

# *Individual aerosol analysis using transmission electron microscopy*

Examples of electron energy-loss spectra and high-resolution images  
(Preliminary results)

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and Kouji Adachi, Postdoctoral Research Associate

Analysis method: transmission electron microscopy (TEM) with electron energy-loss spectroscopy (EELS)

TEM: Tecnai F20 (at John M. Cowley Center for High Resolution Electron Microscopy, ASU)

Aircraft: C130

Sampler: MPS-3 (California Measurements, Inc.)

Sampling: Thomas Karl (NCAR)

TEM analysis: Kouji Adachi (ASU)

PI: Peter R. Buseck (Arizona State University)

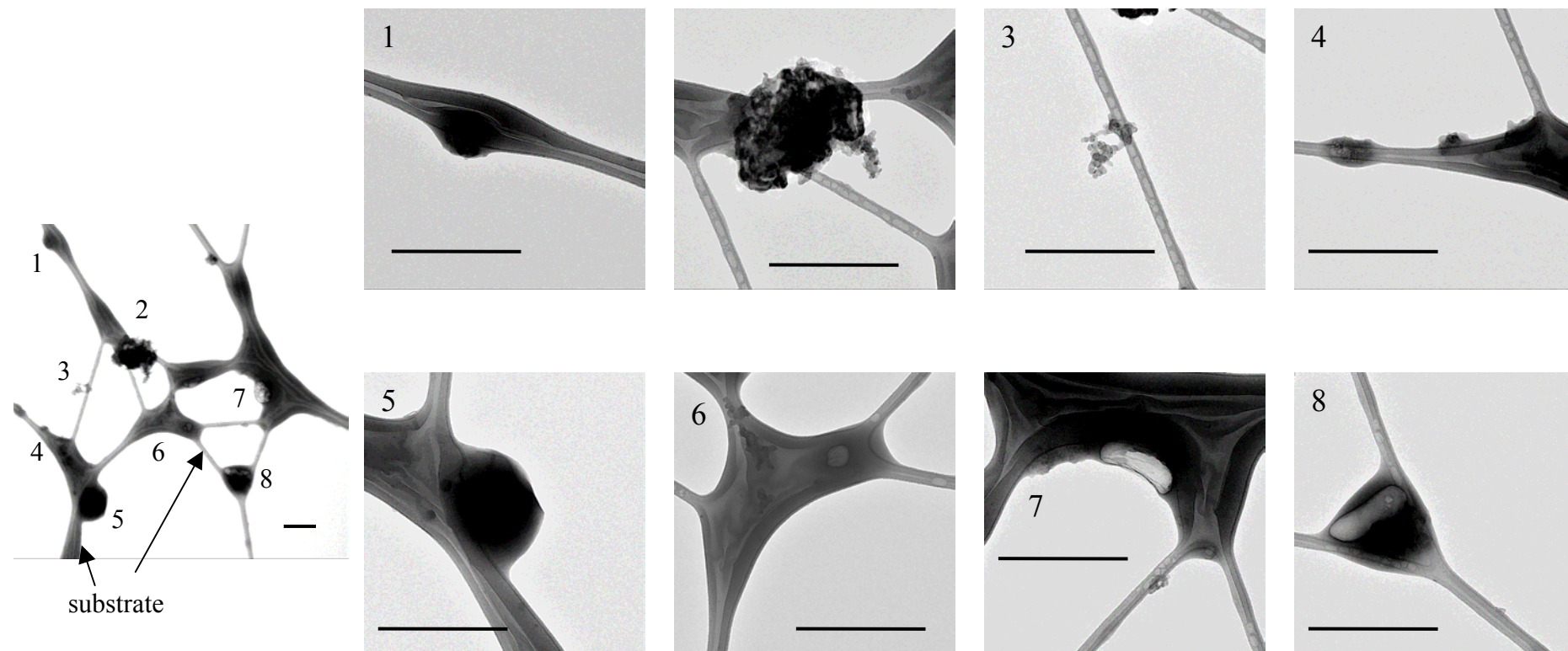
Sample in this report: 03/10/06-#3 (sampling time, 20:44:45-20:50:17 (UTC)), C130, Flight # RF3.

# Sampling table

sampling date	sample number	start time (UTC)	end time (UTC)	sampling time (seconds)	Start_UTC, (number of seconds from 0000 UTC)	End_UTC, (number of seconds from 0000 UTC)	LATITUDE	LONGITUDE	altitude
30806	1	182700	183126	266	66420	66686	18.00	260.82	3.24
30806	2	203352	203809	257	74032	74289	18.81	260.79	2.96
30806	3	211726	212203	277	76646	76923	19.23	260.97	4.09
31006	1	163525	163952	267	59725	59992	21.04	265.96	5.62
31006	2	184504	185345	521	67504	68025	21.00	262.27	2.41
31006	3	204445	205017	332	74685	75017	19.71	260.86	3.75
31206	1	193412	195047	995	70452	71447	21.30	261.87	2.97
31206	2	204110	204502	232	74470	74702	19.51	262.33	4.75
31206	3	233001	233403	242	84601	84843	20.41	261.84	3.52
31606	1	172916	173400	284	62956	63240	21.50	258.34	2.85
31606	2	185700	190131	271	68220	68491	20.86	259.89	3.14
31606	3	200401	200814	253	72241	72494	20.26	260.21	2.86
31806	1	165002	165548	346	60602	60948	22.20	259.75	4.11
31806	2	183243	183653	250	66763	67013	22.20	259.90	3.50
31806	3	205437	205852	255	75277	75532	20.00	260.97	3.77
31906	1	204434	204842	248	74674	74922	24.97	265.34	4.78
31906	2	231337	231743	246	83617	83863	24.25	263.57	3.24
31906	3	242934	243341	247	88174	88421	21.90	262.01	3.95
32206	1	161239	161641	242	58359	58601	20.78	263.81	4.91
32206	2	173848	174259	251	63528	63779	20.08	263.53	4.15
32206	3	204855	205305	250	74935	75185	19.73	260.73	4.09
32306	1	184530	184929	239	67530	67769	20.61	270.00	3.68
32306	2	191902	193019	677	69542	70219	19.30	270.66	5.06
32306	3	223004	223600	356	81004	81360	18.53	264.01	4.78
32806	1	113308	113817	309	41588	41897	20.64	261.84	4.14
32806	2	123007	123517	310	45007	45317	20.95	261.59	2.30
32806	3	153223	153811	348	55943	56291	19.85	264.67	4.88
32906	1	182654	183101	247	66414	66661	20.01	261.60	3.75
32906	2	185529	185945	256	68129	68385	20.00	261.11	3.46
32906	3	193852	194301	249	70732	70981	19.50	260.71	3.72

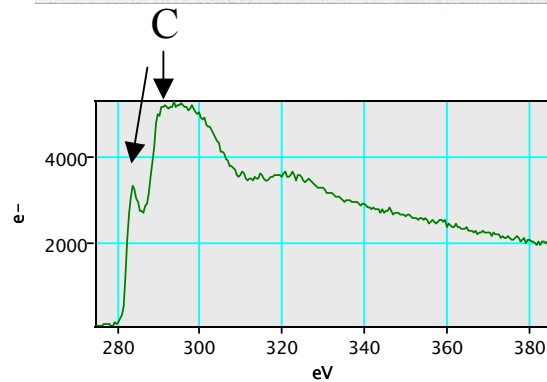
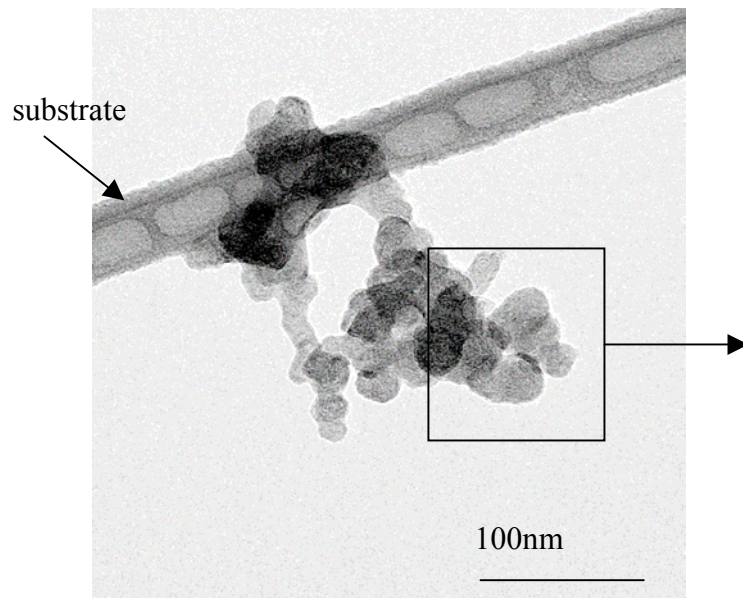
Start and end times (6 digit) show hour, minute, and second in UTC (ex.182700, 18:27:00 UTC). Latitude, longitude, and altitude are averaged over the sampling time.

TEM images of various kinds of aerosol particles: sample 03/10/06- #3 (sampling time, 20:44:45-20:50:17 (UTC))



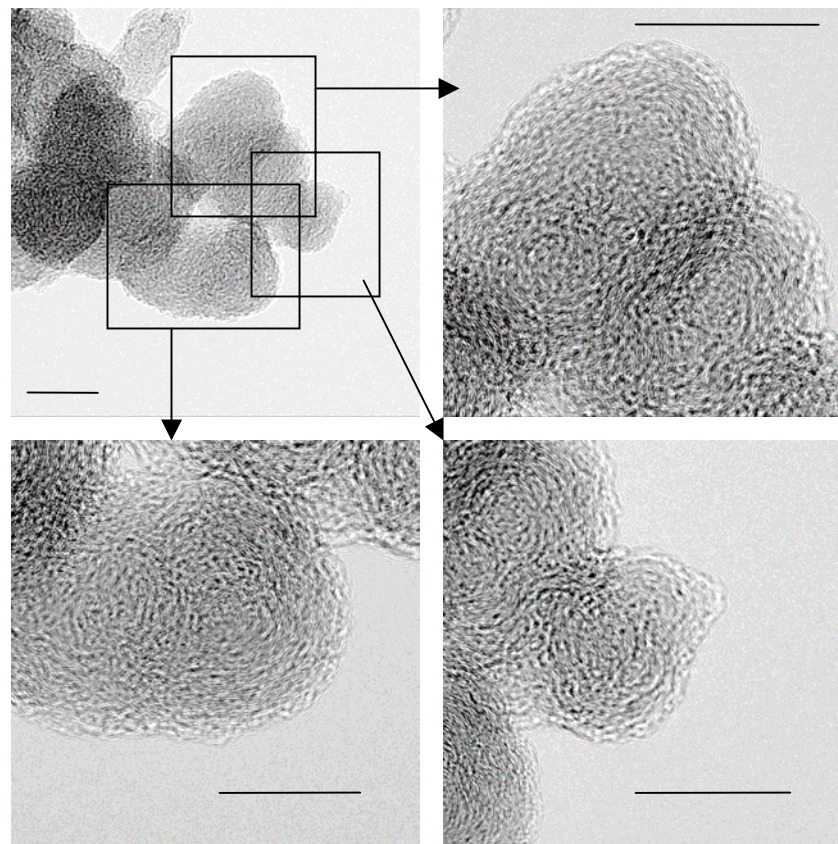
TEM images of various kinds of aerosol particles. The numbers in the low-magnification image (left) correspond to the numbers of the higher magnification TEM images (right 1-8). Electron energy-loss spectra (EELS) analyses were performed to characterize the compositions of particles #2, 3, and 7 in the following slides. Scale bars indicate 500 nm.

## Externally mixed soot: particle #3



EELS

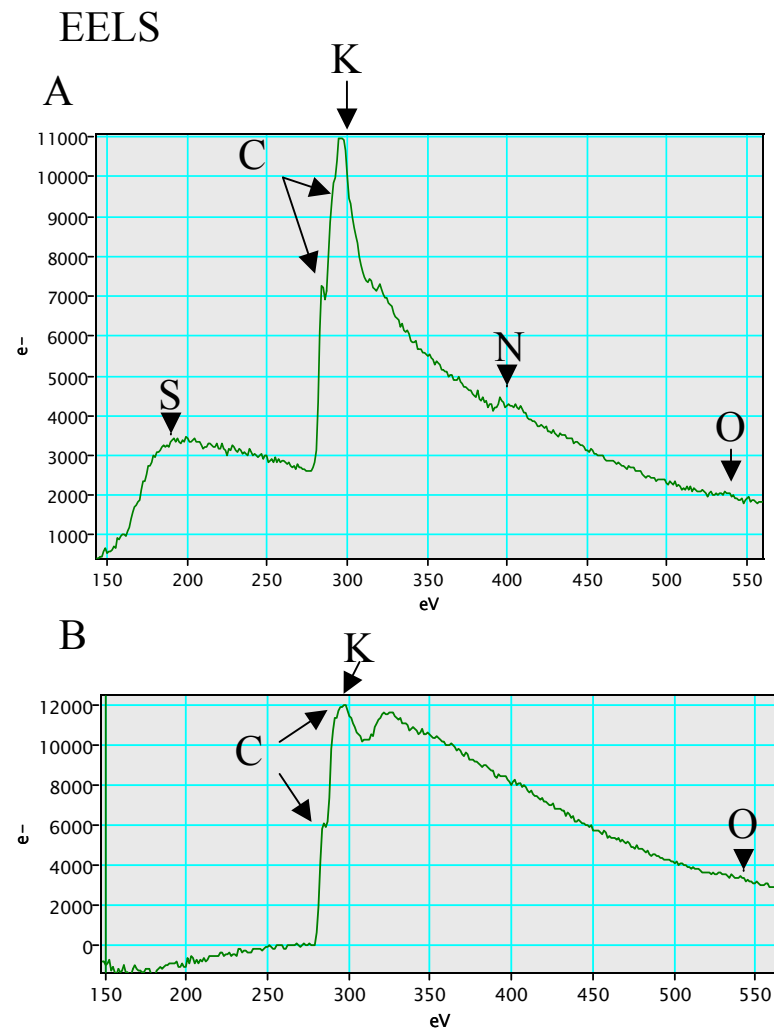
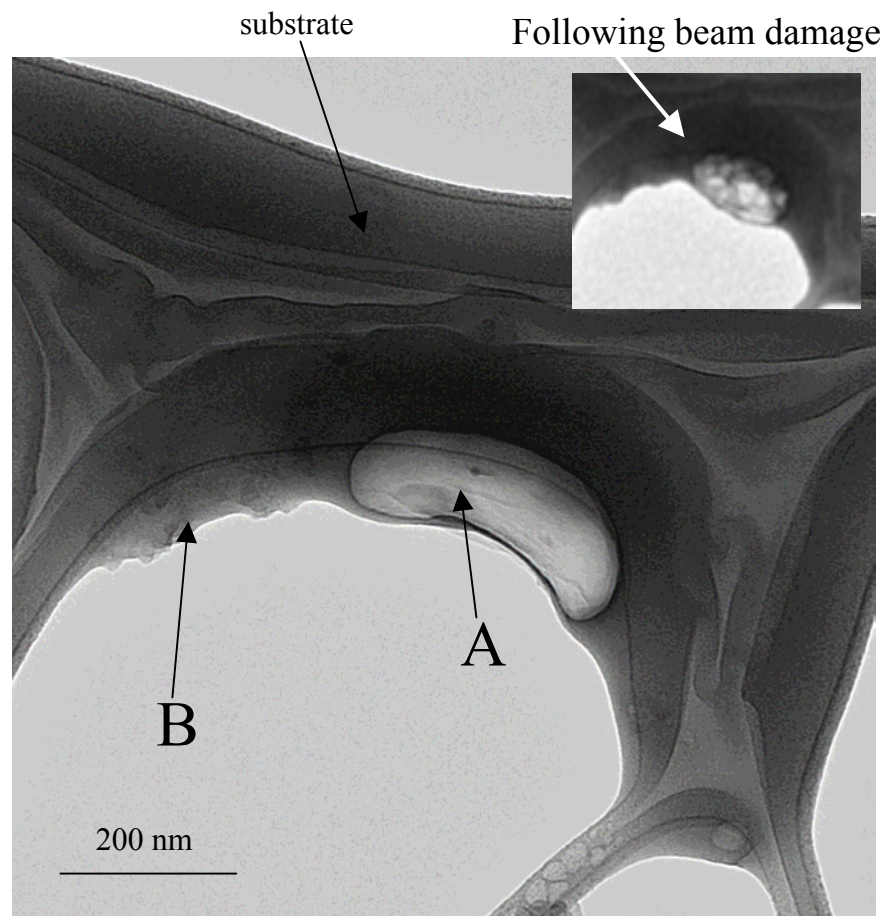
High-resolution images of soot showing its graphitic structure (~onion rings)



High-resolution images of soot aggregate. Right: high-resolution TEM images show “onion-ring structures” that indicate graphitic layers in the soot aggregate. EELS also shows the graphitic layer in the soot ( $\sigma^*$  peak at 291 eV in EELS).

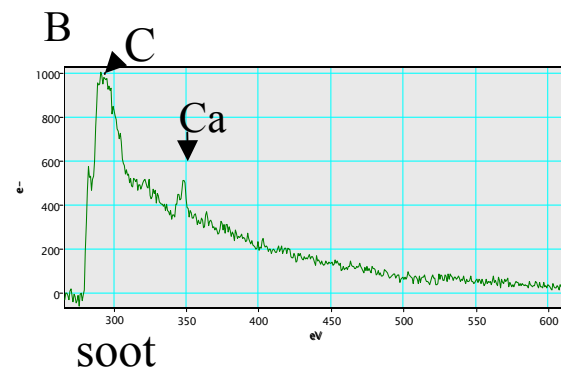
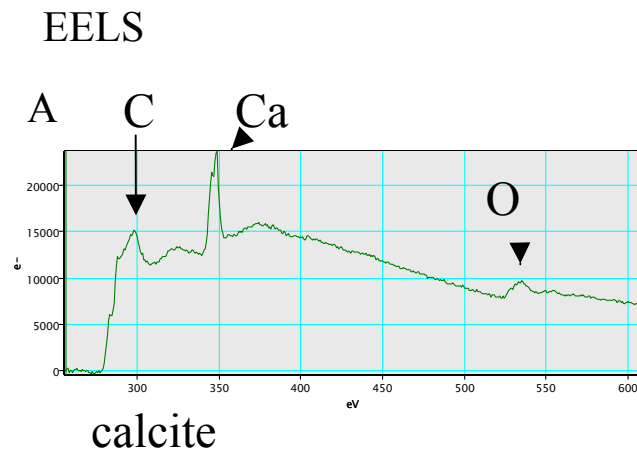
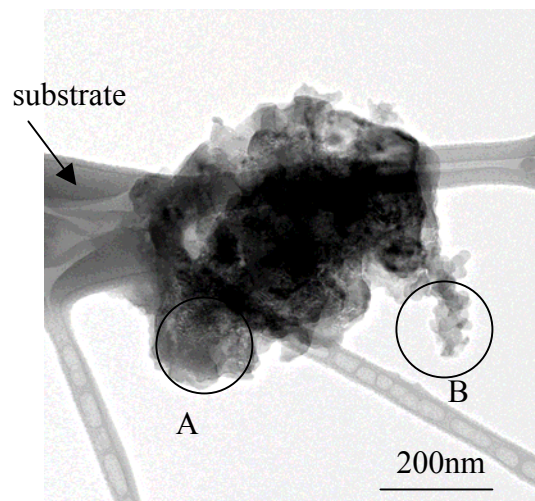


## Associated ammonium sulfate (AS) and organic matter (OM): particle #7

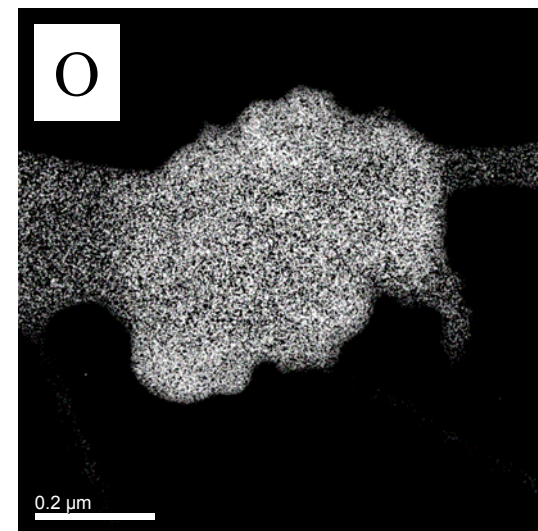
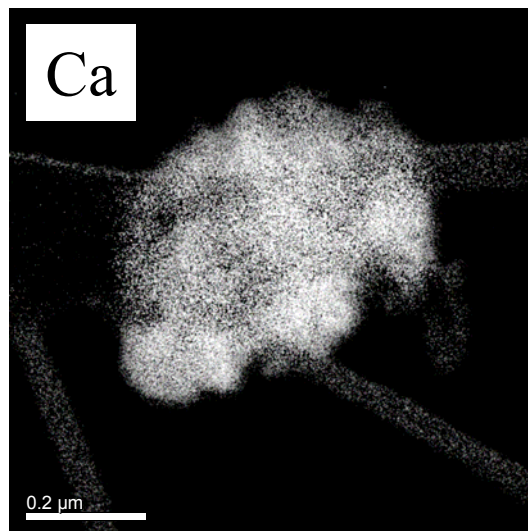
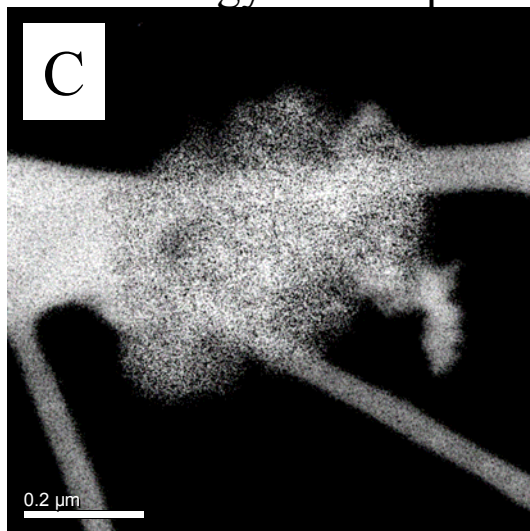


TEM image and EELS of associated ammonium sulfate (AS) and organic matter (OM). The right top TEM image shows the effects of radiation damage on AS. EELS indicates the presence of S, C, K, N, and O (spectrum A). The peak at 294 eV suggests the presence of K. In spectrum (B), C, K, and O (trace) are present. The B area was relatively resistant to beam damage.

## Internally mixed particle of soot and mineral (calcite): particle #2



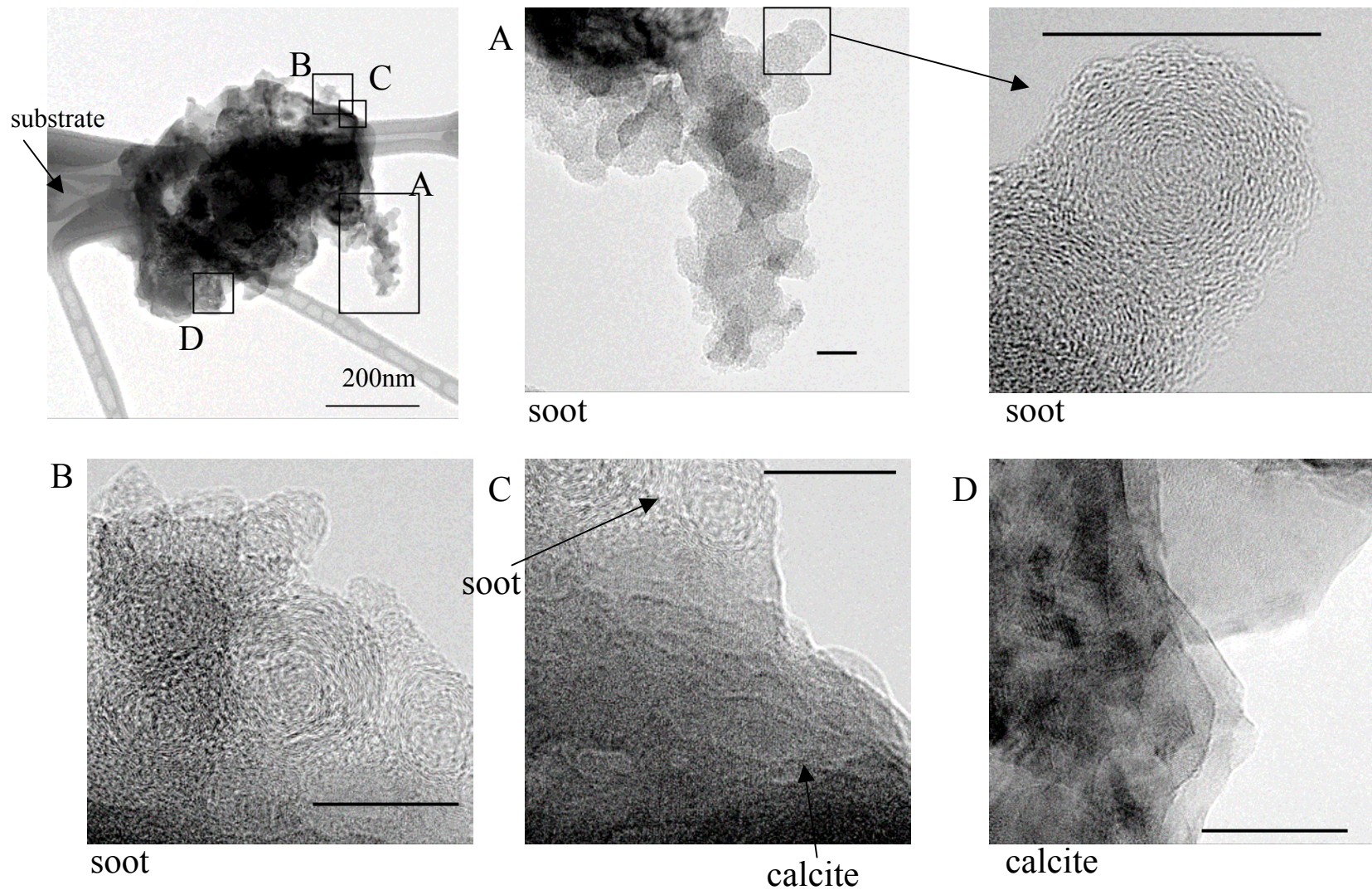
## Electron energy-loss maps



Internally mixed particle of soot and mineral. The presence of C, Ca, and O in EELS (A) suggests that this particle is calcite ( $\text{CaCO}_3$ ). The bottom three images show element distributions as detected by EELS. These images confirm that this particle mostly consists of calcite, and some soot particles are attached. Particles of mixed soot and mineral were not as common during Milagro sampling as were mixtures of soot and AS/OM.

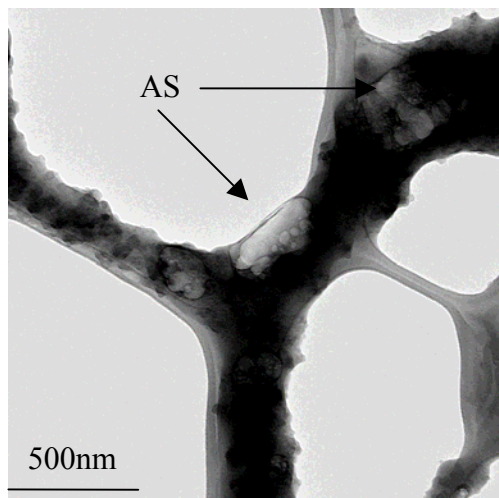


## Internally mixed particle of soot and mineral (calcite): particle #2

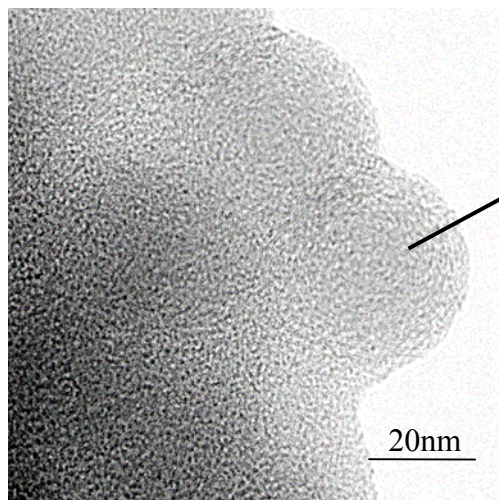
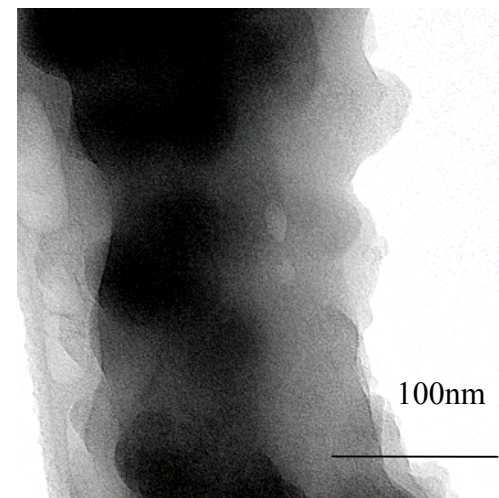
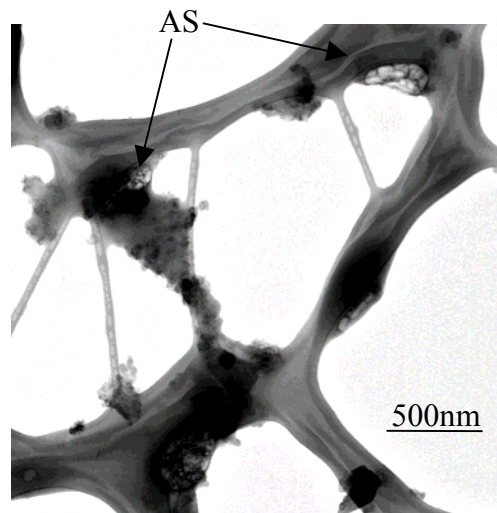


High-resolution (HR) images of a particle of soot and mineral. HR images of soot (A (right), B, and C) indicate onion-ring structures. HR images of mineral (C and D) show lattice fringes. Scale bars indicate 20 nm.

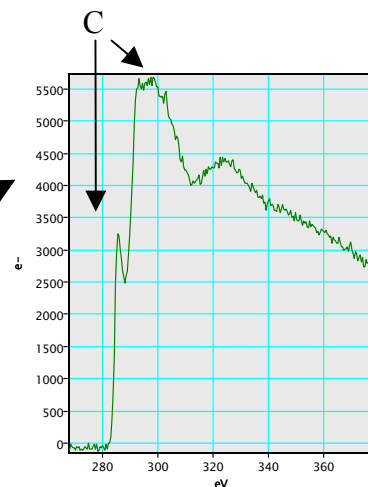
## Internally mixed particle of soot and AS/OM (1)



Mixture of soot and AS/OM



Soot



EELS: Soot

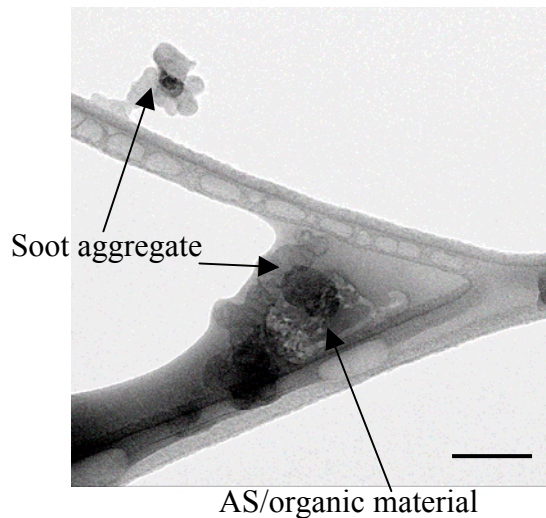
TEM images of internal mixture of soot and AS/OM. These images are from the same sample as the previous images (03/10/06-#3) but of different areas on the TEM grid. Soot and AS/OM form large aggregates. The frothy structure in the lower-magnification images suggest the presence of AS, which is relatively sensitive to the electron beam. The HR image and EELS of soot show the presence of graphitic layers.



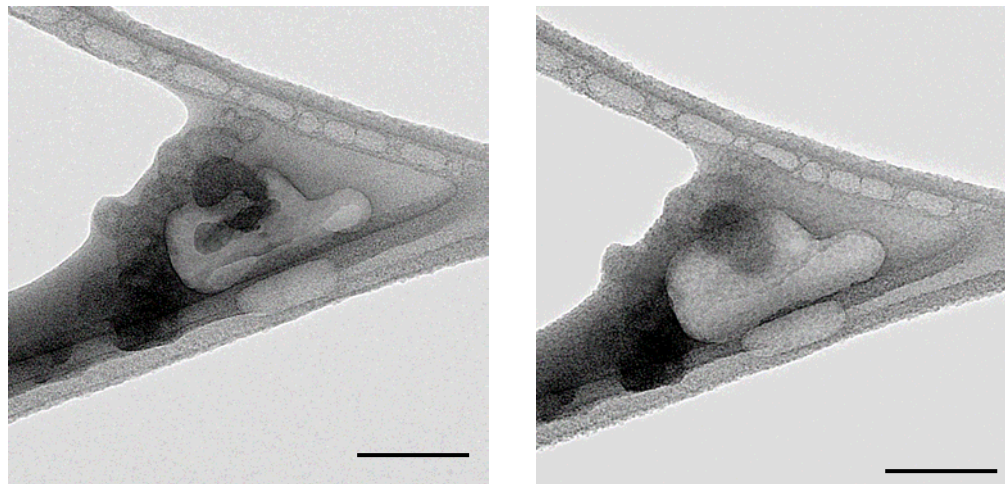
## Internally mixed particle of soot and AS/OM (2)

### Effects of radiation damage on AS

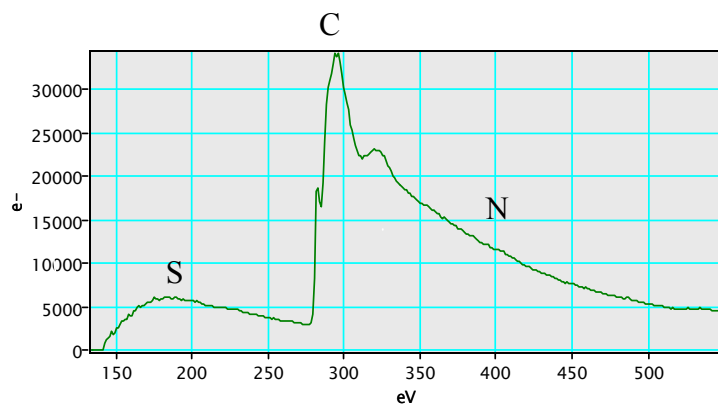
Before beam damage



After beam damage

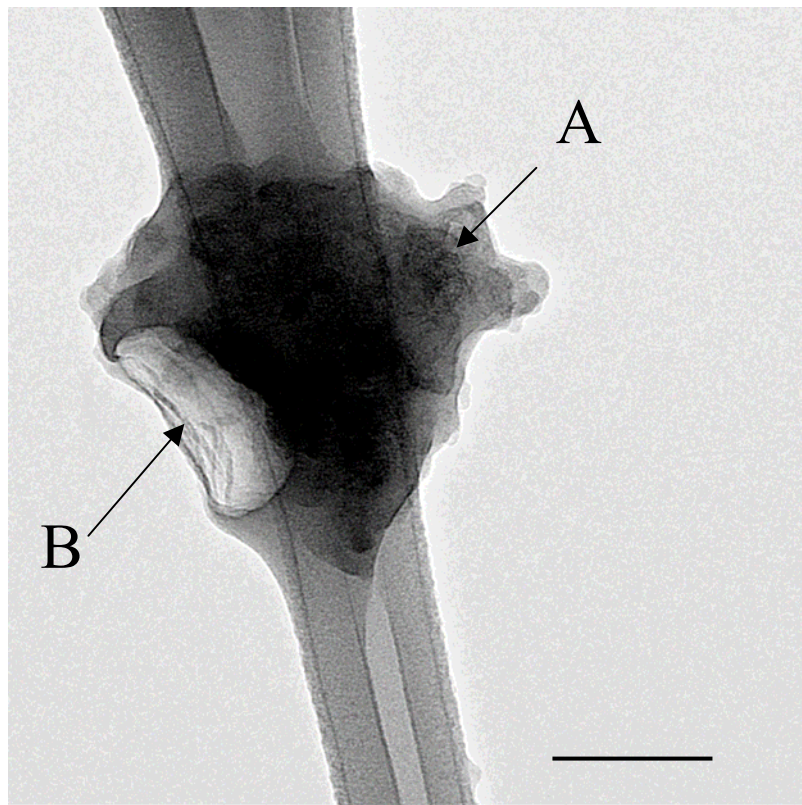


Scale bar: 100nm



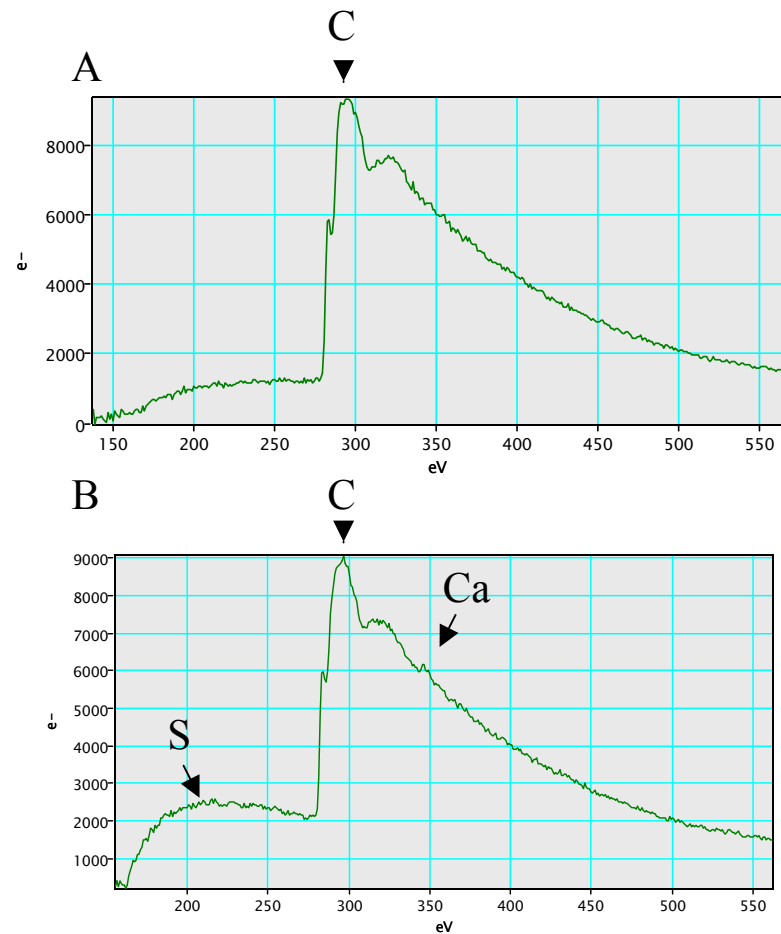
An example of internally mixed soot and AS/OM. Before EELS and HR analysis (left image), the internal soot has a boundary between the primary particles. After analysis, the boundary between the soot and AS/OM became unclear and some of the AS/OM volatilized. The EELS was from the internally mixed area.

## Internally mixed particle of soot and AS/OM (3)



Scale bar: 100 nm

### EELS



An example of internally mixed soot and AS/OM. EELS (A) shows a  $\sigma^*$  peak at 291 eV, which indicates that A area is soot particle. EELS (B) shows S, C, and Ca. The hollow shape in part B suggest that this material is a residue of AS/OM.