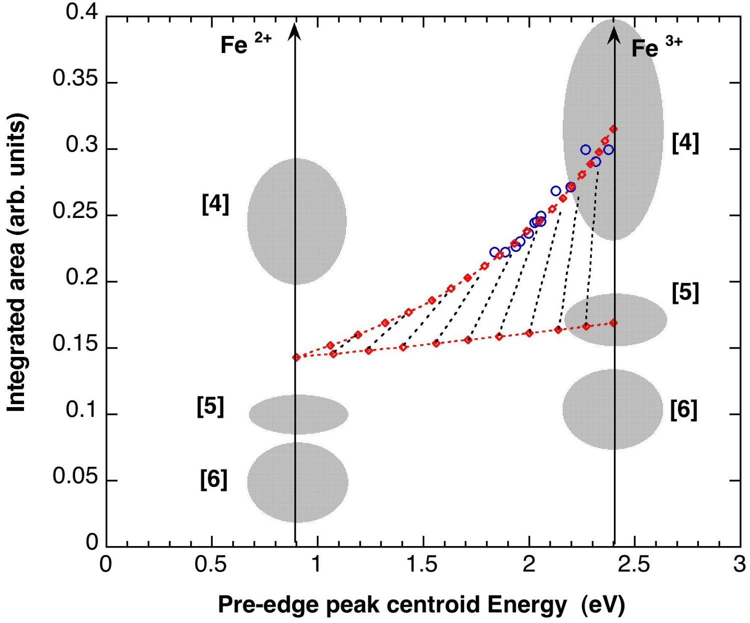


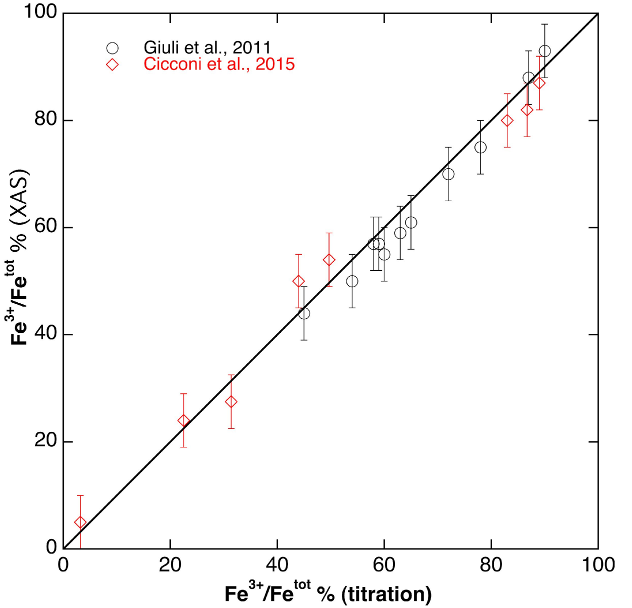
X-ray Absorption Spectroscopy

Element selective
Provide oxidation state and local structure
Down to very low absorber concentration
Micro-probe



Calibration of the $Fe^{3+}/(Fe^{2+} + Fe^{3+})$ ratio



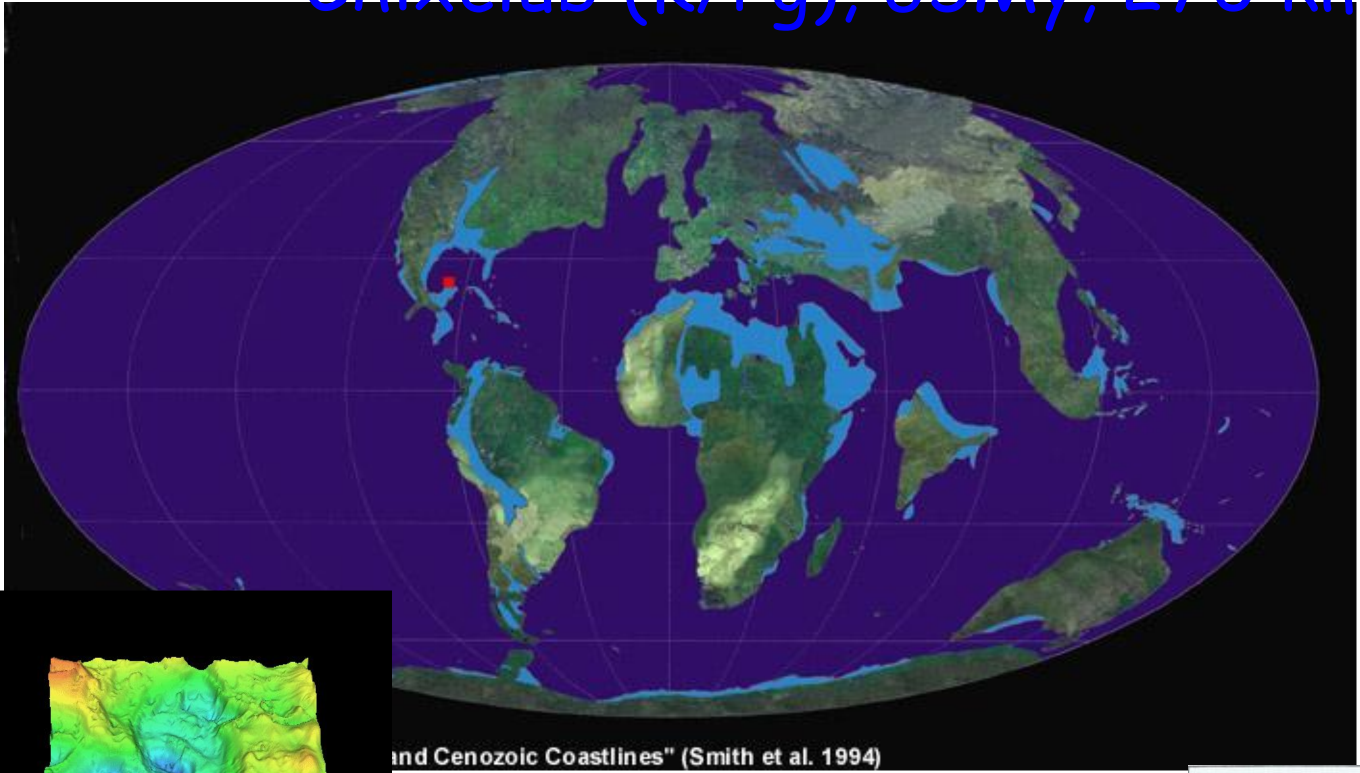


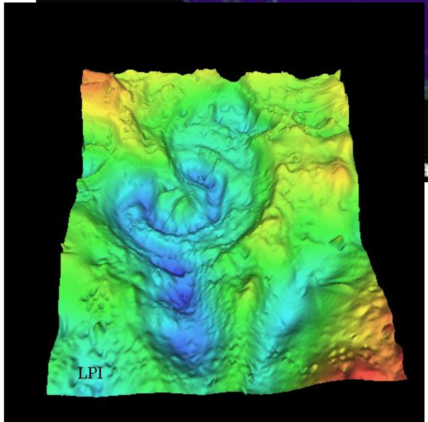
$Fe^{3+}/(Fe^{2+} + Fe^{3+})$ ratio ± 0.05

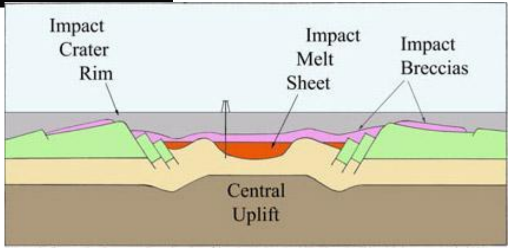
Giuli et al. (2011) Amer. Mineral, 96, 631-636

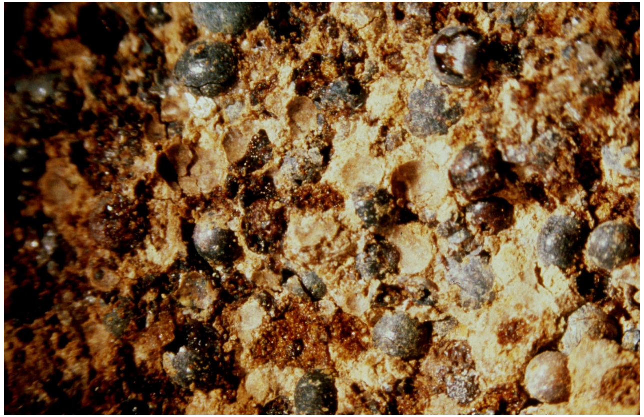
Cicconi et al. (2015) Amer. Mineral, 100, 1610-1619

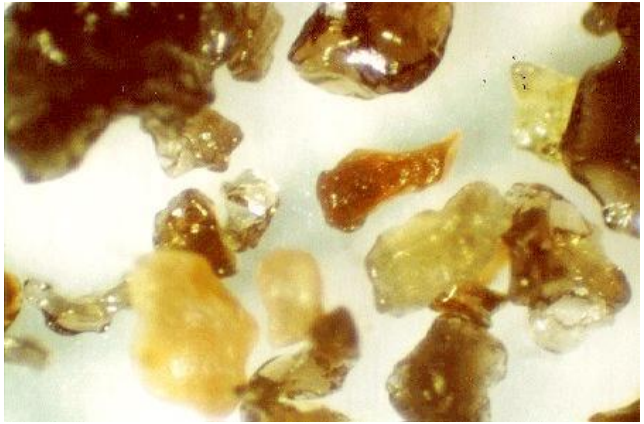
Chixclub (K/Pg), 65My, 270 km ca.

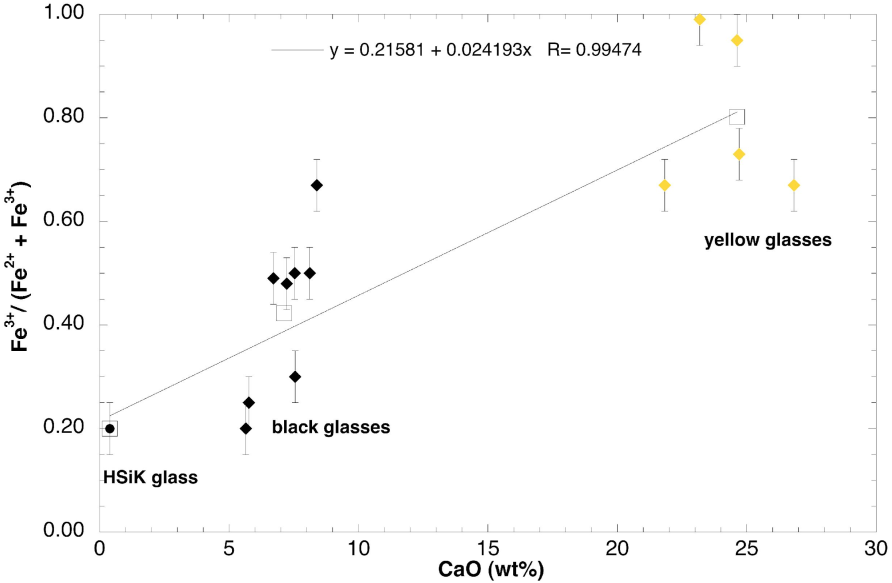


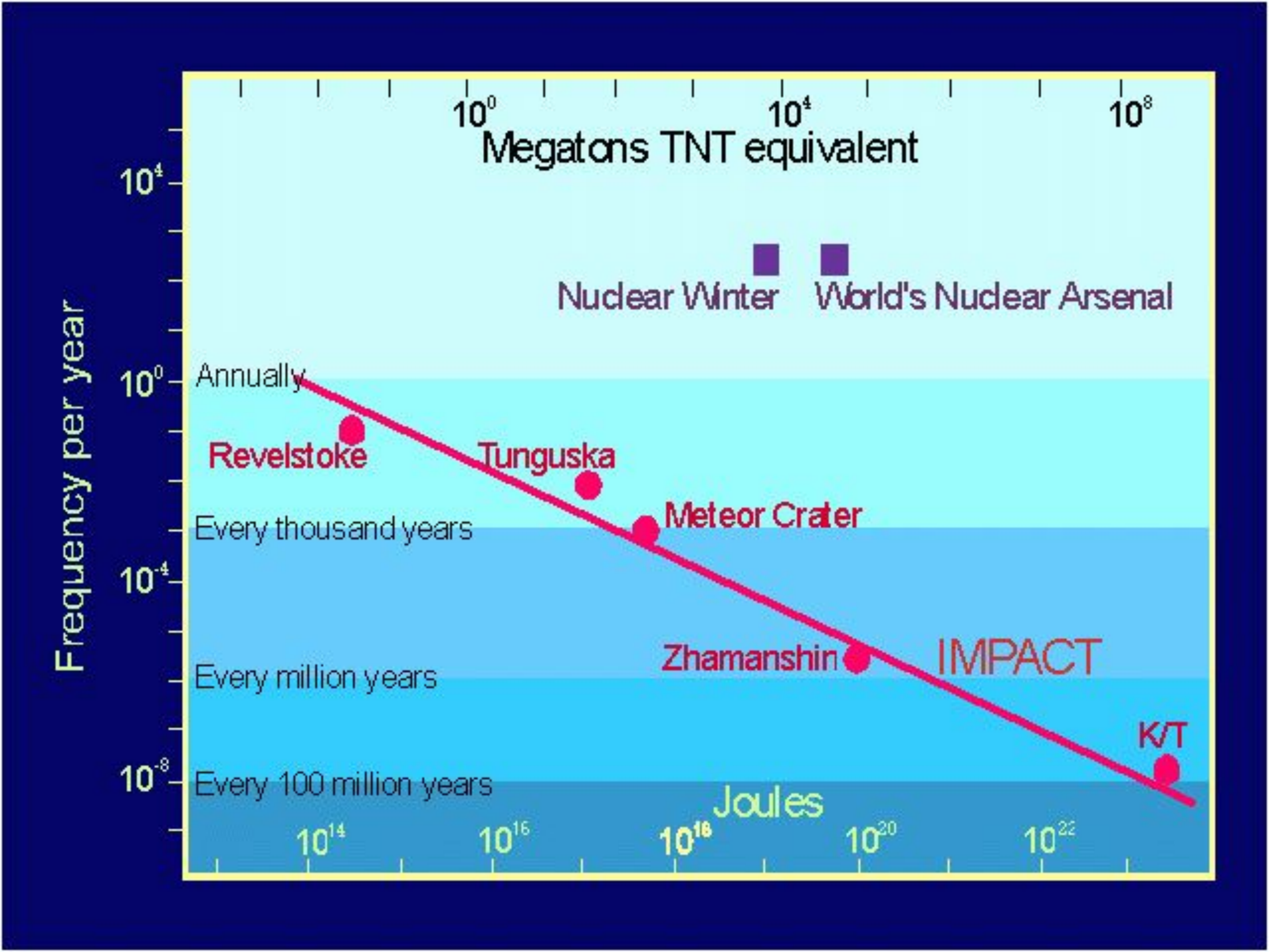








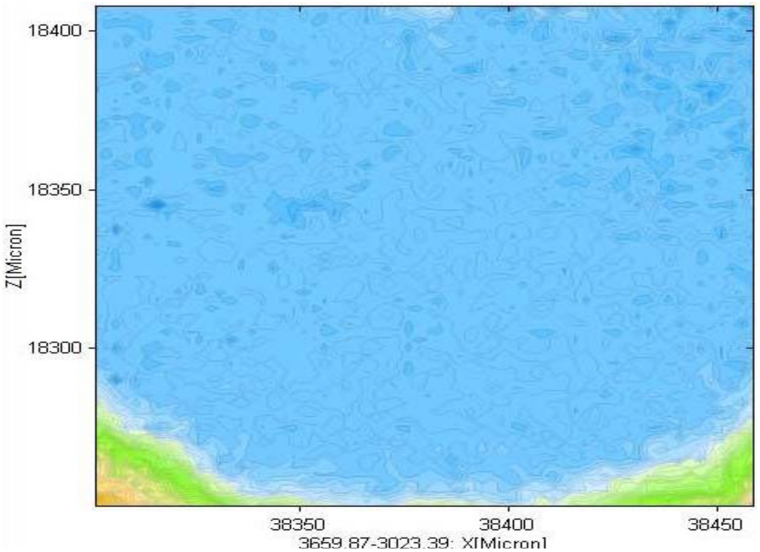

y = 0.21581 + 0.024193x R= 0.99474
Fe^{3+}/ (Fe^{2+} + Fe^{3+})
CaO (wt%)
yellow glasses
black glasses
HSiK glass
1.00
0.80
0.60
0.40
0.20
0.00
0
5
10
15
20
25
30

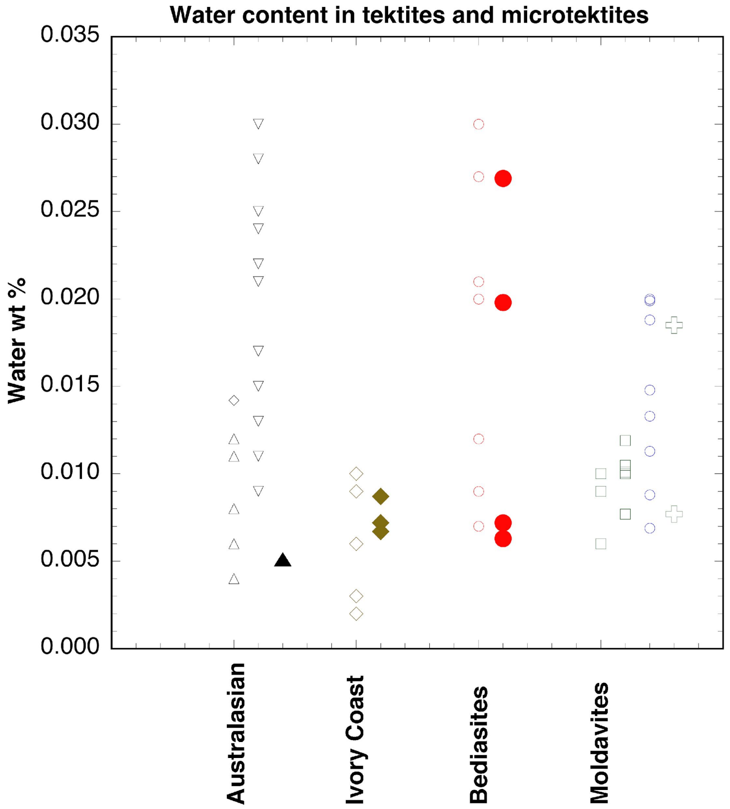


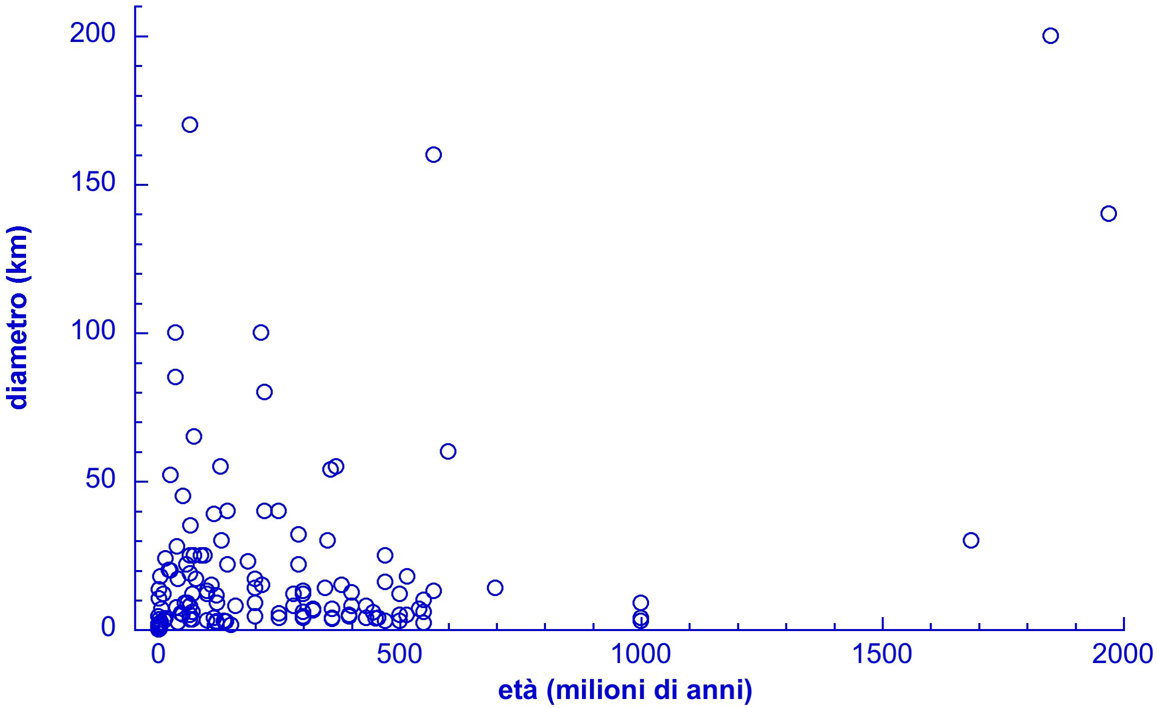
10^0
10^4
10^8
Megatons TNT equivalent
10^4
10^0
10^{-4}
10^{-8}
Frequency per year
Nuclear Winter
World's Nuclear Arsenal
Annually
Revelstoke
Tunguska
Meteor Crater
Every thousand years
Zhamanshin
IMPACT
Every million years
K/T
Every 100 million years
Joules
10^{14}
10^{16}
10^{18}
10^{20}
10^{22}

Water content

µFTIR MAP







200
150
100
50
0
diametro (km)
0
500
1000
1500
2000
età (milioni di anni)