Space weathered ilmenite grains from lunar soils

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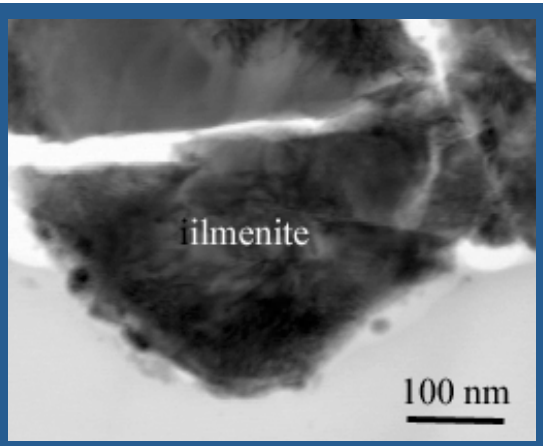
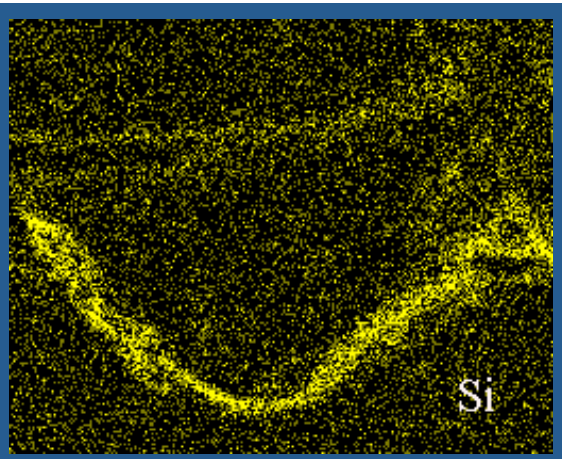
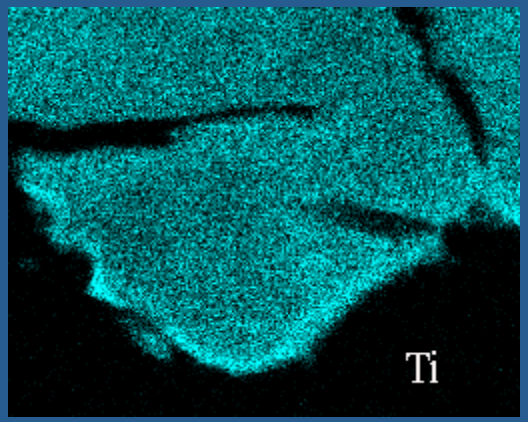
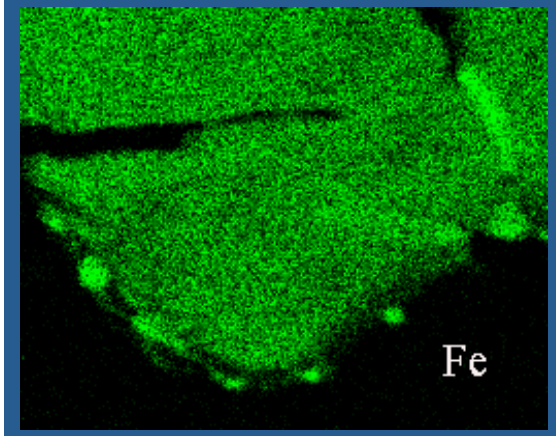
100 nm





Previous research





- Two layer rims in ilmenite with distinctive chemistry: vapor/sputter deposited outer layer (~20 nm) + radiation-derived inner layer (~100 nm).
- Ti, Fe segregation approaching the surface.
- Mixed-valence of Ti^{4+} and Ti^{3+} in the rim.

Christoffersen et al. (1996)

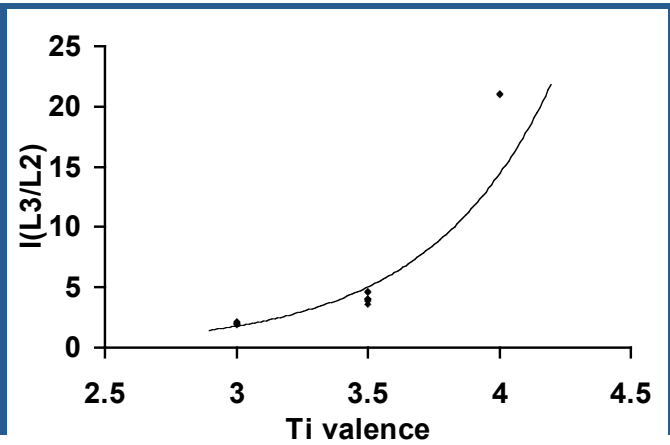
Current research

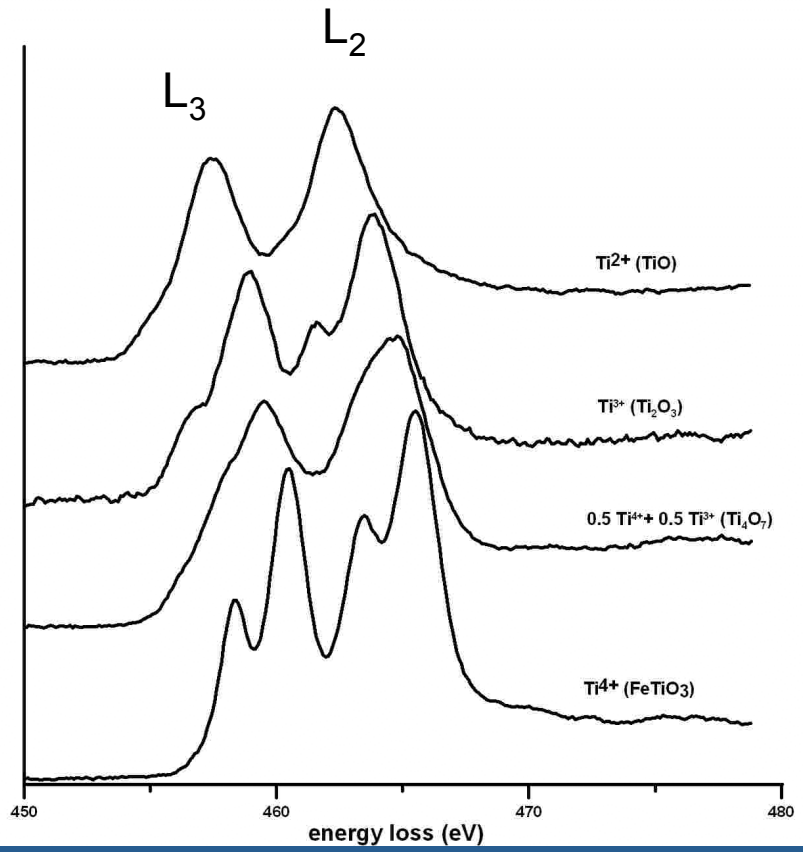
- Higher-resolution (STEM-EELS) studies of $npFe^0$ and reduced Ti oxides distribution in ilmenite rims.

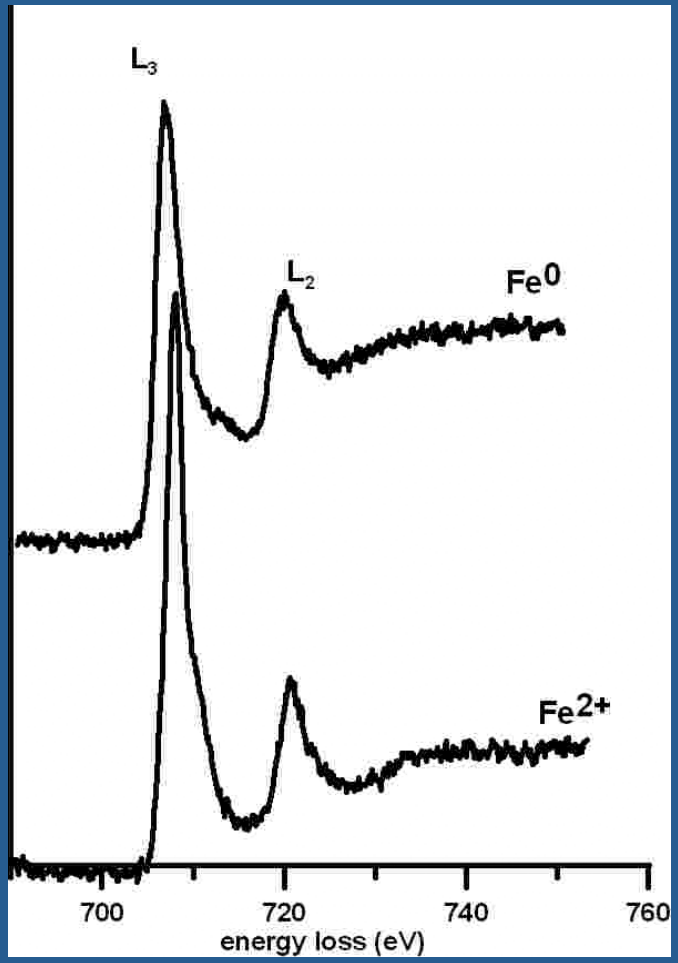
- Irradiation-induced microstructures and their potential effect on the Ti valence variation in ilmenite.

- Effect of radiation from solar ions on formation of $npFe^0$ in ilmenite.

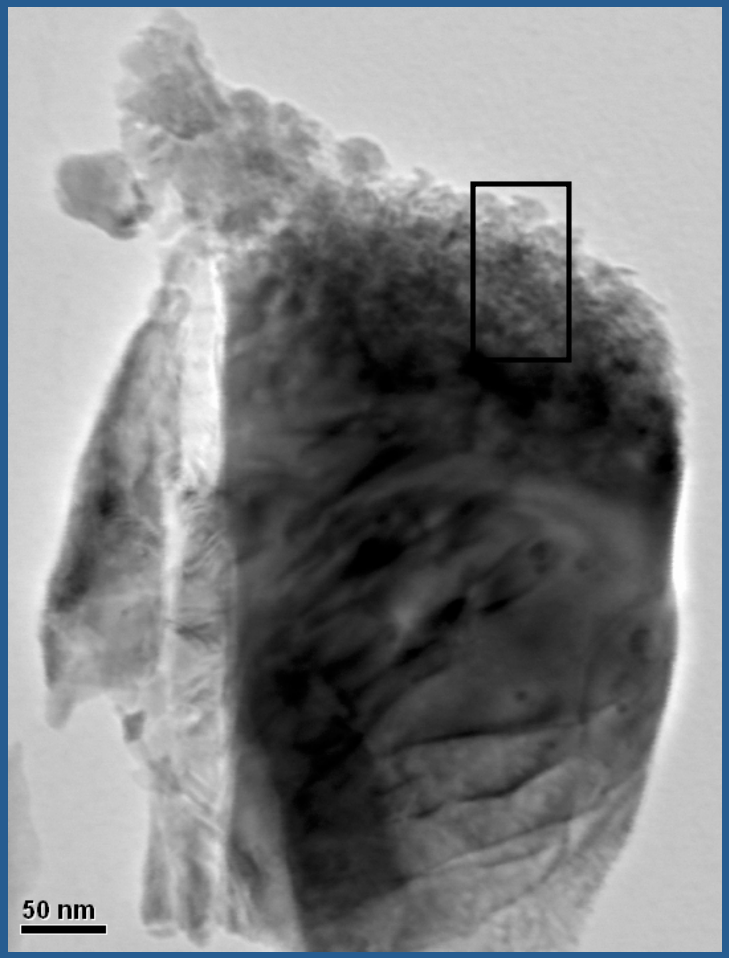
Ti/Fe valence investigation using EELS

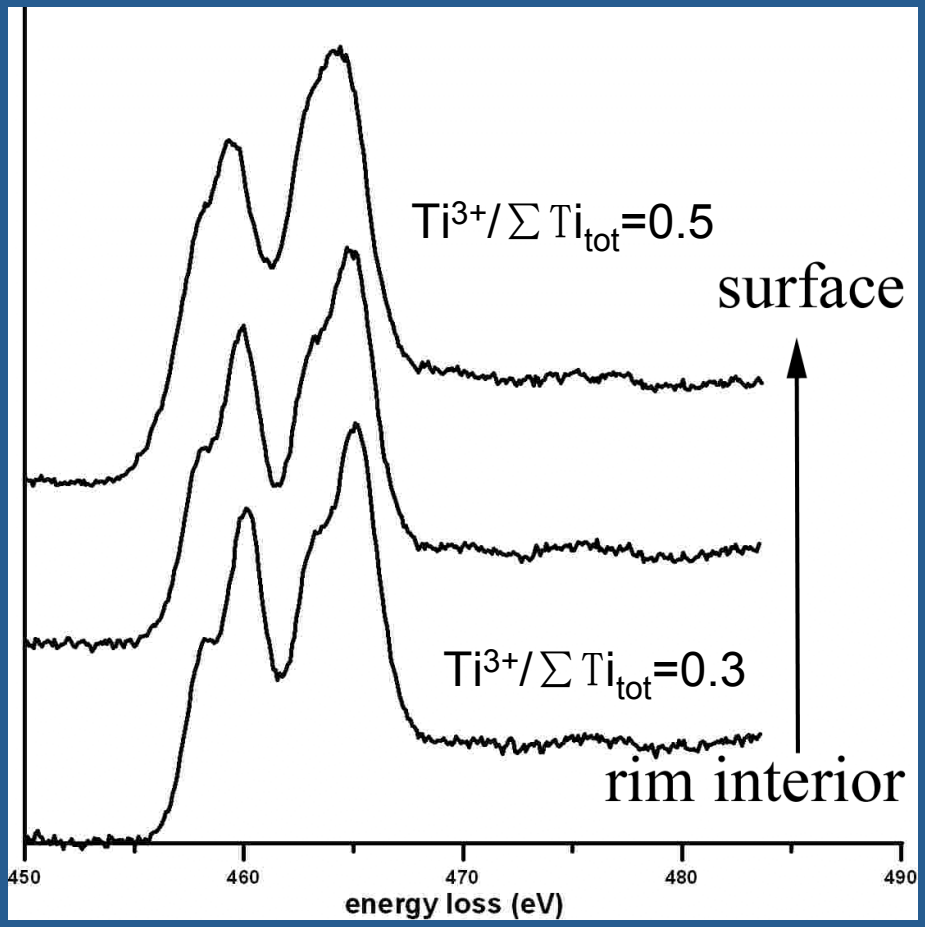






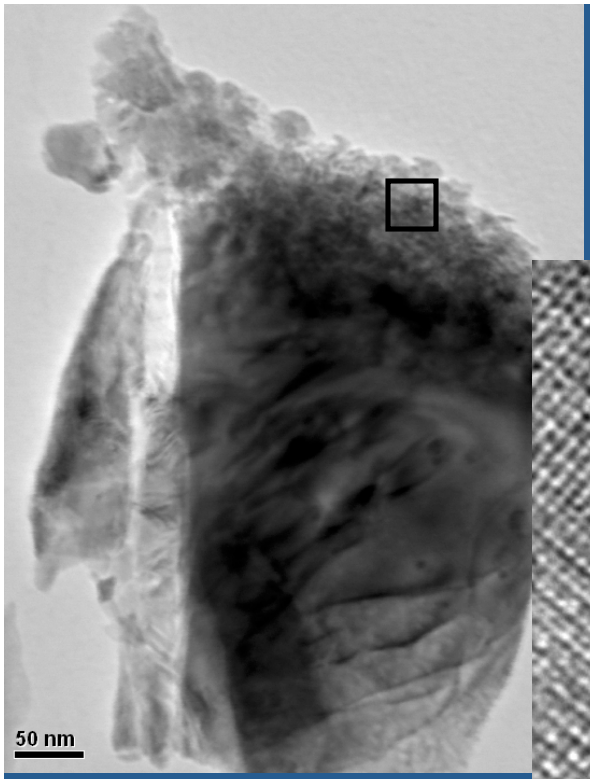
Ti/Fe valence variation

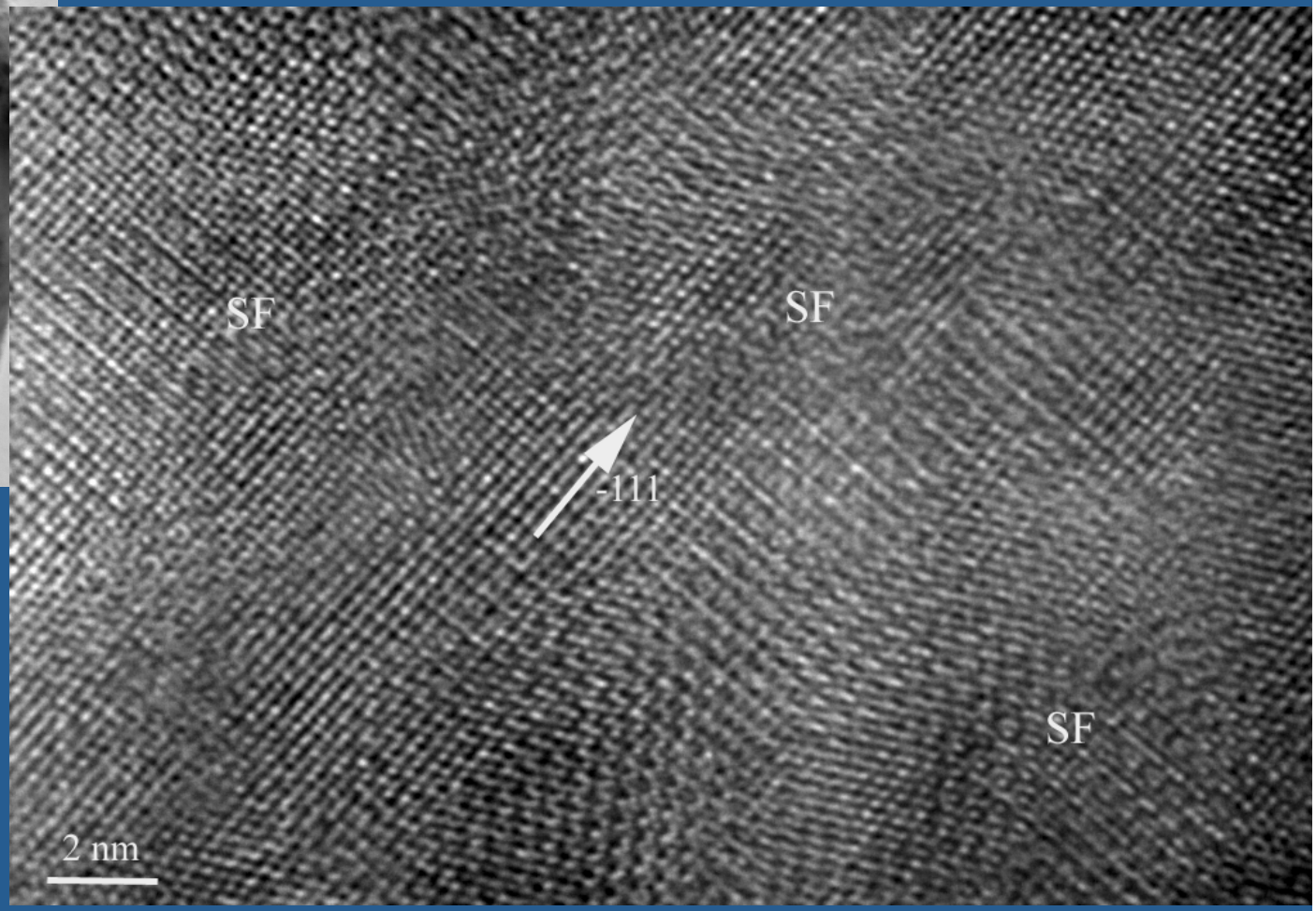




$Fe^{2+}/\sum Fe_{tot}$=1

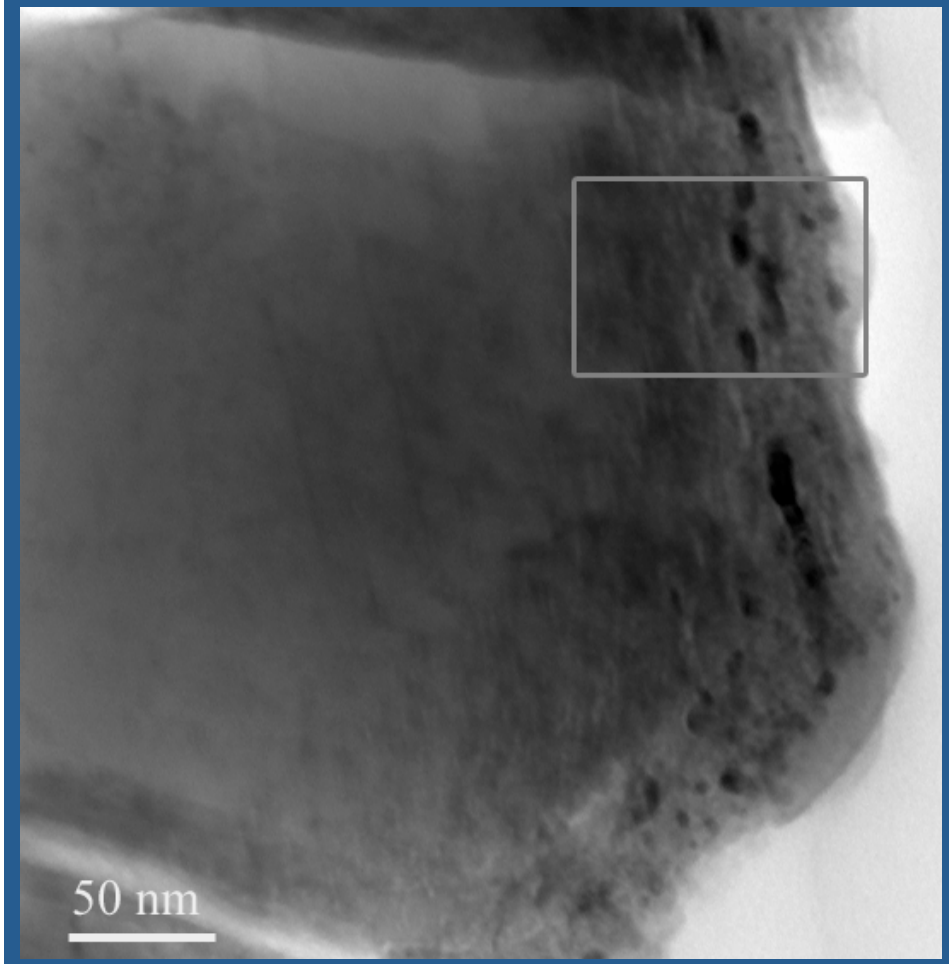
Irradiation-induced stacking fault



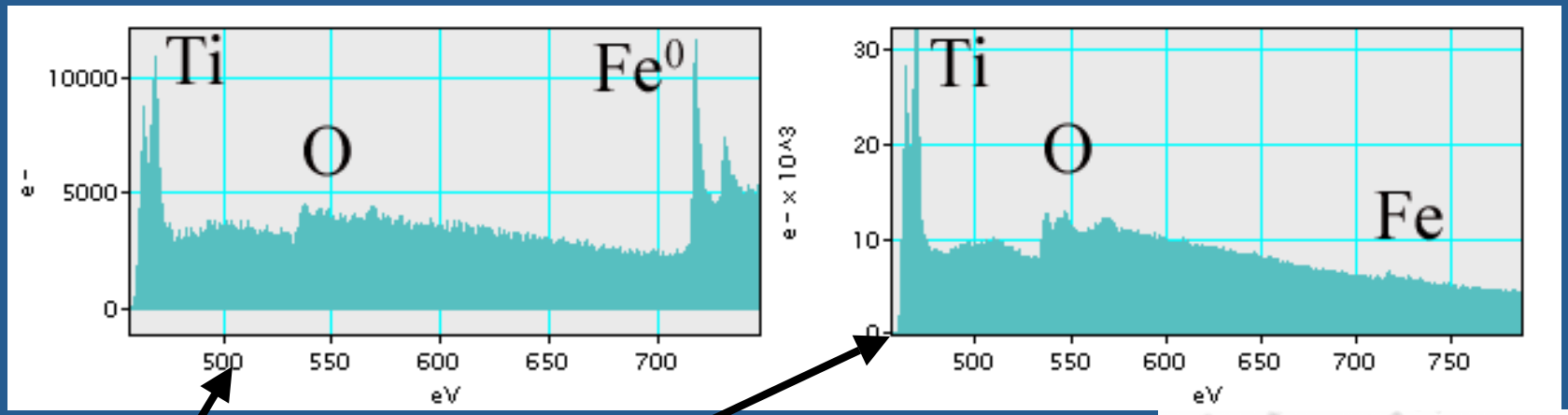


No $npFe^0$ precipitation in the rim, where the ilmenite maintains crystallnity but with stacking faults resulting from O loss.

$npFe^0$ and reduced Ti oxides

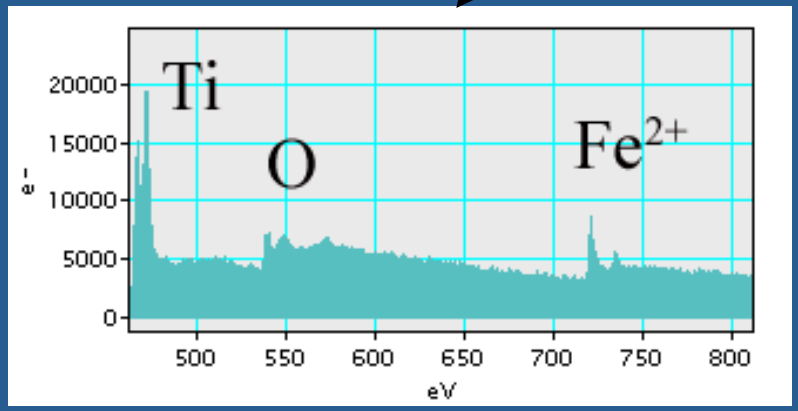


TRIM simulation

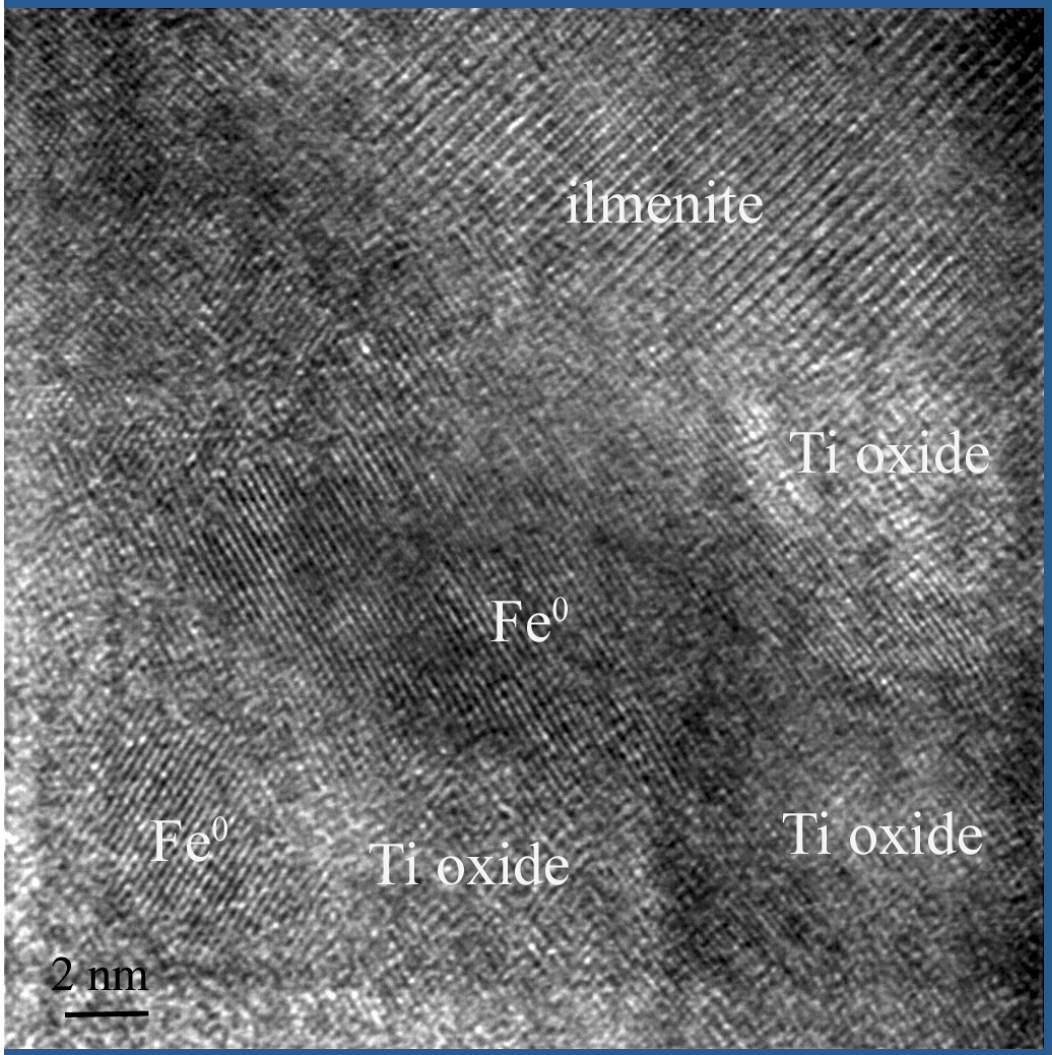

Ti
O
Fe0
e-
10000
5000
0
500
550
600
650
700
eV

Ti
O
Fe
e- x 10^3
30
20
10
0
500
550
600
650
700
750
eV

spectrum image
0.1 µm


Ti
O
Fe2+
e-
20000
15000
10000
5000
0
500
550
600
650
700
750
800
eV

HRTEM of Fe^0 + reduced Ti oxide



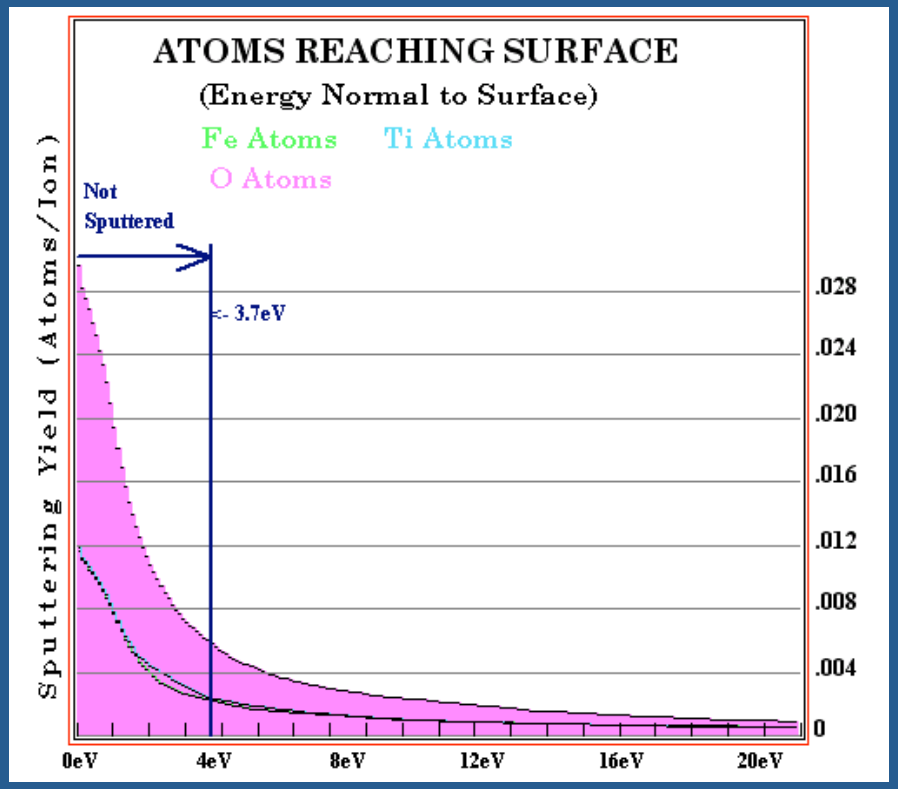
- $npFe^0$ randomly oriented and reduced Ti oxide very poorly crystallized.

Formation of the ilmenite rims

- Summary of observation: Range-correlated chemical and structural changes, including O loss (up to 100 nm); Fe, Ti segregation (up to 50 nm); and Ti/Fe valence variations.

→ Sputtering-driven mechanism: Sputtering of O and Fe ($BS_{Fe-O} = 1/2 BS_{Ti-O}$) from ilmenite produced poorly crystallized and reduced Ti oxide followed by deposition of randomly oriented $npFe^0$.

- Next step: Irradiation experiment to reproduce.



TRIM simulation: sputtering yield