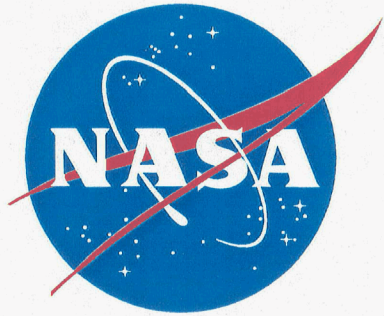


High Temperature Chemistry in the Columbia Accident Investigation

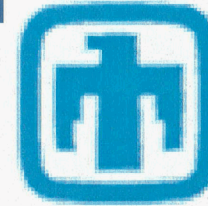
Nathan Jacobson and Elizabeth Opila
NASA Glenn Research Center
Cleveland, OH 44135

David Tallant and Regina Simpson
Sandia National Laboratories
Albuquerque, NM 87185

Initial estimates on the temperature and conditions of the breach in Columbia's wing focused on analyses of the slag deposits. These deposits are complex mixtures of the reinforced carbon/carbon (RCC) constituents, insulation material, and wing structural materials. However it was possible to clearly discern melted/solidified Cerachrome® insulation, indicating the temperatures had exceeded 1760°C. Current research focuses on the carbon/carbon in the path from the breach. Carbon morphology indicates heavy oxidation and erosion. Raman spectroscopy yielded further temperature estimates. A technique developed at Sandia National Laboratories is based on crystallite size in carbon chars. Lower temperatures yield nanocrystalline graphite; whereas higher temperatures yield larger graphite crystals. By comparison to standards the temperatures on the recovered RCC fragments were estimated to have been greater than 2700°C.



High Temperature Chemistry in
the Columbia
Accident Investigation



Sandia
National
Laboratories

Nathan S. Jacobson and Elizabeth J. Opila
NASA Glenn Research Center
Cleveland, OH 44135

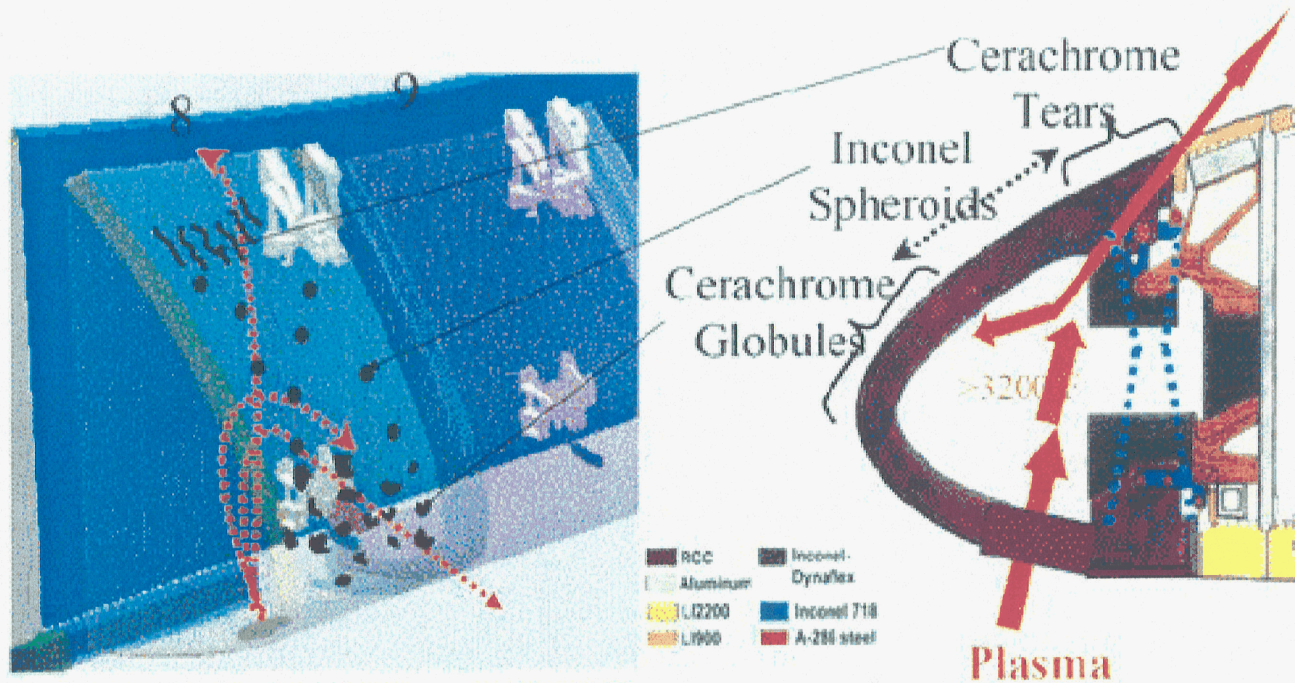
David R. Tallant and Regina Simpson
Sandia National Laboratories
Albuquerque, NM 87185

— ACCIDENT HISTORY, WHAT CAUSED BREACH

- Objectives: *reinforced carbon/carbon*
OV-107
leading edge
 - Examine (RCC) near breach and hot-gas-path
 - Understand response of RCC to extreme conditions
 - Estimate wing leading edge material temperatures near the breach ~~and~~ compare to estimates from slag studies
and
- Techniques
 - Electron microscopy (Glenn)
 - Raman spectroscopy (Sandia)

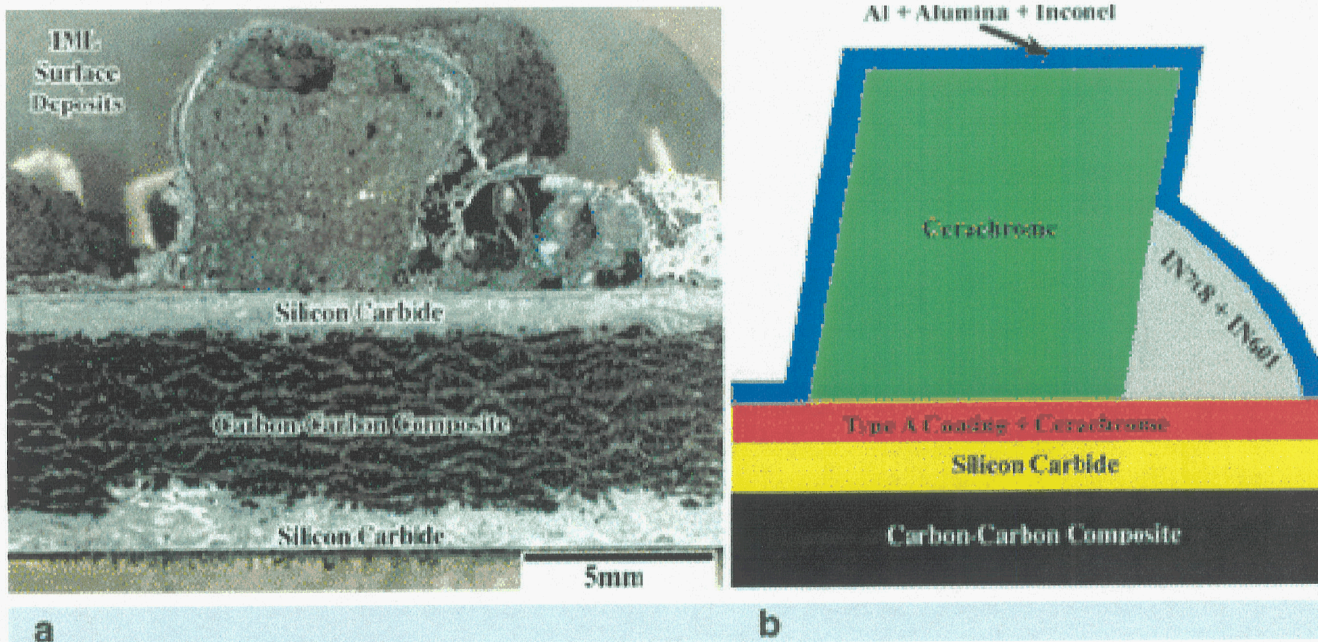
Identification of Breach

- Multi-NASA Center Team Effort—JSC, MSFC, LaRC, GRC
- Key features of recovered leading edge RCC
 - Large deposits of 'slag'—solidified Cerachrome insulation, aluminum alloys, Fe alloys — *on backside*
 - 'Knife edge' appearance of RCC (reinforced carbon/carbon)—known to occur when an exposed edge of RCC is heavily oxidized

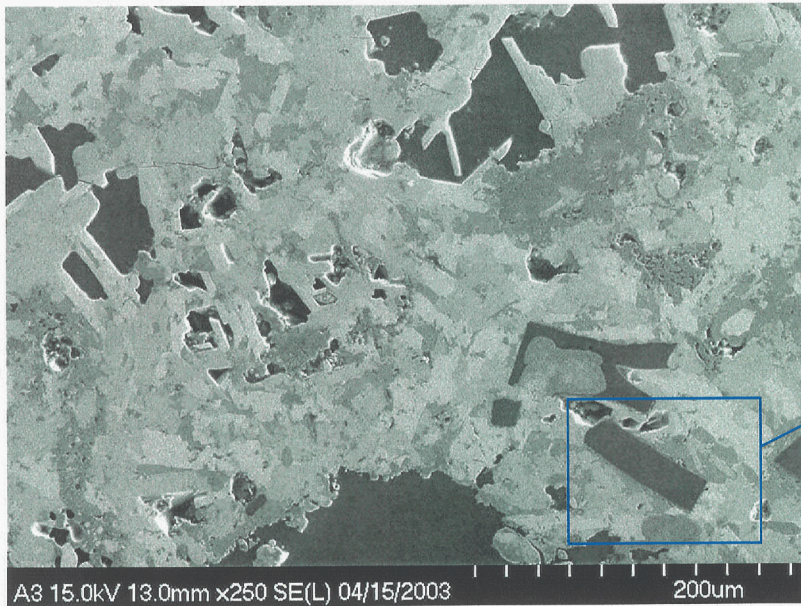


Previous Temperature Estimates

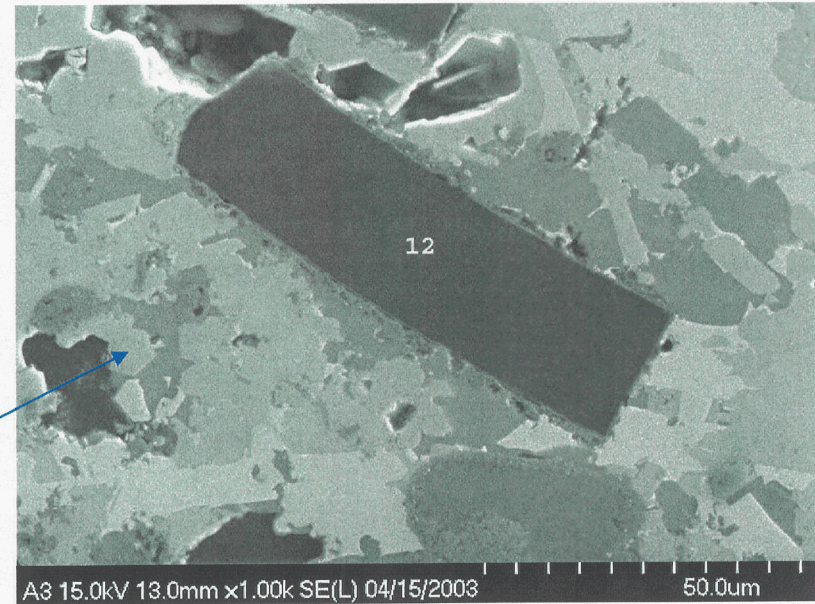
- Cerachrome® mp 1760°C—95% aluminosilicate; 3% chromia
- Mullite forms at ~1100°C
- Examination slag deposits from upper portion of Panel 8 identified mullite and melted Cerachrome ⇒ 1760°C or greater



Slag Deposits—Complex Mixtures of Wing Constituents



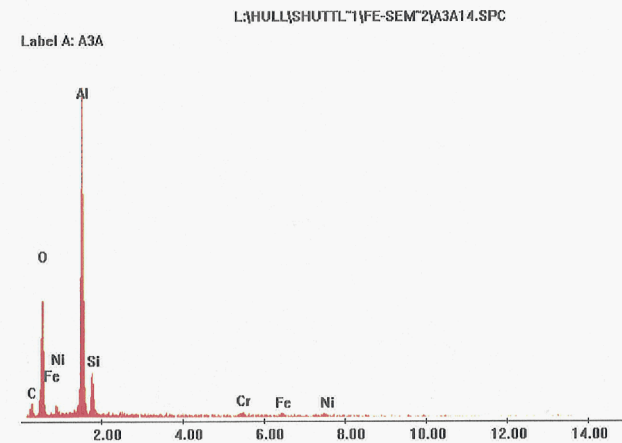
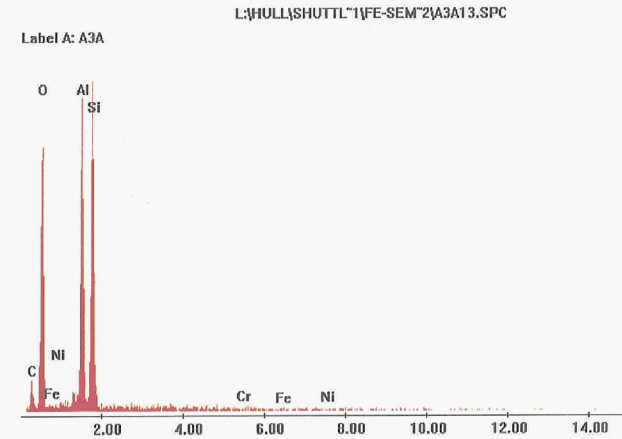
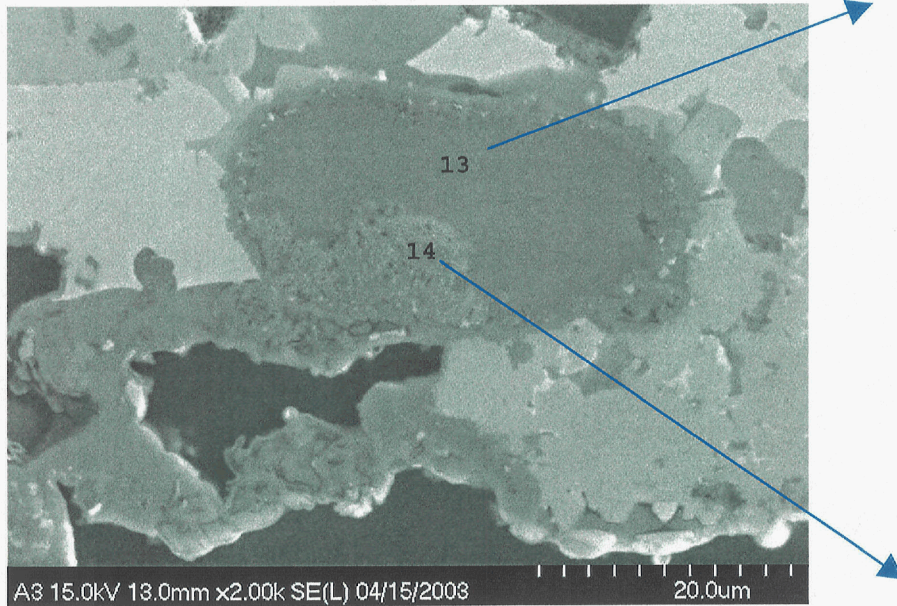
Solidified metals and ceramics



Region 12 – portion of carbon fiber

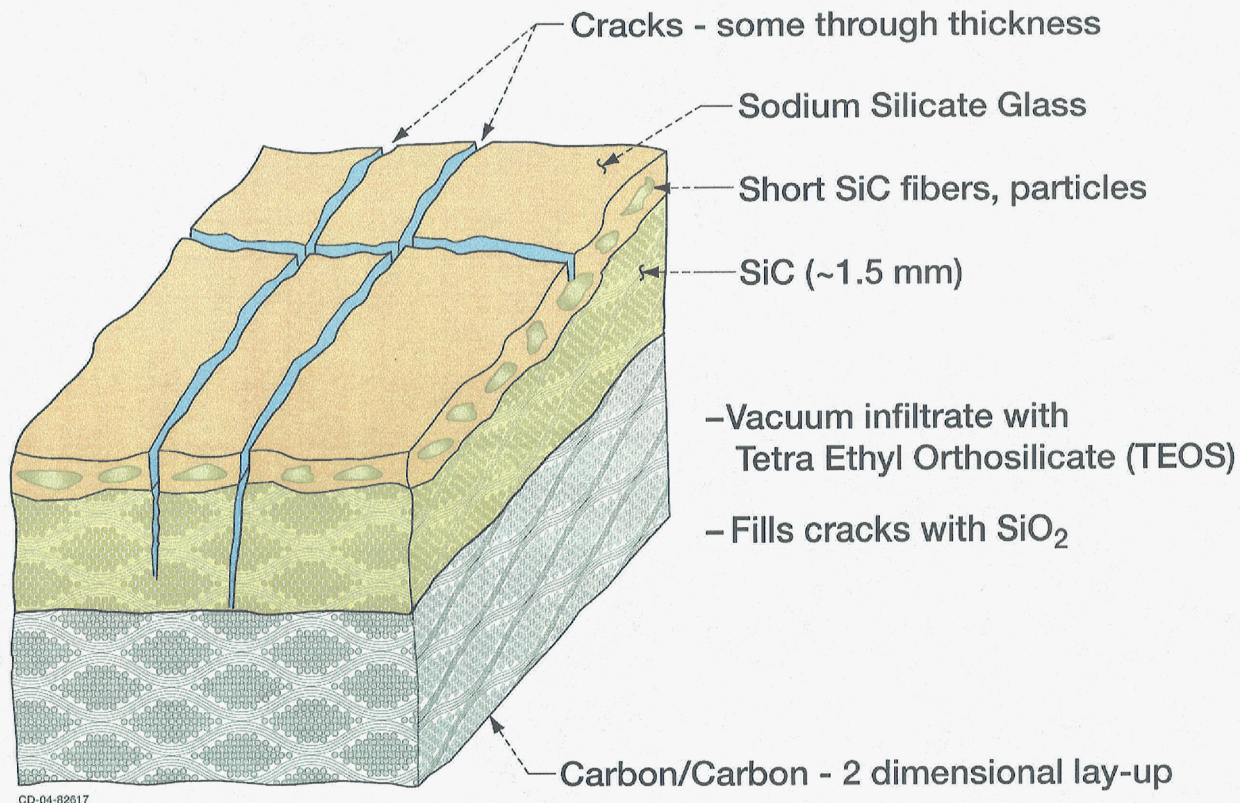
Region of Melted Cerachrome

Only well-understood Feature for Temperature Determination



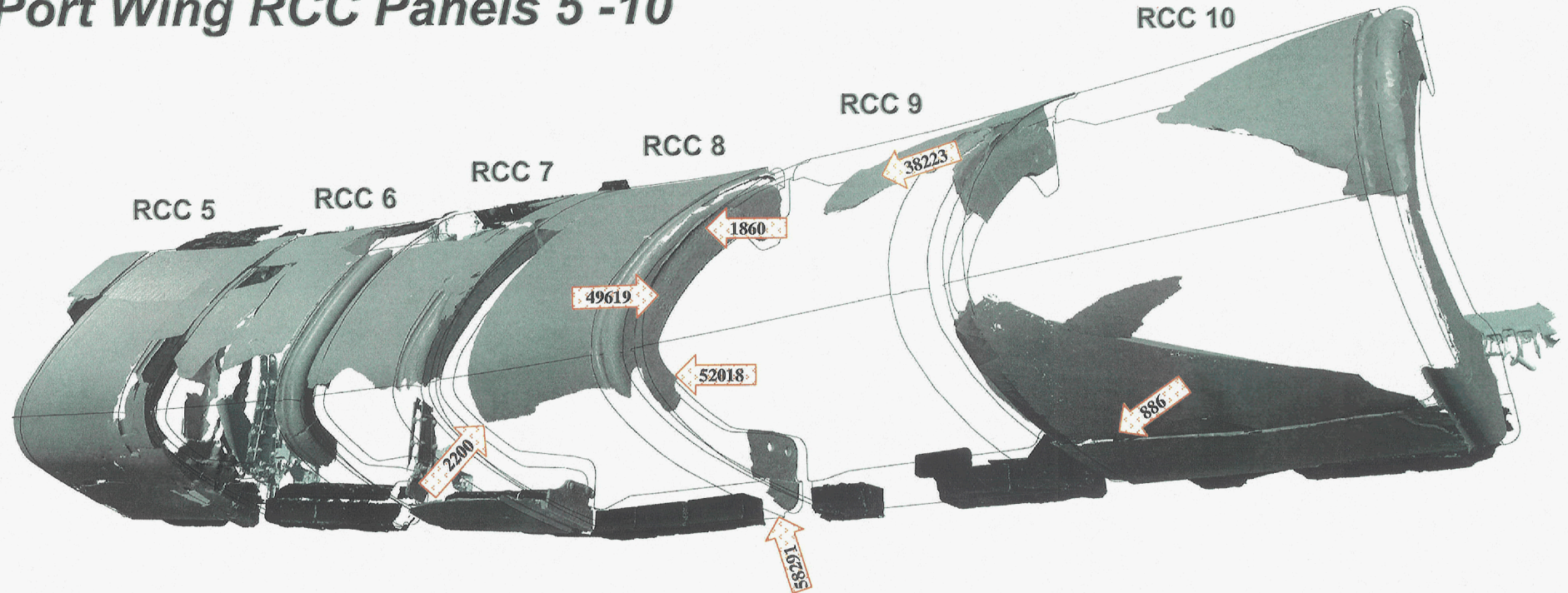
Summary: 'Slag' Deposits on back Side of Wing Leading Edge

- Complex mixture of solidified ceramics, aluminum alloys, iron alloys, and nickel alloys
- Only solidified cerachrome gave temperature clues
- Focus on fractured and oxidized carbon/carbon

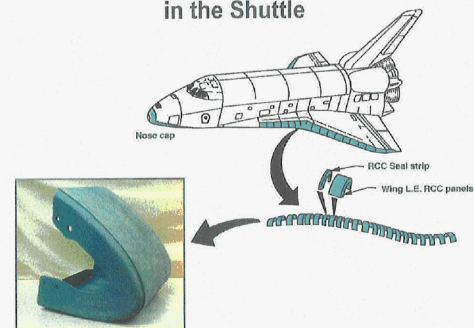


Location of Carbon Samples

Port Wing RCC Panels 5 -10

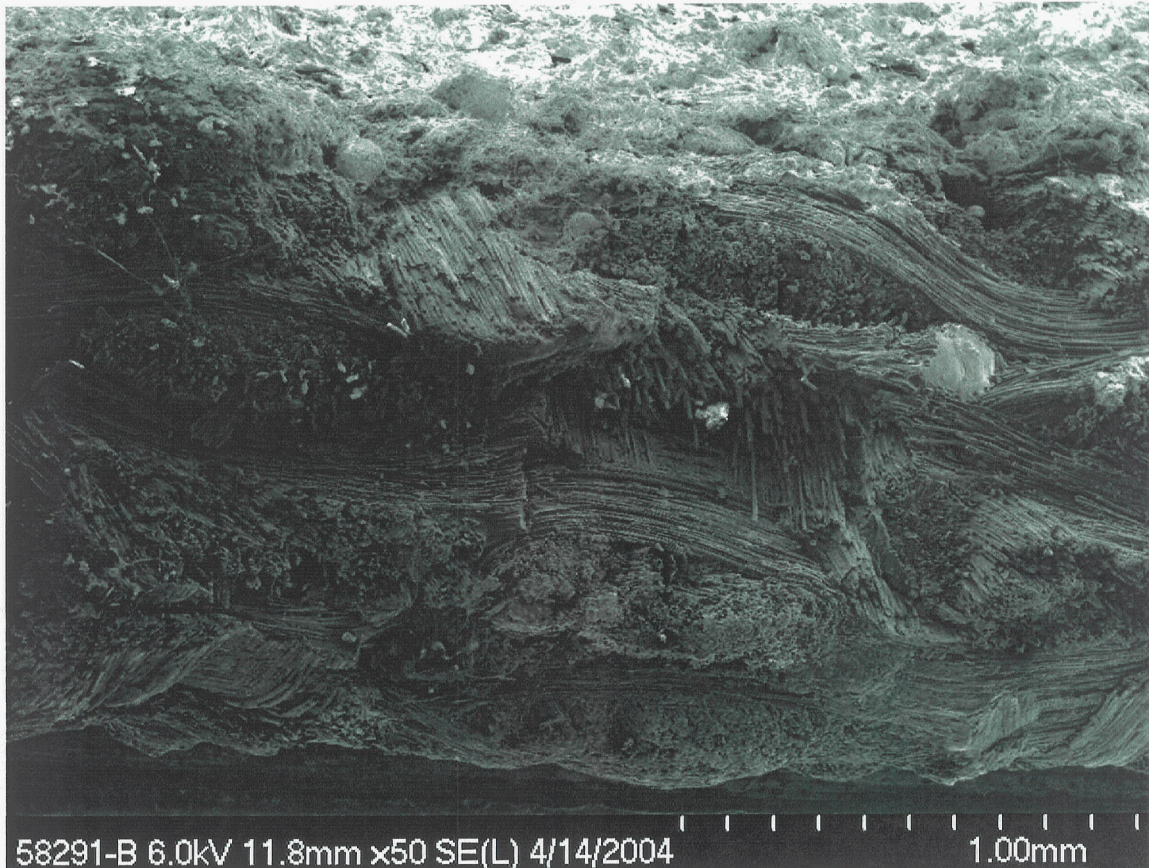


Reinforced Carbon/Carbon (RCC)
in the Shuttle



recovered?

Typical Appearance of RCC Cross Section Fragment



Inner mold line

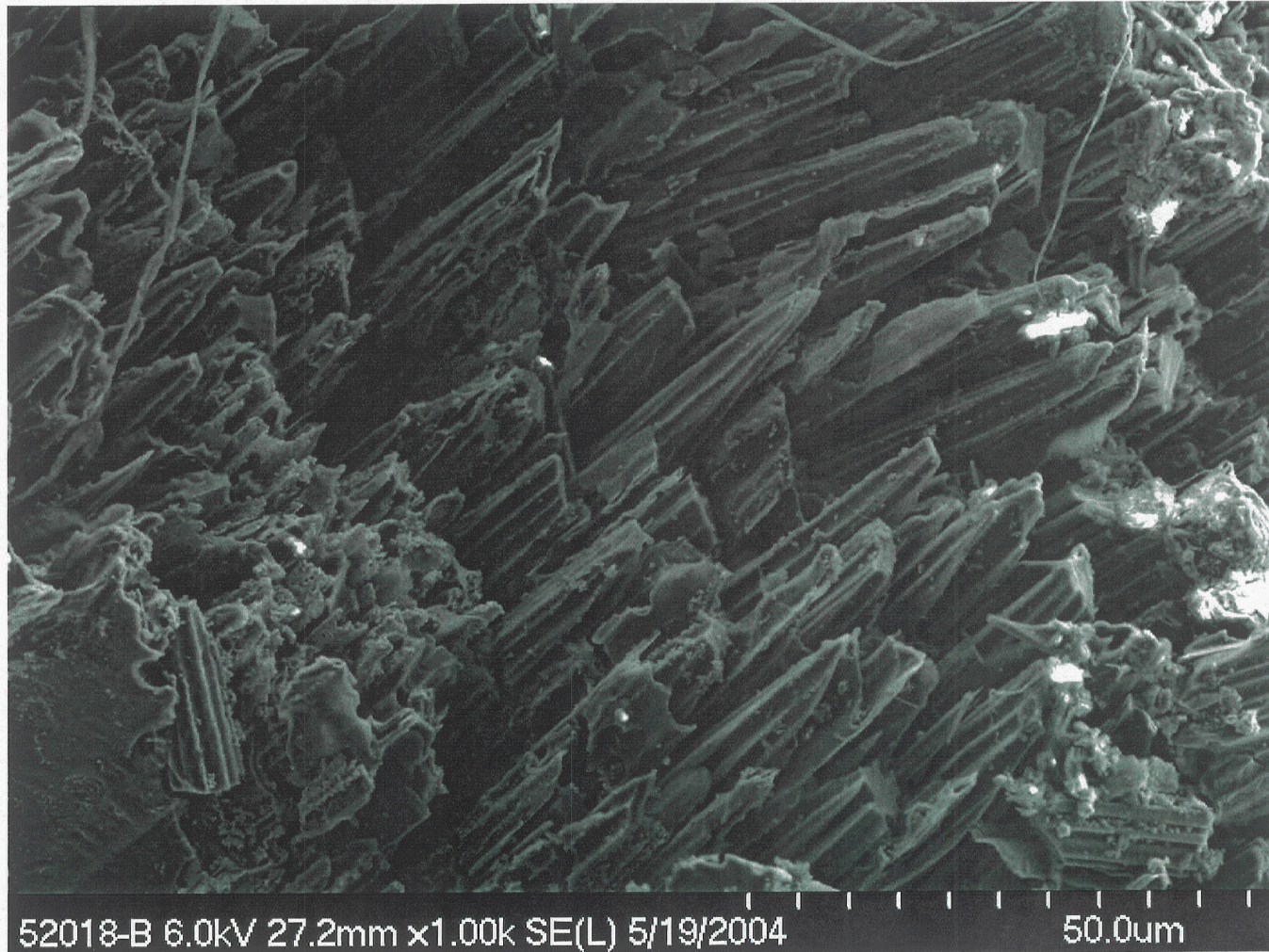
Slag—solidified
insulation (Cerachrome)
and metals

**Fractured/oxidized carbon
fibers and matrix—Focus
of this study**

Outer mold line

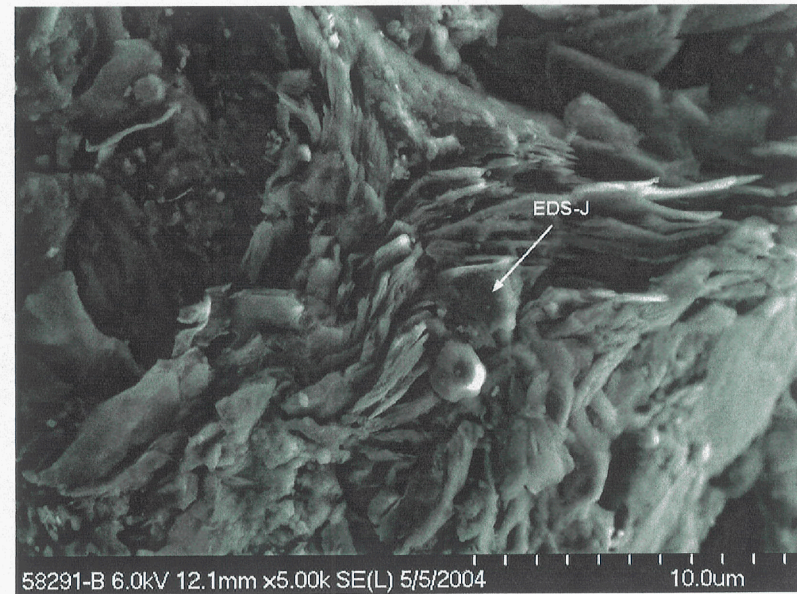
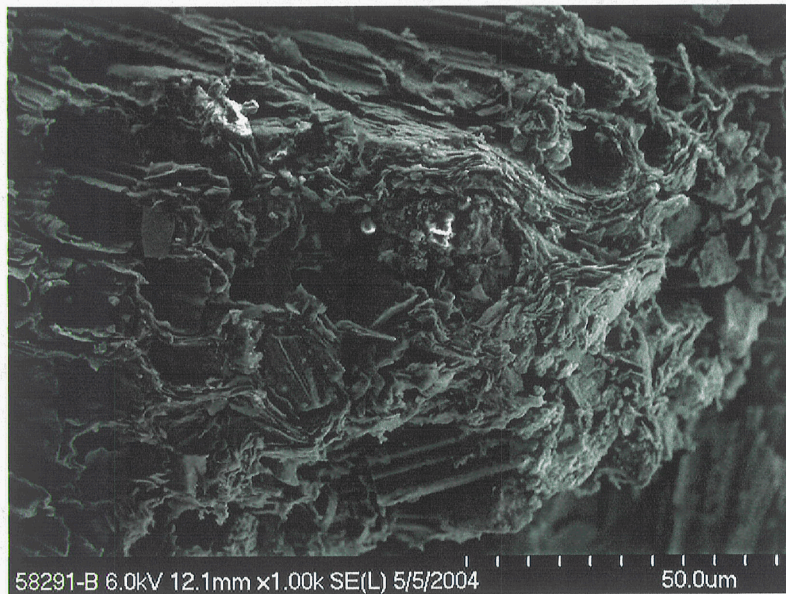
Panel 8--Lower

Characteristic Pointed Fibers from High Temperature Oxidation



Panel 8

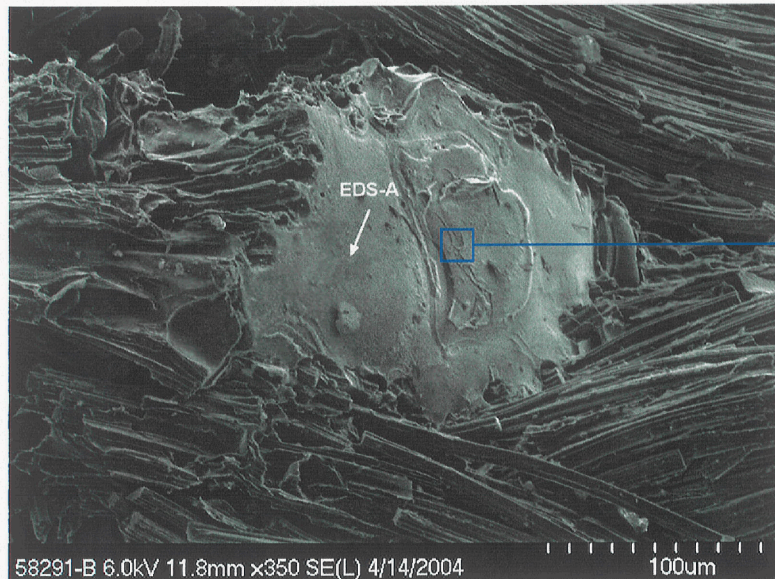
Extensive Oxidation and Erosion of Fibers and Matrix



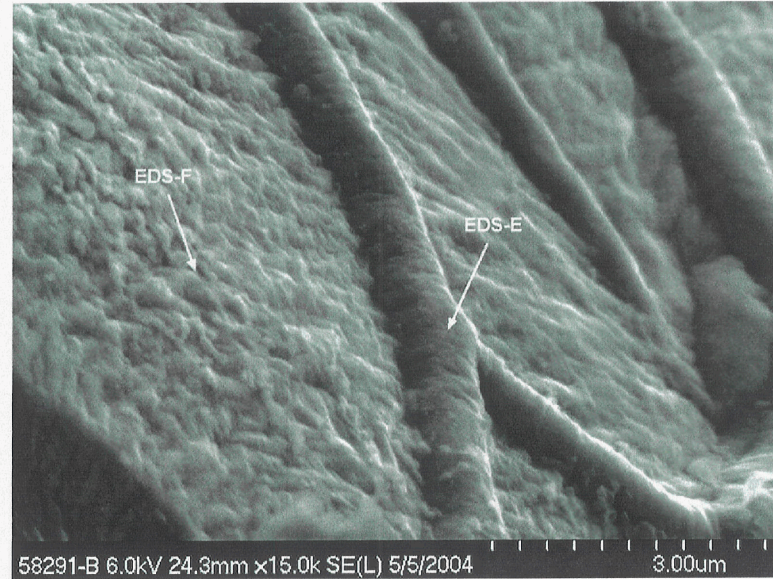
Panel 8—This layered, plate-like structure is characteristic of heavy erosion in Carbon

Unusual Features in Carbon Matrix

Flowing Carbon? Melting Point of Carbon is 3500 K



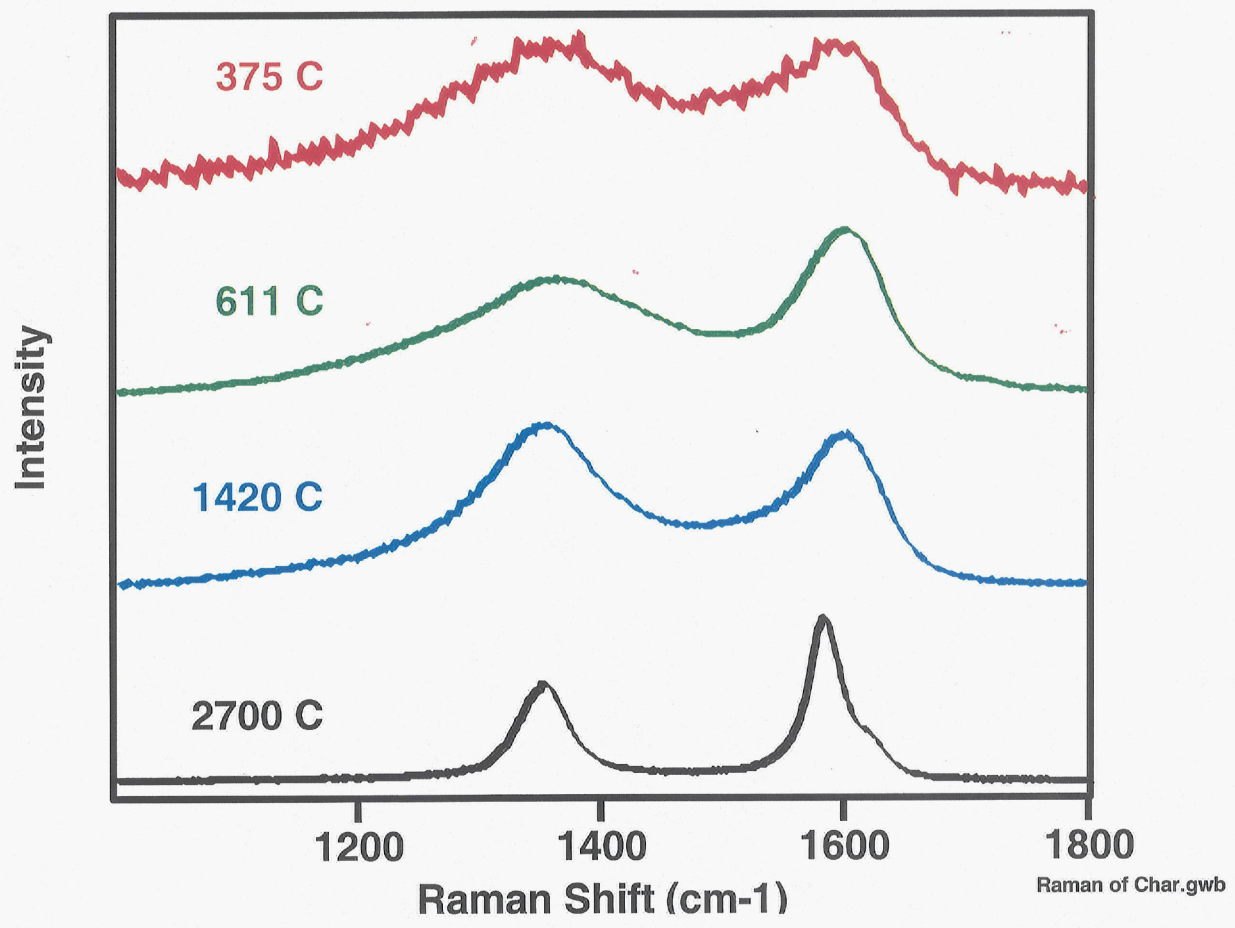
Overall View



Close-up of veins—all Carbon

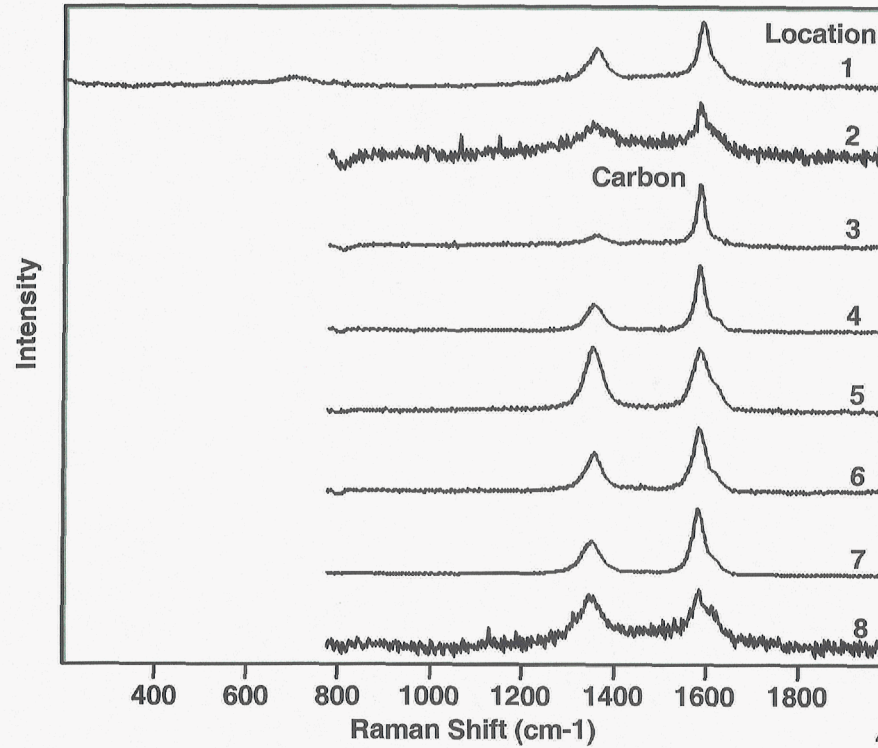
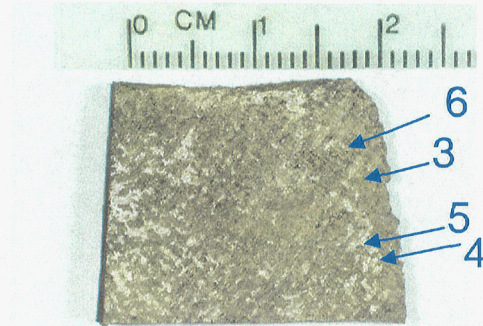
OF C/C ? OF C ?

Raman Standards—Characteristic Peak Heights Change with Temperature

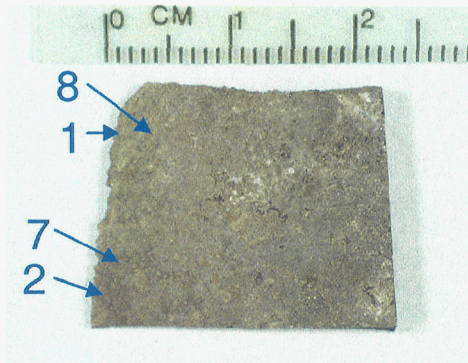


Raman Analyses of Portion of Upper Panel 8, near Breach

Item #49619A



49169A_2.gwb



Location	Location Description	Summary of Identified Bands
1	Knife edge	2700 C carbon plus small amount of low temp carbon
2	Knife edge	2700 C carbon plus small amount of low temp carbon
3	Knife edge	>> 2700 C carbon (off scale of reference carbons)
4	Knife edge	> 2700 C carbon (off scale of reference carbons)
5	Up slope	2400 C carbon
6	Up slope	2700 C carbon
7	Up slope	> 2700 C carbon (off scale of reference carbons)
8	Up slope	2400 C carbon

Conclusions

- Preliminary results suggest temperatures may have been higher than previously derived from melting point of Cerachrome (1760°C).
- Raman spectroscopy $\Rightarrow >> 2700^{\circ}\text{C}$
Flowing carbon $\Rightarrow 3500^{\circ}\text{C} ??$
- Extensive oxidation and erosion
 - Pointed fiber morphology
 - Exposed layers of carbon—erosion

Acknowledgements

Special thanks are due to Terry McCue (QSS, Inc. NASA GRC Group) for electron microscopy. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract DE-AC04-94AL85000.

In Memoriam...

