NLU 55-SS-0010: Summary of PAH Analyses on Bulk Sediment Sample and Separated Fractions

Compounds	Sediment concentration in light density fraction (mg/kg dry weight)	Sediment concentration in heavy density fraction (mg/kg dry weight)	Calculated sediment concentration (mg/kg dry weight)	Measured bulk sediment concentration (mg/kg dry weight)	Mass percentage of PAH in light density fraction (% by weight)
Naphthalene	23.9	0.2	3.5	4.2	94
Acenaphthylene	10.2	0.1	1.5	1.7	95
Acenaphthene	7.5	0.1	1.1	1.8	94
Fluorene	11.5	0.1	1.7	1.9	96
Phenanthrene	91.3	0.7	13.2	12.0	95
Anthracene	22.7	0.2	3.3	2.6	95
Fluoranthene	127.9	1.2	18.7	20.6	94
Pyrene	149.8	1.5	21.9	24.7	94
Benz[a]anthracene	57.3	0.5	8.4	8.4	95
Chrysene	62.0	0.6	9.0	9.7	95
Benzo[b]fluoranthene	47.4	0.4	6.9	7.5	95
Benzo[k]fluoranthene	53.3	0.6	7.9	7.9	93
Benzo[a]pyrene	79.2	0.6	11.5	11.1	95
Indeno[1,2,3-cd]pyrene	55.5	0.5	8.1	7.6	95
Dibenz[a,h]anthracene	9.9	< 0.1	1.4	1.2	100
Benzo[g,h,i]perylene	58.8	0.5	8.6	8.2	95
Total (mg/kg)	**868**	**8**	**127**	**131**	**95**

Note:

- ❖ Reported concentration values are average values of duplicate tests with relative standard deviation (RSD) ranging from 0.2~9% for all PAH compounds of interest.
- ❖ Calculated PAH concentration in the whole sediment samples was calculated by multiplying measured PAH concentrations on light density fraction and heavy density fraction with their respective mass percentage and then summing those up. By comparing with bulk sediment sample PAH measurements, this confirms PAH mass balance in the separated fractions.

NLU 56-SS-0010: Summary of PAH Analyses on Bulk Sediment Sample and Separated Fractions

Compounds	Sediment concentration in light density fraction (mg/kg dry weight)	Sediment concentration in heavy density fraction (mg/kg dry weight)	Calculated sediment concentration (mg/kg dry weight)	Measured bulk sediment concentration (mg/kg dry weight)	Mass percentage of PAH in light density fraction (% by weight)
Naphthalene	37	0.3	4	3	92
Acenaphthylene	62	0.6	6	6	91
Acenaphthene	239	3.5	25	37	87
Fluorene	111	2.2	12	15	83
Phenanthrene	1145	25.1	128	131	82
Anthracene	297	3.6	31	35	89
Fluoranthene	2159	41.1	236	240	84
Pyrene	2713	49.0	294	300	85
Benz[a]anthracene	639	8.2	66	65	89
Chrysene	682	11.7	73	79	86
Benzo[b]fluoranthene	658	6.0	66	65	92
Benzo[k]fluoranthene	670	6.9	68	66	91
Benzo[a]pyrene	1251	8.7	123	114	94
Indeno[1,2,3-cd]pyrene	929	6.4	91	90	94
Dibenz[a,h]anthracene	121	0.9	12	11	93
Benzo[g,h,i]perylene	1066	6.8	98	104	100
Total (mg/kg)	**12779**	**181**	**1334**	**1361**	**88**

Note:

- Reported concentration values are average values of duplicate tests with relative standard deviation (RSD) ranging from 0.2~9% for all PAH compounds of interest.
- Calculated PAH concentration in the whole sediment samples was calculated by multiplying measured PAH concentrations on light density fraction and heavy density fraction with their respective mass percentage and then summing those up. By comparing with bulk sediment sample PAH measurements, this confirms PAH mass balance in the separated fractions.

NLU 57-SS-0010: Summary of PAH Analyses on Bulk Sediment Sample and Separated Fractions

Compounds	Sediment concentration in light density fraction (mg/kg dry weight)	Sediment concentration in heavy density fraction (mg/kg dry weight)	Calculated sediment concentration (mg/kg dry weight)	Measured bulk sediment concentration (mg/kg dry weight)	Mass percentage of PAH in light density fraction (% by weight)
Naphthalene	n.d.	n.d.	n.a.	n.d.	n.a.
Acenaphthylene	n.d.	n.d.	n.a.	n.d.	n.a.
Acenaphthene	< 0.1	< 0.1	n.d.	0.2	n.a.
Fluorene	< 0.1	< 0.1	n.d.	1.0	n.a.
Phenanthrene	4.4	1.2	2.7	3.0	77
Anthracene	2.2	< 0.1	1.0	2.1	100
Fluoranthene	11.8	4.3	7.8	8.3	71
Pyrene	10.7	3.7	7.0	7.0	72
Benz[a]anthracene	5.9	1.0	3.3	2.8	84
Chrysene	8.4	1.2	4.6	4.0	86
Benzo[b]fluoranthene	4.3	1.0	2.6	3.2	80
Benzo[k]fluoranthene	5.3	0.9	2.9	4.6	84
Benzo[a]pyrene	4.5	< 0.1	2.1	3.2	100
Indeno[1,2,3-cd]pyrene	2.9	< 0.1	1.4	3.1	100
Dibenz[a,h]anthracene	< 0.1	< 0.1	n.d.	0.4	n.a.
Benzo[g,h,i]perylene	2.7	< 0.1	1.3	3.2	100
Total (mg/kg)	**63**	**13**	**37**	**46**	**81**

Note:

- Reported concentration values are average values of duplicate tests with relative standard deviation (RSD) ranging from 0.5~15% for all PAH compounds of interest.
- Calculated PAH concentration in the whole sediment samples was calculated by multiplying measured PAH concentrations on light density fraction and heavy density fraction with their respective mass percentage and then summing those up. By comparing with bulk sediment sample PAH measurements, this confirms PAH mass balance in the separated fractions.

NLU 62-SS-0010: Summary of PAH Analyses on Bulk Sediment Sample and Separated Fractions

Compounds	Sediment concentration in light density fraction (mg/kg dry weight)	Sediment concentration in heavy density fraction (mg/kg dry weight)	Calculated sediment concentration (mg/kg dry weight)	Measured bulk sediment concentration (mg/kg dry weight)	Mass percentage of PAH in light density fraction (% by weight)
Naphthalene	11.8	5.7	8.5	3.1	64
Acenaphthylene	2.4	< 0.5	1.1	1.4	100
Acenaphthene	7.8	< 0.5	3.6	3.3	100
Fluorene	5.5	< 0.5	2.5	2.3	100
Phenanthrene	23.5	3.9	12.9	10.7	84
Anthracene	10.2	1.7	5.6	3.3	83
Fluoranthene	42.1	5.8	22.5	22.3	86
Pyrene	51.4	3.1	25.3	28.1	93
Benz[a]anthracene	16.6	2.4	8.9	8.4	85
Chrysene	22.2	1.4	11.0	9.2	93
Benzo[b]fluoranthene	17.2	2.5	9.3	9.6	85
Benzo[k]fluoranthene	17.1	< 0.5	7.8	10.5	100
Benzo[a]pyrene	28.7	1.6	14.1	15.0	94
Indeno[1,2,3-cd]pyrene	17.4	1.0	8.5	13.1	93
Dibenz[a,h]anthracene	2.6	< 0.1	1.2	1.7	100
Benzo[g,h,i]perylene	19.2	< 0.5	8.8	14.6	100
Total (mg/kg)	**296**	**29**	**152**	**157**	**90**

Note:

- Reported concentration values are average values of duplicate tests with relative standard deviation (RSD) ranging from 2~21% for all PAH compounds of interest.
- Calculated PAH concentration in the whole sediment samples was calculated by multiplying measured PAH concentrations on light density fraction and heavy density fraction with their respective mass percentage and then summing those up. By comparing with bulk sediment sample PAH measurements, this confirms PAH mass balance in the separated fractions.

NLU 64-SS-0010: Summary of PAH Analyses on Bulk Sediment Sample and Separated Fractions

Compounds	Sediment concentration in light density fraction (mg/kg dry weight)	Sediment concentration in heavy density fraction (mg/kg dry weight)	Calculated sediment concentration (mg/kg dry weight)	Measured bulk sediment concentration (mg/kg dry weight)	Mass percentage of PAH in light density fraction (% by weight)
Naphthalene	6.5	< 0.5	3.0	3.0	100
Acenaphthylene	9.3	< 0.5	4.3	4.2	100
Acenaphthene	19	1.8	9.6	12.4	90
Fluorene	10	1.2	5.2	6.2	88
Phenanthrene	55	5.0	28.2	31.2	90
Anthracene	16	1.5	8.4	15.5	90
Fluoranthene	262	27.2	135.3	135.8	89
Pyrene	325	32.5	167.2	168.7	89
Benz[a]anthracene	98	6.6	48.5	46.9	93
Chrysene	109	7.7	54.4	51.9	92
Benzo[b]fluoranthene	111	7.1	54.8	56.0	93
Benzo[k]fluoranthene	111	7.9	55.4	55.0	92
Benzo[a]pyrene	208	10.9	101.6	92.6	94
Indeno[1,2,3-cd]pyrene	156	8.3	76.0	75.9	94
Dibenz[a,h]anthracene	18	0.6	8.7	8.9	96
Benzo[g,h,i]perylene	182	9.6	89.1	89.8	94
Total (mg/kg)	**1697**	**128**	**850**	**854**	**92**

Note:

- Reported concentration values are average values of duplicate tests with relative standard deviation (RSD) ranging from 1~6% for all PAH compounds of interest.
- Calculated PAH concentration in the whole sediment samples was calculated by multiplying measured PAH concentrations on light density fraction and heavy density fraction with their respective mass percentage and then summing those up. By comparing with bulk sediment sample PAH measurements, this confirms PAH mass balance in the separated fractions.

NLU 65-SS-0010: Summary of PAH Analyses on Bulk Sediment Sample and Separated Fractions

Compounds	Sediment concentration in light density fraction (mg/kg dry weight)	Sediment concentration in heavy density fraction (mg/kg dry weight)	Calculated sediment concentration (mg/kg dry weight)	Measured bulk sediment concentration (mg/kg dry weight)	Mass percentage of PAH in light density fraction (% by weight)
Naphthalene	33.2	< 0.5	15.4	14.3	100
Acenaphthylene	53.0	< 0.5	24.6	26.5	100
Acenaphthene	123	0.5	57.6	64.2	100
Fluorene	49	0.2	22.9	27.2	99
Phenanthrene	368	2.8	172.2	173.6	99
Anthracene	97	0.4	45.3	47.8	99
Fluoranthene	1527	11.2	714.3	690.0	99
Pyrene	2055	14.1	961.1	908.4	99
Benz[a]anthracene	529	2.4	246.9	242.4	99
Chrysene	593	3.4	276.8	291.0	99
Benzo[b]fluoranthene	542	2.0	252.8	278.8	100
Benzo[k]fluoranthene	576	2.5	268.7	270.4	99
Benzo[a]pyrene	884	2.7	411.8	439.1	100
Indeno[1,2,3-cd]pyrene	647	1.8	301.2	332.7	100
Dibenz[a,h]anthracene	79	< 0.5	36.7	46.6	100
Benzo[g,h,i]perylene	780	2.3	363.4	382.2	100
Total (mg/kg)	**8937**	**46**	**4172**	**4235**	**99**

Note:

- Reported concentration values are average values of duplicate tests with relative standard deviation (RSD) ranging from 0.6~12% for all PAH compounds of interest.
- Calculated PAH concentration in the whole sediment samples was calculated by multiplying measured PAH concentrations on light density fraction and heavy density fraction with their respective mass percentage and then summing those up. By comparing with bulk sediment sample PAH measurements, this confirms PAH mass balance in the separated fractions.

NLU 68-US-S1: Summary of PAH Analyses on Bulk Sediment Sample and Separated Fractions

Compounds	Sediment concentration in light density fraction (mg/kg dry weight)	Sediment concentration in heavy density fraction (mg/kg dry weight)	Calculated sediment concentration (mg/kg dry weight)	Measured bulk sediment concentration (mg/kg dry weight)	Mass percentage of PAH in light density fraction (% by weight)
Naphthalene	133	2.5	36.1	27.5	95
Acenaphthylene	15.1	0.7	4.4	2.4	88
Acenaphthene	11	1.3	3.7	6.6	75
Fluorene	11	1.0	3.6	4.2	80
Phenanthrene	84	5.7	25.8	23.9	83
Anthracene	22	1.5	6.9	6.6	83
Fluoranthene	135	11.3	43.1	41.7	80
Pyrene	174	15.5	56.1	54.6	79
Benz[a]anthracene	64	4.1	19.6	18.6	84
Chrysene	73	5.1	22.6	22.5	83
Benzo[b]fluoranthene	61	3.2	18.0	18.5	87
Benzo[k]fluoranthene	63	3.8	19.1	11.3	85
Benzo[a]pyrene	99	4.2	28.5	27.1	89
Indeno[1,2,3-cd]pyrene	76	3.1	21.9	22.2	90
Dibenz[a,h]anthracene	12	0.6	3.6	3.5	87
Benzo[g,h,i]perylene	85	3.1	24.0	24.8	91
Total (mg/kg)	**1119**	**67**	**337**	**316**	**85**

Note:

- Reported concentration values are average values of duplicate tests with relative standard deviation (RSD) ranging from 0.3~10% for all PAH compounds of interest.
- Calculated PAH concentration in the whole sediment samples was calculated by multiplying measured PAH concentrations on light density fraction and heavy density fraction with their respective mass percentage and then summing those up. By comparing with bulk sediment sample PAH measurements, this confirms PAH mass balance in the separated fractions.

NLU 68-US-S2: Summary of PAH Analyses on Bulk Sediment Sample and Separated Fractions

Compounds	Sediment concentration in light density fraction (mg/kg dry weight)	Sediment concentration in heavy density fraction (mg/kg dry weight)	Calculated sediment concentration (mg/kg dry weight)	Measured bulk sediment concentration (mg/kg dry weight)	Mass percentage of PAH in light density fraction (% by weight)
Naphthalene	98	4.8	26.3	27.9	86
Acenaphthylene	11.1	2.7	4.7	4.2	55
Acenaphthene	7.4	1.9	3.2	3.9	54
Fluorene	13	3.3	5.4	7.1	54
Phenanthrene	52	13.4	22.3	26.2	54
Anthracene	14	3.1	5.5	6.0	57
Fluoranthene	26	6.6	11.1	12.8	54
Pyrene	37	9.5	15.8	18.5	53
Benz[a]anthracene	14	3.5	6.0	6.7	55
Chrysene	16	4.2	6.8	8.4	53
Benzo[b]fluoranthene	7.7	2.0	3.3	3.5	54
Benzo[k]fluoranthene	8.7	2.2	3.7	4.4	54
Benzo[a]pyrene	13.6	2.7	5.2	5.4	60
Indeno[1,2,3-cd]pyrene	7.1	1.1	2.5	3.2	65
Dibenz[a,h]anthracene	1.7	0.3	0.6	0.9	60
Benzo[g,h,i]perylene	7.3	1.3	2.7	3.4	62
Total (mg/kg)	**334**	**63**	**125**	**142**	**61**

Note:

- Reported concentration values are average values of duplicate tests with relative standard deviation (RSD) ranging from 4~20% for all PAH compounds of interest.
- Calculated PAH concentration in the whole sediment samples was calculated by multiplying measured PAH concentrations on light density fraction and heavy density fraction with their respective mass percentage and then summing those up. By comparing with bulk sediment sample PAH measurements, this confirms PAH mass balance in the separated fractions.

NLU 72-SS-0010: Summary of PAH Analyses on Bulk Sediment Sample and Separated Fractions

Compounds	Sediment concentration in light density fraction (mg/kg dry weight)	Sediment concentration in heavy density fraction (mg/kg dry weight)	Calculated sediment concentration (mg/kg dry weight)	Measured bulk sediment concentration (mg/kg dry weight)	Mass percentage of PAH in light density fraction (% by weight)
Naphthalene	7.4	3.1	5.1	0.7	68
Acenaphthylene	< 0.5	< 0.5	n.a.	0.6	n.a.
Acenaphthene	< 0.5	< 0.5	n.a.	0.6	n.a.
Fluorene	< 0.5	< 0.5	n.a.	0.3	n.a.
Phenanthrene	9.0	2.8	5.7	3.2	74
Anthracene	4.1	1.3	2.6	0.8	73
Fluoranthene	25	4.3	13.8	13.5	84
Pyrene	27	3.6	14.6	17.0	87
Benz[a]anthracene	9.7	2.0	5.6	5.6	81
Chrysene	9.0	2.0	5.3	5.8	80
Benzo[b]fluoranthene	12.7	2.1	7.1	7.7	84
Benzo[k]fluoranthene	12.1	1.8	6.6	8.5	86
Benzo[a]pyrene	19.9	2.0	10.4	12.1	90
Indeno[1,2,3-cd]pyrene	12.9	1.2	6.7	11.0	90
Dibenz[a,h]anthracene	1.5	< 0.5	0.7	1.2	100
Benzo[g,h,i]perylene	14.6	1.3	7.6	12.1	91
Total (mg/kg)	**165**	**28**	**92**	**100**	**84**

Note:

- Reported concentration values are average values of duplicate tests with relative standard deviation (RSD) ranging from 2~13% for all PAH compounds of interest.
- Calculated PAH concentration in the whole sediment samples was calculated by multiplying measured PAH concentrations on light density fraction and heavy density fraction with their respective mass percentage and then summing those up. By comparing with bulk sediment sample PAH measurements, this confirms PAH mass balance in the separated fractions.

NLU 73-SS-0010: Summary of PAH Analyses on Bulk Sediment Sample and Separated Fractions

Compounds	Sediment concentration in light density fraction (mg/kg dry weight)	Sediment concentration in heavy density fraction (mg/kg dry weight)	Calculated sediment concentration (mg/kg dry weight)	Measured bulk sediment concentration (mg/kg dry weight)	Mass percentage of PAH in light density fraction (% by weight)
Naphthalene	9.4	< 0.5	4.4	5.0	100
Acenaphthylene	7.5	< 0.5	3.5	3.4	100
Acenaphthene	15.2	< 0.5	7.0	6.3	100
Fluorene	10	< 0.5	4.5	3.9	100
Phenanthrene	65.5	1.0	30.8	26.4	98
Anthracene	21.3	< 0.5	9.8	7.6	100
Fluoranthene	121	1.6	56.8	44.5	98
Pyrene	157	2.1	73.4	56.5	98
Benz[a]anthracene	44.8	0.6	21.0	18.3	98
Chrysene	51.5	0.8	24.2	23.0	98
Benzo[b]fluoranthene	45.5	0.9	21.5	18.7	98
Benzo[k]fluoranthene	48.3	1.1	22.9	22.1	97
Benzo[a]pyrene	79.0	1.1	37.1	30.6	98
Indeno[1,2,3-cd]pyrene	55.3	1.0	26.1	23.5	98
Dibenz[a,h]anthracene	8.0	< 0.5	3.7	3.4	100
Benzo[g,h,i]perylene	61.7	1.1	29.1	25.8	98
Total (mg/kg)	**800**	**11**	**376**	**319**	**98**

Note:

- Reported concentration values are average values of duplicate tests with relative standard deviation (RSD) ranging from 0.2~9% for all PAH compounds of interest.
- Calculated PAH concentration in the whole sediment samples was calculated by multiplying measured PAH concentrations on light density fraction and heavy density fraction with their respective mass percentage and then summing those up. By comparing with bulk sediment sample PAH measurements, this confirms PAH mass balance in the separated fractions.

NLU 73-Stanford: Summary of PAH Analyses on Bulk Sediment Sample and Separated Fractions

Compounds	Sediment concentration in light density fraction (mg/kg dry weight)	Sediment concentration in heavy density fraction (mg/kg dry weight)	Calculated sediment concentration (mg/kg dry weight)	Measured bulk sediment concentration (mg/kg dry weight)	Mass percentage of PAH in light density fraction (% by weight)
Naphthalene	491	15.6	362	326	99
Acenaphthylene	37	3.1	28	17	97
Acenaphthene	203	7.5	150	150	99
Fluorene	88	3.7	65	71	98
Phenanthrene	517	24.9	383	362	98
Anthracene	116	5.7	86	86	98
Fluoranthene	273	23.5	205	219	97
Pyrene	353	32.6	266	276	97
Benz[a]anthracene	81	8.6	62	60	96
Chrysene	97	10.3	73	75	96
Benzo[b]fluoranthene	51	7.2	39	48	95
Benzo[k]fluoranthene	60	9.1	46	51	95
Benzo[a]pyrene	82	12.8	63	74	94
Indeno[1,2,3-cd]pyrene	47	8.0	36	50	94
Dibenz[a,h]anthracene	12	0.9	9	12	97
Benzo[g,h,i]perylene	53	9.3	41	55	94
Total (mg/kg)	**2561**	**183**	**1917**	**1932**	**97**

Note:

- Reported concentration values are average values of duplicate tests with relative standard deviation (RSD) ranging from 0.1~11% for all PAH compounds of interest.
- Calculated PAH concentration in the whole sediment samples was calculated by multiplying measured PAH concentrations on light density fraction and heavy density fraction with their respective mass percentage and then summing those up. By comparing with bulk sediment sample PAH measurements, this confirms PAH mass balance in the separated fractions.

NLU 45-SS-0010: Summary of PAH Analyses on Bulk Sediment Sample and Separated Fractions

Compounds	Sediment concentration in light density fraction (mg/kg dry weight)	Sediment concentration in heavy density fraction (mg/kg dry weight)	Calculated sediment concentration (mg/kg dry weight)	Measured bulk sediment concentration (mg/kg dry weight)	Mass percentage of PAH in light density fraction (% by weight)
Naphthalene	1.9	< 0.5	1.1	1.0	100
Acenaphthylene	1.9	< 0.5	1.1	1.2	100
Acenaphthene	3.8	0.5	2.3	3.0	91
Fluorene	2.0	0.3	1.3	1.4	88
Phenanthrene	20	2.4	12	10	91
Anthracene	5.6	0.6	3.4	2.6	92
Fluoranthene	77	9.6	48	37	91
Pyrene	94	11.5	58	46	91
Benz[a]anthracene	27	2.7	16	14	93
Chrysene	27	2.9	17	15	92
Benzo[b]fluoranthene	29	2.8	17	16	93
Benzo[k]fluoranthene	31	3.3	19	17	92
Benzo[a]pyrene	53	4.2	31	26	94
Indeno[1,2,3-cd]pyrene	38	3.6	23	21	93
Dibenz[a,h]anthracene	3.0	0.4	1.8	2.6	90
Benzo[g,h,i]perylene	43	4.0	26	23	93
Total (mg/kg)	**457**	**49**	**278**	**237**	**92**

Note:

- Reported concentration values are average values of duplicate tests with relative standard deviation (RSD) ranging from 4~17% for all PAH compounds of interest.
- Calculated PAH concentration in the whole sediment samples was calculated by multiplying measured PAH concentrations on light density fraction and heavy density fraction with their respective mass percentage and then summing those up. By comparing with bulk sediment sample PAH measurements, this confirms PAH mass balance in the separated fractions.

NLU 58-SS-0010: Summary of PAH Analyses on Bulk Sediment Sample and Separated Fractions

Compounds	Sediment concentration in light density fraction (mg/kg dry weight)	Sediment concentration in heavy density fraction (mg/kg dry weight)	Calculated sediment concentration (mg/kg dry weight)	Measured bulk sediment concentration (mg/kg dry weight)	Mass percentage of PAH in light density fraction (% by weight)
Naphthalene	4.1	< 0.5	3.3	3.2	100
Acenaphthylene	5.1	< 0.5	4.0	3.2	100
Acenaphthene	5.7	< 0.5	4.5	2.2	100
Fluorene	4.9	< 0.5	3.8	2.2	100
Phenanthrene	33	1.3	26	20	99
Anthracene	8.2	< 0.5	6.4	4.5	100
Fluoranthene	47	1.8	37	30	99
Pyrene	61	2.3	49	37	99
Benz[a]anthracene	21	0.7	17	13	99
Chrysene	25	1.0	20	16	99
Benzo[b]fluoranthene	19	0.8	15	13	99
Benzo[k]fluoranthene	22	1.2	18	15	99
Benzo[a]pyrene	33	1.0	26	19	99
Indeno[1,2,3-cd]pyrene	22	1.0	18	16	99
Dibenz[a,h]anthracene	4.6	< 0.5	3.6	2.5	100
Benzo[g,h,i]perylene	24	1.1	19	17	99
Total (mg/kg)	**340**	**12**	**270**	**214**	**99**

Note:

- ❖ Reported concentration values are average values of duplicate tests with relative standard deviation (RSD) ranging from 6~21% for all PAH compounds of interest.
- ❖ Calculated PAH concentration in the whole sediment samples was calculated by multiplying measured PAH concentrations on light density fraction and heavy density fraction with their respective mass percentage and then summing those up. By comparing with bulk sediment sample PAH measurements, this confirms PAH mass balance in the separated fractions.

NLU 68-SS-0010: Summary of PAH Analyses on Bulk Sediment Sample and Separated Fractions

Compounds	Sediment concentration in light density fraction (mg/kg dry weight)	Sediment concentration in heavy density fraction (mg/kg dry weight)	Calculated sediment concentration (mg/kg dry weight)	Measured bulk sediment concentration (mg/kg dry weight)	Mass percentage of PAH in light density fraction (% by weight)
Naphthalene	12	0.6	6	4	94
Acenaphthylene	21	0.7	9	5	96
Acenaphthene	48	8	26	32	81
Fluorene	35	4.4	18	21	86
Phenanthrene	129	6.9	60	45	94
Anthracene	95	10	48	43	88
Fluoranthene	396	51	202	192	86
Pyrene	524	68	267	244	86
Benz[a]anthracene	173	15	84	65	90
Chrysene	191	17	93	77	90
Benzo[b]fluoranthene	134	11	65	59	91
Benzo[k]fluoranthene	154	15	76	63	89
Benzo[a]pyrene	270	20	129	101	92
Indeno[1,2,3-cd]pyrene	177	14	85	76	91
Dibenz[a,h]anthracene	30	2.4	15	11	91
Benzo[g,h,i]perylene	195	15	94	86	91
Total (mg/kg)	**2584**	**259**	**1277**	**1124**	**89**

Note:

- Reported concentration values are average values of duplicate tests with relative standard deviation (RSD) ranging from 4~20% for all PAH compounds of interest.
- Calculated PAH concentration in the whole sediment samples was calculated by multiplying measured PAH concentrations on light density fraction and heavy density fraction with their respective mass percentage and then summing those up. By comparing with bulk sediment sample PAH measurements, this confirms PAH mass balance in the separated fractions.

SUB-ATTACHMENT 2D-7.2

Summary of Data for PAH Aqueous Equilibrium Experiments with Sediment Samples

Table 1

NLU 44-SS-0010: Aqueous Equilibrium Experiments (f_{oc} = 14.8%)

Compounds	Measured aqueous equilibrium concentrations (µg/L)	Calculated site-specific log K_d (L/kg)	Orgainc carbon-normalized log K_{oc} (L/kg)	Predicted log K_d = log $(f_{oc}\ K_{oc})$ (L/kg)
Naphthalene	n.d.	n.a.	n.a.	2.1
Acenaphthylene	n.a.	n.a.	n.a.	3.0
Acenaphthene	n.d.	n.a.	n.a.	2.8
Fluorene	n.d.	n.a.	n.a.	3.1
Phenanthrene	0.074 ± 0.005	4.2 ± 0.05	5.0 ± 0.05	3.3
Anthracene	0.017 ± 0.002	4.3 ± 0.10	5.1 ± 0.10	3.5
Fluoranthene	0.043 ± 0.004	4.9 ± 0.06	5.7 ± 0.06	4.0
Pyrene	0.063 ± 0.005	4.9 ± 0.05	5.7 ± 0.05	3.9
Benz[a]anthracene	0.004 ± 0.0006	5.6 ± 0.09	6.4 ± 0.09	4.7
Chrysene	0.004 ± 0.0002	5.6 ± 0.03	6.4 ± 0.03	4.6
Benzo[b]fluoranthene	0.001 ± 0.002	6.3 ± 0.09	7.1 ± 0.09	4.7
Benzo[k]fluoranthene	0.002 ± 0.004	6.3 ± 0.11	7.1 ± 0.11	4.8
Benzo[a]pyrene	0.001 ± 0.002	6.6 ± 0.14	7.4 ± 0.14	4.9
Indeno[1,2,3-cd]pyrene	n.a.	n.a.	n.a.	
Dibenz[a,h]anthracene	n.a.	n.a.	n.a.	5.5
Benzo[g,h,i]perylene	n.a.	n.a.	n.a.	5.8

Note:

- ❖ Duplicate aqueous equilibrium tests were conducted for this sample. Aqueous equilibrium concentrations and site-specific sediment-water partition coefficients for PAHs reported in the table are average values along with standard deviations.
- ❖ Organic carbon normalized sediment-water distribution coefficients K_{oc} were calculated by: $K_{oc} = K_d / f_{oc}$.

Table 2

NLU 47-SS-0010: Aqueous Equilibrium Experiments (f_{oc} = 14.1%)

Compounds	Measured aqueous equilibrium concentrations (μg/L)	Calculated site-specific log K_d (L/kg)	Orgainc carbon-normalized log K_{oc} (L/kg)	Predicted log K_d = log $(f_{oc}\ K_{oc})$ (L/kg)
Naphthalene	0.423 ± 0.012	3.2 ± 0.01	4.1 ± 0.01	2.1
Acenaphthylene	n.a.	n.a.	n.a.	3.0
Acenaphthene	0.128 ± 0.005	3.6 ± 0.03	4.5 ± 0.03	2.8
Fluorene	0.078 ± 0.002	3.7 ± 0.02	4.6 ± 0.02	3.1
Phenanthrene	0.178 ± 0.012	4.3 ± 0.05	5.2 ± 0.05	3.3
Anthracene	0.021 ± 0.003	4.6 ± 0.11	5.5 ± 0.11	3.4
Fluoranthene	0.089 ± 0.008	5.1 ± 0.06	6.0 ± 0.06	4.0
Pyrene	0.102 ± 0.008	5.1 ± 0.05	6.0 ± 0.05	3.9
Benz[a]anthracene	0.003 ± 0.0004	6.2 ± 0.10	7.1 ± 0.10	4.6
Chrysene	0.007 ± 0.0004	5.7 ± 0.03	6.6 ± 0.03	4.5
Benzo[b]fluoranthene	0.0008 ± 0.0001	6.8 ± 0.10	7.7 ± 0.10	4.6
Benzo[k]fluoranthene	0.001 ± 0.0002	6.7 ± 0.12	7.6 ± 0.12	4.7
Benzo[a]pyrene	n.d.	n.d.	n.d.	4.9
Indeno[1,2,3-cd]pyrene	n.a.	n.a.	n.a.	
Dibenz[a,h]anthracene	n.a.	n.a.	n.a.	5.5
Benzo[g,h,i]perylene	n.a.	n.a.	n.a.	5.8

Note:

❖ Duplicate aqueous equilibrium tests were conducted for this sample. Aqueous equilibrium concentrations and site-specific sediment-water partition coefficients for PAHs reported in the table are average values along with standard deviations.

❖ Organic carbon normalized sediment-water distribution coefficients K_{oc} were calculated by: $K_{oc} = K_d / f_{oc}$.

Table 3

NLU 51-SS-0010: Aqueous Equilibrium Experiments (f_{oc} = 40.3%)

Compounds	Measured aqueous equilibrium concentrations (μg/L)	Calculated site-specific log K_d (L/kg)	Orgainc carbon-normalized log K_{oc} (L/kg)	Predicted log K_d = log $(f_{oc}\ K_{oc})$ (L/kg)
Naphthalene	7.29 ± 0.20	3.4 ± 0.02	3.8 ± 0.02	2.6
Acenaphthylene	n.a.	n.a.	n.a.	3.4
Acenaphthene	73.8 ± 2.7	2.9 ± 0.02	3.3 ± 0.02	3.2
Fluorene	22.8 ± 0.7	3.2 ± 0.02	3.6 ± 0.02	3.5
Phenanthrene	103 ± 7	3.7 ± 0.04	4.1 ± 0.04	3.8
Anthracene	15.4 ± 2.3	4.0 ± 0.09	4.4 ± 0.09	3.9
Fluoranthene	26.9 ± 2.4	4.5 ± 0.05	4.9 ± 0.05	4.4
Pyrene	27.0 ± 2.2	4.6 ± 0.05	5.0 ± 0.05	4.3
Benz[a]anthracene	1.27 ± 0.20	5.3 ± 0.08	5.7 ± 0.08	5.1
Chrysene	1.22 ± 0.06	5.3 ± 0.03	5.7 ± 0.03	5.0
Benzo[b]fluoranthene	0.182 ± 0.033	6.0 ± 0.09	6.4 ± 0.09	5.1
Benzo[k]fluoranthene	0.305 ± 0.063	5.8 ± 0.10	6.2 ± 0.10	5.2
Benzo[a]pyrene	0.326 ± 0.086	6.0 ± 0.13	6.4 ± 0.13	5.3
Indeno[1,2,3-cd]pyrene	n.a.	n.a.	n.a.	
Dibenz[a,h]anthracene	n.a.	n.a.	n.a.	6.0
Benzo[g,h,i]perylene	n.a.	n.a.	n.a.	6.3

Note:

❖ Duplicate aqueous equilibrium tests were conducted for this sample. Aqueous equilibrium concentrations and site-specific sediment-water partition coefficients for PAHs reported in the table are average values along with standard deviations.

❖ Organic carbon normalized sediment-water distribution coefficients K_{oc} were calculated by: $K_{oc} = K_d / f_{oc}$.

Table 4

NLU402-GE15-16.5: Aqueous Equilibrium Experiments (f_{oc} = 0.7%)

Compounds	Measured aqueous equilibrium concentrations (µg/L)	Calculated site-specific log K_d (L/kg)	Orgainc carbon-normalized log K_{oc} (L/kg)	Predicted log K_d = log $(f_{oc}\ K_{oc})$ (L/kg)
Naphthalene	41 ± 1	1.3 ± 0.006	3.5 ± 0.006	0.8
Acenaphthylene	n.a.	n.a.	n.a.	1.7
Acenaphthene	176 ± 6	1.3 ± 0.01	3.5 ± 0.01	1.5
Fluorene	55 ± 2	2.0 ± 0.01	4.2 ± 0.01	1.8
Phenanthrene	86 ± 6	2.6 ± 0.03	4.8 ± 0.03	2.0
Anthracene	11.9 ± 1.7	3.0 ± 0.07	5.2 ± 0.07	2.1
Fluoranthene	6.60 ± 0.60	3.5 ± 0.04	5.7 ± 0.04	2.7
Pyrene	6.03 ± 0.50	3.6 ± 0.04	5.8 ± 0.04	2.6
Benz[a]anthracene	0.405 ± 0.064	4.4 ± 0.07	6.6 ± 0.07	3.3
Chrysene	0.427 ± 0.023	4.4 ± 0.02	6.6 ± 0.02	3.2
Benzo[b]fluoranthene	0.029 ± 0.005	5.2 ± 0.08	7.4 ± 0.08	3.3
Benzo[k]fluoranthene	0.053 ± 0.011	5.0 ± 0.09	7.2 ± 0.09	3.4
Benzo[a]pyrene	0.054 ± 0.014	5.2 ± 0.11	7.4 ± 0.11	3.6
Indeno[1,2,3-cd]pyrene	n.a.	n.a.	n.a.	
Dibenz[a,h]anthracene	n.a.	n.a.	n.a.	4.2
Benzo[g,h,i]perylene	n.a.	n.a.	n.a.	4.5

Note:

❖ Duplicate aqueous equilibrium tests were conducted for this sample. Aqueous equilibrium concentrations and site-specific sediment-water partition coefficients for PAHs reported in the table are average values along with standard deviations.

❖ Organic carbon normalized sediment-water distribution coefficients K_{oc} were calculated by: $K_{oc} = K_d / f_{oc}$.

Table 5

NLU 54-SS-0010: Aqueous Equilibrium Experiments (f_{oc} = 15.2%)

Compounds	Measured aqueous equilibrium concentrations (μg/L)	Calculated site-specific log K_d (L/kg)	Orgainc carbon-normalized log K_{oc} (L/kg)	Predicted log K_d = log $(f_{oc}\ K_{oc})$ (L/kg)
Naphthalene	0.301 ± 0.063	n.a.	n.a.	2.1
Acenaphthylene	n.a.	n.a.	n.a.	3.0
Acenaphthene	0.238 ± 0.045	n.a.	n.a.	2.8
Fluorene	0.166 ± 0.019	3.1 ± 0.03	3.9 ± 0.03	3.1
Phenanthrene	0.072 ± 0.008	4.2 ± 0.03	5.0 ± 0.03	3.4
Anthracene	0.017 ± 0.004	4.2 ± 0.07	5.0 ± 0.07	3.5
Fluoranthene	0.033 ± 0.007	4.8 ± 0.07	5.6 ± 0.07	4.0
Pyrene	0.040 ± 0.007	4.8 ± 0.06	5.6 ± 0.06	3.9
Benz[a]anthracene	0.006 ± 0.0007	5.2 ± 0.04	6.0 ± 0.04	4.7
Chrysene	0.004 ± 0.0007	5.4 ± 0.05	6.2 ± 0.05	4.6
Benzo[b]fluoranthene	0.001 ± 0.0003	6.4 ± 0.15	7.2 ± 0.15	4.7
Benzo[k]fluoranthene	0.001 ± 0.0002	6.5 ± 0.07	7.3 ± 0.07	4.8
Benzo[a]pyrene	n.d.	n.d.	n.d.	4.9
Indeno[1,2,3-cd]pyrene	n.a.	n.a.	n.a.	
Dibenz[a,h]anthracene	n.a.	n.a.	n.a.	5.6
Benzo[g,h,i]perylene	n.a.	n.a.	n.a.	5.9

Note:

❖ Duplicate aqueous equilibrium tests were conducted for this sample. Aqueous equilibrium concentrations and site-specific sediment-water partition coefficients for PAHs reported in the table are average values along with standard deviations.

❖ Organic carbon normalized sediment-water distribution coefficients K_{oc} were calculated by: $K_{oc} = K_d / f_{oc}$.

Table 6

NLU 55-SS-0010: Aqueous Equilibrium Experiments (f_{oc} = 3.8%)

Compounds	Measured aqueous equilibrium concentrations (µg/L)	Calculated site-specific log K_d (L/kg)	Orgainc carbon-normalized log K_{oc} (L/kg)	Predicted log K_d = log $(f_{oc}\ K_{oc})$ (L/kg)
Naphthalene	31 ± 6.5	2.0 ± 0.05	3.4 ± 0.05	1.5
Acenaphthylene	n.a.	n.a.	n.a.	2.4
Acenaphthene	5.87 ± 1.09	2.4 ± 0.04	3.8 ± 0.04	2.2
Fluorene	1.81 ± 0.21	3.0 ± 0.03	4.4 ± 0.03	2.5
Phenanthrene	4.04 ± 0.43	3.4 ± 0.03	4.8 ± 0.03	2.8
Anthracene	0.521 ± 0.122	3.7 ± 0.06	5.1 ± 0.06	2.9
Fluoranthene	1.13 ± 0.23	4.2 ± 0.06	5.6 ± 0.06	3.4
Pyrene	1.14 ± 0.20	4.3 ± 0.05	5.7 ± 0.05	3.3
Benz[a]anthracene	0.073 ± 0.008	5.0 ± 0.04	6.4 ± 0.04	4.1
Chrysene	0.098 ± 0.015	5.0 ± 0.05	6.4 ± 0.05	4.0
Benzo[b]fluoranthene	0.013 ± 0.005	5.7 ± 0.14	7.1 ± 0.14	4.1
Benzo[k]fluoranthene	0.022 ± 0.004	5.5 ± 0.06	6.9 ± 0.06	4.2
Benzo[a]pyrene	0.015 ± 0.004	5.9 ± 0.10	7.3 ± 0.10	4.3
Indeno[1,2,3-cd]pyrene	n.a.	n.a.	n.a.	
Dibenz[a,h]anthracene	n.a.	n.a.	n.a.	5.0
Benzo[g,h,i]perylene	n.a.	n.a.	n.a.	5.3

Note:

- ❖ Duplicate aqueous equilibrium tests were conducted for this sample. Aqueous equilibrium concentrations and site-specific sediment-water partition coefficients for PAHs reported in the table are average values along with standard deviations.
- ❖ Organic carbon normalized sediment-water distribution coefficients K_{oc} were calculated by: $K_{oc} = K_d / f_{oc}$.

Table 7

NLU 56-SS-0010: Aqueous Equilibrium Experiments (f_{oc} = 2.7%)

Compounds	Measured aqueous equilibrium concentrations (µg/L)	Calculated site-specific log K_d (L/kg)	Orgainc carbon-normalized log K_{oc} (L/kg)	Predicted log K_d = log $(f_{oc}\ K_{oc})$ (L/kg)
Naphthalene	3.83 ± 0.11	2.9 ± 0.01	4.5 ± 0.01	1.4
Acenaphthylene	n.a.	n.a.	n.a.	2.2
Acenaphthene	161 ± 6	2.2 ± 0.02	3.8 ± 0.02	2.0
Fluorene	31.2 ± 0.9	2.5 ± 0.01	4.1 ± 0.01	2.4
Phenanthrene	107 ± 7	3.0 ± 0.04	4.6 ± 0.04	2.6
Anthracene	14.4 ± 2.1	3.3 ± 0.08	4.9 ± 0.08	2.7
Fluoranthene	30.4 ± 2.8	3.8 ± 0.04	5.4 ± 0.04	3.3
Pyrene	32.7 ± 2.7	3.9 ± 0.07	5.5 ± 0.07	3.2
Benz[a]anthracene	1.26 ± 0.20	4.7 ± 0.07	6.3 ± 0.07	3.9
Chrysene	1.43 ± 0.08	4.7 ± 0.02	6.3 ± 0.02	3.8
Benzo[b]fluoranthene	0.188 ± 0.034	5.5 ± 0.08	7.1 ± 0.08	3.9
Benzo[k]fluoranthene	0.299 ± 0.062	5.3 ± 0.09	6.9 ± 0.09	4.0
Benzo[a]pyrene	0.345 ± 0.092	5.5 ± 0.12	7.1 ± 0.12	4.1
Indeno[1,2,3-cd]pyrene	n.a.	n.a.	n.a.	
Dibenz[a,h]anthracene	n.a.	n.a.	n.a.	4.8
Benzo[g,h,i]perylene	n.a.	n.a.	n.a.	5.1

Note:

❖ Duplicate aqueous equilibrium tests were conducted for this sample. Aqueous equilibrium concentrations and site-specific sediment-water partition coefficients for PAHs reported in the table are average values along with standard deviations.

❖ Organic carbon normalized sediment-water distribution coefficients K_{oc} were calculated by: $K_{oc} = K_d / f_{oc}$.

Table 8

NLU 57-SS-0010: Aqueous Equilibrium Experiments (f_{oc} = 14.1%)

Compounds	Measured aqueous equilibrium concentrations (µg/L)	Calculated site-specific log K_d (L/kg)	Orgainc carbon-normalized log K_{oc} (L/kg)	Predicted log K_d = log $(f_{oc}\ K_{oc})$ (L/kg)
Naphthalene	0.396 ± 0.083	n.a.	n.a.	2.1
Acenaphthylene	n.a.	n.a.	n.a.	3.0
Acenaphthene	0.337 ± 0.064	2.8 ± 0.05	3.7 ± 0.05	2.8
Fluorene	0.602 ± 0.068	3.1 ± 0.03	4.0 ± 0.03	3.1
Phenanthrene	0.477 ± 0.051	3.8 ± 0.03	4.7 ± 0.03	3.3
Anthracene	0.225 ± 0.053	3.9 ± 0.07	4.8 ± 0.07	3.4
Fluoranthene	0.457 ± 0.094	4.2 ± 0.06	5.1 ± 0.06	4.0
Pyrene	0.284 ± 0.051	4.4 ± 0.05	5.3 ± 0.05	3.9
Benz[a]anthracene	0.017 ± 0.002	5.2 ± 0.04	6.1 ± 0.04	4.6
Chrysene	0.022 ± 0.003	5.2 ± 0.05	6.1 ± 0.05	4.5
Benzo[b]fluoranthene	0.002 ± 0.0008	6.2 ± 0.15	7.1 ± 0.15	4.6
Benzo[k]fluoranthene	0.003 ± 0.0005	6.2 ± 0.07	7.1 ± 0.07	4.7
Benzo[a]pyrene	0.001 ± 0.0004	6.3 ± 0.11	7.2 ± 0.11	4.9
Indeno[1,2,3-cd]pyrene	n.a.	n.a.	n.a.	
Dibenz[a,h]anthracene	n.a.	n.a.	n.a.	5.5
Benzo[g,h,i]perylene	n.a.	n.a.	n.a.	5.8

Note:

❖ Duplicate aqueous equilibrium tests were conducted for this sample. Aqueous equilibrium concentrations and site-specific sediment-water partition coefficients for PAHs reported in the table are average values along with standard deviations.

❖ Organic carbon normalized sediment-water distribution coefficients K_{oc} were calculated by: $K_{oc} = K_d / f_{oc}$.

Table 9

NLU 62-SS-0010: Aqueous Equilibrium Experiments (f_{oc} = 16.8%)

Compounds	Measured aqueous equilibrium concentrations (µg/L)	Calculated site-specific log K_d (L/kg)	Orgainc carbon-normalized log K_{oc} (L/kg)	Predicted log K_d = log $(f_{oc} K_{oc})$ (L/kg)
Naphthalene	4.0 ± 0.83	2.9 ± 0.06	3.7 ± 0.06	2.2
Acenaphthylene	n.a.	n.a.	n.a.	3.0
Acenaphthene	1.69 ± 0.32	3.3 ± 0.05	4.1 ± 0.05	2.8
Fluorene	0.434 ± 0.049	3.7 ± 0.03	4.5 ± 0.03	3.2
Phenanthrene	0.427 ± 0.045	4.4 ± 0.04	5.2 ± 0.04	3.4
Anthracene	0.101 ± 0.024	4.5 ± 0.08	5.3 ± 0.08	3.5
Fluoranthene	0.220 ± 0.045	5.0 ± 0.07	5.8 ± 0.07	4.1
Pyrene	0.223 ± 0.040	5.1 ± 0.06	5.9 ± 0.06	4.0
Benz[a]anthracene	0.015 ± 0.002	5.7 ± 0.04	6.5 ± 0.04	4.7
Chrysene	0.023 ± 0.004	5.6 ± 0.06	6.4 ± 0.06	4.6
Benzo[b]fluoranthene	0.004 ± 0.001	6.4 ± 0.15	7.2 ± 0.15	4.7
Benzo[k]fluoranthene	0.006 ± 0.001	6.2 ± 0.07	7.0 ± 0.07	4.8
Benzo[a]pyrene	0.005 ± 0.001	6.5 ± 0.11	7.3 ± 0.11	4.9
Indeno[1,2,3-cd]pyrene	n.a.	n.a.	n.a.	
Dibenz[a,h]anthracene	n.a.	n.a.	n.a.	5.6
Benzo[g,h,i]perylene	n.a.	n.a.	n.a.	5.9

Note:

❖ Duplicate aqueous equilibrium tests were conducted for this sample. Aqueous equilibrium concentrations and site-specific sediment-water partition coefficients for PAHs reported in the table are average values along with standard deviations.

❖ Organic carbon normalized sediment-water distribution coefficients K_{oc} were calculated by: $K_{oc} = K_d / f_{oc}$.

Table 10

NLU 64-SS-0010: Aqueous Equilibrium Experiments (f_{oc} = 18.2%)

Compounds	Measured aqueous equilibrium concentrations (μg/L)	Calculated site-specific log K_d (L/kg)	Orgainc carbon-normalized log K_{oc} (L/kg)	Predicted log K_d = log $(f_{oc}\ K_{oc})$ (L/kg)
Naphthalene	0.71 ± 0.15	3.6 ± 0.08	4.3 ± 0.08	2.2
Acenaphthylene	n.a.	n.a.	n.a.	3.1
Acenaphthene	13 ± 2.5	2.9 ± 0.05	3.6 ± 0.05	2.9
Fluorene	3.27 ± 0.37	3.2 ± 0.03	3.9 ± 0.03	3.2
Phenanthrene	3.26 ± 0.35	4.0 ± 0.03	4.7 ± 0.03	3.4
Anthracene	1.09 ± 0.26	4.1 ± 0.07	4.8 ± 0.07	3.5
Fluoranthene	3.12 ± 0.64	4.6 ± 0.06	5.3 ± 0.06	4.1
Pyrene	3.1 ± 0.55	4.7 ± 0.06	5.4 ± 0.06	4.0
Benz[a]anthracene	0.149 ± 0.017	5.5 ± 0.04	6.2 ± 0.04	4.8
Chrysene	0.187 ± 0.030	5.4 ± 0.05	6.1 ± 0.05	4.7
Benzo[b]fluoranthene	0.024 ± 0.009	6.4 ± 0.15	7.1 ± 0.15	4.7
Benzo[k]fluoranthene	0.037 ± 0.006	6.2 ± 0.07	6.9 ± 0.07	4.8
Benzo[a]pyrene	0.037 ± 0.010	6.4 ± 0.11	7.1 ± 0.11	5.0
Indeno[1,2,3-cd]pyrene	n.a.	n.a.	n.a.	
Dibenz[a,h]anthracene	n.a.	n.a.	n.a.	5.6
Benzo[g,h,i]perylene	n.a.	n.a.	n.a.	5.9

Note:

❖ Duplicate aqueous equilibrium tests were conducted for this sample. Aqueous equilibrium concentrations and site-specific sediment-water partition coefficients for PAHs reported in the table are average values along with standard deviations.

❖ Organic carbon normalized sediment-water distribution coefficients K_{oc} were calculated by: $K_{oc} = K_d / f_{oc}$.

Table 11

NLU 65-SS-0010: Aqueous Equilibrium Experiments (f_{oc} = 77.1%)

Compounds	Measured aqueous equilibrium concentrations (µg/L)	Calculated site-specific log K_d (L/kg)	Orgainc carbon-normalized log K_{oc} (L/kg)	Predicted log K_d = log $(f_{oc}\ K_{oc})$ (L/kg)
Naphthalene	6.2 ± 0.17	3.4 ± 0.02	3.5 ± 0.02	2.8
Acenaphthylene	n.a.	n.a.	n.a.	3.7
Acenaphthene	62 ± 2.2	3.0 ± 0.03	3.1 ± 0.03	3.5
Fluorene	9.6 ± 0.28	3.4 ± 0.02	3.5 ± 0.02	3.8
Phenanthrene	22 ± 1.5	3.9 ± 0.05	4.0 ± 0.05	4.1
Anthracene	3.2 ± 0.46	4.2 ± 0.10	4.3 ± 0.10	4.2
Fluoranthene	11.7 ± 1.07	4.8 ± 0.05	4.9 ± 0.05	4.7
Pyrene	13 ± 1.1	4.8 ± 0.05	4.9 ± 0.05	4.6
Benz[a]anthracene	0.606 ± 0.096	5.6 ± 0.03	5.7 ± 0.03	5.4
Chrysene	0.720 ± 0.038	5.6 ± 0.03	5.7 ± 0.03	5.3
Benzo[b]fluoranthene	0.105 ± 0.019	6.4 ± 0.09	6.5 ± 0.09	5.4
Benzo[k]fluoranthene	0.172 ± 0.036	6.2 ± 0.11	6.3 ± 0.11	5.5
Benzo[a]pyrene	0.176 ± 0.047	6.4 ± 0.14	6.5 ± 0.14	5.6
Indeno[1,2,3-cd]pyrene	n.a.	n.a.	n.a.	
Dibenz[a,h]anthracene	n.a.	n.a.	n.a.	6.3
Benzo[g,h,i]perylene	n.a.	n.a.	n.a.	6.6

Note:

❖ Duplicate aqueous equilibrium tests were conducted for this sample. Aqueous equilibrium concentrations and site-specific sediment-water partition coefficients for PAHs reported in the table are average values along with standard deviations.

❖ Organic carbon normalized sediment-water distribution coefficients K_{oc} were calculated by: $K_{oc} = K_d / f_{oc}$.

Table 12

NLU 68-US-S1: Aqueous Equilibrium Experiments (f_{oc} = 15.8%)

Compounds	Measured aqueous equilibrium concentrations (µg/L)	Calculated site-specific log K_d (L/kg)	Orgainc carbon-normalized log K_{oc} (L/kg)	Predicted log K_d = log $(f_{oc}\ K_{oc})$ (L/kg)
Naphthalene	53 ± 11	2.7 ± 0.06	3.5 ± 0.06	2.1
Acenaphthylene	n.a.	n.a.	n.a.	3.0
Acenaphthene	4.72 ± 0.89	3.1 ± 0.05	3.9 ± 0.05	2.8
Fluorene	1.67 ± 0.19	3.4 ± 0.03	4.2 ± 0.03	3.1
Phenanthrene	2.96 ± 0.31	3.9 ± 0.03	4.7 ± 0.03	3.4
Anthracene	0.659 ± 0.154	4.0 ± 0.07	4.8 ± 0.07	3.5
Fluoranthene	1.42 ± 0.29	4.4 ± 0.06	5.2 ± 0.06	4.0
Pyrene	1.60 ± 0.29	4.5 ± 0.06	5.3 ± 0.06	3.9
Benz[a]anthracene	0.104 ± 0.011	5.2 ± 0.04	6.0 ± 0.04	4.7
Chrysene	0.160 ± 0.025	5.1 ± 0.05	5.9 ± 0.05	4.6
Benzo[b]fluoranthene	0.019 ± 0.008	6.0 ± 0.14	6.8 ± 0.14	4.7
Benzo[k]fluoranthene	0.036 ± 0.006	5.5 ± 0.06	6.3 ± 0.06	4.8
Benzo[a]pyrene	0.025 ± 0.007	6.0 ± 0.10	6.8 ± 0.10	4.9
Indeno[1,2,3-cd]pyrene	n.a.	n.a.	n.a.	
Dibenz[a,h]anthracene	n.a.	n.a.	n.a.	5.6
Benzo[g,h,i]perylene	n.a.	n.a.	n.a.	5.9

Note:

❖ Duplicate aqueous equilibrium tests were conducted for this sample. Aqueous equilibrium concentrations and site-specific sediment-water partition coefficients for PAHs reported in the table are average values along with standard deviations.

❖ Organic carbon normalized sediment-water distribution coefficients K_{oc} were calculated by: $K_{oc} = K_d / f_{oc}$.

Table 13

NLU 68-US-S2: Aqueous Equilibrium Experiments (f_{oc} = 14.6%)

Compounds	Measured aqueous equilibrium concentrations (µg/L)	Calculated site-specific log K_d (L/kg)	Orgainc carbon-normalized log K_{oc} (L/kg)	Predicted log K_d = log $(f_{oc}\ K_{oc})$ (L/kg)
Naphthalene	56 ± 12	2.7 ± 0.06	3.5 ± 0.06	2.1
Acenaphthylene	n.a.	n.a.	n.a.	3.0
Acenaphthene	9.86 ± 1.86	2.5 ± 0.04	3.3 ± 0.04	2.8
Fluorene	7.21 ± 0.82	2.9 ± 0.03	3.7 ± 0.03	3.1
Phenanthrene	8.91 ± 0.95	3.4 ± 0.03	4.2 ± 0.03	3.3
Anthracene	1.42 ± 0.33	3.6 ± 0.06	4.4 ± 0.06	3.4
Fluoranthene	0.96 ± 0.20	4.1 ± 0.06	4.9 ± 0.06	4.0
Pyrene	1.15 ± 0.21	4.2 ± 0.05	5.0 ± 0.05	3.9
Benz[a]anthracene	0.103 ± 0.011	4.8 ± 0.03	5.6 ± 0.03	4.7
Chrysene	0.137 ± 0.021	4.8 ± 0.05	5.6 ± 0.05	4.6
Benzo[b]fluoranthene	0.014 ± 0.005	5.4 ± 0.14	6.2 ± 0.14	4.7
Benzo[k]fluoranthene	0.024 ± 0.004	5.2 ± 0.06	6.0 ± 0.06	4.8
Benzo[a]pyrene	0.022 ± 0.006	5.4 ± 0.09	6.2 ± 0.09	4.9
Indeno[1,2,3-cd]pyrene	n.a.	n.a.	n.a.	
Dibenz[a,h]anthracene	n.a.	n.a.	n.a.	5.5
Benzo[g,h,i]perylene	n.a.	n.a.	n.a.	5.8

Note:

❖ Duplicate aqueous equilibrium tests were conducted for this sample. Aqueous equilibrium concentrations and site-specific sediment-water partition coefficients for PAHs reported in the table are average values along with standard deviations.

❖ Organic carbon normalized sediment-water distribution coefficients K_{oc} were calculated by: $K_{oc} = K_d / f_{oc}$.

Table 14

NLU 72-SS-0010: Aqueous Equilibrium Experiments (f_{oc} = 16.6%)

Compounds	Measured aqueous equilibrium concentrations (μg/L)	Calculated site-specific log K_d (L/kg)	Orgainc carbon-normalized log K_{oc} (L/kg)	Predicted log K_d = log $(f_{oc}\ K_{oc})$ (L/kg)
Naphthalene	0.789 ± 0.165	2.9 ± 0.06	3.7 ± 0.06	2.2
Acenaphthylene	n.a.	n.a.	n.a.	3.0
Acenaphthene	0.278 ± 0.052	3.3 ± 0.05	4.1 ± 0.05	2.8
Fluorene	0.082 ± 0.009	3.6 ± 0.03	4.4 ± 0.03	3.1
Phenanthrene	0.138 ± 0.014	4.4 ± 0.03	5.2 ± 0.03	3.4
Anthracene	0.029 ± 0.007	4.4 ± 0.07	5.2 ± 0.07	3.5
Fluoranthene	0.186 ± 0.038	4.9 ± 0.07	5.7 ± 0.07	4.0
Pyrene	0.190 ± 0.034	4.9 ± 0.06	5.7 ± 0.06	3.9
Benz[a]anthracene	0.013 ± 0.001	5.6 ± 0.04	6.4 ± 0.04	4.7
Chrysene	0.015 ± 0.002	5.6 ± 0.06	6.4 ± 0.06	4.6
Benzo[b]fluoranthene	0.003 ± 0.0012	6.4 ± 0.14	7.2 ± 0.14	4.7
Benzo[k]fluoranthene	0.005 ± 0.0008	6.2 ± 0.07	7.0 ± 0.07	4.8
Benzo[a]pyrene	0.004 ± 0.0011	6.5 ± 0.11	7.3 ± 0.11	4.9
Indeno[1,2,3-cd]pyrene	n.a.	n.a.	n.a.	
Dibenz[a,h]anthracene	n.a.	n.a.	n.a.	5.6
Benzo[g,h,i]perylene	n.a.	n.a.	n.a.	5.9

Note:

❖ Duplicate aqueous equilibrium tests were conducted for this sample. Aqueous equilibrium concentrations and site-specific sediment-water partition coefficients for PAHs reported in the table are average values along with standard deviations.

❖ Organic carbon normalized sediment-water distribution coefficients K_{oc} were calculated by: $K_{oc} = K_d / f_{oc}$.

Table 15

NLU 73-SS-0010: Aqueous Equilibrium Experiments (f_{oc} = 15.4%)

Compounds	Measured aqueous equilibrium concentrations (µg/L)	Calculated site-specific log K_d (L/kg)	Orgainc carbon-normalized log K_{oc} (L/kg)	Predicted log K_d = log $(f_{oc} K_{oc})$ (L/kg)
Naphthalene	2.69 ± 0.56	2.9 ± 0.06	3.7 ± 0.06	2.1
Acenaphthylene	n.a.	n.a.	n.a.	3.0
Acenaphthene	2.19 ± 0.41	3.3 ± 0.05	4.1 ± 0.05	2.8
Fluorene	0.541 ± 0.062	3.6 ± 0.03	4.4 ± 0.03	3.1
Phenanthrene	0.730 ± 0.078	4.4 ± 0.03	5.2 ± 0.03	3.4
Anthracene	0.124 ± 0.029	4.4 ± 0.07	5.2 ± 0.07	3.5
Fluoranthene	0.234 ± 0.048	4.9 ± 0.07	5.7 ± 0.07	4.0
Pyrene	0.251 ± 0.045	4.9 ± 0.06	5.7 ± 0.06	3.9
Benz[a]anthracene	0.016 ± 0.002	5.6 ± 0.04	6.4 ± 0.04	4.7
Chrysene	0.024 ± 0.004	5.6 ± 0.06	6.4 ± 0.06	4.6
Benzo[b]fluoranthene	0.004 ± 0.0017	6.4 ± 0.14	7.2 ± 0.14	4.7
Benzo[k]fluoranthene	0.007 ± 0.0011	6.2 ± 0.07	7.0 ± 0.07	4.8
Benzo[a]pyrene	0.004 ± 0.0012	6.5 ± 0.11	7.3 ± 0.11	4.9
Indeno[1,2,3-cd]pyrene	n.a.	n.a.	n.a.	
Dibenz[a,h]anthracene	n.a.	n.a.	n.a.	5.6
Benzo[g,h,i]perylene	n.a.	n.a.	n.a.	5.9

Note:

❖ Duplicate aqueous equilibrium tests were conducted for this sample. Aqueous equilibrium concentrations and site-specific sediment-water partition coefficients for PAHs reported in the table are average values along with standard deviations.

❖ Organic carbon normalized sediment-water distribution coefficients K_{oc} were calculated by: $K_{oc} = K_d / f_{oc}$.

Table 16

NLU 73-Stanford: Aqueous Equilibrium Experiments (f_{oc} = 74.8%)

Compounds	Measured aqueous equilibrium concentrations (μg/L)	Calculated site-specific log K_d (L/kg)	Orgainc carbon-normalized log K_{oc} (L/kg)	Predicted log K_d = log $(f_{oc}\ K_{oc})$ (L/kg)
Naphthalene	31 ± 6.5	4.0 ± 0.09	4.1 ± 0.09	2.8
Acenaphthylene	n.a.	n.a.	n.a.	3.7
Acenaphthene	1.64 ± 0.31	5.0 ± 0.08	5.1 ± 0.08	3.5
Fluorene	0.288 ± 0.033	5.4 ± 0.05	5.5 ± 0.05	3.8
Phenanthrene	0.512 ± 0.054	5.8 ± 0.05	5.9 ± 0.05	4.0
Anthracene	0.071 ± 0.017	6.1 ± 0.10	6.2 ± 0.10	4.2
Fluoranthene	0.081 ± 0.017	6.4 ± 0.08	6.5 ± 0.08	4.7
Pyrene	0.105 ± 0.019	6.4 ± 0.08	6.5 ± 0.08	4.6
Benz[a]anthracene	0.011 ± 0.001	6.7 ± 0.05	6.8 ± 0.05	5.4
Chrysene	0.012 ± 0.002	6.8 ± 0.07	69 ± 0.07	5.3
Benzo[b]fluoranthene	0.003 ± 0.0011	7.3 ± 0.14	7.4 ± 0.14	5.4
Benzo[k]fluoranthene	0.006 ± 0.0009	6.9 ± 0.07	7.0 ± 0.07	5.5
Benzo[a]pyrene	0.005 ± 0.0015	7.2 ± 0.12	7.3 ± 0.12	5.6
Indeno[1,2,3-cd]pyrene	n.a.	n.a.	n.a.	
Dibenz[a,h]anthracene	n.a.	n.a.	n.a.	6.3
Benzo[g,h,i]perylene	n.a.	n.a.	n.a.	6.5

Note:

❖ Duplicate aqueous equilibrium tests were conducted for this sample. Aqueous equilibrium concentrations and site-specific sediment-water partition coefficients for PAHs reported in the table are average values along with standard deviations.

❖ Organic carbon normalized sediment-water distribution coefficients K_{oc} were calculated by: $K_{oc} = K_d / f_{oc}$.

Table 17

NLU 45-SS-0010: Aqueous Equilibrium Experiments (f_{oc} = 13.5%)

Compounds	Measured aqueous equilibrium concentrations (μg/L)	Calculated site-specific log K_d (L/kg)	Orgainc carbon-normalized log K_{oc} (L/kg)	Predicted log K_d = log $(f_{oc}\ K_{oc})$ (L/kg)
Naphthalene	0.363 ± 0.076	3.4 ± 0.08	4.3 ± 0.08	2.1
Acenaphthylene	n.a.	n.a.	n.a.	2.9
Acenaphthene	3.45 ± 0.65	2.9 ± 0.05	3.8 ± 0.05	2.7
Fluorene	0.644 ± 0.074	3.3 ± 0.03	4.2 ± 0.03	3.1
Phenanthrene	1.594 ± 0.169	3.8 ± 0.03	4.7 ± 0.03	3.3
Anthracene	0.239 ± 0.056	4.0 ± 0.07	4.9 ± 0.07	3.4
Fluoranthene	1.338 ± 0.274	4.4 ± 0.06	5.3 ± 0.06	4.0
Pyrene	1.355 ± 0.243	4.5 ± 0.06	5.4 ± 0.06	3.9
Benz[a]anthracene	0.080 ± 0.009	5.2 ± 0.04	6.1 ± 0.04	4.6
Chrysene	0.098 ± 0.015	5.2 ± 0.05	6.1 ± 0.05	4.5
Benzo[b]fluoranthene	0.015 ± 0.006	6.0 ± 0.14	6.9 ± 0.14	4.6
Benzo[k]fluoranthene	0.024 ± 0.004	5.8 ± 0.06	6.7 ± 0.06	4.7
Benzo[a]pyrene	0.021 ± 0.006	6.1 ± 0.10	7.0 ± 0.10	4.8
Indeno[1,2,3-cd]pyrene	n.a.	n.a.	n.a.	
Dibenz[a,h]anthracene	n.a.	n.a.	n.a.	5.5
Benzo[g,h,i]perylene	n.a.	n.a.	n.a.	5.8

Note:

❖ Duplicate aqueous equilibrium tests were conducted for this sample. Aqueous equilibrium concentrations and site-specific sediment-water partition coefficients for PAHs reported in the table are average values along with standard deviations.

❖ Organic carbon normalized sediment-water distribution coefficients K_{oc} were calculated by: $K_{oc} = K_d / f_{oc}$.

Table 18

NLU 58-SS-0010: Aqueous Equilibrium Experiments (f_{oc} = 16.2%)

Compounds	Measured aqueous equilibrium concentrations (μg/L)	Calculated site-specific log K_d (L/kg)	Orgainc carbon-normalized log K_{oc} (L/kg)	Predicted log K_d = log $(f_{oc}\ K_{oc})$ (L/kg)
Naphthalene	1.78 ± 0.37	3.2 ± 0.07	4.0 ± 0.07	2.2
Acenaphthylene	n.a.	n.a.	n.a.	3.0
Acenaphthene	0.772 ± 0.146	3.4 ± 0.06	4.2 ± 0.06	2.8
Fluorene	0.405 ± 0.046	3.7 ± 0.03	4.5 ± 0.03	3.1
Phenanthrene	0.984 ± 0.105	4.3 ± 0.03	5.1 ± 0.03	3.4
Anthracene	0.132 ± 0.031	4.5 ± 0.08	5.3 ± 0.08	3.5
Fluoranthene	0.346 ± 0.071	4.9 ± 0.07	5.7 ± 0.07	4.0
Pyrene	0.366 ± 0.066	5.0 ± 0.06	5.8 ± 0.06	3.9
Benz[a]anthracene	0.027 ± 0.003	5.7 ± 0.04	6.5 ± 0.04	4.7
Chrysene	0.038 ± 0.006	5.6 ± 0.06	6.4 ± 0.06	4.6
Benzo[b]fluoranthene	0.005 ± 0.0022	6.4 ± 0.14	7.2 ± 0.14	4.7
Benzo[k]fluoranthene	0.009 ± 0.0016	6.2 ± 0.06	7.0 ± 0.06	4.8
Benzo[a]pyrene	0.006 ± 0.0017	6.5 ± 0.11	7.3 ± 0.11	4.9
Indeno[1,2,3-cd]pyrene	n.a.	n.a.	n.a.	
Dibenz[a,h]anthracene	n.a.	n.a.	n.a.	5.6
Benzo[g,h,i]perylene	n.a.	n.a.	n.a.	5.9

Note:

❖ Duplicate aqueous equilibrium tests were conducted for this sample. Aqueous equilibrium concentrations and site-specific sediment-water partition coefficients for PAHs reported in the table are average values along with standard deviations.

❖ Organic carbon normalized sediment-water distribution coefficients K_{oc} were calculated by: $K_{oc} = K_d / f_{oc}$.

Table 19

NLU 68-SS-0010: Aqueous Equilibrium Experiments (f_{oc} = 26.5%)

Compounds	Measured aqueous equilibrium concentrations (μg/L)	Calculated site-specific log K_d (L/kg)	Orgainc carbon-normalized log K_{oc} (L/kg)	Predicted log K_d = log $(f_{oc}\ K_{oc})$ (L/kg)
Naphthalene	5.38 ± 0.15	2.8 ± 0.01	3.4 ± 0.01	2.4
Acenaphthylene	n.a.	n.a.	n.a.	3.2
Acenaphthene	35.9 ± 1.3	2.9 ± 0.02	3.5 ± 0.02	3.0
Fluorene	15.5 ± 0.45	3.1 ± 0.02	3.7 ± 0.02	3.3
Phenanthrene	5.86 ± 0.40	3.9 ± 0.05	4.5 ± 0.05	3.6
Anthracene	6.15 ± 0.90	3.8 ± 0.09	4.4 ± 0.09	3.7
Fluoranthene	8.18 ± 0.74	4.3 ± 0.05	4.9 ± 0.05	4.2
Pyrene	8.38 ± 0.70	4.4 ± 0.04	5.0 ± 0.04	4.2
Benz[a]anthracene	0.406 ± 0.065	5.2 ± 0.08	5.8 ± 0.08	4.9
Chrysene	0.525 ± 0.028	5.2 ± 0.03	5.8 ± 0.03	4.8
Benzo[b]fluoranthene	0.059 ± 0.011	6.0 ± 0.09	6.6 ± 0.09	4.9
Benzo[k]fluoranthene	0.103 ± 0.021	5.8 ± 0.10	6.4 ± 0.10	5.0
Benzo[a]pyrene	0.095 ± 0.025	6.0 ± 0.13	6.6 ± 0.13	5.1
Indeno[1,2,3-cd]pyrene	n.a.	n.a.	n.a.	
Dibenz[a,h]anthracene	n.a.	n.a.	n.a.	5.8
Benzo[g,h,i]perylene	n.a.	n.a.	n.a.	6.1

Note:

❖ Duplicate aqueous equilibrium tests were conducted for this sample. Aqueous equilibrium concentrations and site-specific sediment-water partition coefficients for PAHs reported in the table are average values along with standard deviations.

❖ Organic carbon normalized sediment-water distribution coefficients K_{oc} were calculated by: $K_{oc} = K_d / f_{oc}$.

Table 20

CR10-NAPL-1523: Aqueous Equilibrium Experiments

Compounds	Measured aqueous equilibrium concentrations (µg/L)	Calculated site-specific log K_d (L/kg)	Predicted log K_d based on Raoult's law (L/kg)
Naphthalene	8790 ± 3605	3.4 ± 0.2	3.7
Acenaphthylene	12.3 ± 2.9	4.7 ± 0.1	4.5
Acenaphthene	261 ± 70	4.4 ± 0.1	4.5
Fluorene	48 ± 11	4.7 ± 0.1	4.6
Phenanthrene	79 ± 15	5.3 ± 0.08	5.1
Anthracene	14 ± 2.0	5.3 ± 0.06	5.3
Fluoranthene	9.2 ± 1.6	6.0 ± 0.08	5.6
Pyrene	11 ± 1.9	6.0 ± 0.08	5.5
Benz[a]anthracene	0.32 ± 0.009	6.9 ± 0.01	6.6
Chrysene	0.34 ± 0.004	6.9 ± 0.01	6.4
Benzo[b]fluoranthene	0.05 ± 0.014	7.6 ± 0.13	7.4
Benzo[k]fluoranthene	0.05 ± 0.014	7.9 ± 0.27	7.2
Benzo[a]pyrene	0.053 ± 0.013	7.9 ± 0.11	6.9
Indeno[1,2,3-cd]pyrene	0.046 ± 0.016	7.8 ± 0.17	7.9
Dibenz[a,h]anthracene	0.035 ± 0.006	7.1 ± 0.08	6.9
Benzo[g,h,i]perylene	0.060 ± 0.002	7.7 ± 0.01	7.0

Note:

1. Duplicate aqueous equilibrium tests were conducted for this sample. Aqueous equilibrium concentrations and site-specific sediment-water partition coefficients for PAHs reported in the table are average values along with standard deviations.
2. Air-bridge technique instead of POM-SPE (polymethylene-solid phase extraction) method was adopted in aqueous equilibrium tests with this NAPL sample.
3. A coal tar-water partitioning model by Peters et al. (5, 13) was used to predict the PAH aqueous equilibrium concentrations from the NAPL sample assuming its average molecular weight is 250. In this approach, the aqueous equilibrium concentration of a PAH is calculated by the following equation:

$$C_{aq,i} = x_i S_i$$

Where x_i is the mole fraction of PAH i in the NAPL mixture, and S_i is the subcooled liquid solubility of PAH i.

ATTACHMENT 2D-8

Stanford Identification of Black Carbon Materials in Sediments from Lake Union

Draft Final Report II - September 13, 2005

Identification of Black Carbon Materials in Sediments from Lake Union

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This secondary report complements the bioavailability study and presents results of physical identification of black carbonaceous materials in sediment samples from Lake Union using scanning electron microscopy (SEM) and petrographic analyses. Specifically, light microscopy and scanning electron microscopy (SEM) imaging were employed on the black carbon fraction separated from each sediment sample to assess whether the material looked like lampblack, charcoal, or coal-derived materials. Petrographic analyses were performed on the light-density black carbon fraction to determine the percentage by volume lampblack/soot, coal, coke, cenoshpere, tar and pitch, as well as plantative and diatomaceous matter. The complete petrographic analysis results were provided by R&D Carbon Petrography (Monroeville, PA) and have been submitted separately in a CD format.

EXPERIMENTAL METHODS

Light Microscopy and Scanning Electron Microscopy (SEM). A Leica WILD M3Z microscope (65-400x magnification) was used for light microscopy imaging of sediment particles. A Kodak DX3900 digital camera was attached to the imaging tube of the microscope to capture pictures. The micromorphology of separated black carbonaceous particles was examined with a high-resolution Sirion SEM at room temperature and 5.0 kV. Samples were mounted on 12-mm aluminum pins with graphite paste and sputter-coated with Au-Pd alloy prior to imaging.

Petrographic Analysis. Petrographic analyses were performed on the light fraction of each sediment sample by R&D Carbon Petrography (Monroeville, PA). This laboratory identified the composition of the black carbonaceous particles in sediment samples. The sediment particles were prepared for petrographic analyses according to ASTM standard methods, D2797 (Standard Practices for Preparing Coal Samples for Microscopical Analysis by Reflected Light). The identification process was conducted by following D2798 (Standard Test Method for Microscopical Determination of the Reflectance of Vitrinite in a Polished Specimen of Coal), D2799 (Standard Test Method for Microscopical Determination of Volume Percent of Physical Components of Coal), and D4616 (Standard Test Method for Microscopical Analysis by Reflected Light and Determination of Mesophase in a Pitch).

As presented in the attached petrographic analysis reports, the petrographic results for each sample comprised a physical composition determination in terms of volume percent of the organic components and of mineral matter, and microscopic images of representative component particles in the sample at 250X in air and at 600X in oil with reflected light. Materials in samples were classified into four main categories, consisting of carbon, organic plant material, diatoms, and mineral matter. Each category is further divided into more specific groups of the same or similar properties. In the current study, the classification of the microscopic constituents in light-density, particulate fractions of the sediment samples is as follows:

Category I – Carbon

The submicron carbon forms consist of carbon with one or two probable origins. *Carbon black* is a colloidal carbon material in the form of nanometer-sized spheres and their fused aggregates up to several microns in size. It is produced by thermal decomposition or incomplete combustion of hydrocarbon materials, such as natural gas and petroleum oil. It is used as a black pigment for inks and paints, and is used in large amounts by the tire industry in the production of vulcanized rubber (1). *Lampblack*, often used as a synonym for carbon black, is specifically designated to the solid product manufactured by burning liquid hydrocarbons and is often somewhat oily compared to manufactured carbon black. Lampblack is a major byproduct of the oil-gas manufacturing process (2).

QI or quinoline insolubles is a carbon-black like solid phase in coal tar pitch. It is produced by vapor phase cracking in a by-product coke oven and colloidally dispersed in the tar/pitch that is collected as the byproduct of coal carbonization. The individual spherically-shaped particles are usually less than 2 μm in diameter. A typical coal tar pitch may contain from 1% to about 20% (by weight) of normal quinoline insolubles (3).

In this study, carbon black along with quinoline insolubles are described as dense or loose aggregate, individual QI, green or less coked aggregates, and very dark matter. The related materials are termed pitch, tar-like, and pitch coke. *Cenoshperes*, usually a minor component of coal tar pitch, are counted separately. They are formed by the rapid pyrolysis of unconfined coal particles that carry over from the coke oven to the tar. Microscopically they appear like hollow spheres or segments thereof, and are typically sized from 10 to 500 μm.

The volume percents of coal and different types of coke such as petroleum coke, metallurgical coke, and oxidized coke are reported. The term metallurgical coke is used to distinguish that from by-product coke, which is produced from tar or petroleum residuals, rather than in a coal-based coking process itself.

Category II – Organic plant material

The organic plant material in samples is described in terms of their degree of preservation. The portion that displays intact cellular structure is counted separately from the portion that is degraded and occurs as particulate and less ordered plant structures. Much of this degraded organic matter that occurs in sediments and sedimentary rocks is described as kerogen.

Category III – Diatoms

Diatoms are unicellular organisms that have a variety of shapes and forms comprising planktonic colonies. Their internal skeletons consist of pure silica with minute fine cellular microstructures. The fossils or skeletons of diatoms have a wide variety of uses as fillers and filtering materials. From a scientific standpoint their sensitivity to temperatures and water depths are good indicators of their habitat.

Category IV – Mineral matter

The identifiable mineral matter consists of quartz (SiO_2), a variety of carbonates including shells, pyrite (FeS_2), brown grainy aggregates, white grainy materials, slag, metallics, and other minerals. The brown stains on materials may be from humic sources. Slag is thermally altered mineral matter that has a variety of forms and shapes and ranges from glassy to crystalline. Most pyrite is associated with the plant material and occurs as framboids consisting of small circular aggregates of crystals. These forms are usually indicators of brackish water conditions.

RESULTS

Scanning electron microscopic images were taken to reveal the morphology of representative organic particles in selected sediment samples. Sediment sample NLU 64-SS-0010 represents one of the samples primarily comprised of organic plantative matter and diatomaceous materials with a minor fraction of black carbon particles. Figure 1 shows the different morphology of various kinds of organic particles identified in the sediment sample, including carbon black aggregates (Figure 1b) that appear as a cluster of carbon globules of submicron to microns in size and the diatomaceous particles (Figure 1d) on plantative materials. In contrast, sample NLU 65-SS-0010 in Figure 2 represents one of the samples in which the presence of carbon black aggregates is very prevalent. This observation agrees with the quantification results provided by petrographic analysis that the carbon black aggregates actually account for as high as 88% by volume of the entire light fraction of this sample, with scattered diatomaceous matter. Figure 2 illustrates the morphological properties of a typical carbon black aggregate that existed in the sample, which, not surprisingly, shares the same feature with those in NLU 64-SS-0010 (Figure 1b).

NLU73-Stanford is the sample exhibiting the widest variety of black carbonaceous particles. Figures 3 and 4 show for sample NLU 73-Stanford some examples of carbon black aggregates, pitch/tar-like substance with embedded small carbon black aggregates, and wood-derived charcoal.

Petrographic analyses results were provided by subcontract to a commercial laboratory, R&D Carbon Petrography (Monroeville, PA). The results are included in this final report in a CD format. Petrographic analysis involves preparation of a polished particle surface followed by the identification of physical components in the representative specimen under a microscope according to their reflectance, optical properties, and morphology. This technique has been used historically to identify coal maceral structures, rank coals, identify different stages of coal pyrolysis and coke formation, determine coal tar and pitch quality, and identify chars and cenospheres (4). Recently several research groups, including us, have successfully used this technique to identify the types of particulate organic matter, i.e., coal and coal-derived particles in sediment and aquifer materials (5, 6).

Literature Cited

(1) McNaught, A.; Wilkinson, A.; International Union of Pure and Applied Chemistry. *Compendium of chemical terminology : IUPAC recommendations;* Blackwell Science: Oxford Oxfordshire ; Malden, MA: 1997; p 450.

(2) Hong, L.; Ghosh, U.; Mahajan, T.; Zare, R. N.; Luthy, R. G. PAH sorption mechanism and partitioning behavior in lampblack-impacted soils from former oil-gas plant sites. *Environmental Science and Technology* **2003,** *37* (16), 3625-3634.

(3) American Society for Testing and Materials. Annual book of ASTM standards, section five, petroleum products, lubricants, and fossil fuels. **2002,** *05.06 Gaseous Fuels; Coal and Coke*.

(4) Ghosh, U.; Zimmerman, J. R.; Luthy, R. G. PCB and PAH speciation among particle types in contaminated harbor sediments and effects on PAH bioavailability. *Environmental Science and Technology* **2003,** *37* (10), 2209-2217.

(5) Karapanagioti, H. K.; Kleineidam, S.; Sabatini, D. A.; Grathwohl, P.; Ligouis, B. Impacts of heterogeneous organic matter on phenanthrene sorption: equilibrium and kinetic studies with aquifer material. *Environmental Science and Technology* **2000,** *34* (3), 406-414.

(6) Ghosh, U.; Gillette, J. S.; Luthy, R. G.; Zare, R. N. Microscale location, characterization, and association of polycyclic aromatic hydrocarbons on harbor sediment particles. *Environmental Science and Technology* **2000,** *34* (9), 1729-1736.

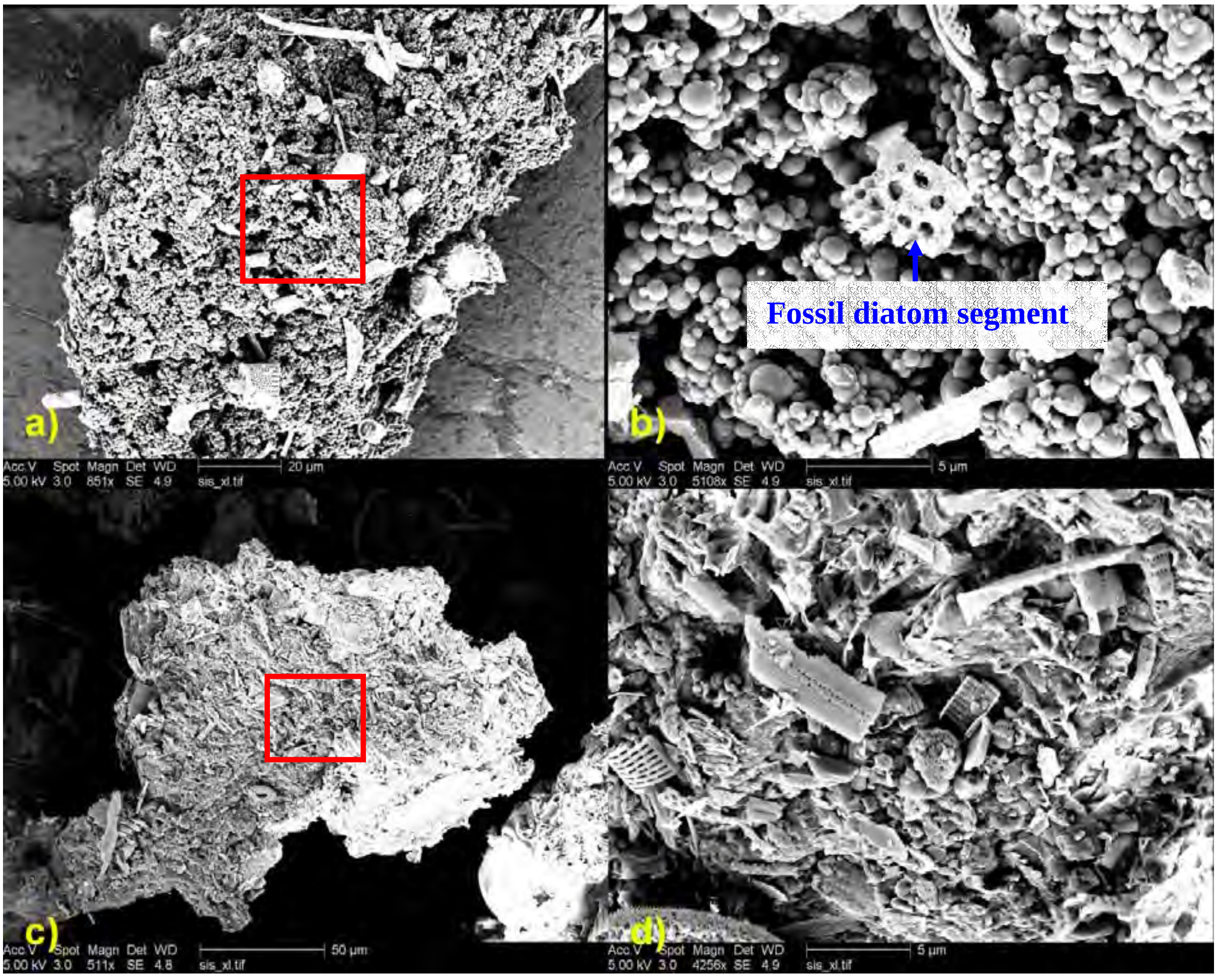

Figure 1. Scanning electron microscopic images of representative organic particles in sediment sample NLU64-SS-0010: **a)** carbon black aggregate and fossil diatom segment, magnification x 850 **b)** blowup image of the area in the red rectangle of image a) with a magnification of x 5000, showing that the carbon black aggregate is comprised of clustered spherically-shaped carbon particles at sizes of submicron to microns **c)** organic plantative matter mingled with diatom and fossil diatom segments **d)** blowup image of the area in the red box of image c), illustrating the perforated surface of diatomaceous materials with a magnification x 4200.

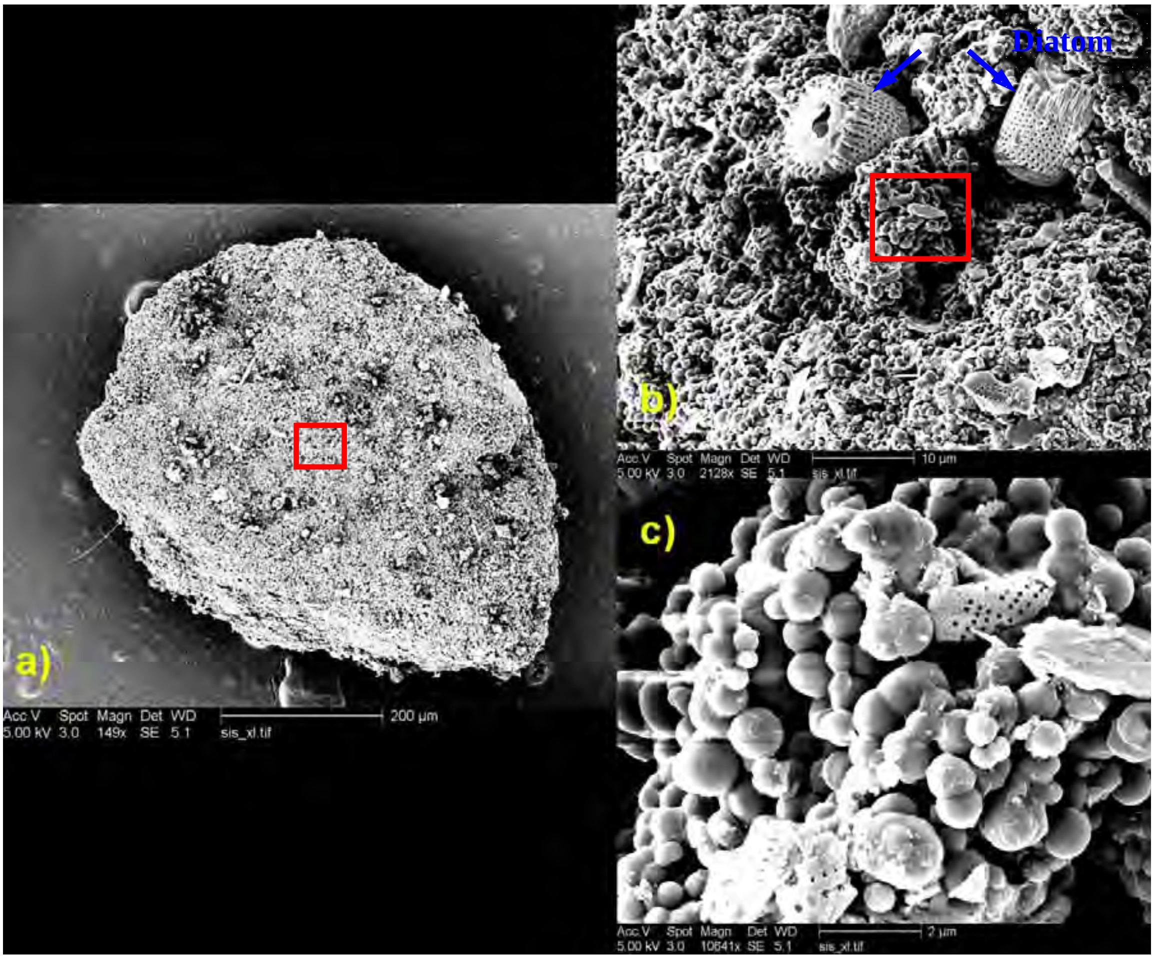

Figure 2. Scanning electron microscopic images of representative organic particles in sediment sample NLU65-SS-0010: **a)** black carbonaceous particle that is abundant and prevalent in the light fraction of this sediment sample **b)** blowup image of the area in the red box of image a) with a magnification of x 2100, showing scattered diatoms present among carbon black aggregates **c)** secondary blowup image with respect to image b), providing a clearer image of submicron carbon black globules.

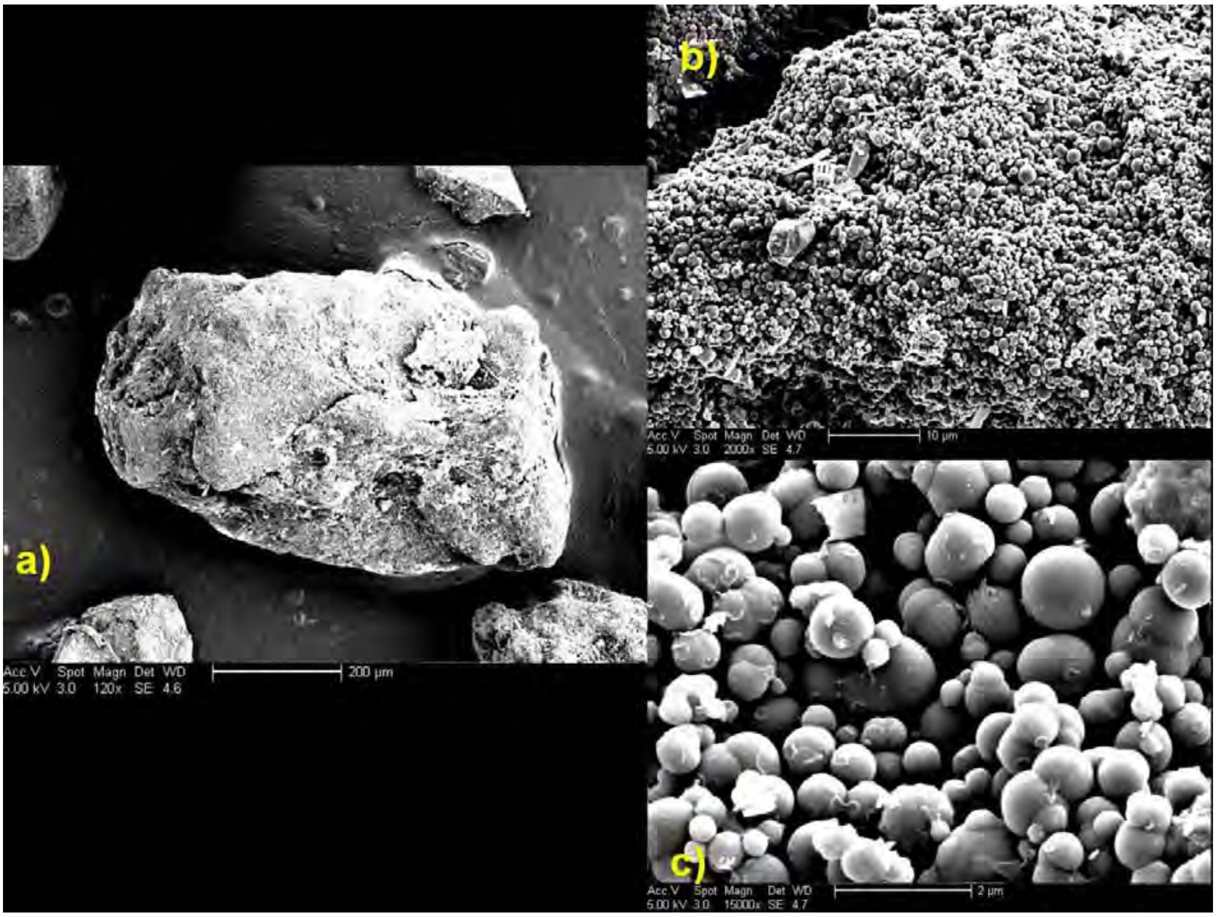

Figure 3. Scanning electron microscopic images of representative carbon black particles in sediment sample NLU73-Stanford: **a)** black carbonaceous particle that is abundant and prevalent in the light fraction of this sediment sample **b)** blowup image of the centric area of image a) with a magnification of x 2100, showing the surface and morphology of carbon black aggregates **c)** secondary blowup image with respect to image b), providing a clearer image of submicron carbon black globules.

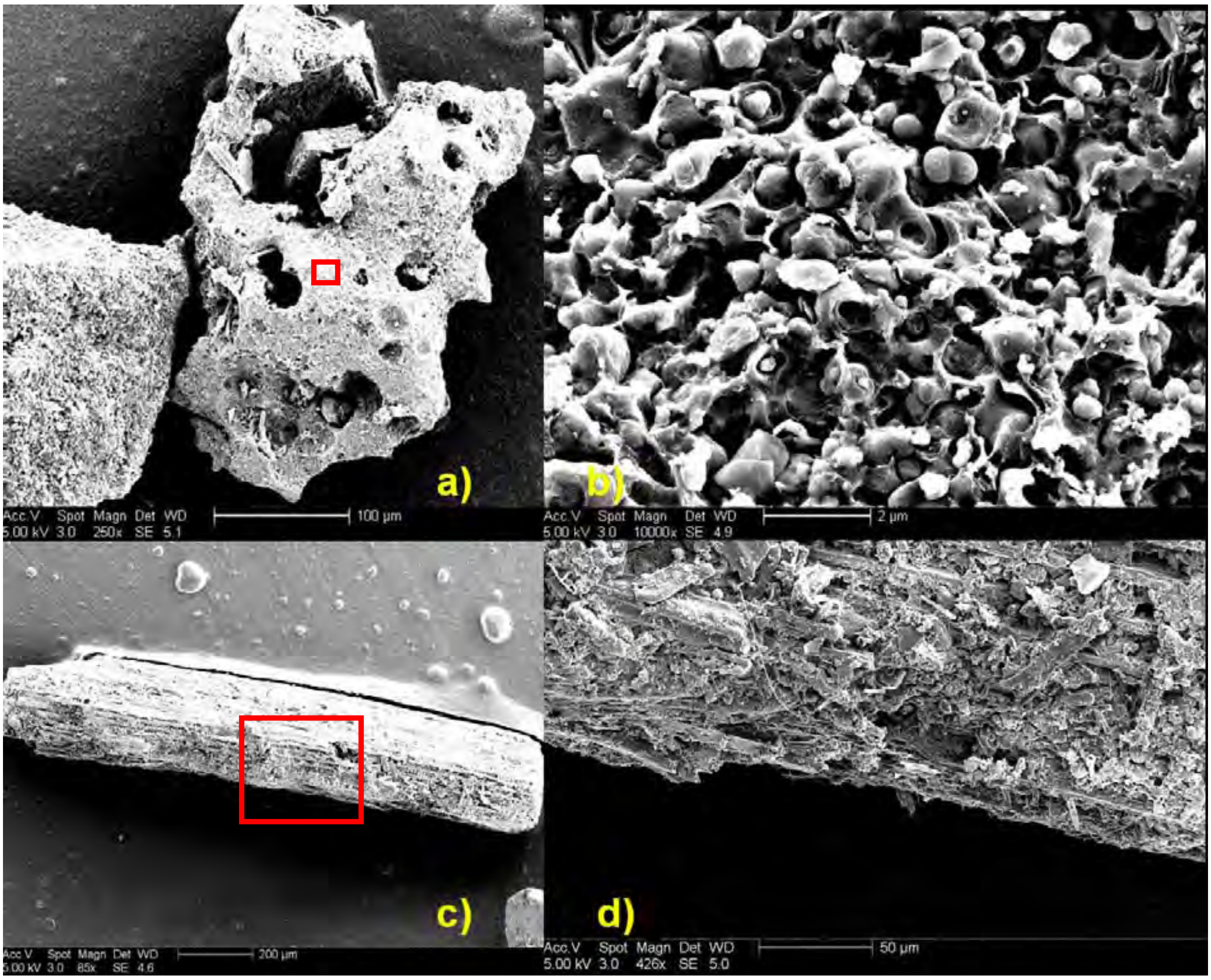

Figure 4. Scanning electron microscopic images of representative organic particles in sediment sample NLU73-Stanford: **a)** pitch/tar-like carbonaceous particle in the light fraction of this sediment sample **b)** blowup image of the centric area of image a) with a magnification of x 10000, showing the surface and morphology of this material, and noting the embedded small carbon black aggregates and individual carbon black particles **c)** charcoal particle with magnified image **d)** showing the woody texture in the charcoal material.

SUB-ATTACHMENT 2D-8.1
Carbon Petrography Analysis Reports

R & D CARBON PETROGRAPHY
CONSULTING - COAL, COKE & CARBONS
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E-mail: ralphgray@aol.com

May 26, 2005

Ms. Lei Hong
Stanford University
Civil and Environmental Engineering
380 Panama Mall Terman Engineering, B15
Stanford, CA 94305-4020

Dear Ms. Hong;

Your Purchase Order Number 14642990 of April 27, 2005 requested petrographic analysis for four samples of sediment material. The samples are identified and described as follows:

R & D NO.	***DESCRIPTION***
1103	NAPL
1104	NLU – 65
1100	NLU – 68-SS
1107	NLU – 73

The solids from the four sediment samples were prepared for petrographic analysis and photographed at 250X in air and at 600X in oil with reflected light. A total of 1000 points were counted for composition. The materials were separated into four main categories which consist of carbon, organic plant material, diatoms and mineral matter. Each category is further subdivided into more specific materials.

The submicron carbon forms consist of carbon with one or two probable origins. Carbon black is a solid product of incomplete combustion. It has many commercial uses including filler in tires. In contrast QI or quinoline insolubles occur as solids in coal tar/pitch. In by-product coking the material from incomplete coal combustion and vapor phase cracking occur colloidally dispersed in the tar/pitch that are collected as by-products of carbonization. In the current work these materials are described as dense or loose aggregate, individual QI, green or less coked aggregates and very dark mattes. The related material is described as pitch, tar-like and pitch coke. Cenospheres are counted separately. They are produced when coal is heated rapidly in an unconfined condition. The rapidly heated coal becomes plastic and the internally trapped gases expand to produce very porous commonly spherical bodies of coke. Depositional carbon may be spherulitic or pyrolytic. Liquid distillation products of coal may crack to form spherulitic carbons. The high hydrogen gaseous materials from coal carbonization form pyrolytic carbon.

The organic plant material in the samples are described in terms of there degree of preservation. The portion that displays the cellular structure is counted separately from the portion that is degraded and occurs as particulate and less ordered plant structures. Much of this material that occurs in sediments and sedimentary rocks are described as kerogen.

Diatoms are unicellular organisms that have a variety of shapes and forms that form planktonic colonies. These plant forms are capable of photosynthesis. They contain skeletons called frustules consisting of two valves that fit together like a box. These internal skeletons consist of pure silica which has very minute fine cellular microstructures. The fossils or skeletons of diatoms have a wide variety of uses as fillers, filtering materials and from a scientific standpoint there sensitivity to temperatures and water depth are good indicators of there habitat. Some of the material that we refer to as mattes maybe associated due to specific gravity separation rather than due to natural occurrences.

The identifiable mineral matter consist of quartz SiO_2, a variety of carbonates including shells, pyrite FeS_2, brown grainy aggregates, white grainy materials, slag, metallics and other minerals. The brown stains on materials may be from humic sources. The slag is thermally altered mineral matter that has a variety of forms and shapes and ranges from glassy to crystalline. Most of the pyrite that occurs is associates with the plant material and occurs as framboids consisting of small circular aggregates of crystals. These forms are usually indicators of brackish water conditions.

In the current work we use the terms metallurgical coke and by-product coking to separate coal based coking processes from those that are based on petroleum residuals.

Stanford Sample – NAPL

The Stanford sample labeled NAPL has 93.1% by volume of total carbon. The most abundant carbon related material is coal tar pitch which makes up 74.4% of the sample. The next most common carbon is the fine sized Normal QI (10.4%) which occurs as small aggregates and individual micron and submicron sized spherical solids. Also, there are 2.4% of the larger aggregates of carbon black or Normal QI aggregates. The remainder of the carbon is related to by-product coke oven products. There is 3.4% of metallurgical coke and oxidized coke, with 1.3% of 'Carry-Over' cenospheres, 0.7% of coal, 0.2% of pitch coke and 0.3% bug plant residue. There is only 1.2% of total organic plant material which consists of 0.3% with cellular structure and 0.9% of particulate plant material. There is very little (0.3%) diatomaceous material most of which occur as individual siliceous diatoms. There is 5.4% of total mineral matter which consists of 1.8% of unidentified mineral matter, with 1.2% of slag and lesser amounts of quartz, a white grainy mineral, a brown grainy aggregate and carbonates. The petrographic composition data is listed in Table 1 and most of the materials are illustrated in Figures 1 through 4.

The majority of the NAPL sample is coal tar pitch with the other various carbon and mineral materials incorporated into the mass. Almost all of the other carbons are common to by-product coke oven materials with the exception of the larger aggregates of carbon black / Normal QI.

Stanford Sample – NLU - 65

The majority of the material in the Stanford sample labeled NLU-65 is carbon and totals 94.3% by volume. The majority of the carbon occurs as aggregates which are made up of small micron and submicron sized spherical carbon which is produced from vapor and gas phase cracking. The size of the aggregates varies from very small aggregates and individual QI to relatively large aggregates some of which exceed 500 microns in size. The density of the aggregates also varies from relatively loose aggregates to very dense and the degree to which they have been carbonized range from green to coked. The remainder of the carbon is related to by-product coke oven products with the exception of a small amount (0.6%) of petroleum coke. There is 2.9% of metallurgical coke and oxidized coke, with 1.6% of pitch and pitch coke, 0.4% of coal, 0.4% of deposition carbon and 0.1% of 'Carry-Over' cenospheres. There is 3.5% of total organic plant material which consists of 3.3% with cellular structure and 0.2% of particulate plant material. There is no diatomaceous material in this sample. There is 2.2% of total mineral matter which consists of 0.9% of slag, with 0.9% of unidentified minerals and 0.4% of quartz and carbonates. The petrographic composition data is listed in Table 1 and most of the materials are illustrated in Figures 5 through 9.

The carbon related material is the most abundant material in this sample and the majority of the carbon (88.3%) consists of the micron and submicron sized spherical carbon that is either carbon black or aggregates of Normal QI. The by-product related carbons make up the remainder (6.0%) of the total carbon. There is only a small amount (5.7%) of organic plant material and mineral matter that makes up the remainder of the sample.

Stanford Sample – NLU – 68-SS

Approximately half of the material in the Stanford sample labeled NLU-68-SS is carbon and totals 47.3% by volume. The most abundant (28.7%) of the carbon related material is aggregates of carbon black and/or Normal QI. The remainder of the carbon is associated with by-product coking with the exception of the petroleum coke (1.8%). There is 16.8% of by-product coke oven related carbon. Most of which is pitch related and consists of 5.6% pitch coke, 3.7% thermally altered pitch, 2.0% of normal pitch and 0.8% of tar-like material. The rest of the carbon consists of 1.7% of metallurgical coke and oxidized coke, 1.3% of bug plant residue, 0.9% of coal and 0.8% of cenospheres. There is 25.8% of total organic plant material which consists of 20.8% with cellular kerogen-like structure and 5.0% of particulate plant material. There is 11.3% of diatomaceous material which consists of clusters or mattes of siliceous diatoms or individual diatoms. There is 15.6% of total mineral matter which consists mostly of a brown grainy aggregate (5.3% - maybe humic) and 4.0% of unidentified mineral matter, with lesser amounts of white grainy aggregates, slag, carbonates, pyrite, quartz and metallics. The petrographic composition data is listed in Table 1 and most of the materials are illustrated in Figures 10 through 13.

The carbon related material is the most abundant single material in this sample and the majority of the carbon consists of the submicron spherical carbon (28.7%) that is either carbon black or aggregates of Normal QI. The by-product coke related carbons make up the remainder of the carbon (18.6%). The organic plant material, mineral matter and diatomaceous material make up a little over half (52.7%) of the NLU-68-SS sample.

Stanford Sample – NLU - 73

The majority of the material in the Stanford sample labeled NLU-73 is carbon and totals 89.6% by volume. The majority of the carbon occurs as aggregates which are made up of small micron and submicron sized spherical carbon which is produced from vapor and gas phase cracking. This sample has the widest variety of aggregates which range from loose to dense in structure and from green to coked in the degree of carbonization. Also, the size of the aggregates varies from very small aggregates and individual QI to relatively large aggregates some of which exceed 500 microns in size. There is 58.3% of total aggregate type carbon which consist of 19.2% of loose aggregates, with 17.5% of dense aggregates, 13.7% of green (less carbonized) aggregate, 5.7% of very dark QI matt and 2.7% of small aggregates and individual QI. In addition, this sample has the most carbon from by-product coking 29.1%. The byproduct carbon consists of 13.0% of metallurgical coke and oxidized coke, with 8.8% of coal, 5.5% of pitch and pitch coke, 1.6% of cenospheres and 0.2% of depositional carbon. There is 3.5% of total organic plant material which consists of 2.4% with cellular structure and 1.1% of particulate plant material. There is a relatively small amount diatomaceous material which consists mostly of small clusters or mattes of diatoms and individual siliceous diatoms. There is 5.2% of total mineral matter which consists of 1.8% of a white grainy mineral, with 1.6% of thermally altered slag, 1.2% of unidentified minerals and 0.4% of pyrite. The petrographic composition data is listed in Table 1 and most of the materials are illustrated in Figures 14 through 18.

The NLU-73 sediment sample has the widest variety of carbons of any of the subject samples. The carbons in this particular sample appear to have greater optical contrast due to the size and degree of carbonization than in most of the other samples.

Please do not hesitate to call us at (724) 327-5019 or e-mail us at ralphgray@aol.com if you have any questions or wish to discuss this work.

Sincerely,

Ra1ph J Gray
Daniel P. Gray

Table 1

Petrographic Composition Analysis of Soil Sample from Stanford University

R & D No.	**1103**	**1104**	**1100**	**1107**
Stanford Sample ID	**NAPL**	**NLU – 65**	**NLU -68-SS**	**NLU - 73**
Carbon:				
Carbon Black: /Normal QI				
Dense Aggregates	**---**	**26.6**	**---**	**17.5**
Loose Aggregates	**2.4**	**44.5**	**18.7**	**19.2**
Small Aggregates and Individual QI	**10.4**	**16.6**	**10.0**	**2.7**
Green Aggregates	**---**	**0.6**	**---**	**13.7**
Very Dark QI Matt	**---**	**---**	**---**	**5.2**
Pitch - Normal	**74.4**	**1.0**	**2.0**	**1.9**
Pitch – High Reflecting (thermally altered)	**---**	**---**	**3.7**	**---**
Tar-Like	**---**	**---**	**0.8**	**---**
Pitch Coke	**0.2**	**0.6**	**5.6**	**3.6**
Cenospheres	**1.3**	**0.1**	**0.8**	**1.6**
Petroleum Coke	**---**	**0.6**	**1.8**	**2.2**
Metallurgical Coke – coal related	**3.0**	**2.4**	**1.3**	**9.6**
Oxidized Coke	**0.4**	**0.5**	**0.4**	**3.4**
Depositional carbon –Spherulytic	**---**	**0.2**	**---**	**---**
Pyrolytic	**---**	**0.2**	**---**	**0.2**
Bug Plant Residue	**0.3**	**---**	**1.3**	**----**
Coal	**0.7**	**0.4**	**0.9**	**8.8**
Total Carbon	**93.1**	**94.3**	**47.3**	**89.6**
Plant (Kerogen-Like)				
Cellular	**0.3**	**3.3**	**20.8**	**2.4**
Particulate	**0.9**	**0.2**	**5.0**	**1.1**
Total Plant	**1.2**	**3.5**	**25.8**	**3.5**
Diatom	**0.3**	**---**	**11.3**	**1.7**
Diatom Related - with Mineral Matter	**---**	**---**	**---**	**---**
Total Diatom	**0.3**	**0.0**	**11.3**	**1.7**
Mineral Matter				
Quartz	**0.8**	**0.2**	**0.4**	**---**
Carbonates	**0.1**	**0.2**	**0.9**	**---**
Pyrite	**---**	**---**	**0.6**	**0.4**
Brown grainy aggregate	**0.7**	**---**	**5.3**	**0.2**
White Grainy	**0.8**	**---**	**1.9**	**1.8**
Slag	**1.2**	**0.9**	**1.7**	**1.6**
Metallics	**---**	**---**	**0.8**	**---**
Other Mineral Matter:	**1.8**	**0.9**	**4.0**	**1.2**
Total Mineral Matter	**5.4**	**2.2**	**15.6**	**5.2**
Grand Total	**100.0**	**100.0**	**100.0**	**100.0**

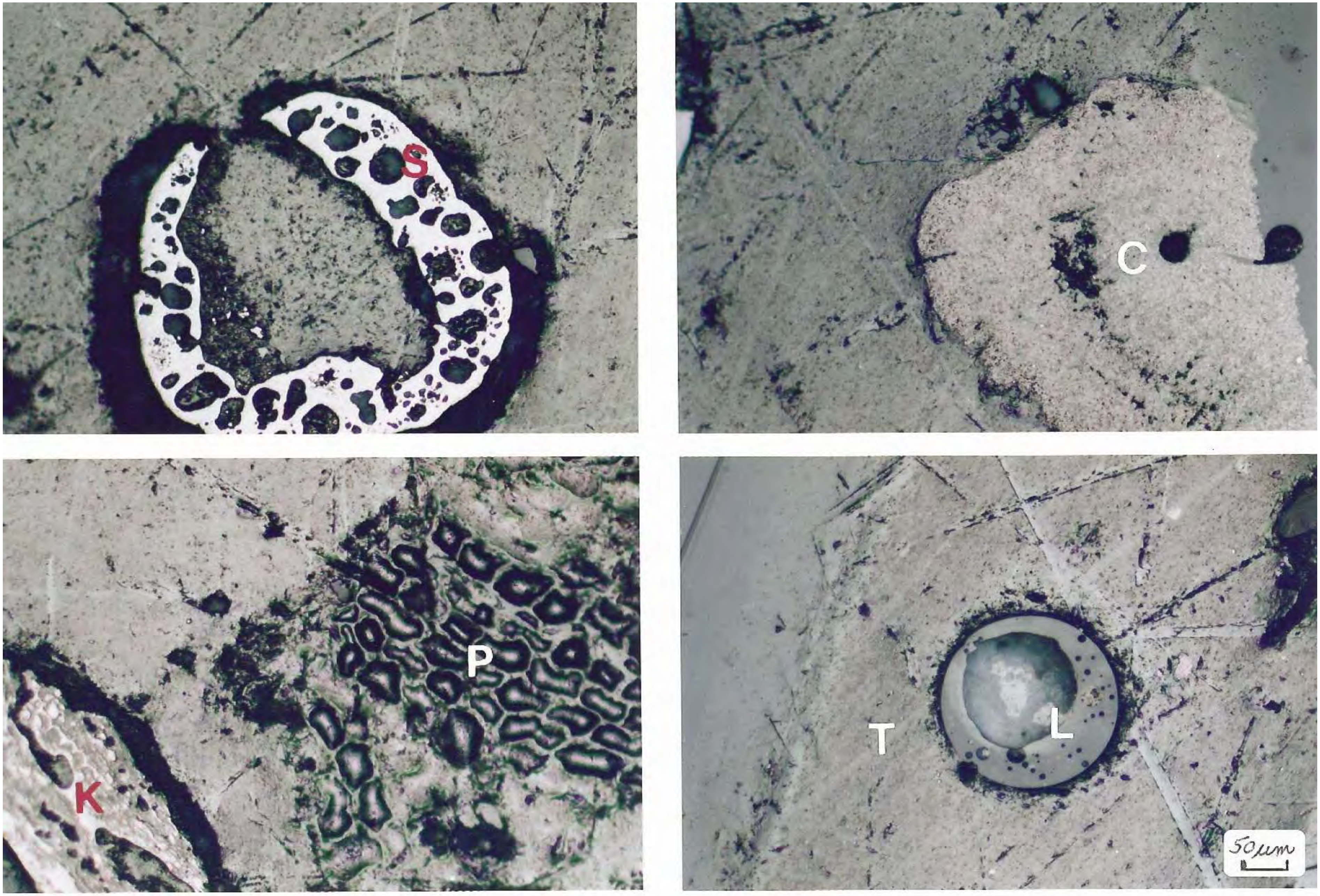


Figure 1: **Photomicrographs of Stanford's Sample Labeled NAPL Showing; C=Carbon Black Aggregate in Pitch, T=Pitch (normal), S=Cenosphere, P=Cellular Organic Plant Material, K=Met Coke and L=Slag. Reflected Light In Air, X250.**

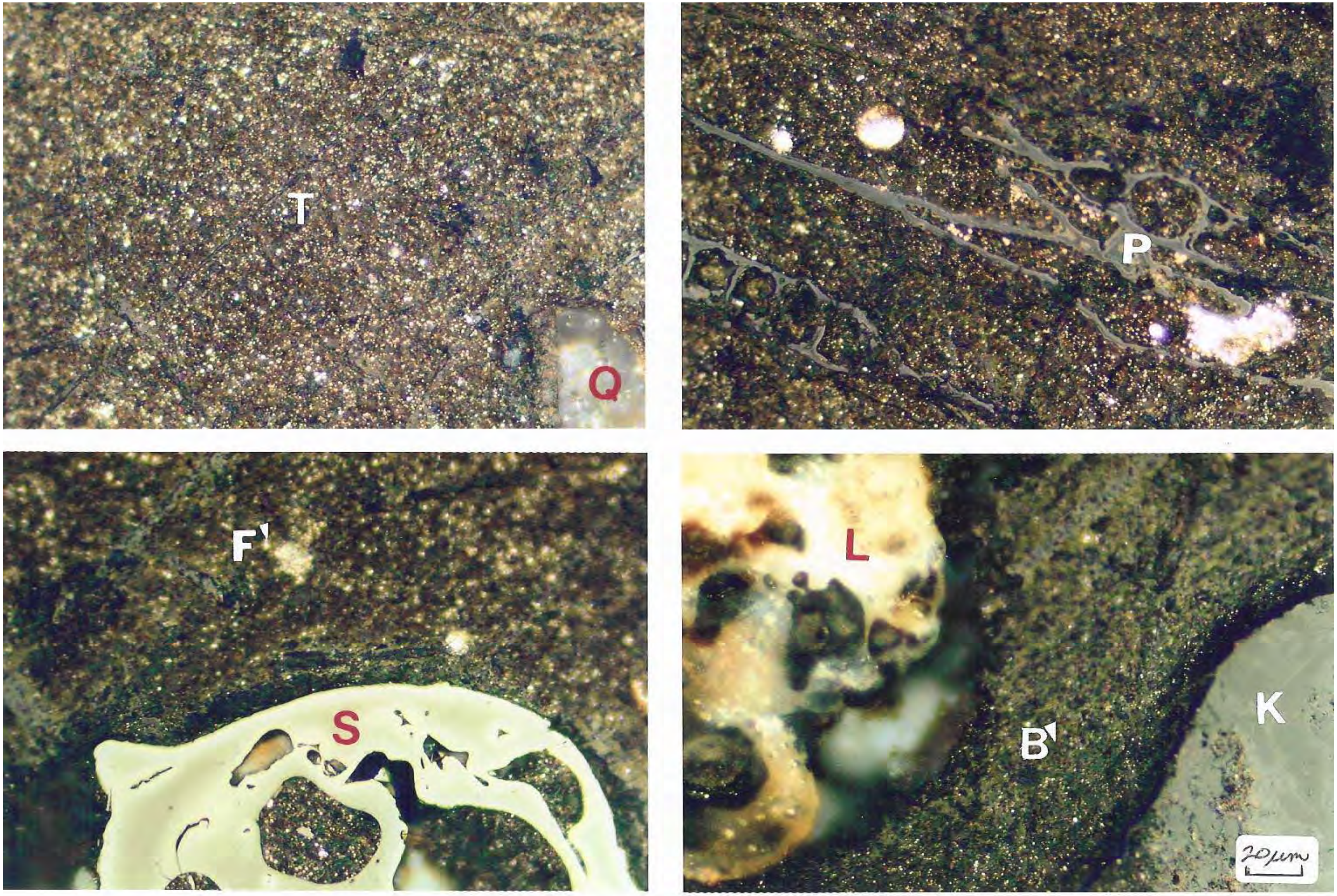


Figure 2: Photomicrographs of Stanford's Sample Labeled NAPL Showing; T=Pitch (normal), B=Binder Phase Pitch, F=Filler Phase Pitch (Normal QI), S=Oxidized Cenosphere, P=Cellular Organic Plant Material, K=Coal, Q=Quartz and L=Slag. Reflected Light In Oil, X600.

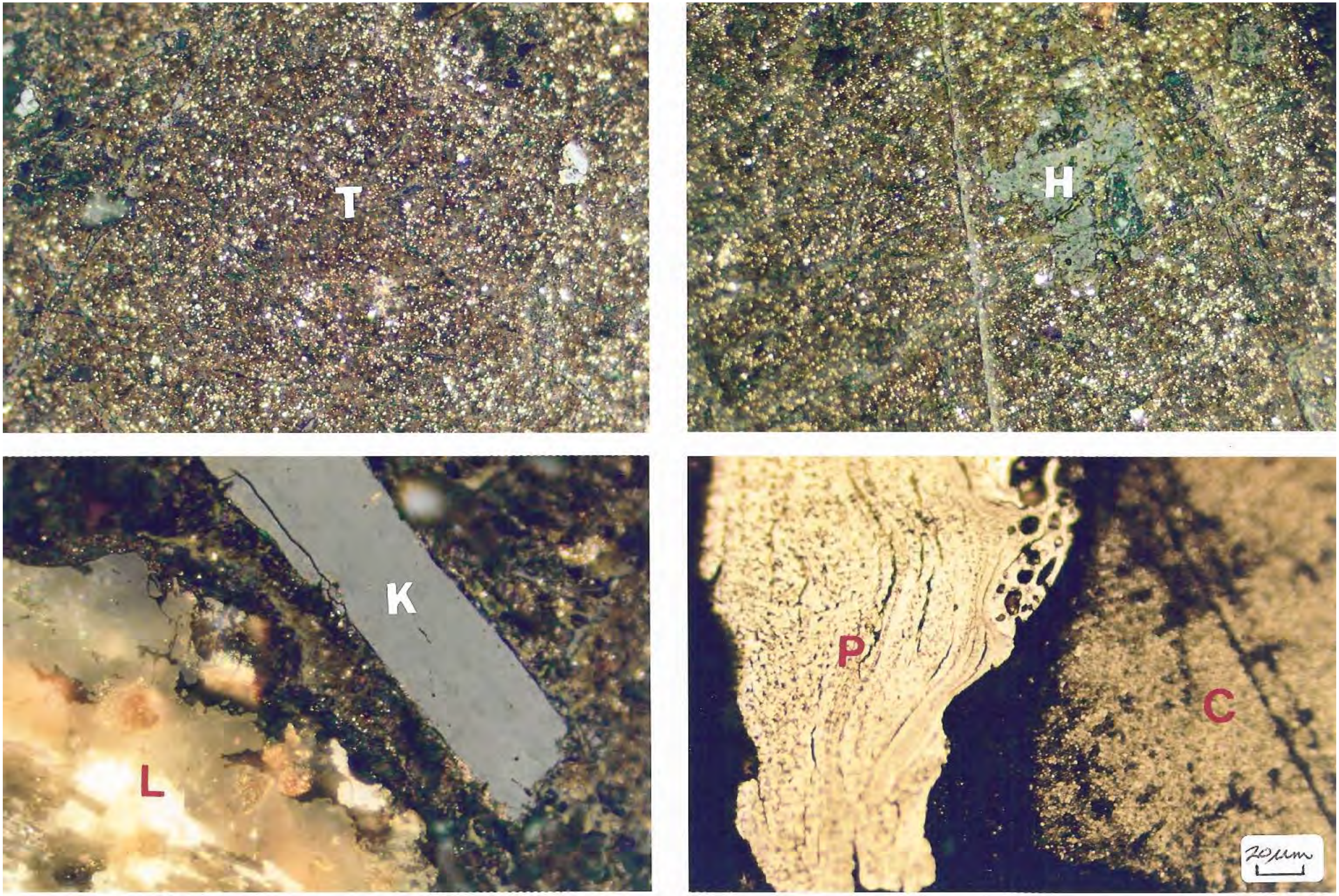
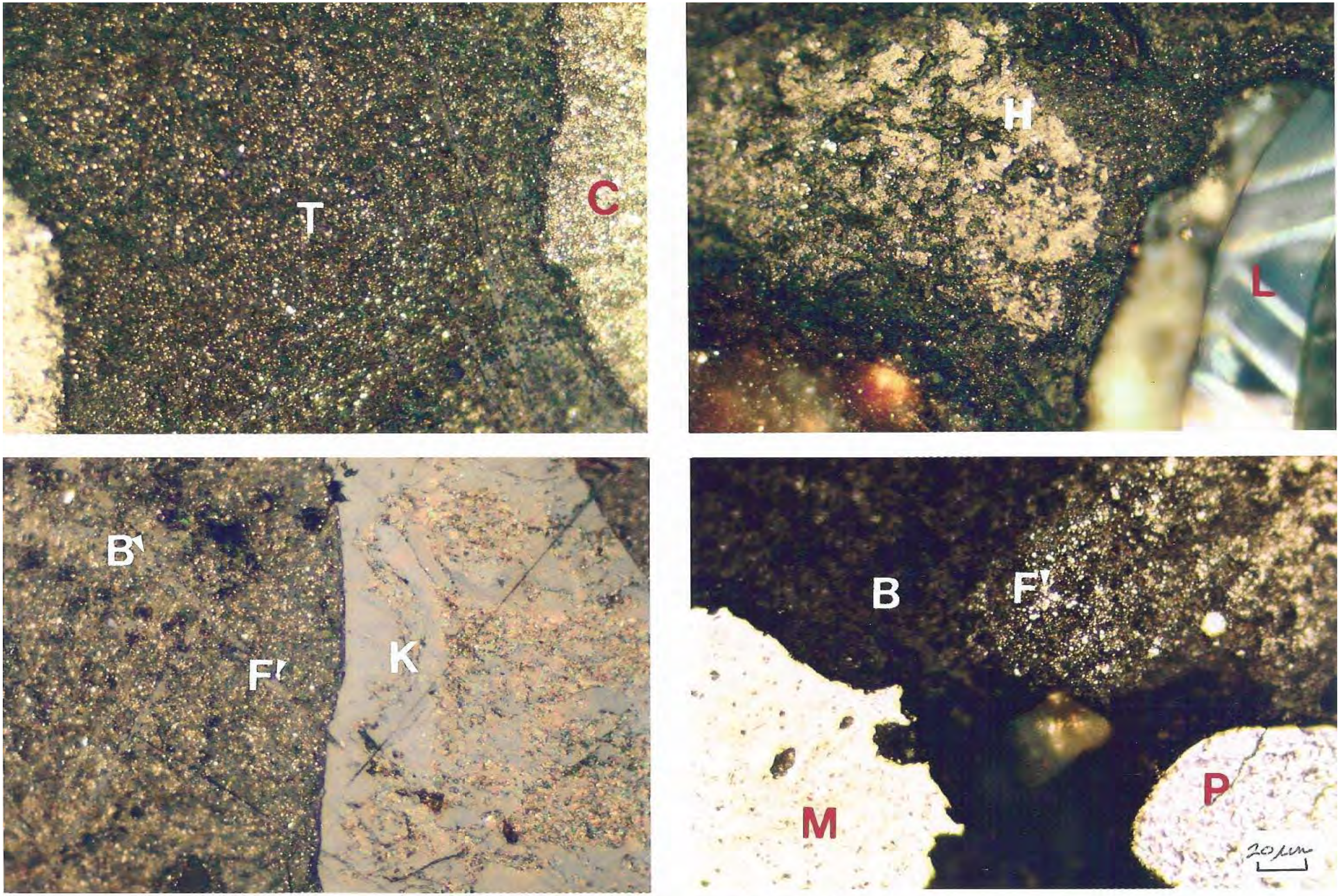


Figure 3: Photomicrographs of Stanford's Sample Labeled NAPL Showing; C=Carbon Black Aggregate, T=Pitch With Normal QI, H=Hard Pitch, K=Coal, P=Petroleum Coke and L=Slag. Reflected Light In Oil, X600.



<u>Figure 4:</u> **Photomicrographs of Stanford's Sample Labeled NAPL Showing; C=Carbon Black Aggregate, T=Pitch With Normal QI, B=Binder Phase Pitch, F=Filler Phase (QI), H=Hard Pitch or Pitch Coke, K=Coal, M=Metallurgical Coke, P=Petroleum Coke and L=Slag. Reflected Light In Oil, X600.**

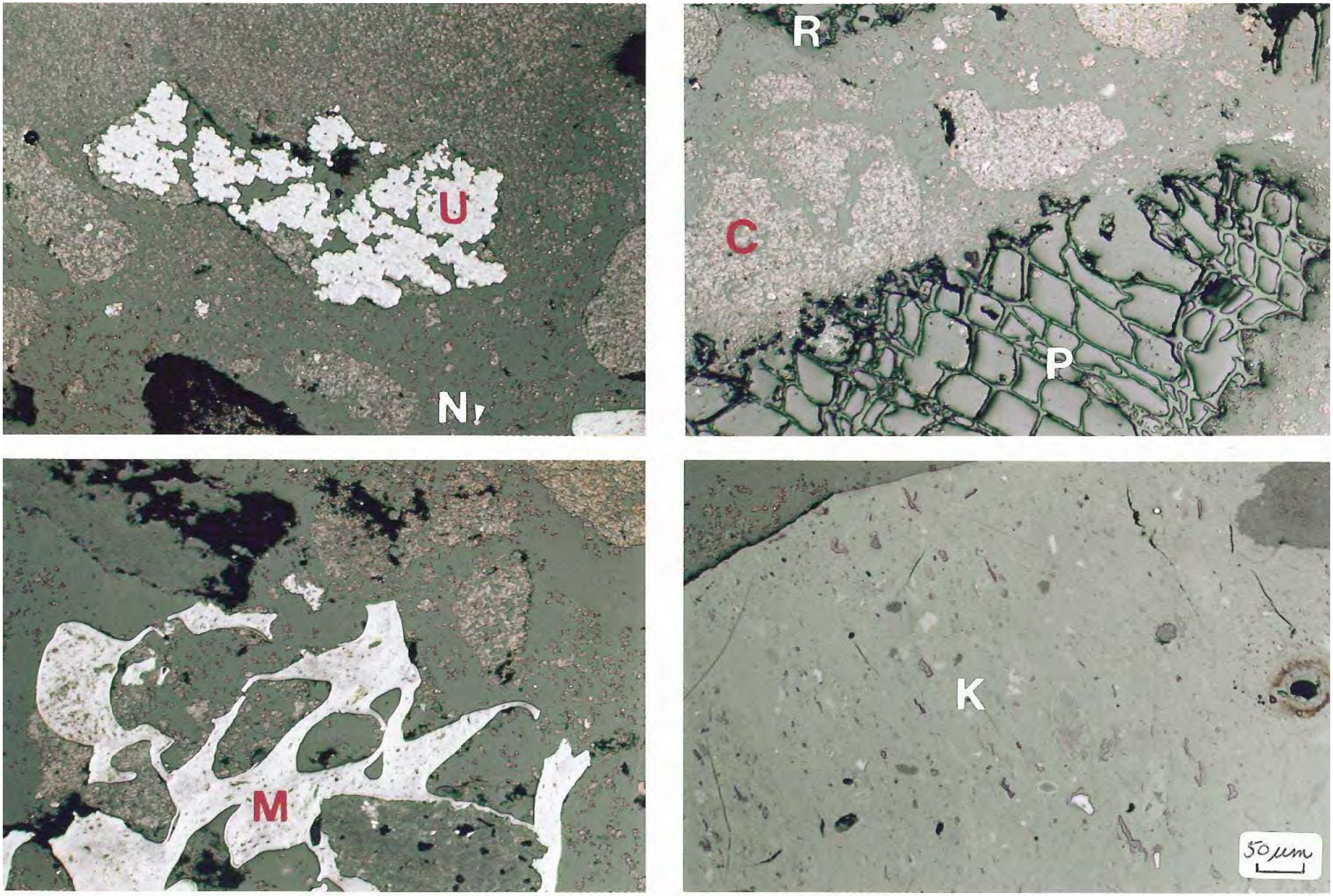


Figure 5: Photomicrographs of Stanford's Sample Labeled NLU-65 Showing; C=Carbon Black Aggregate (loose), N=Individual QI, U=Spherulytic Carbon, P=Cellular Organic Plant Material, R=Particulate Plant, K=Coal and M=Metallurgical Coke. Reflected Light In Air, X250.

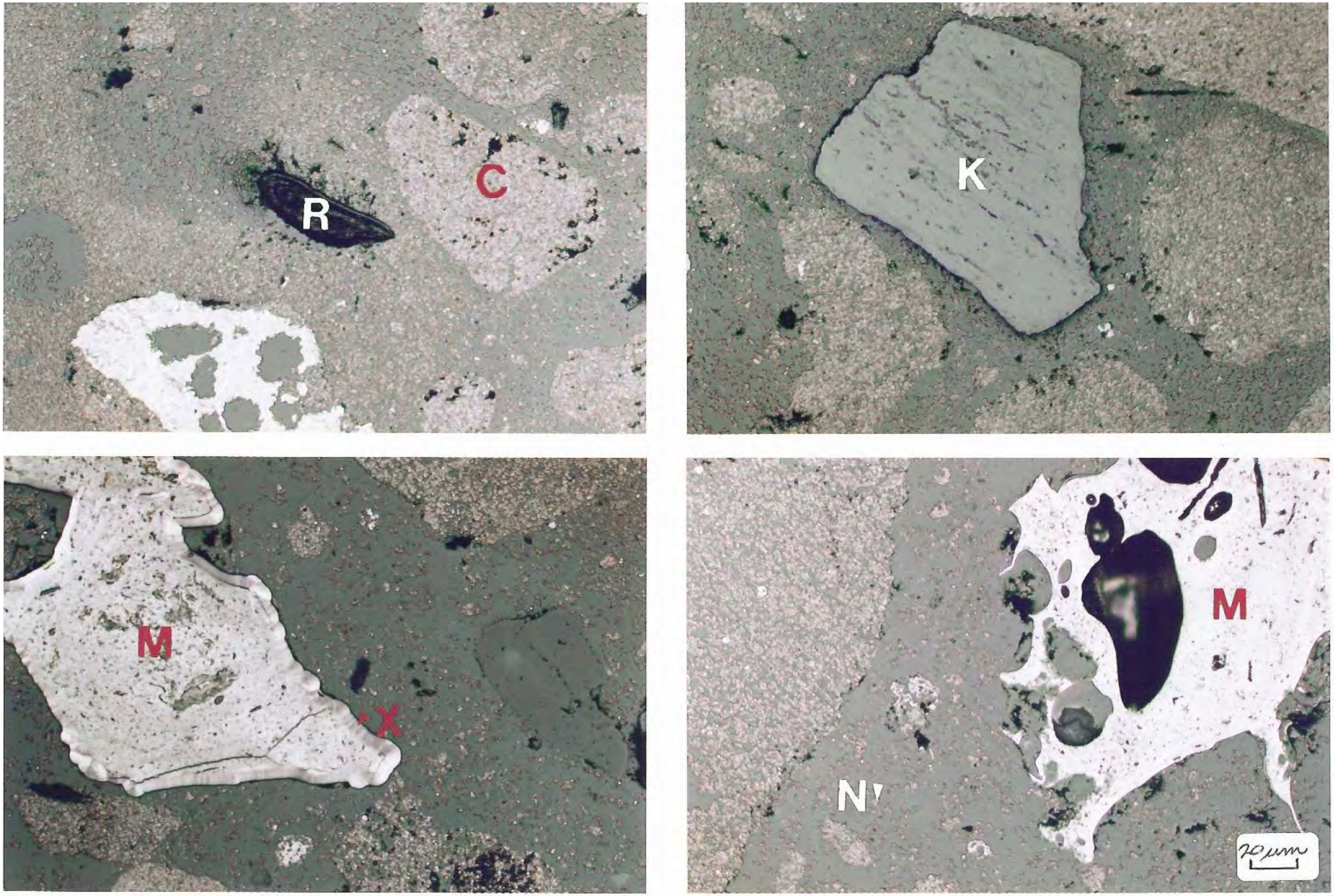


Figure 6: Photomicrographs of Stanford's Sample Labeled NLU-65 Showing; C=Carbon Black Aggregate (loose), N=Individual QI, X=Pyrolytic Carbon, R=Particulate Plant, K=Coal and M=Metallurgical Coke. Reflected Light In Air, X600.

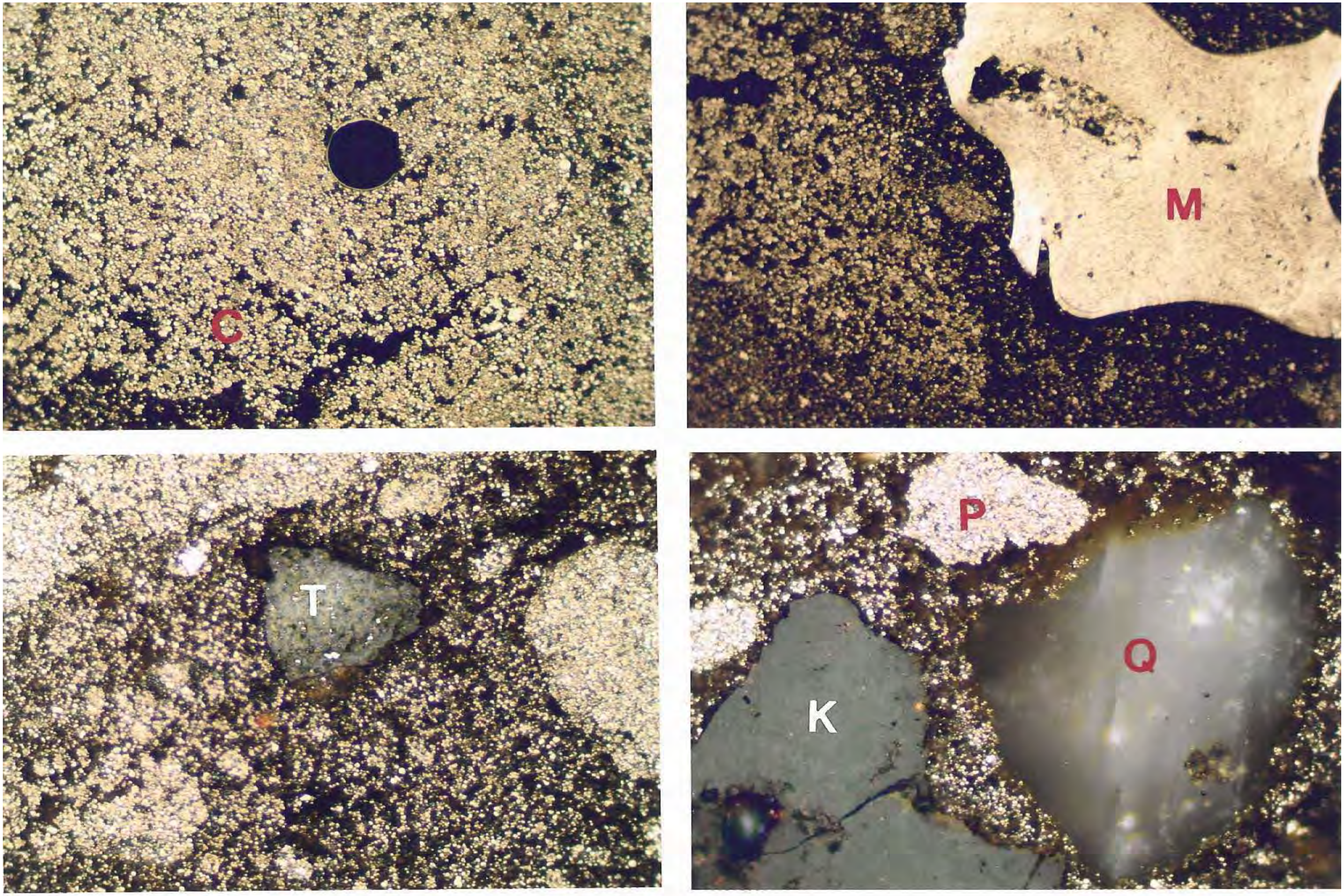


Figure 7: **Photomicrographs of Stanford's Sample Labeled NLU-65 Showing; C=Carbon Black Aggregate (loose), N=Individual QI, T=Pitch, P=Pitch coke, K=Coal, M=Metallurgical Coke and Q=Quartz. Reflected Light In Oil, X600.**

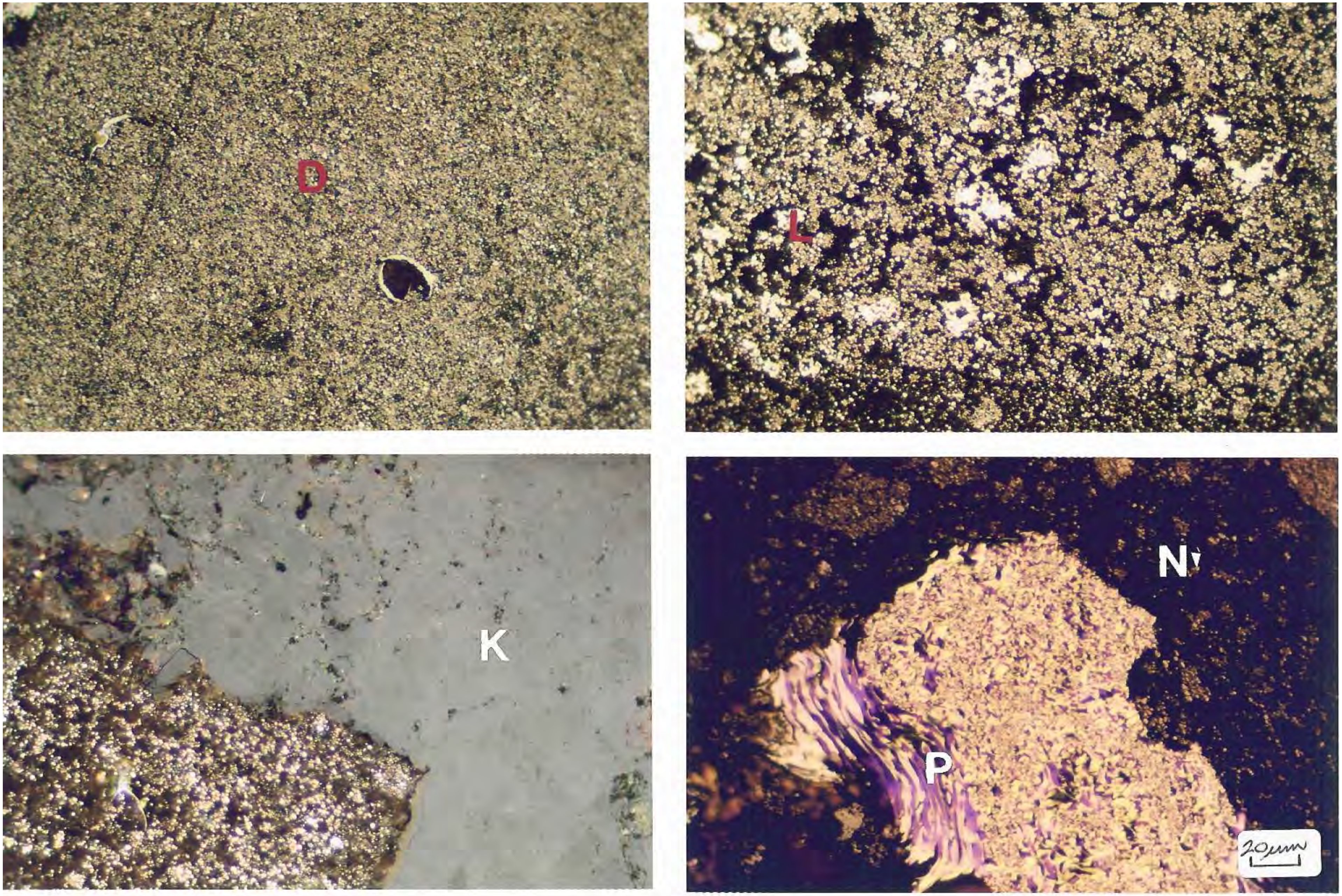


Figure 8: Photomicrographs of Stanford's Sample Labeled NLU-65 Showing; D=Fine Grain Dense Carbon Black Aggregate, L=Loose Aggregate with Pitch Coke Inclusions, N=Individual QI, P=Pitch Coke (pol.) and K=Coal. Reflected Light In Oil, X600.

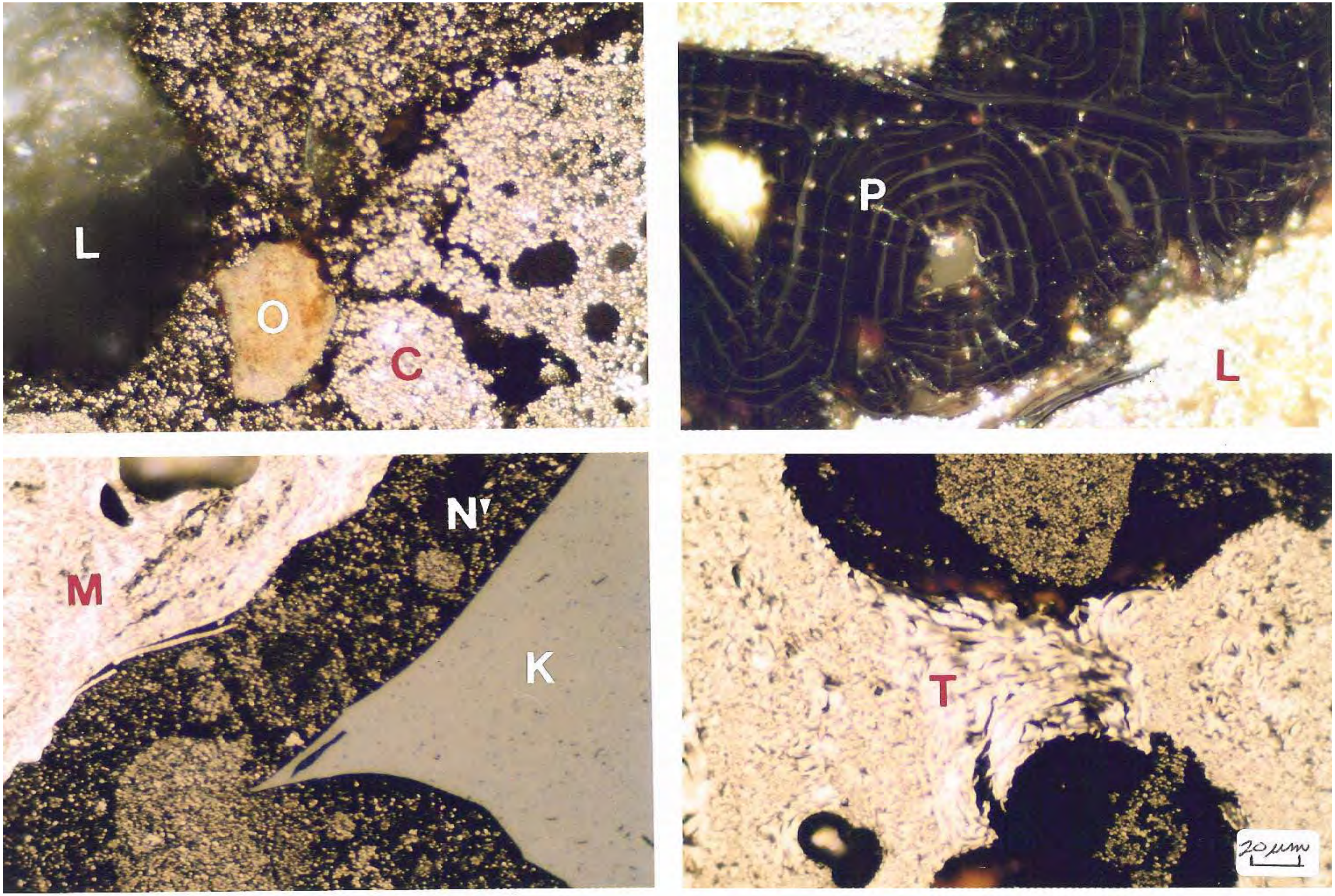


Figure 9: Photomicrographs of Stanford's Sample Labeled NLU-65 Showing; C=Coked Aggregate, N=Small Aggregates or Individual QI, T=Pitch Coke (non-pol.), K=Coal (softened), M=Metallurgical Coke, P=Cellular Organic Plant Material, L=Slag and O=Other Mineral. Reflected Light In Oil, X600.

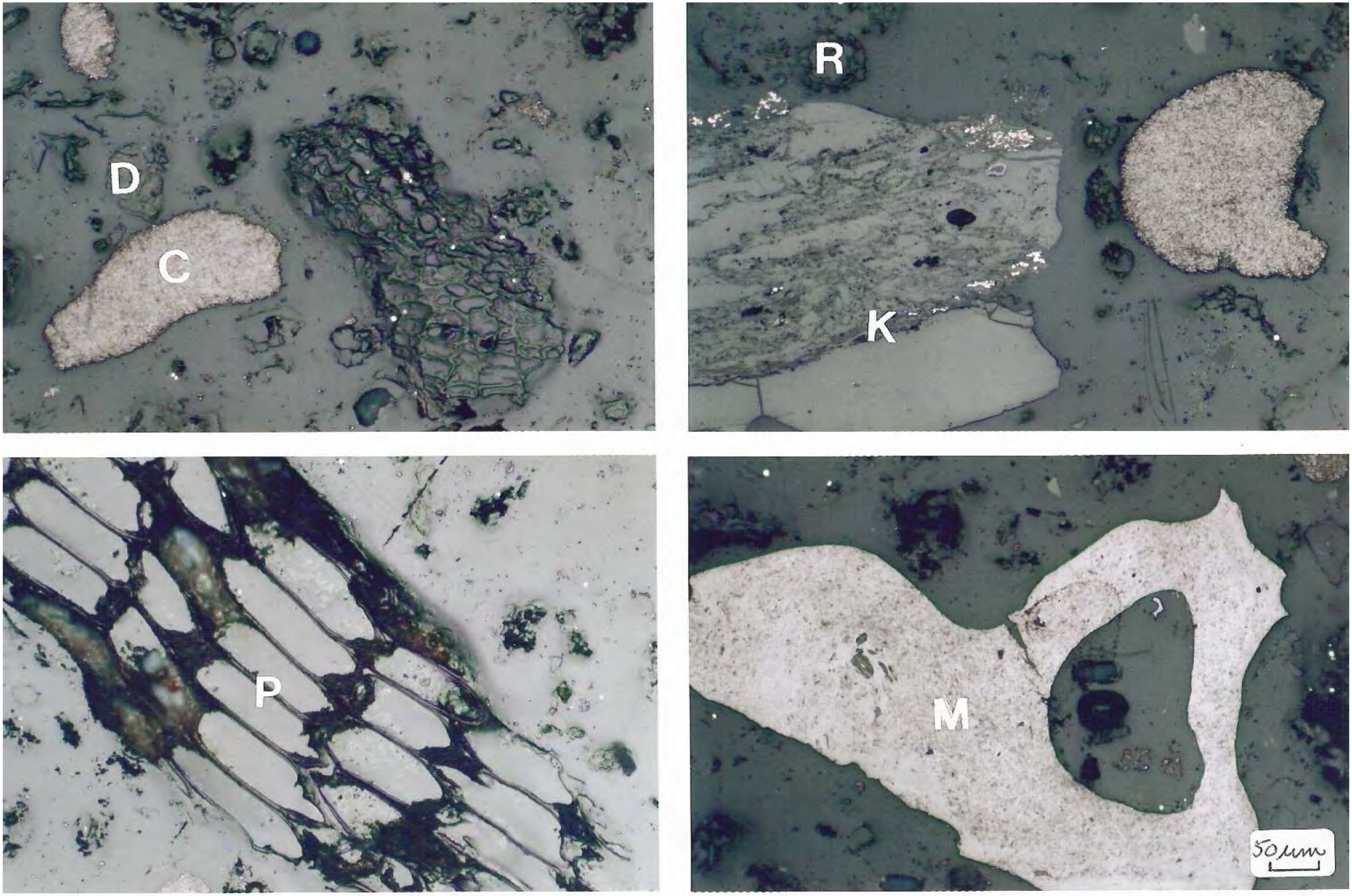


Figure 10: Photomicrographs of Stanford's Sample Labeled NLU-68-SS Showing; C=Carbon Black Aggregate, P=Cellular Organic Plant Material, R=Particulate Plant, D=Diatom Aggregate, K=Coal (softened), M=Metallurgical Coke. Reflected Light In Air, X250.

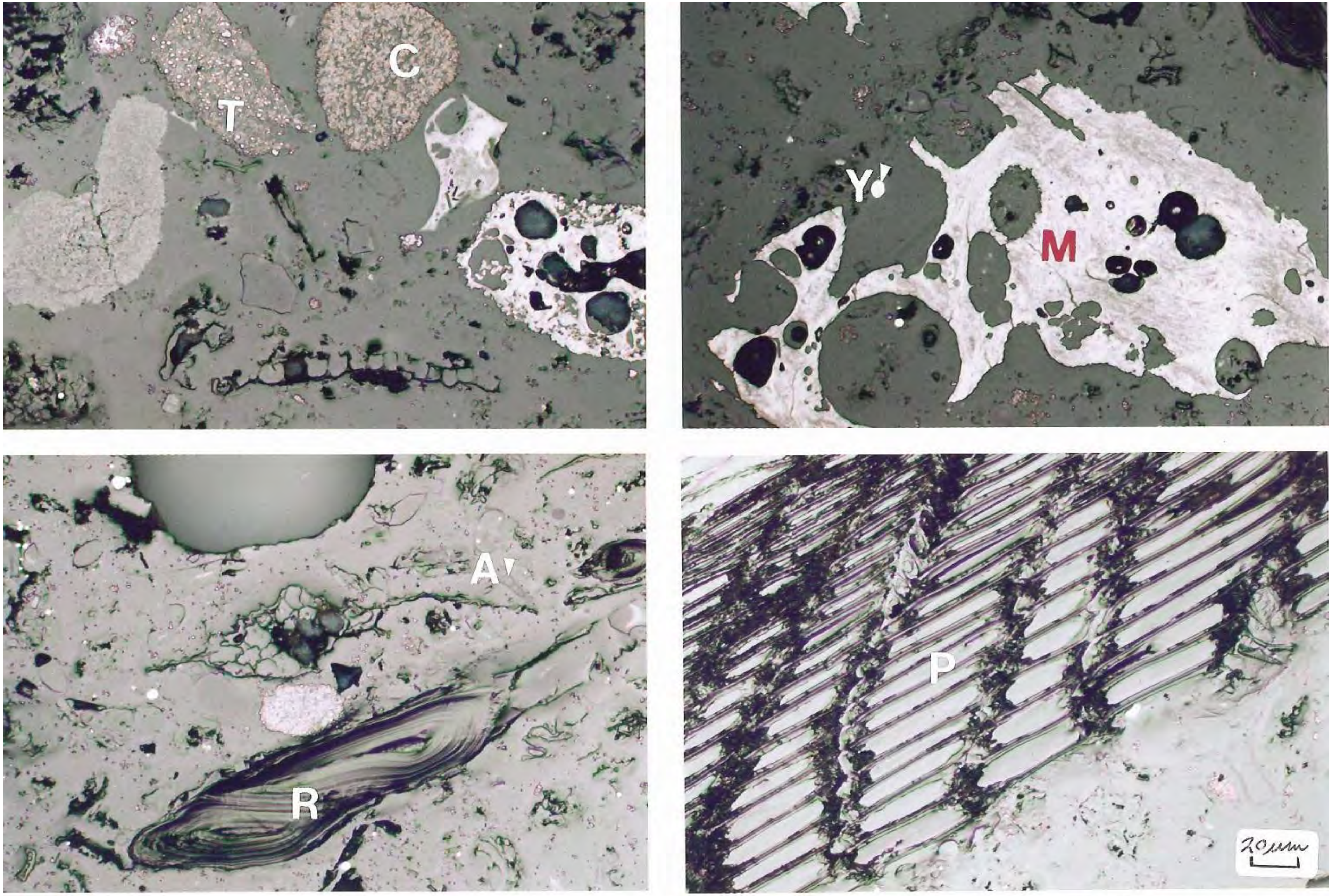


Figure 11: Photomicrographs of Stanford's Sample Labeled NLU-68-SS Showing; C=Carbon Black Aggregate, T=Thermally Altered Pitch, P=Cellular Organic Plant Material, R=Particulate Plant, A=Diatom, M=Metallurgical Coke and Y=Pyrite. Reflected Light In Air, X600.

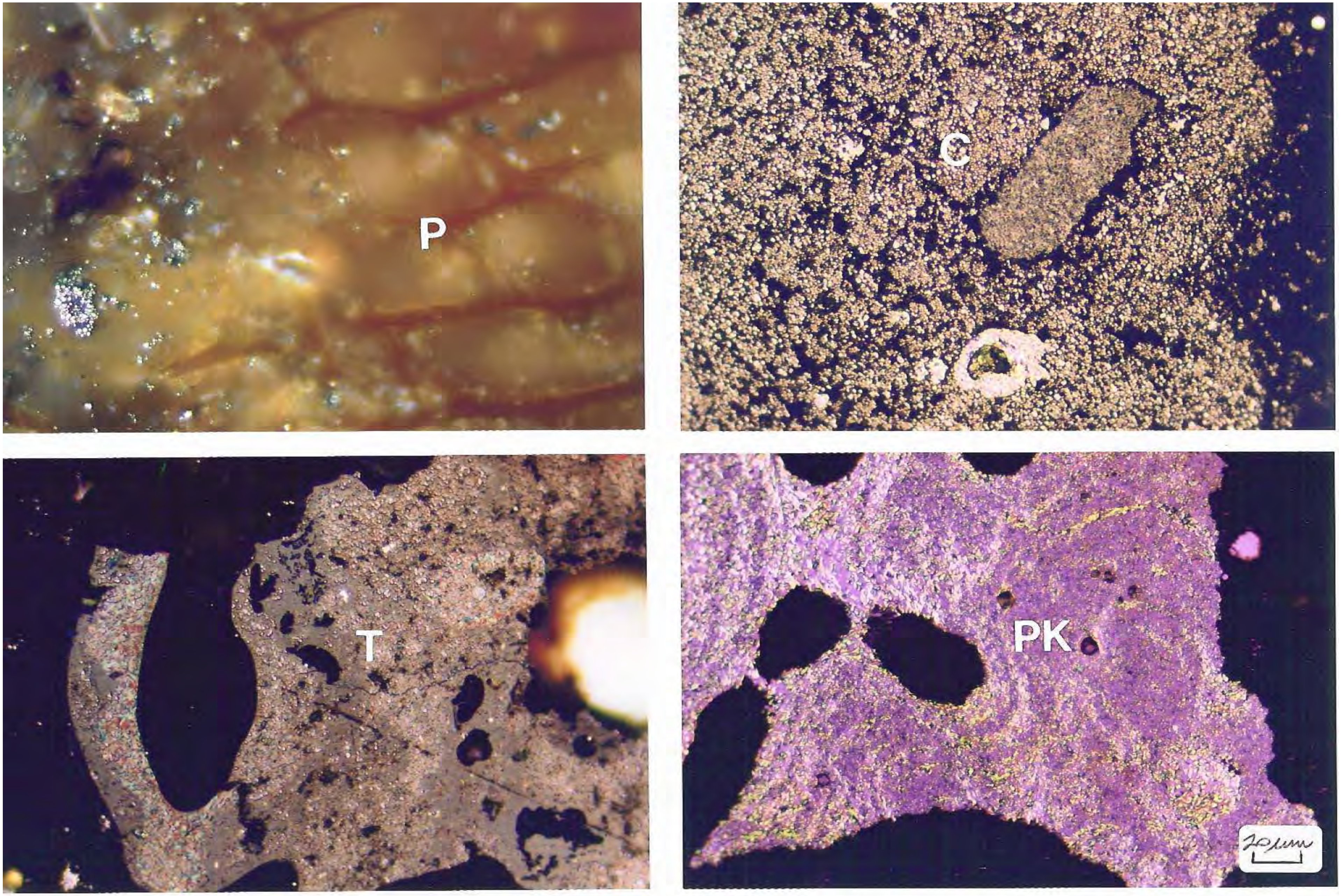


Figure 12: Photomicrographs of Stanford's Sample Labeled NLU-68-SS Showing; C=Carbon Black Aggregate, T=Thermally Altered Pitch, P=Cellular Organic Plant Material and PK=Pitch Coke (pol.). Reflected Light In Oil, X600.

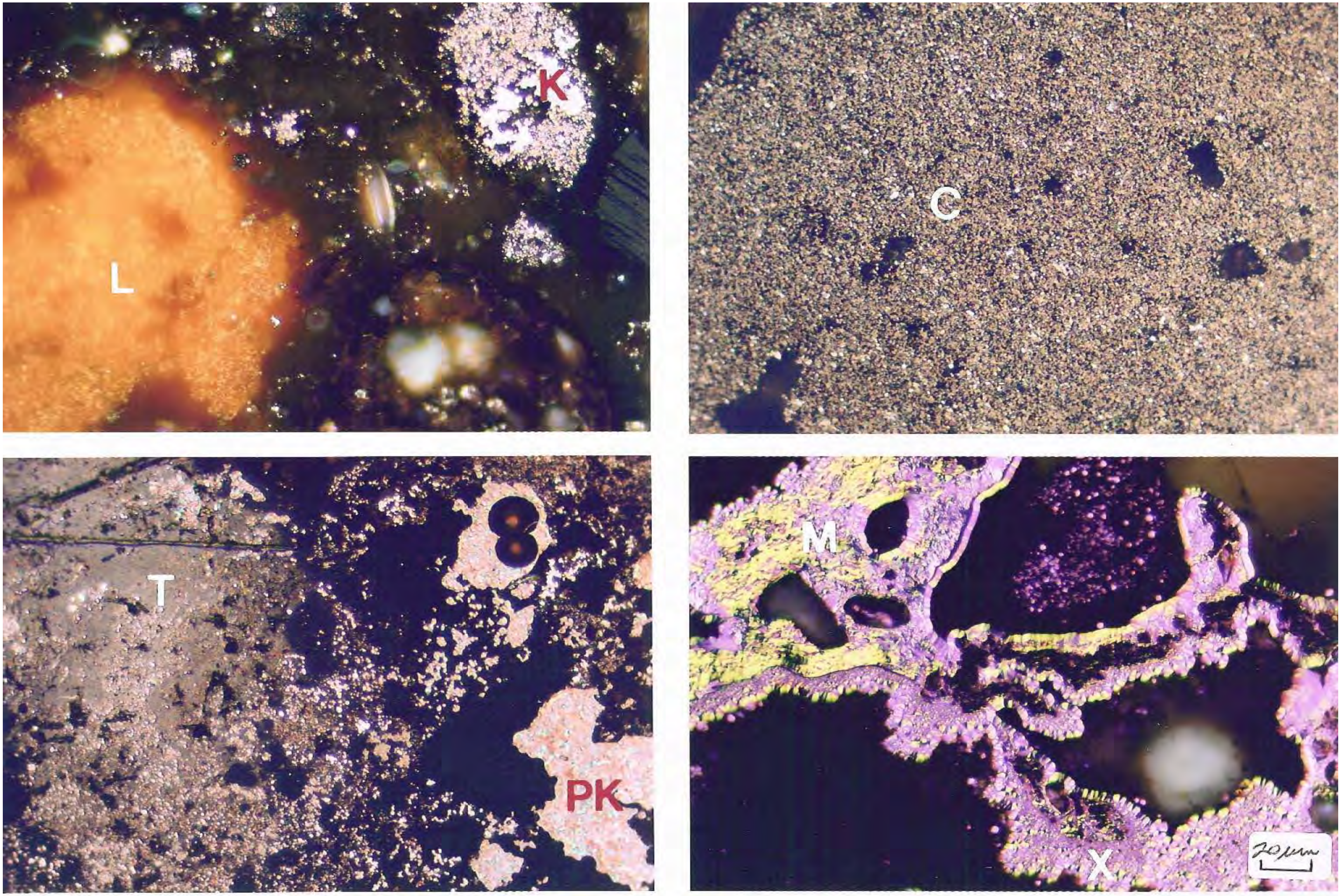


Figure 13: Photomicrographs of Stanford's Sample Labeled NLU-68-SS Showing; C=Carbon Black Aggregate, K=Coked Aggregate, T=Thermally Altered Pitch, PK=Pitch Coke (pol.), M=Met. Coke with X=Pyrolytic Carbon Coating, P=Cellular Plant Material and L=Slag. Reflected Light In Oil, X600.

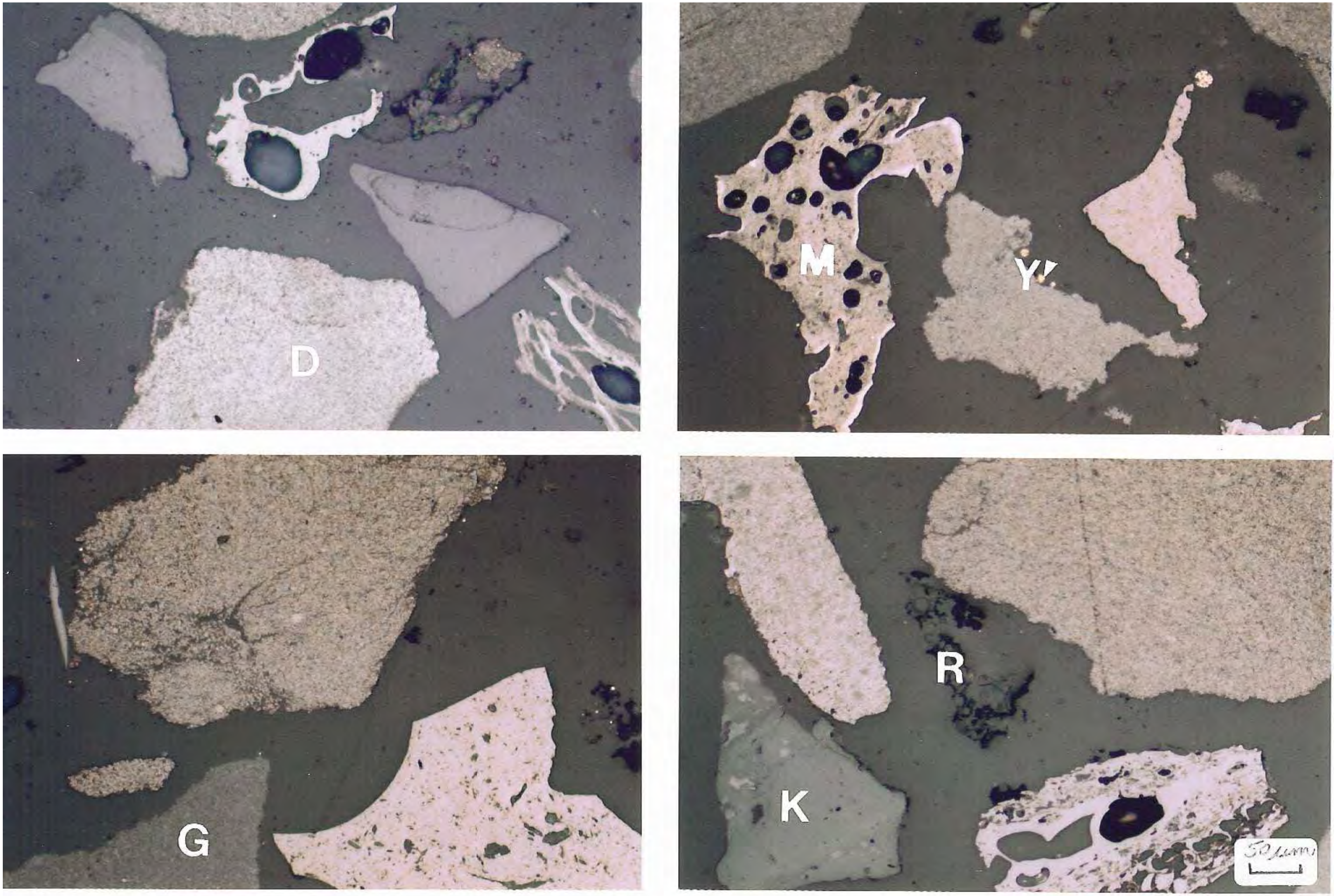


Figure 14: Photomicrographs of Stanford's Sample Labeled NLU-73 Showing; D=Fine Grain Dense Carbon Black Aggregate, G=Green Carbon Aggregate, K=Coal, M=Metallurgical Coke, R=Particulate Plant Material and Y=Pyrite. Reflected Light In Air, X250.

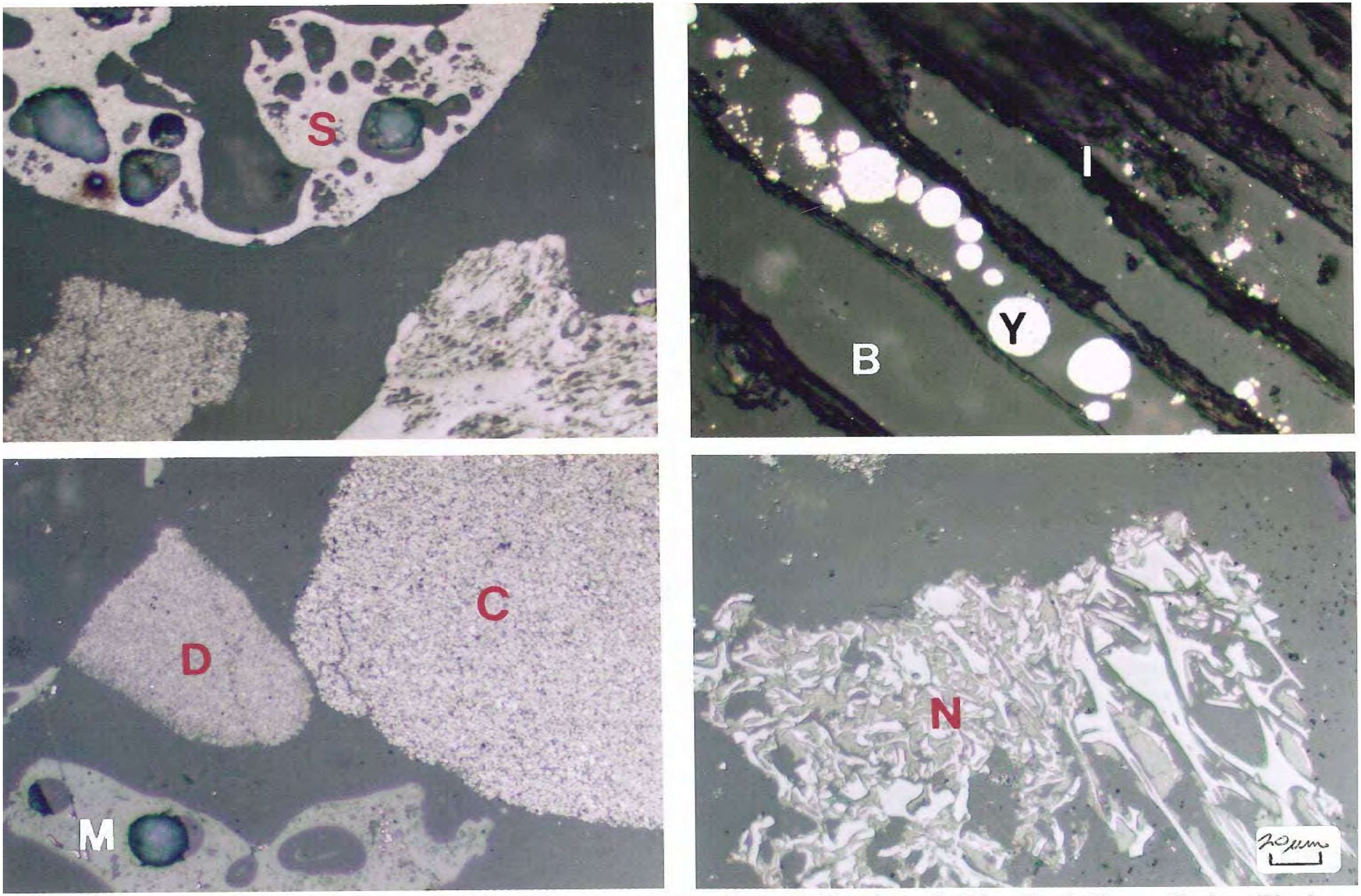


Figure 15: **Photomicrographs of Stanford's Sample Labeled NLU-73 Showing; D=Fine Grain Dense Carbon Black Aggregate, C=Coarse Grain Dense Carbon Aggregate, S=Cenosphere, M=Green Metallurgical Coke, I=Impregnated Plant Tissue with Y=Pyrite and B=Carbonate and N=Coal Inert. Reflected Light In Air, X600.**

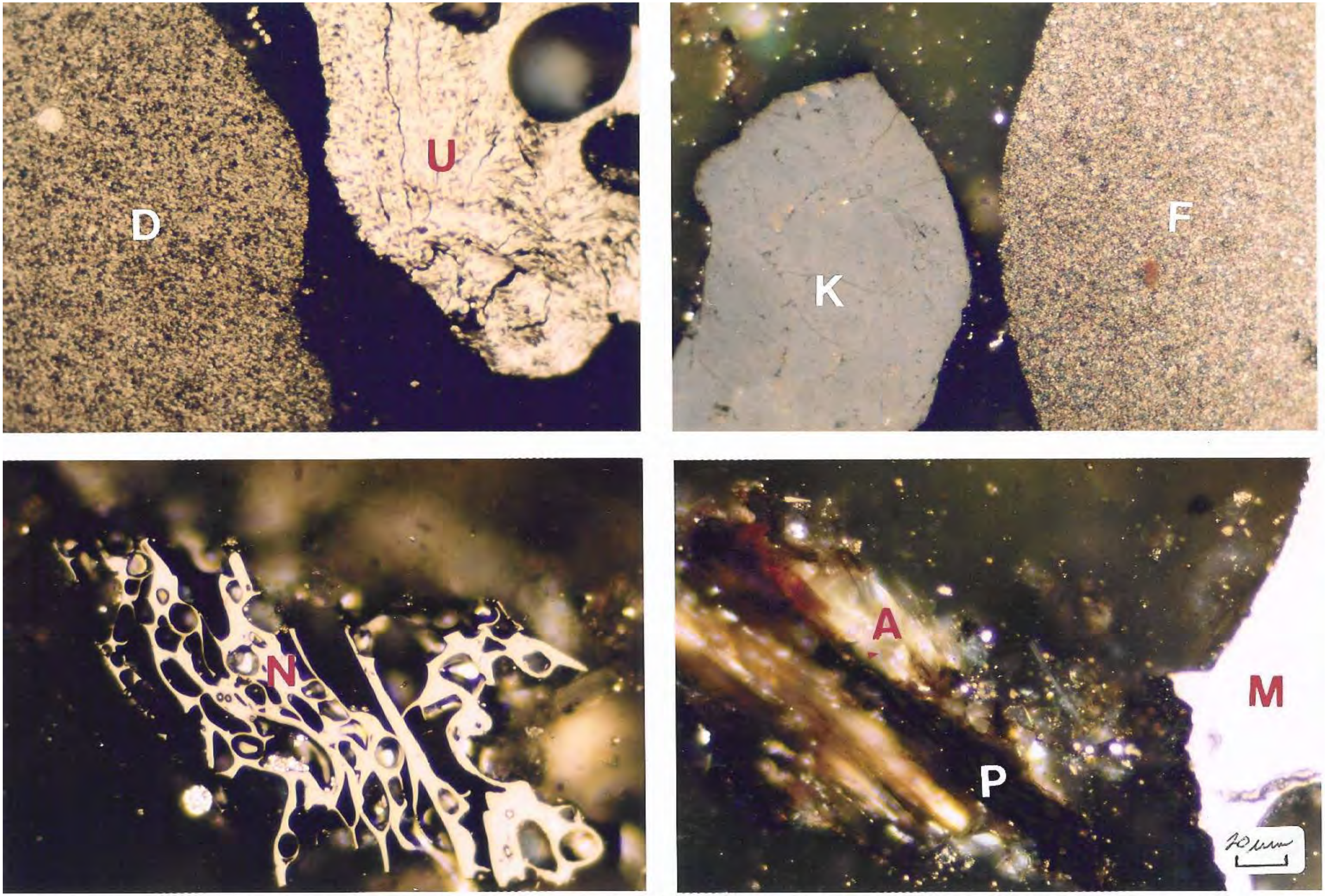
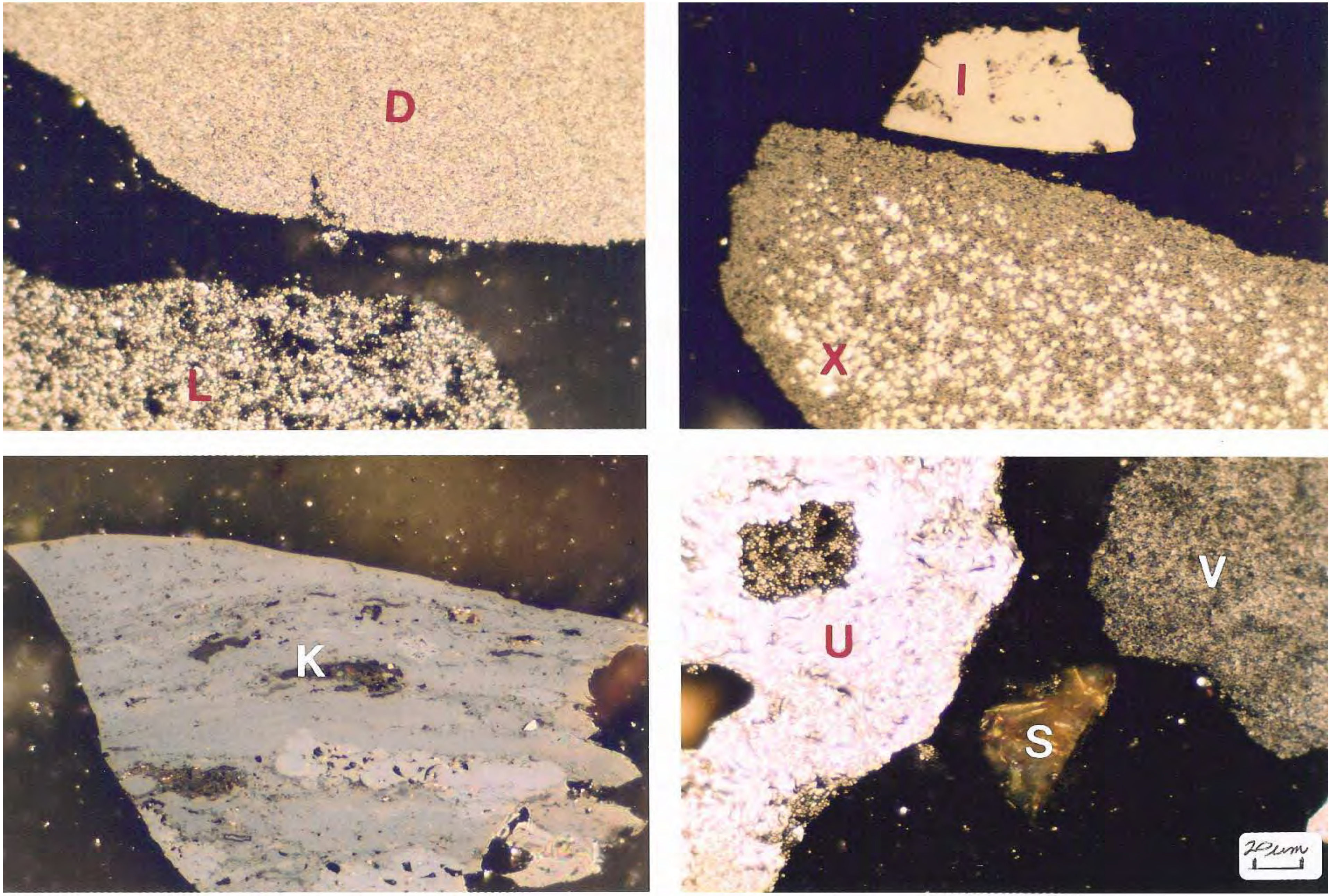


Figure 16: **Photomicrographs of Stanford's Sample Labeled NLU-73 Showing; D=Dense Coarser Aggregate, F=Dense Fine Grain Aggragate, U=Petroleum Coke, M=Metallurgical Coke, N=Coal Inert, K=Coal, P=Cellular Plant Material and A=Diatomaceous Mass. Reflected Light In Oil, X600.**



<u>Figure 17:</u> **Photomicrographs of Stanford's Sample Labeled NLU-73 Showing; D=Dense Fine Aggregate, L=Loose Coarse Aggregate, V=Very Dark QI Matt, X=Mesophase Coke in Fine Aggregate, U=Petroleum Coke, I=Isotropic Met Coke, K=Coal and S=Slag. Reflected Light In Oil, X600.**

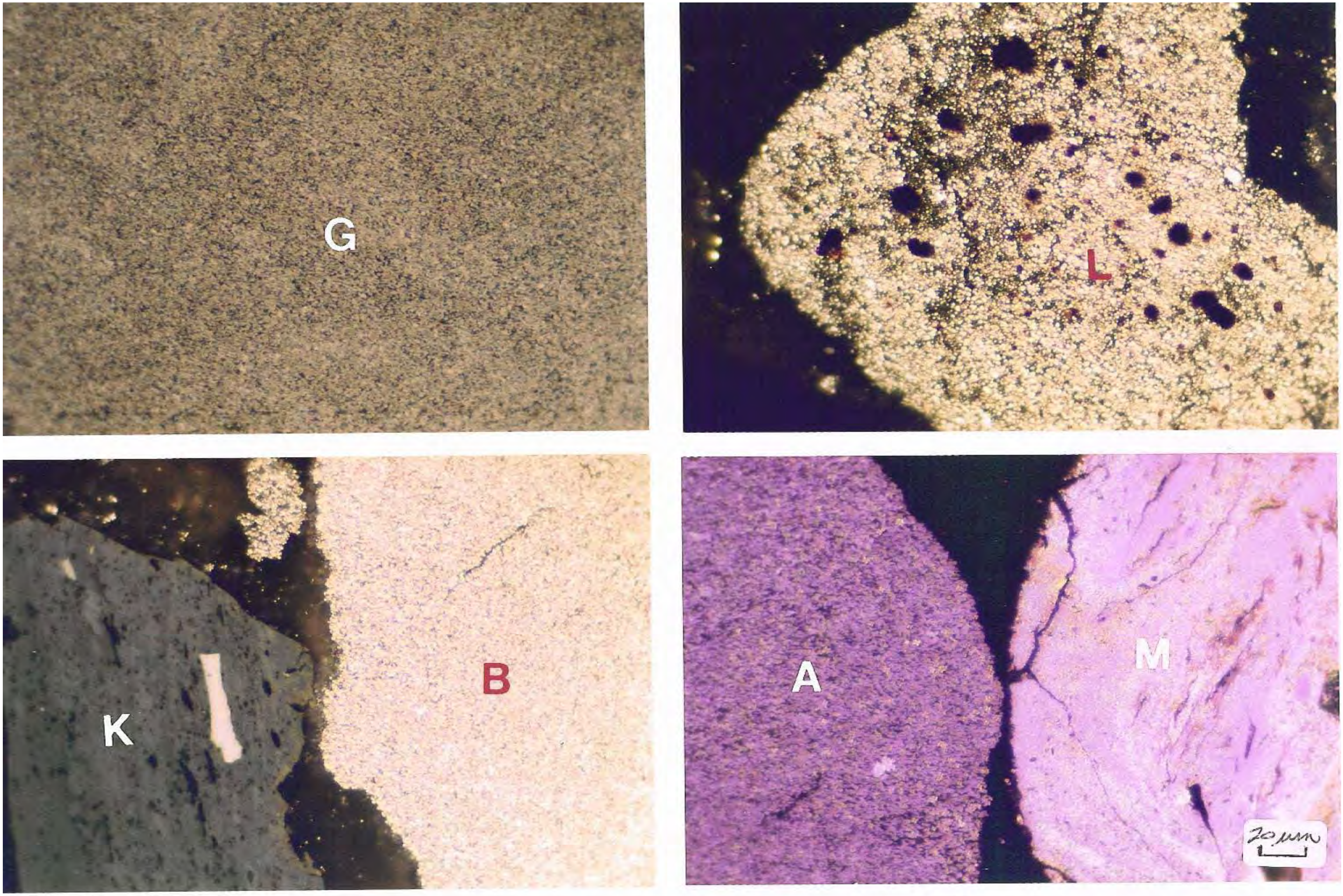


Figure 18: Photomicrographs of Stanford's Sample Labeled NLU-73 Showing; G=Green Fine Grain Aggregate, L=Loose Coarse Aggregate, B=Dense Coked Aggregate, K=Coal, M=Metallurgical Coke (pol.) and A=Coked Aggregate (pol.). Reflected Light In Oil, X600.

R & D CARBON PETROGRAPHY
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May 26, 2005

Ms. Lei Hong
Stanford University
Civil and Environmental Engineering
380 Panama Mall Terman Engineering, B15
Stanford, CA 94305-4020

Dear Ms. Hong;

Your Purchase Order Number 14642820 of April 27, 2005 requested petrographic analysis for five samples of sediment material. The samples are identified and described as follows:

_R & D NO._	_DESCRIPTION_
1105	NLU – 44
1099	NLU – 47
1101	NLU – 51
1102	NLU – 56
1106	NLU – 64

The solids from the five sediment samples were prepared for petrographic analysis and photographed at 250X in air and at 600X in oil with reflected light. A total of 1000 points were counted for composition. The materials were separated into four main categories which consist of carbon, organic plant material, diatoms and mineral matter. Each category is further subdivided into more specific materials.

The submicron carbon forms consist of carbon with one or two probable origins. Carbon black is a solid product of incomplete combustion. It has many commercial uses including filler in tires. In contrast QI or quinoline insolubles occur as solids in coal tar/pitch. In by-product coking the material from incomplete coal combustion and vapor phase cracking occur colloidally dispersed in the tar/pitch that are collected as by-products of carbonization. In the current work these materials are described as dense or loose aggregate, individual QI, green or less coked aggregates and very dark mattes. The related material is described as pitch, tar-like and pitch coke. Cenospheres are counted separately. They are produced when coal is heated rapidly in an unconfined condition. The rapidly heated coal becomes plastic and the internally trapped gases expand to produce very porous commonly spherical bodies of coke. Depositional carbon may be spherulitic or pyrolytic. Liquid distillation products of coal may crack to form spherulitic carbons. The high hydrogen gaseous materials from coal carbonization form pyrolytic carbon.

The organic plant material in the samples are described in terms of there degree of preservation. The portion that displays the cellular structure is counted separately from the portion that is degraded and occurs as particulate and less ordered plant structures. Much of this material that occurs in sediments and sedimentary rocks are described as kerogen.

Diatoms are unicellular organisms that have a variety of shapes and forms that form planktonic colonies. These plant forms are capable of photosynthesis. They contain skeletons called frustules consisting of two valves that fit together like a box. These internal skeletons consist of pure silica which has very minute fine cellular microstructures. The fossils or skeletons of diatoms have a wide variety of uses as fillers, filtering materials and from a scientific standpoint there sensitivity to temperatures and water depth are good indicators of there habitat. Some of the material that we refer to as mattes maybe associated due to specific gravity separation rather than being due to natural associations.

The identifiable mineral matter consist of quartz SiO_2, a variety of carbonates including shells, pyrite FeS_2, brown grainy aggregates, white grainy materials, slag, metallics and other minerals. The brown stains on materials may be from humic sources. The slag is thermally altered mineral matter that has a variety of forms and shapes and ranges from glassy to crystalline. Most of the pyrite that occurs is associates with the plant material and occurs as framboids consisting of small circular aggregates of crystals. These forms are usually indicators of brackish water conditions.

In the current work we use the terms metallurgical coke and by-product coking to separate coal based coking processes from those that are based on petroleum residuals.

Stanford Sample – NLU - 44

The Stanford sample labeled NLU-44 has 2.6% by volume of total carbon which consists of 0.9% carbon black/Normal QI, with 0.8% tar-like material and lesser amounts of metallurgical coke, coal and cenospheres. There is 24.2% of total organic plant material which consists of 16.1% with cellular structure and 8.1% of particulate plant material. The majority of this sample 66.0% is diatomaceous material which consists of 43.3% of clusters or mattes of siliceous diatoms and individual diatoms and 22.7% diatomaceous mattes that are mixed with other minerals. There is 7.2% of total mineral matter which consist mostly 3.5% of unidentified mineral matter with lesser amounts of quartz, a white grainy mineral, slag, a brown grainy aggregate, carbonate and pyrite. The petrographic composition data is listed in Table 1 and most of the materials are illustrated in Figures 1 through 4.

The diatomaceous material and the organic plant material make up the majority of this sample and totals 84.2% by volume. The remainder of the material is various types of mineral matter and carbon related material. The carbon related material is the least common material in the LUI-44 sample.

Stanford Sample – NLU - 47

The Stanford sample labeled NLU-47 has 7.0% by volume of total carbon which consists of 5.0% carbon black/Normal QI, with 0.9% of coal, 0.6% of metallurgical coke, 0.4% of pitch and 0.1% of cenospheres. There is 30.6% of total organic plant material which consists of 17.8% with cellular structure and 12.8% of particulate plant material. A major portion of this sample 36.6% is diatomaceous material which consists of clusters or mattes of siliceous diatoms, individual Skeletons of diatoms and diatom mattes mixed with minerals. There is 25.8% of total mineral matter which consists of 7.8% of unidentified mineral matter, with 8.6% of brown (probably humic matter) grainy aggregates, 5.0% of a white grainy mineral, 3.8% of quartz and a small amount of pyrite and metallics. The pyrite is commonly associated with organic plant material. The petrographic composition data is listed in Table 1 and most of the materials are illustrated in Figures 5 through 9.

The diatomaceous material, organic plant material and the mineral matter make up the majority of this sample and totals 93.0% by volume. The remainder of the material is carbon which is primarily aggregates of carbon black or Normal QI.

Stanford Sample – NLU - 51

The majority of the material in the Stanford sample labeled NLU-51 is carbon and totals 77.6% by volume. The most abundant (37.9%) carbon related material is aggregates of carbon black/Normal QI, with 18.0% of metallurgical coke and oxidized coke, 6.5% of depositional carbon, 5.5% of coal and lesser amounts of petroleum coke, tar-like, pitch coke, pitch and cenospheres. There is 10.4% of total organic plant material which consists of 9.5% with cellular structure and 0.9% of kerogen-like particulate plant material. A small portion of this sample 2.0% is diatomaceous material which consists of clusters or mattes of diatoms and individual diatoms. There is 10.0% of total mineral matter which consists of 4.2% of brown grainy aggregates, with 3.1% of slag or thermally altered mineral matter, 1.3% of quartz and lesser amounts of carbonates, unidentified minerals, pyrite and metallics. The petrographic composition data is listed in Table 1 and most of the materials are illustrated in Figures 10 through 14.

The carbon related material is the most abundant material in this sample and the carbons are relatively equally divided between aggregates of submicron spherical carbon that is either carbon black or aggregates of Normal QI (37.9%) and by-product or petroleum related carbons (39.7%). The remainder of the material is mostly plant material or mineral matter with a small amount of diatoms.

Stanford Sample – NLU - 56

The majority of the material in the Stanford sample labeled NLU-56 is carbon and totals 87.3% by volume. The majority (81.5%) of the carbon related material is aggregates of carbon black and/or Normal QI. There is a small amount (5.8%) of by-product related carbon which consists of 2.3% coal, with 2.0% of metallurgical coke and 1.5% of pitch and petroleum coke, depositional carbon (pyrolytic and spherulitic) and cenospheres. There is 6.2% of total organic plant material which consists of 5.6% with cellular structure and 0.6% of particulate plant material. A very small portion of this sample 0.3% is diatomaceous material which consists mostly of individual siliceous diatoms. There is 6.2% of total mineral matter which consists of 1.8% of slag, 1.2% of carbonates and lesser amounts of the unidentified mineral matter, quartz, brown and white grainy aggregates. The petrographic composition data is listed in Table 1 and most of the materials are illustrated in Figures 15 through 19.

The carbon related material is the most abundant material in this sample and the majority of the carbon consists of the submicron spherical carbon that is either carbon black or aggregates of Normal QI from coal tar or pitch. The other by-product related carbons make up a small amount of the total carbon. The organic plant material and mineral matter make up the remainder of the sample (12.7%) with a very small amount of diatoms (0.3%).

Stanford Sample – NLU - 64

The Stanford sample labeled NLU-64 has 15.0% by volume of total carbon which consists mostly (13.1%) of carbon black/Normal QI, with 1.0% of coal, 0.4% of pitch, 0.3% of metallurgical coke and oxidized coke and 0.2% of cenospheres. There is 41.1% of total organic plant material which consists of 31.2% with cellular structure and 9.9% of particulate plant material. A major portion of this sample 36.3% is diatomaceous material which consists of clusters or mattes of diatoms, individual siliceous diatoms and diatom mattes that are mixed with minerals. There is 7.6% of total mineral matter which consists mostly of a white grainy mineral (3.6%) and lesser amounts of brown grainy aggregates, unidentified minerals, pyrite, quartz and slag. The petrographic composition data is listed in Table 1 and most of the materials are illustrated in Figures 20 through 23.

The organic plant material, diatomaceous material and mineral matter make up the majority of this sample totaling 85.0% by volume. The remainder of the material is carbon (15.0%) which is primarily aggregates of carbon black or Normal QI.

Please do not hesitate to call us at (724) 327-5019 or e-mail us at ralphgray@aol.com if you have any questions or wish to discuss this work.

Sincerely,

Ra1ph J Gray
Daniel P. Gray

Table 1

Petrographic Composition Analysis of Soil Sample from Stanford University

R & D No.	**1105**	**1099**	**1101**	**1102**	**1106**
Stanford Sample ID	**NLU - 44**	**NLU - 47**	**NLU - 51**	**NLU - 56**	**NLU - 64**
Carbon:					
Carbon Black: / Normal QI					
Dense Aggregates	---	0.5	---	0.6	---
Loose Aggregates	0.1	2.8	19.3	52.3	4.7
Small Aggregates and Individual QI	0.8	1.7	18.4	28.6	8.2
Green Aggregates	---	---	0.2	---	0.2
Very Dark QI Matt	---	---	---	---	---
Pitch – Normal	---	0.4	1.3	---	0.4
Pitch – High Reflecting (thermally altered)	---	---	---	---	---
Tar-Like	0.8	---	2.4	---	---
Pitch Coke	---	---	2.2	0.6	---
Cenospheres	0.1	0.1	0.6	0.2	0.2
Petroleum Coke	---	---	3.2	0.4	---
Metallurgical Coke – coal related	0.6	0.6	15.9	2.0	0.1
Oxidized Coke	---	---	2.1	---	0.2
Depositional carbon –spherulytic	---	---	6.0	0.1	---
Pyrolytic		---	0.5	0.2	---
Coal	0.2	0.9	5.5	2.3	1.0
Total Carbon	**2.6**	**7.0**	**77.6**	**87.3**	**15.0**
Organic Plant Material (Kerogen-Like)					
Cellular	16.1	17.8	9.5	5.6	31.2
Particulate	8.1	12.8	0.9	0.6	9.9
Total Plant	**24.2**	**30.6**	**10.4**	**6.2**	**41.1**
Diatom	43.3	36.6	2.0	0.3	29.1
Diatom Related - with Mineral Matter	22.7	---	---	---	7.2
Total Diatom	**66.0**	**36.6**	**2.0**	**0.3**	**36.3**
Mineral Matter					
Quartz	1.3	3.8	1.3	0.9	0.6
Carbonates	0.1	---	0.6	1.2	---
Pyrite	0.1	0.5	0.1	---	0.8
Brown grainy aggregate	0.3	8.6	4.2	0.9	1.2
White Grainy	1.3	5.0	---	0.2	3.6
Slag	0.6	---	3.1	1.8	0.5
Metallics	---	0.1	0.1	---	---
Other Mineral Matter:	3.5	7.8	0.6	1.2	0.9
Total Mineral Matter	**7.2**	**25.8**	**10.0**	**6.2**	**7.6**
Grand Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

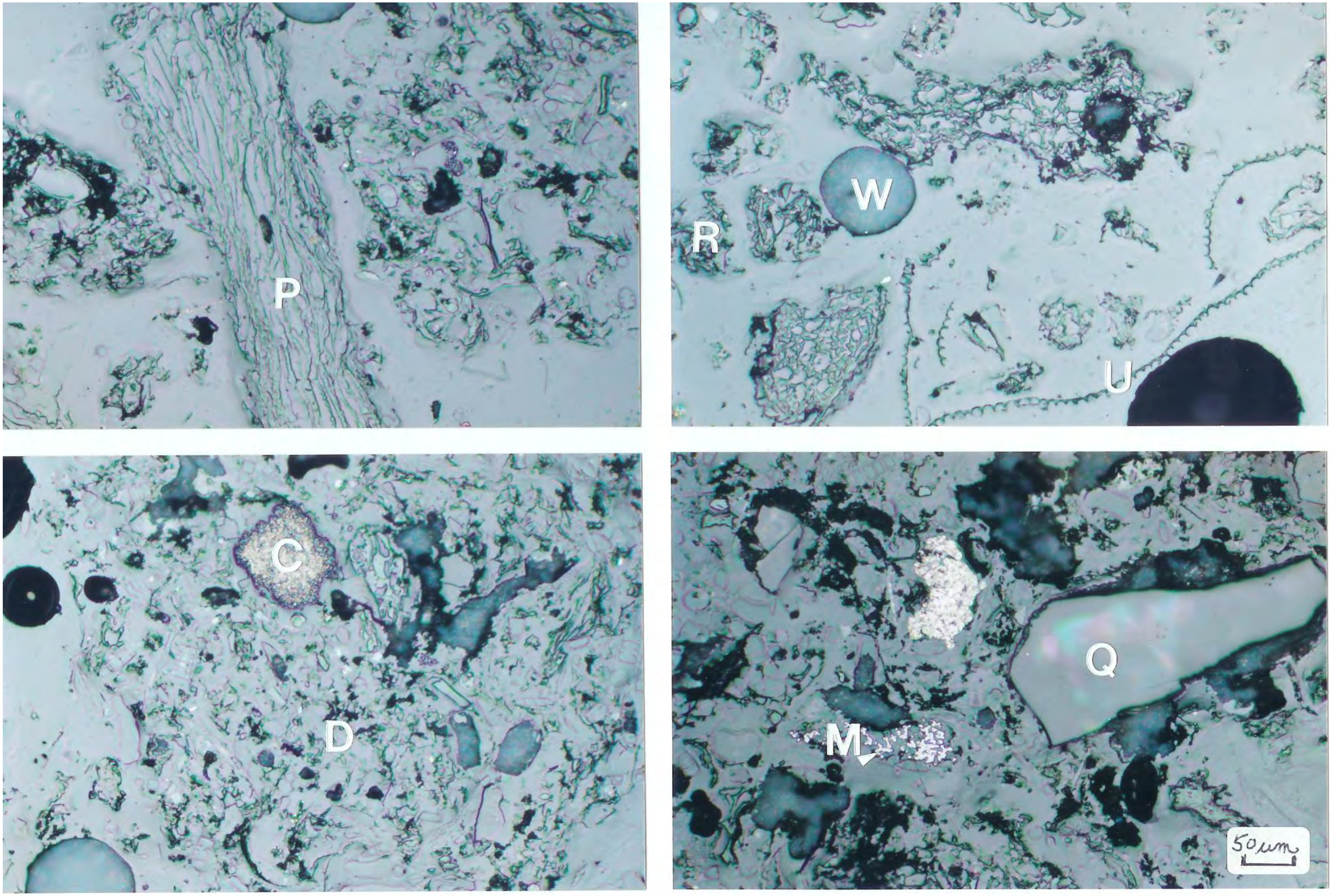


Figure 1: Photomicrographs of Stanford's Sample Labeled NLU-44 Showing; C=Carbon Black Aggregate, P=Cellular Organic Plant Material, R=Particulate Plant, U=Cutical (plant), Q=Quartz, D=Diatomaceous Mass, W=White Grainy and M=Metallics. Reflected Light In Air, X250.

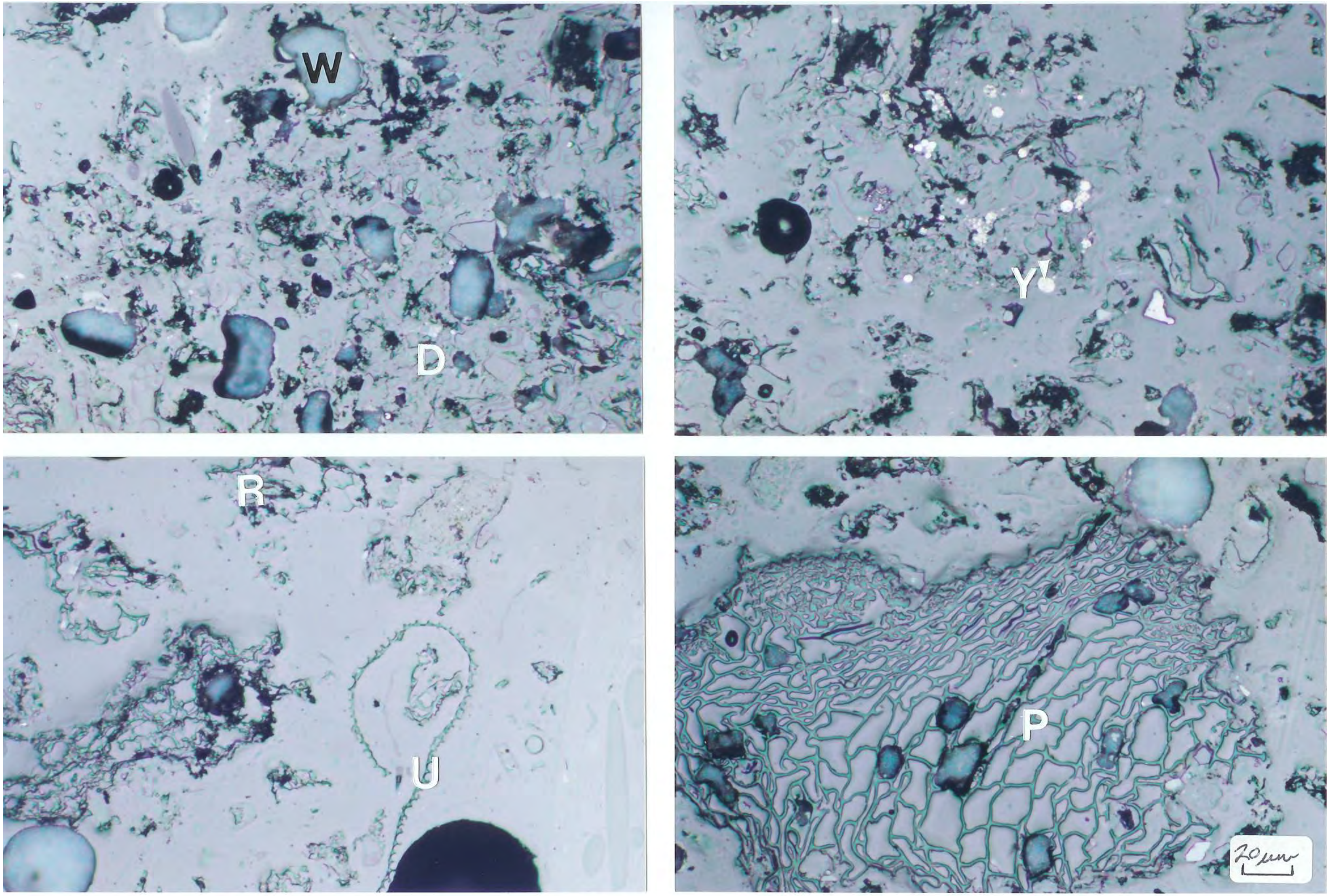


Figure 2: Photomicrographs of Stanford's Sample Labeled NLU-44 Showing; P=Cellular Organic Plant Material, R=Particulate Plant, U=Cutical (plant), D=Diatomaceous Mass, W=White Grainy and Y=Pyrite. Reflected Light In Air, X600.

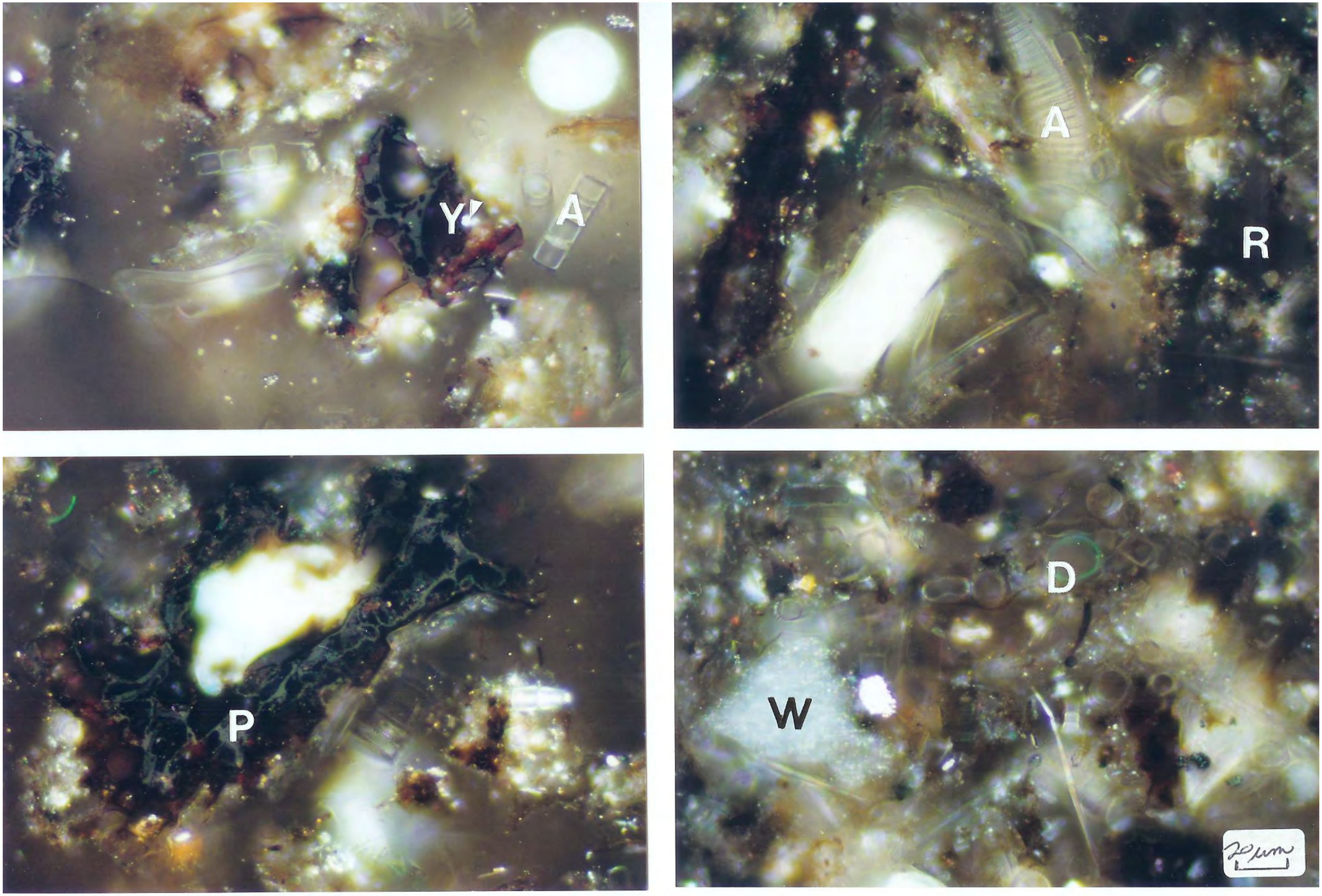


Figure 3: Photomicrographs of Stanford's Sample Labeled NLU-44 Showing; N=Individual QI, P=Cellular Organic Plant Material, R=Particulate Plant, D=Diatomaceous Mass, A=Diatom, W=White Grainy, O=Other Mineral Matter and Y=Pyrite. Reflected Light In Oil, X600.

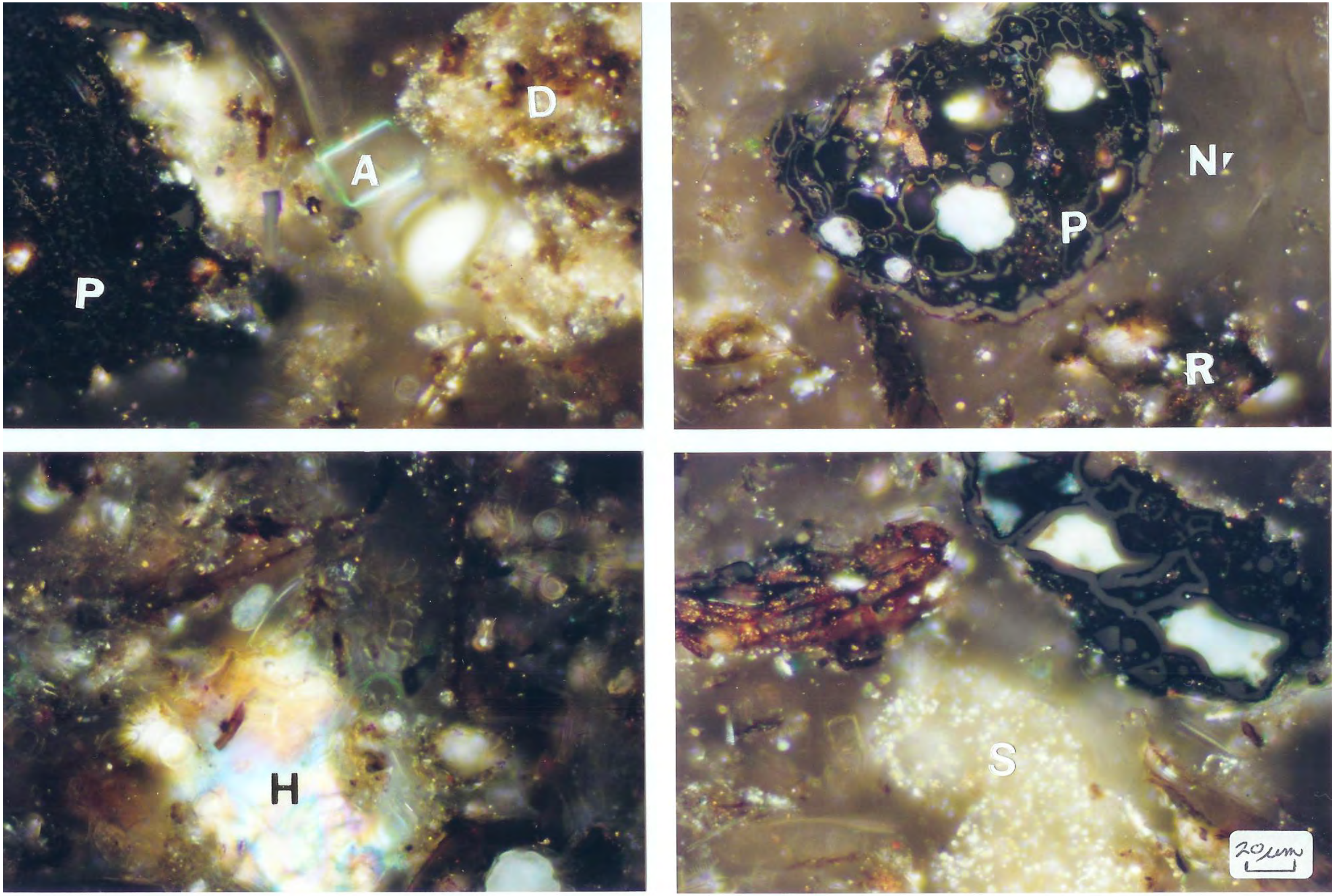


Figure 4: Photomicrographs of Stanford's Sample Labeled NLU-44 Showing; N=Individual QI, P=Cellular Organic Plant Material, R=Particulate Plant, D=Diatomaceous Mass, A=Diatom, S=Slag and H=Shell/Carbonates. Reflected Light In Oil, X600.

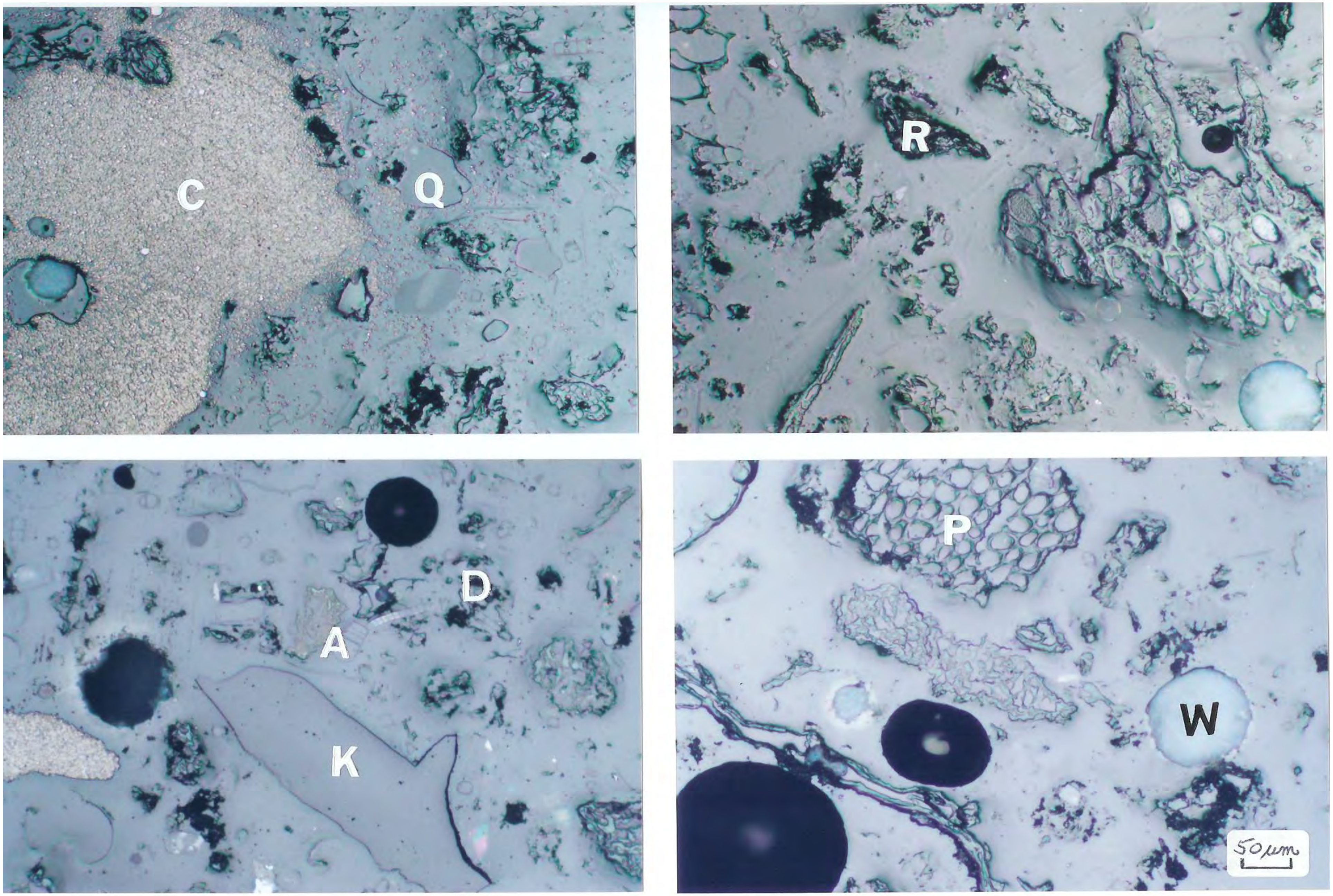


Figure 5: Photomicrographs of Stanford's Sample Labeled NLU-47 Showing; C=Carbon Black Aggregate, P=Cellular Organic Plant Material, R=Particulate Plant, K=Coal, Q=Quartz, D=Diatomaceous Mass, A=Diatom, W=White Grainy. Reflected Light In Air, X250.

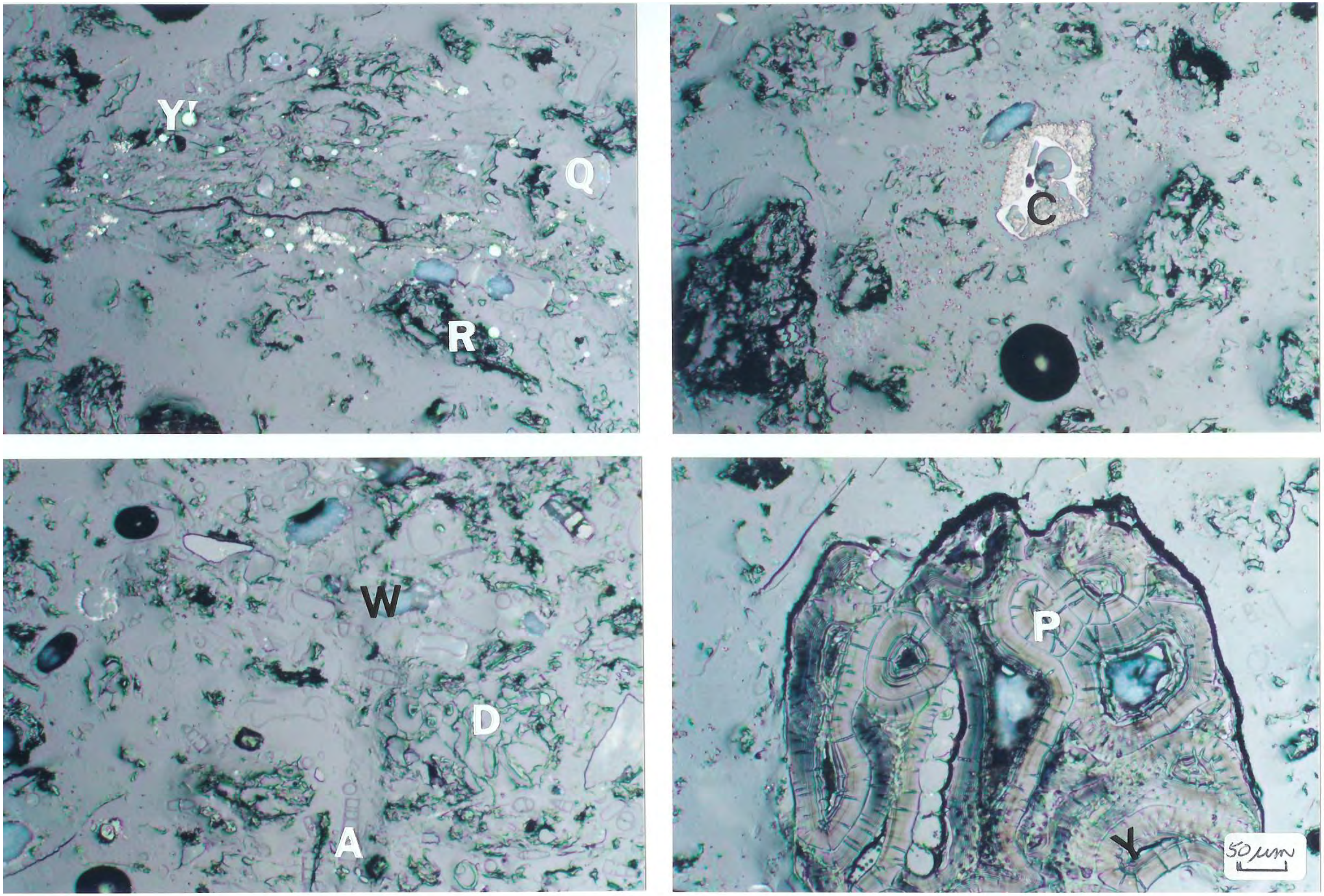


Figure 6: **Photomicrographs of Stanford's Sample Labeled NLU-47 Showing; C=Cenosphere in Carbon Black Aggregate, P=Cellular Organic Plant Material, R=Particulate Plant, Q=Quartz, D=Diatomaceous Mass, A=Diatom, W=White Grainy and Y=Pyrite. Reflected Light In Air, X250.**

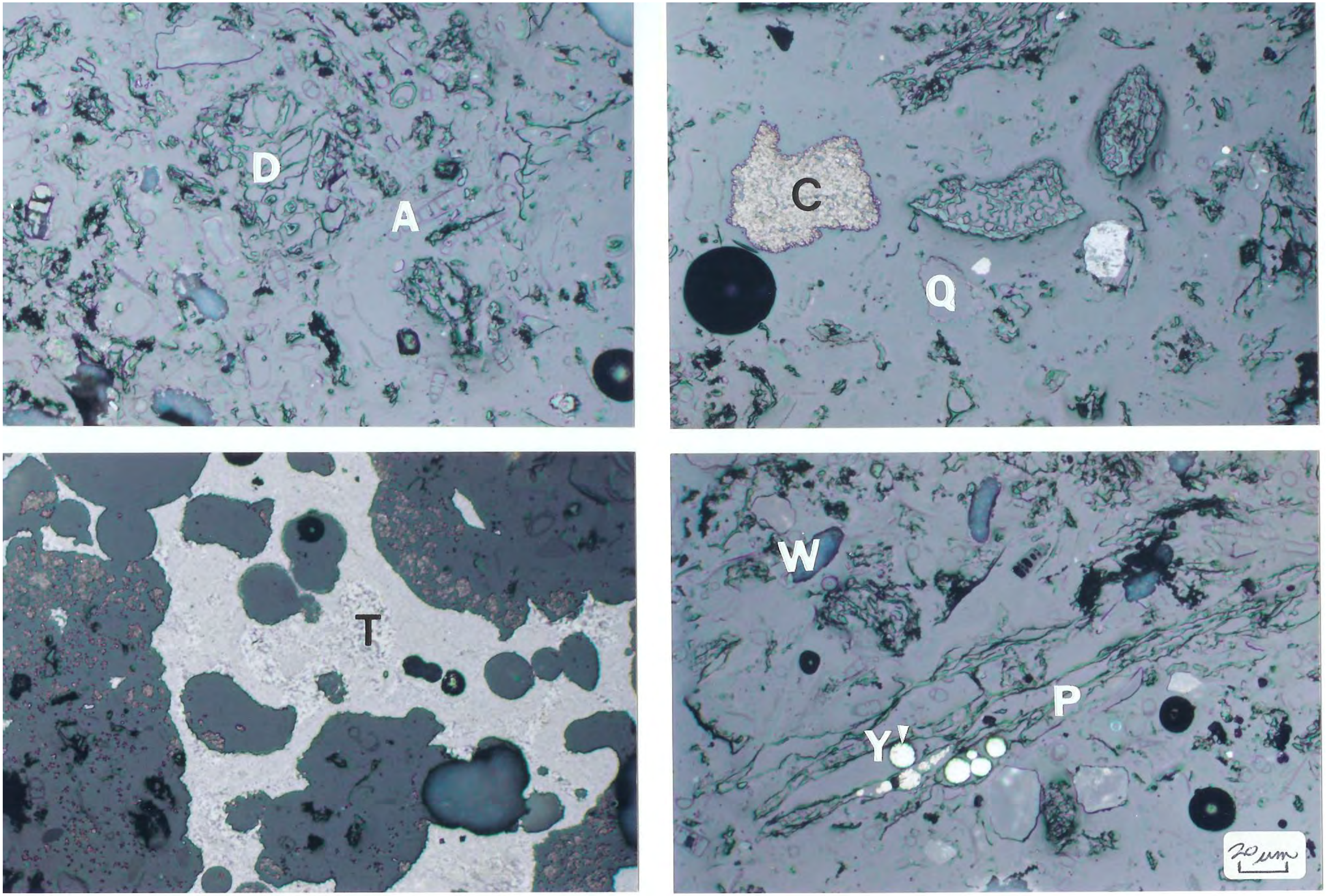


Figure 7: Photomicrographs of Stanford's Sample Labeled NLU-47 Showing; C=Carbon Black Aggregate, T=Pitch Coke, P=Cellular Organic Plant Material, R=Particulate Plant, Q=Quartz, D=Diatomaceous Mass, A=Diatom, W=White Grainy and Y=Pyrite. Reflected Light In Air, X600.

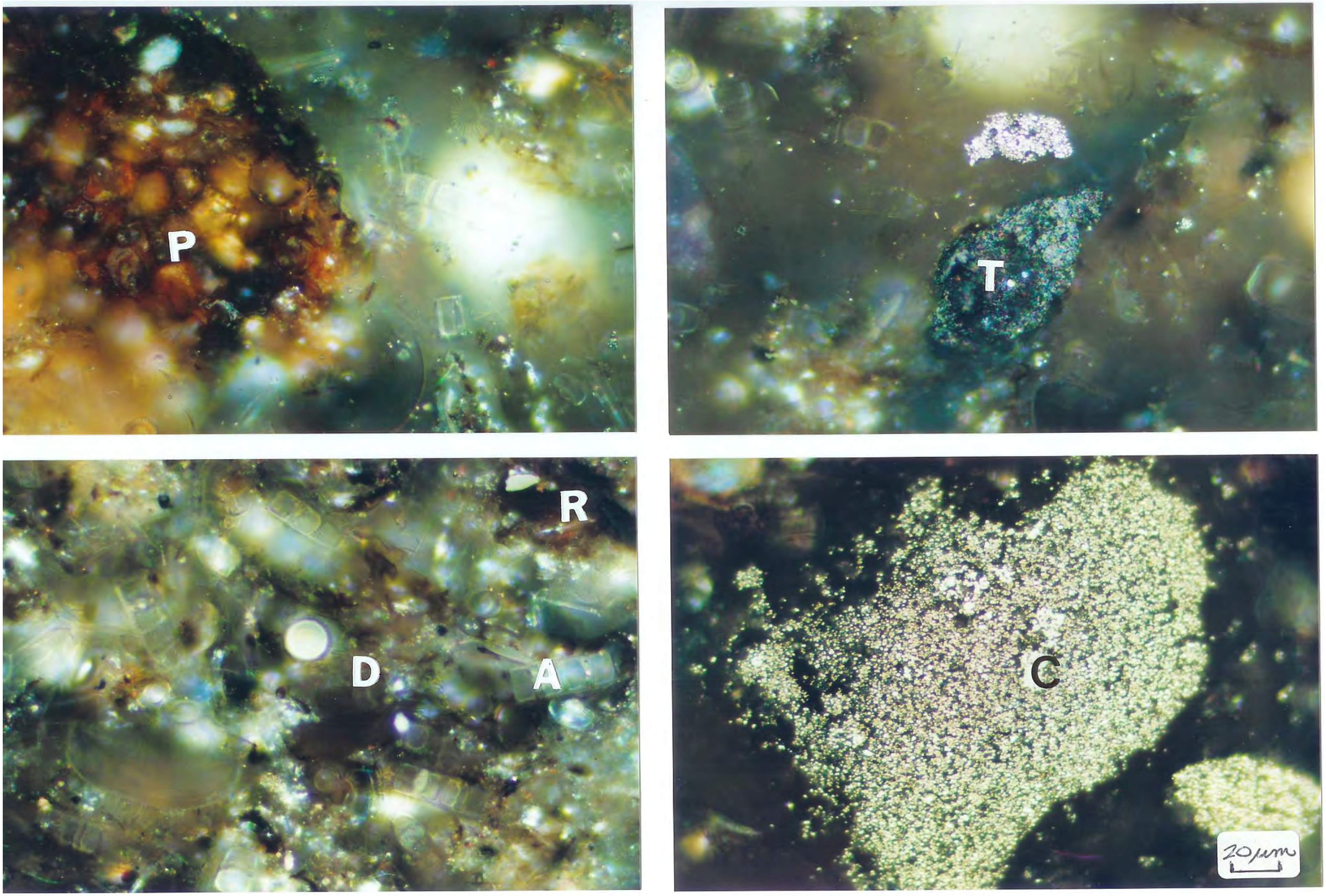


Figure 8: **Photomicrographs of Stanford's Sample Labeled NLU-47 Showing; C=Carbon Black Aggregate, T=Tar-Like, P=Cellular Organic Plant Material, R=Particulate Plant, D=Diatomaceous Mass and A=Diatom. Reflected Light In Oil, X600.**

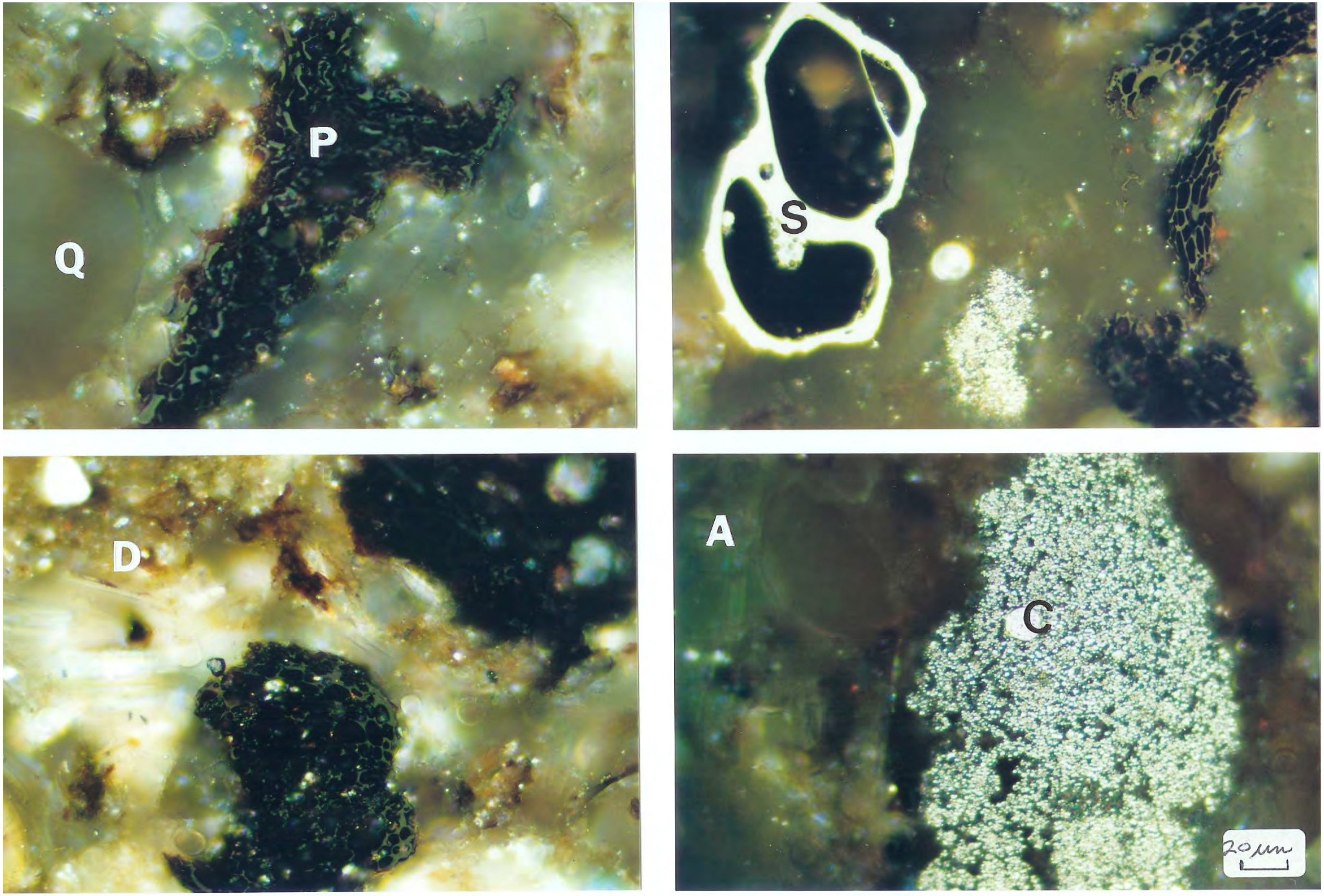


Figure 9: Photomicrographs of Stanford's Sample Labeled NLU-47 Showing; C=Carbon Black Aggregate, P=Cellular Organic Plant Material, R=Particulate Plant, S=Cenosphere, Q=Quartz, D=Diatomaceous Mass and A=Diatom. Reflected Light In Oil, X600.

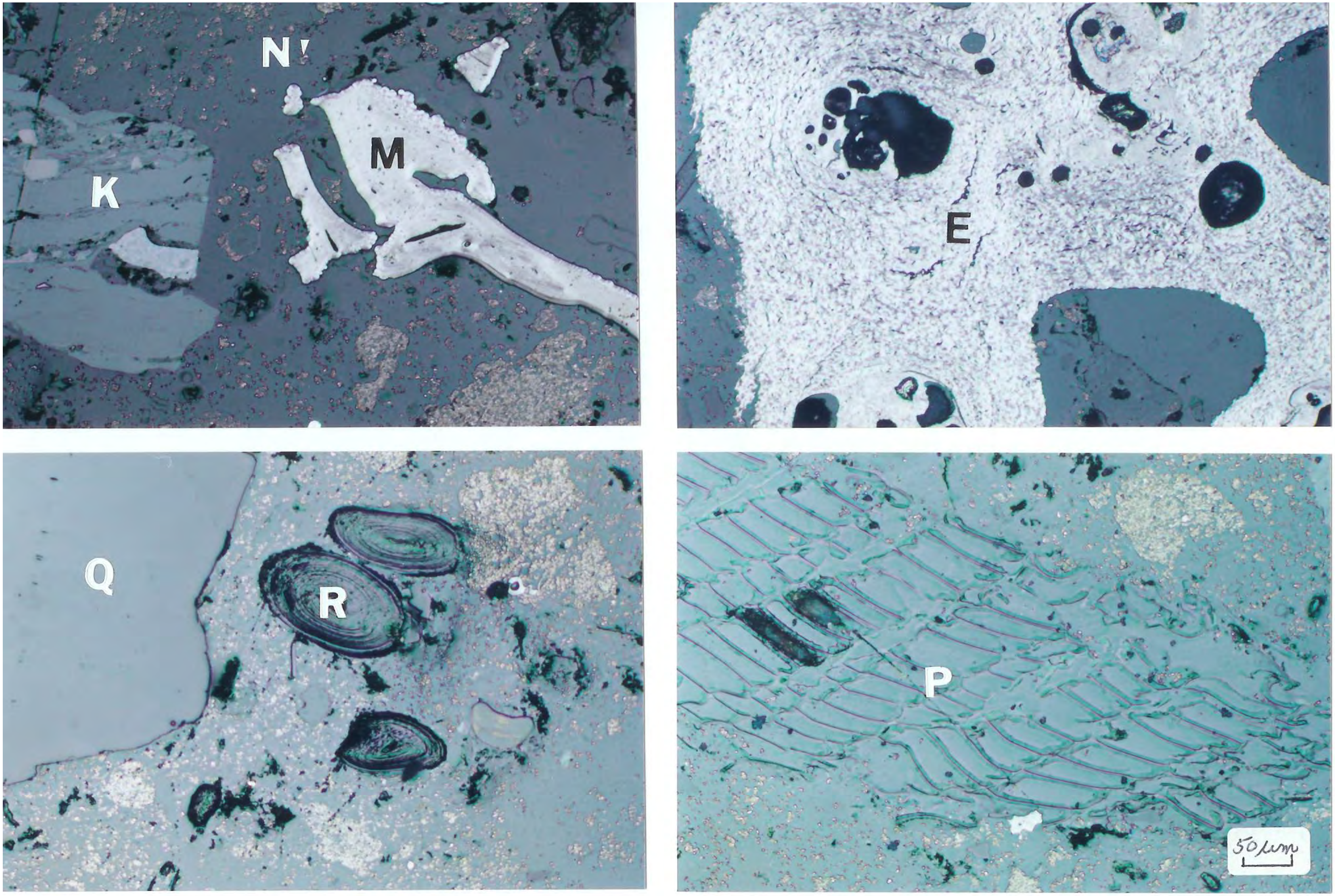


Figure 10: Photomicrographs of Stanford's Sample Labeled NLU-51 Showing; C=Carbon Black Aggregate, N=Individual QI, K=Coal, M=Metallurgical Coke, E=Petroleum Coke, P=Cellular Organic Plant Material, R=Particulate Plant and Q=Quartz. Reflected Light In Air, X250.

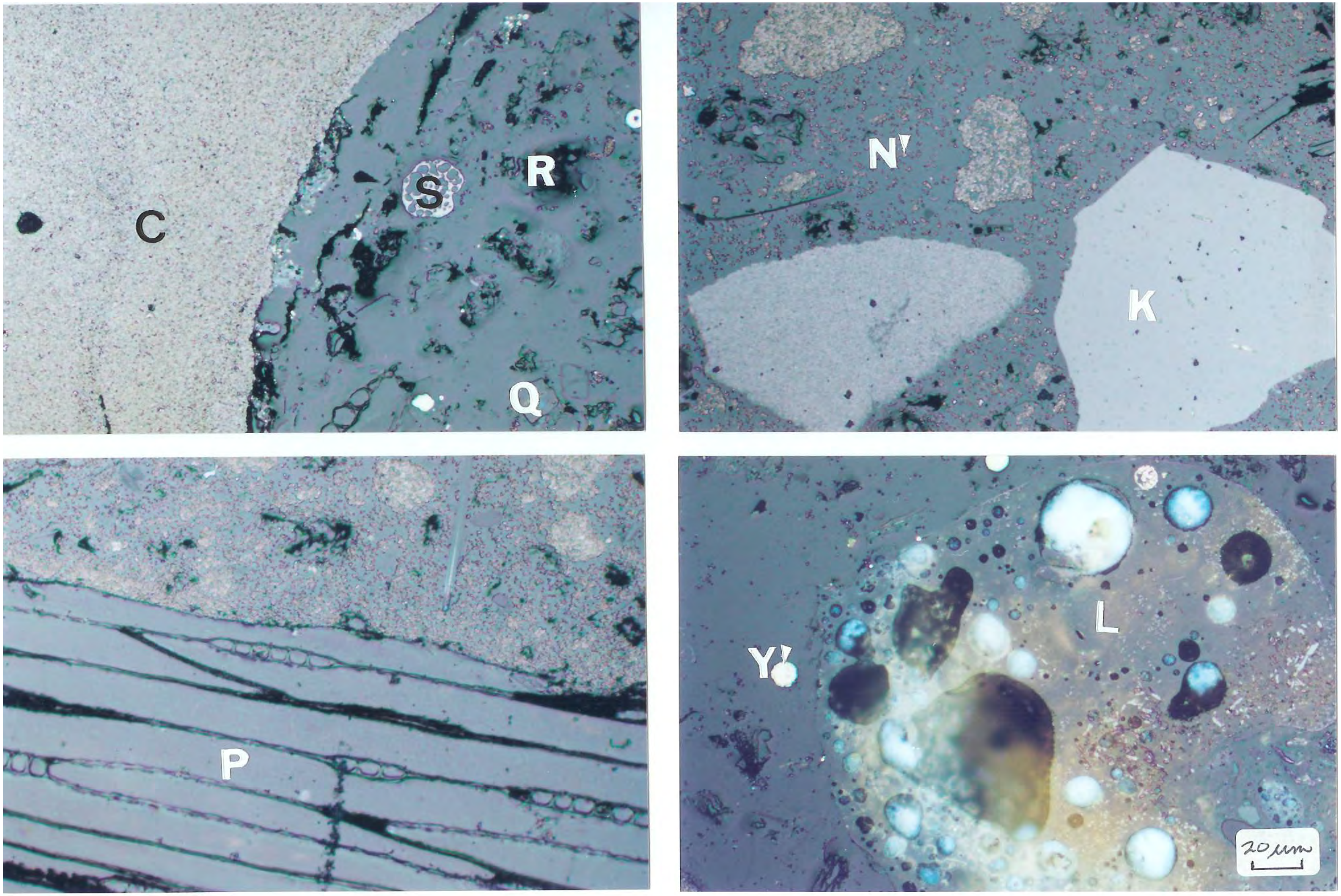


Figure 11: **Photomicrographs of Stanford's Sample Labeled NLU-51 Showing; C=Carbon Black Aggregate, N=Individual QI, K=Coal, S=Cenosphere, P=Cellular Organic Plant Material, R=Particulate Plant, L=Slag, Y=Pyrite and Q=Quartz. Reflected Light In Air, X600.**

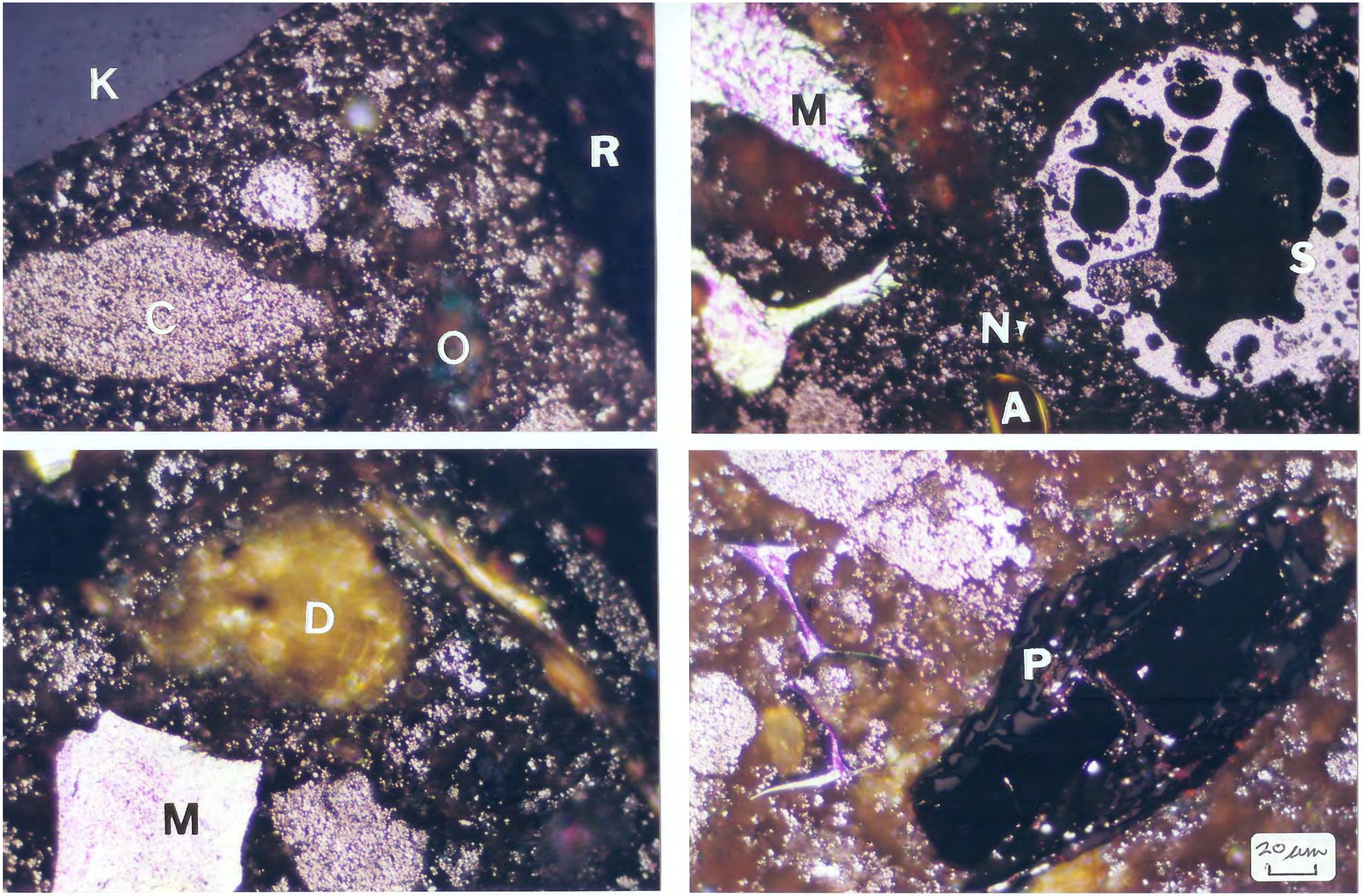


Figure 12: Photomicrographs of Stanford's Sample Labeled NLU-51 Showing; C=Carbon Black Aggregate, N=Individual QI, K=Coal, S=Cenosphere, M=Metallurgical Coke, P=Cellular Organic Plant Material, R=Particulate Plant, D=Diatomaceous Mass, A=Diatom and O=Other Mineral. Reflected Light In Oil, X600.

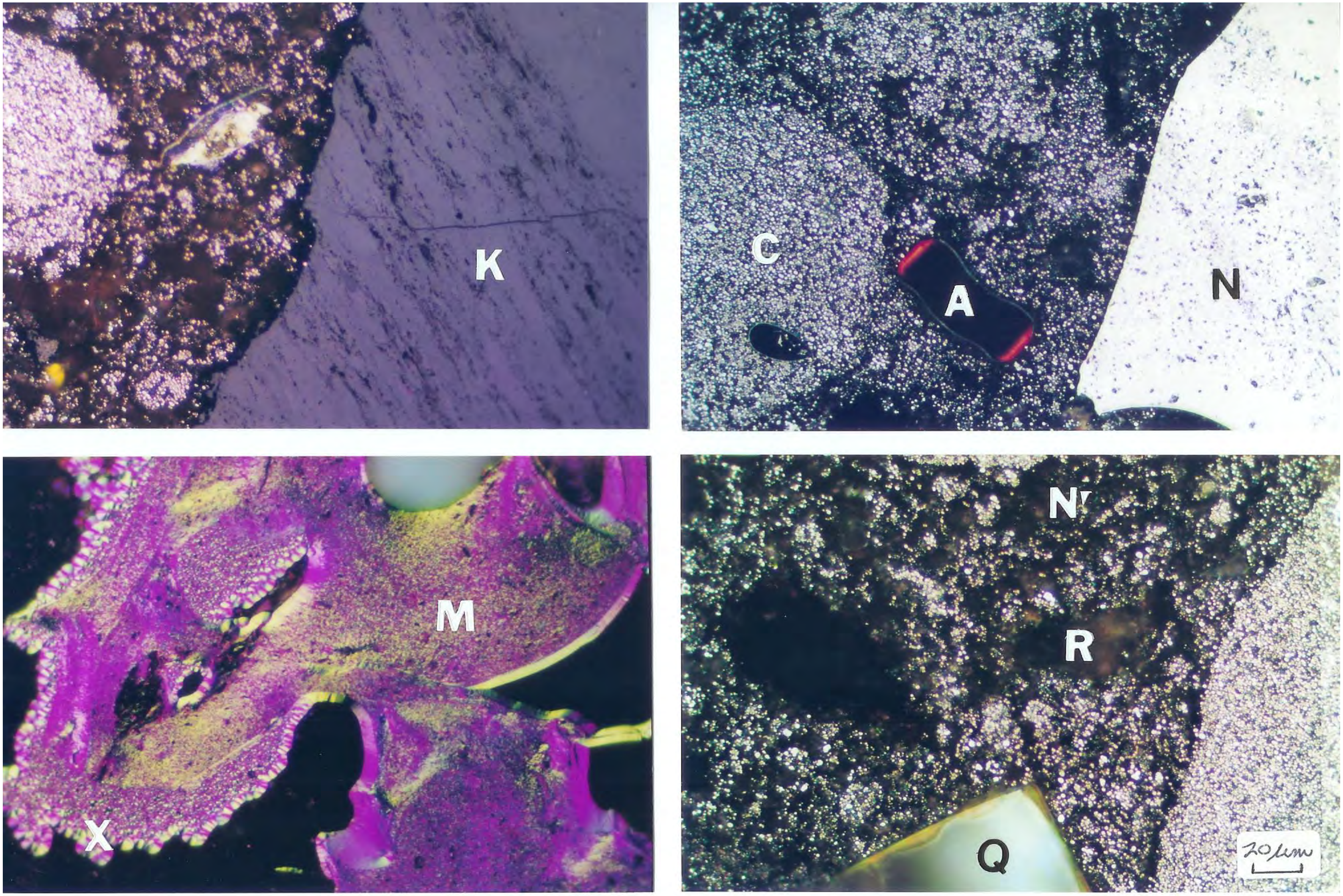


Figure 13: **Photomicrographs of Stanford's Sample Labeled NLU-51 Showing; C=Carbon Black Aggregate, N=Individual QI, K=Coal, M=Metallurgical Coke(pol), N=Metallurgical Coke(non-pol), X=Pyrolytic Carbon, R=Particulate Plant, A=Diatom and Q=Quartz. Reflected Light In Oil, X600.**

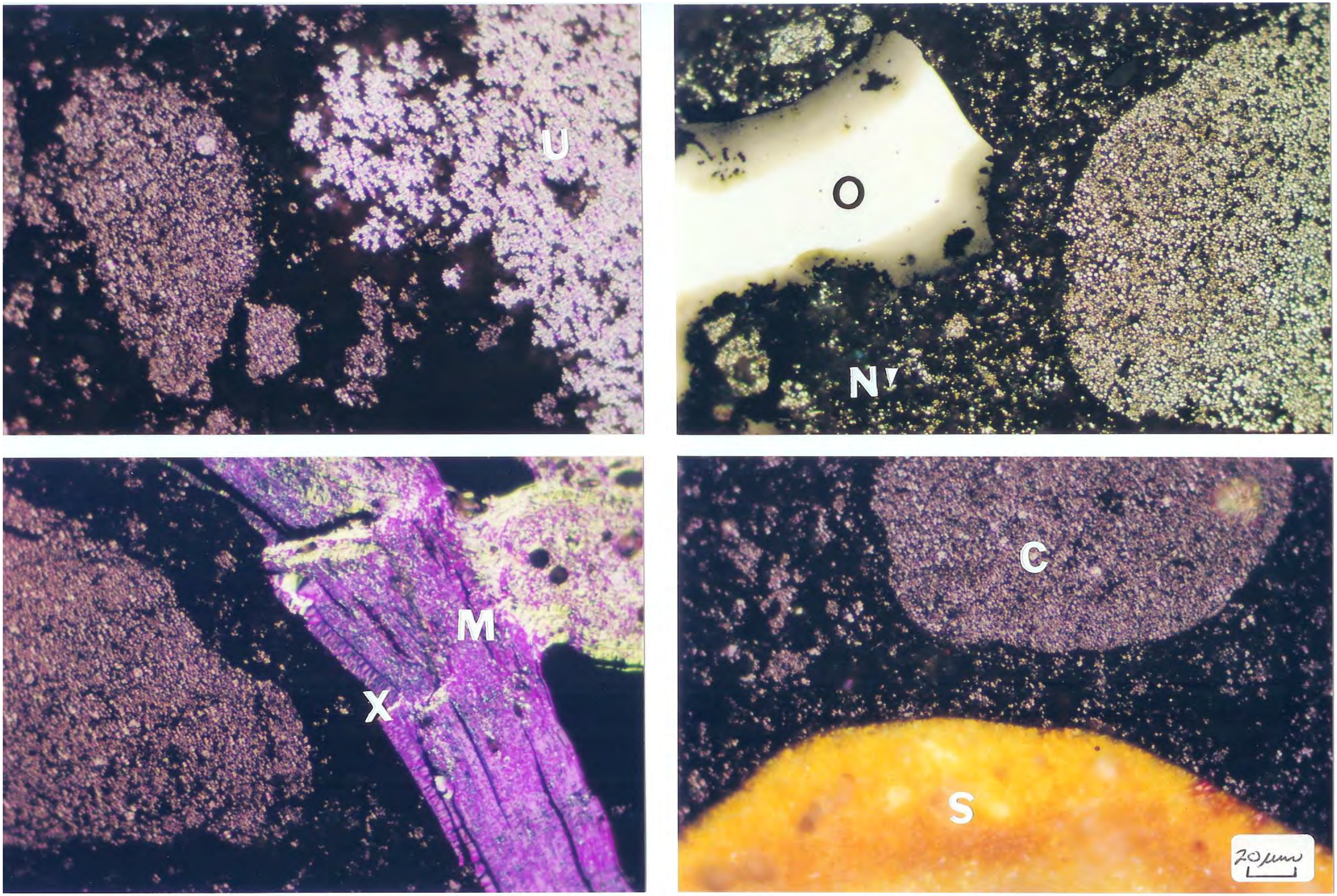


Figure 14: Photomicrographs of Stanford's Sample Labeled NLU-51 Showing; C=Carbon Black Aggregate, N=Individual QI, M=Metallurgical Coke(pol), U=Spherulytic Carbon, X=Pyrolytic Carbon, O=Oxidized Coke and L=Slag. Reflected Light In Oil, X600.

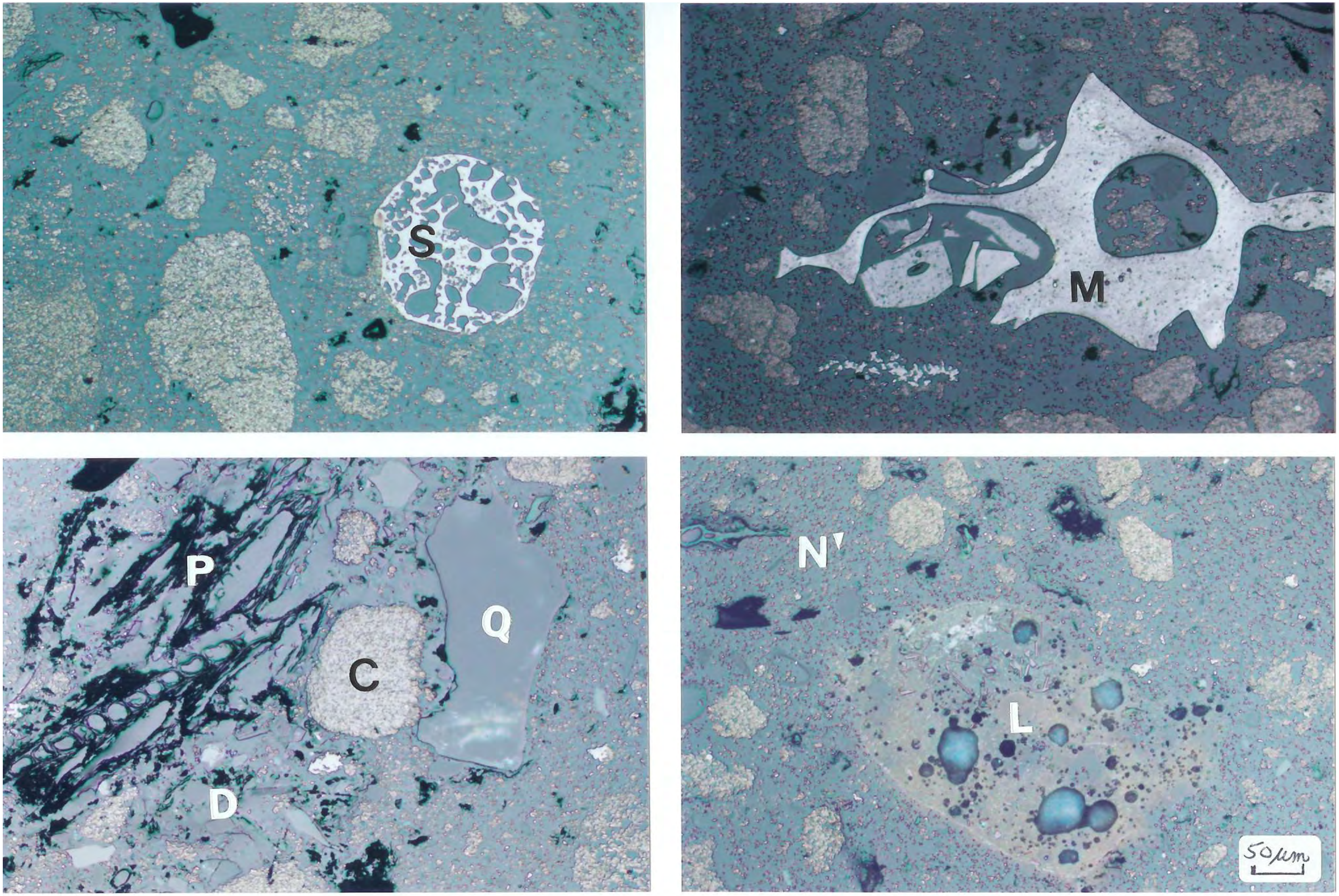
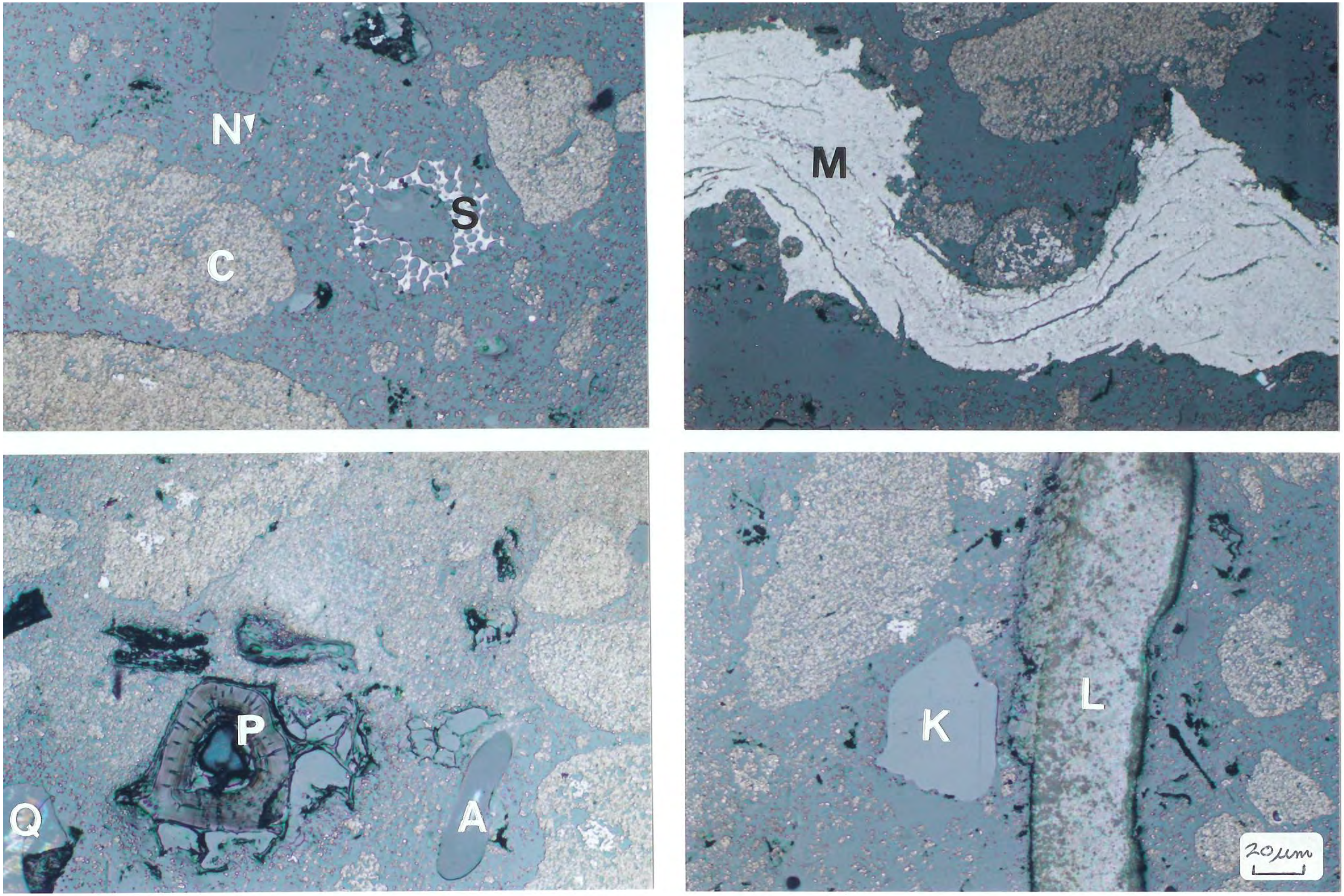


Figure 15: Photomicrographs of Stanford's Sample Labeled NLU-56 Showing; C=Carbon Black Aggregate, N=Individual QI, S=Cenosphere, M=Metallurgical Coke, P=Cellular Organic Plant Material, D=Diatomaceous Mass, Q=Quartz and L=Slag. Reflected Light In Air, X250.



<u>Figure 16:</u> Photomicrographs of Stanford's Sample Labeled NLU-56 Showing; C=Carbon Black Aggregate, N=Individual QI, K=Coal, S=Cenosphere, M=Metallurgical Coke, P=Cellular Organic Plant Material, A=Diatom, Quartz and L=Slag. Reflected Light In Air, X600.

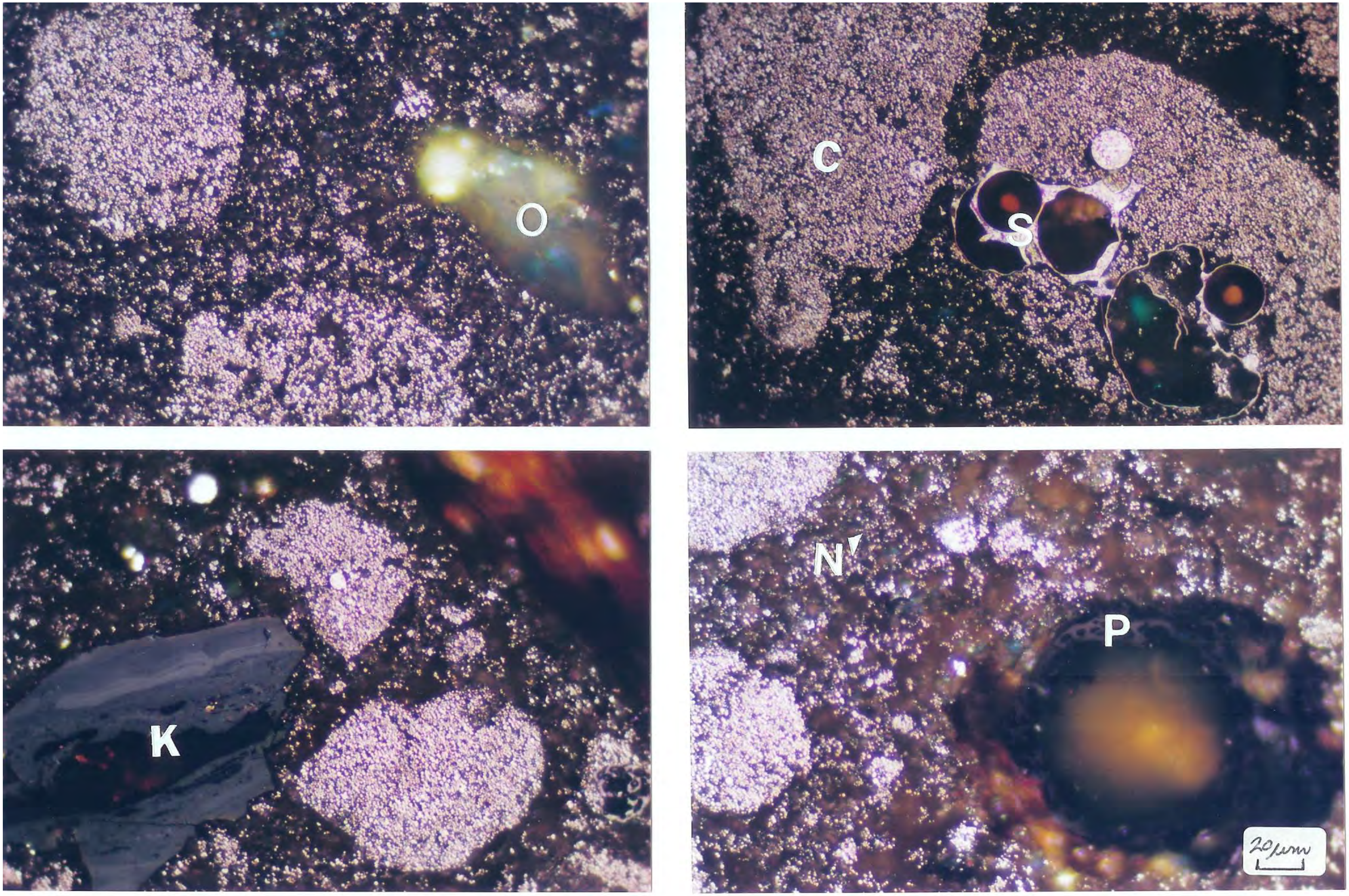


Figure 17: Photomicrographs of Stanford's Sample Labeled NLU-56 Showing; C=Carbon Black Aggregate, N=Individual QI, K=Coal, S=Cenosphere, P=Cellular Organic Plant Material and O=Other Mineral. Reflected Light In Oil, X600.

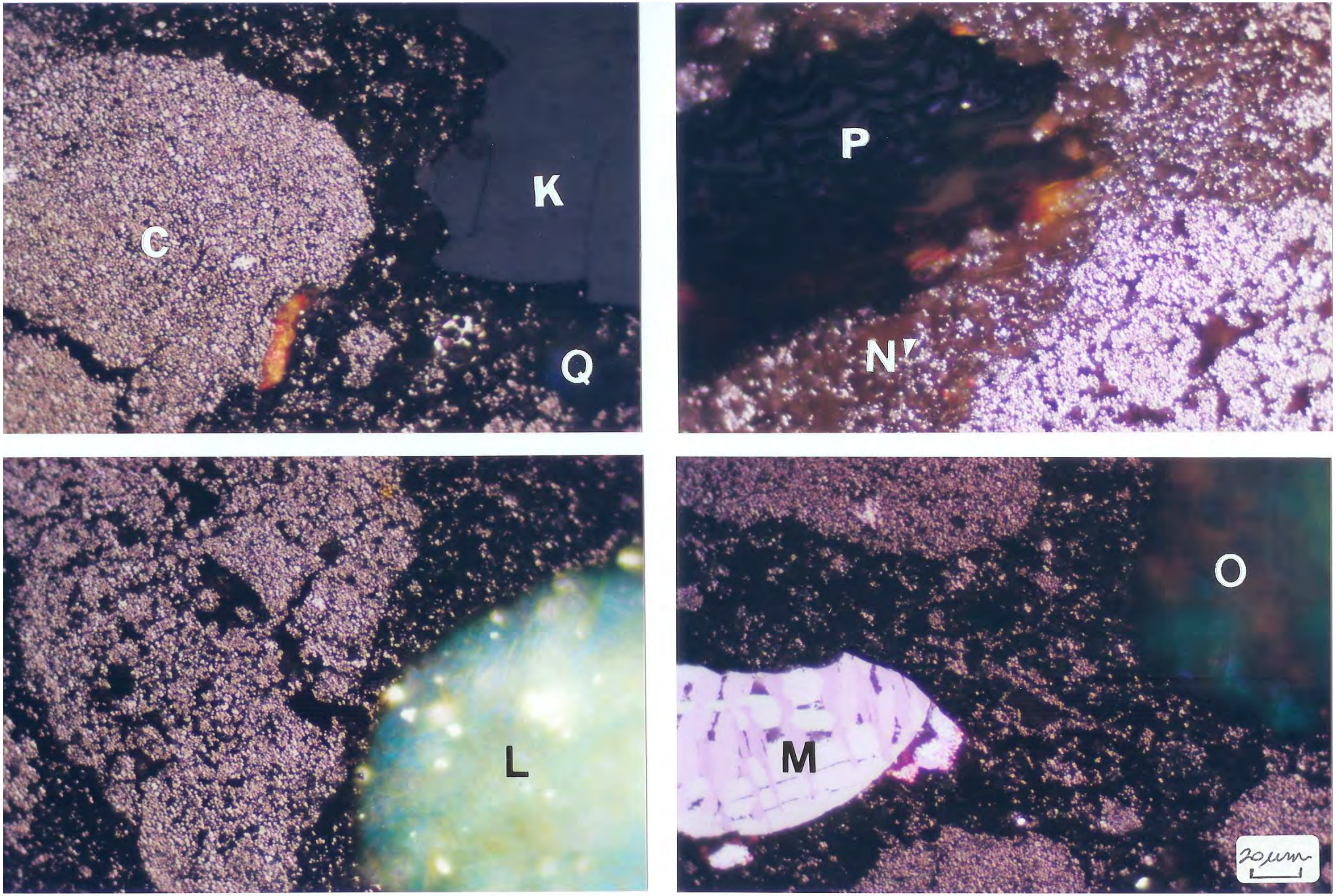


Figure 18: Photomicrographs of Stanford's Sample Labeled NLU-56 Showing; C=Carbon Black Aggregate, N=Individual QI, K=Coal, P=Cellular Organic Plant Material, L=Slag, Q=Quartz, O=Other Mineral and M=Metallic. Reflected Light In Oil, X600.

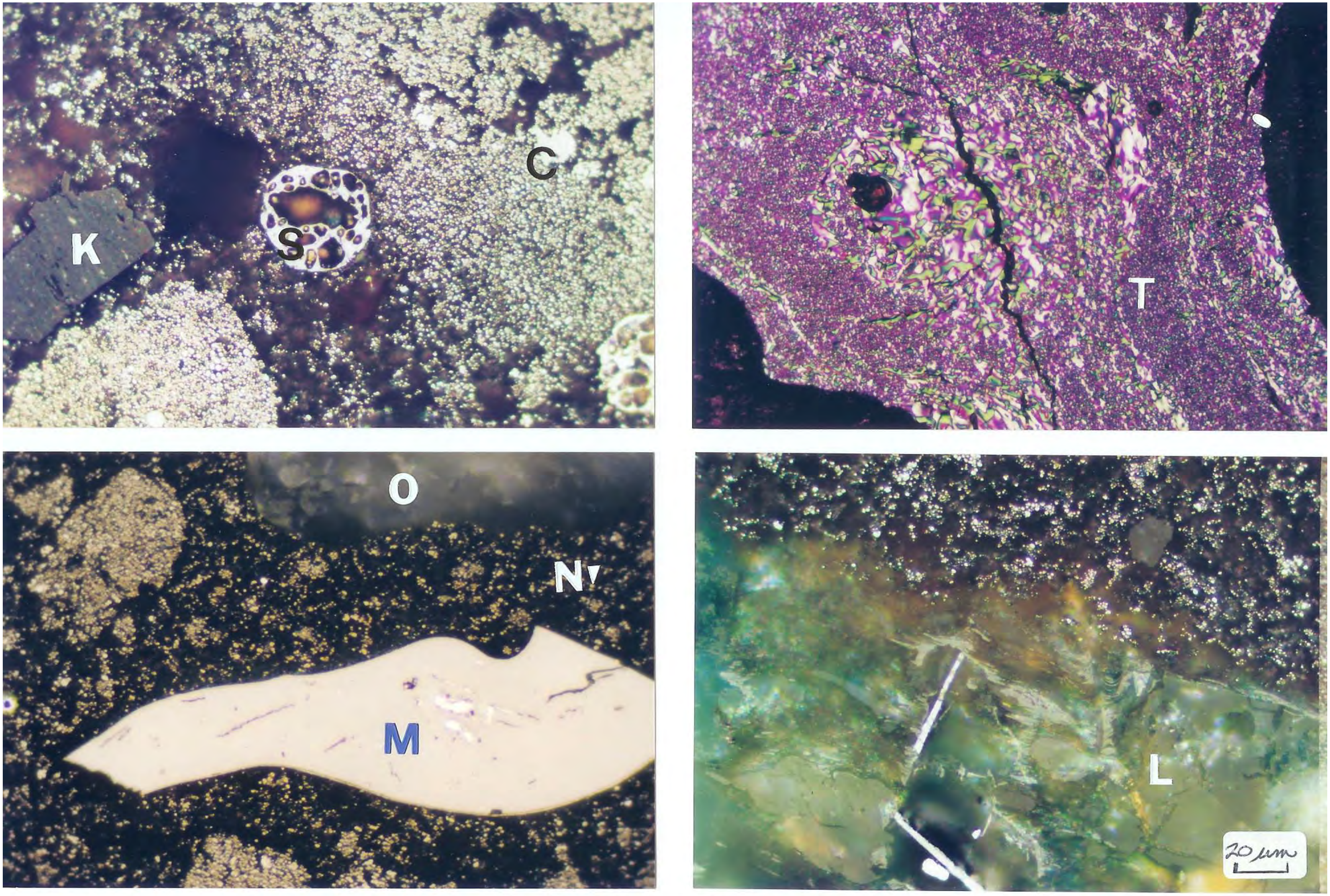


Figure 19: **Photomicrographs of Stanford's Sample Labeled NLU-56 Showing; C=Carbon Black Aggregate, N=Individual QI, K=Coal, T=Pitch Coke, M=Metallurgical Coke, S=Cenosphere, R=Particulate Plant, L=Slag and O=Other Mineral. Reflected Light In Oil, X600.**

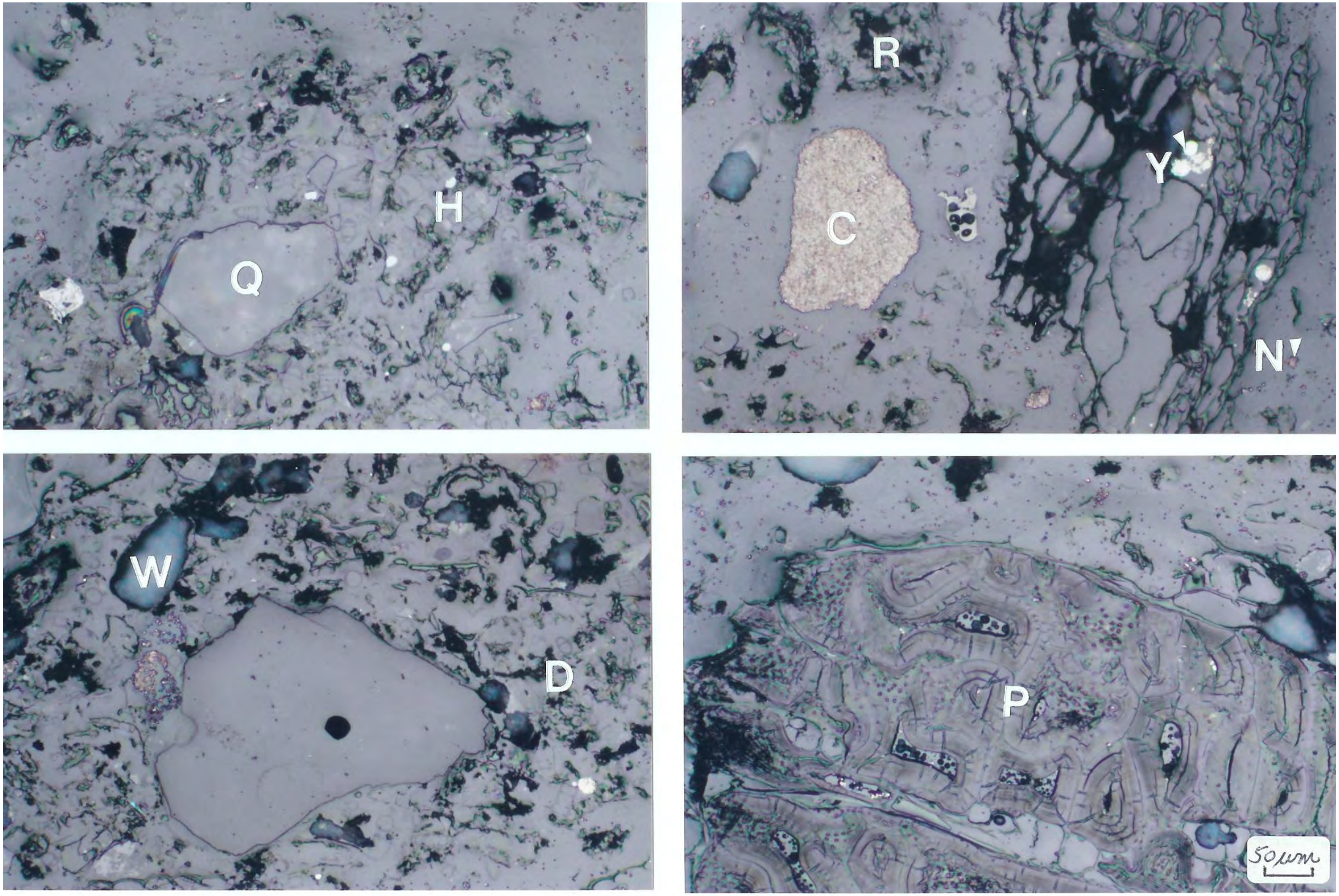


Figure 20: Photomicrographs of Stanford's Sample Labeled NLU-64 Showing; C=Carbon Black Aggregate, N=Individual QI, S=Cenosphere, P=Cellular Organic Plant Material, R=Particulate Plant, D=Diatomaceous Mass, Y=Pyrite, Q=Quartz and White Grainy. Reflected Light In Air, X250.

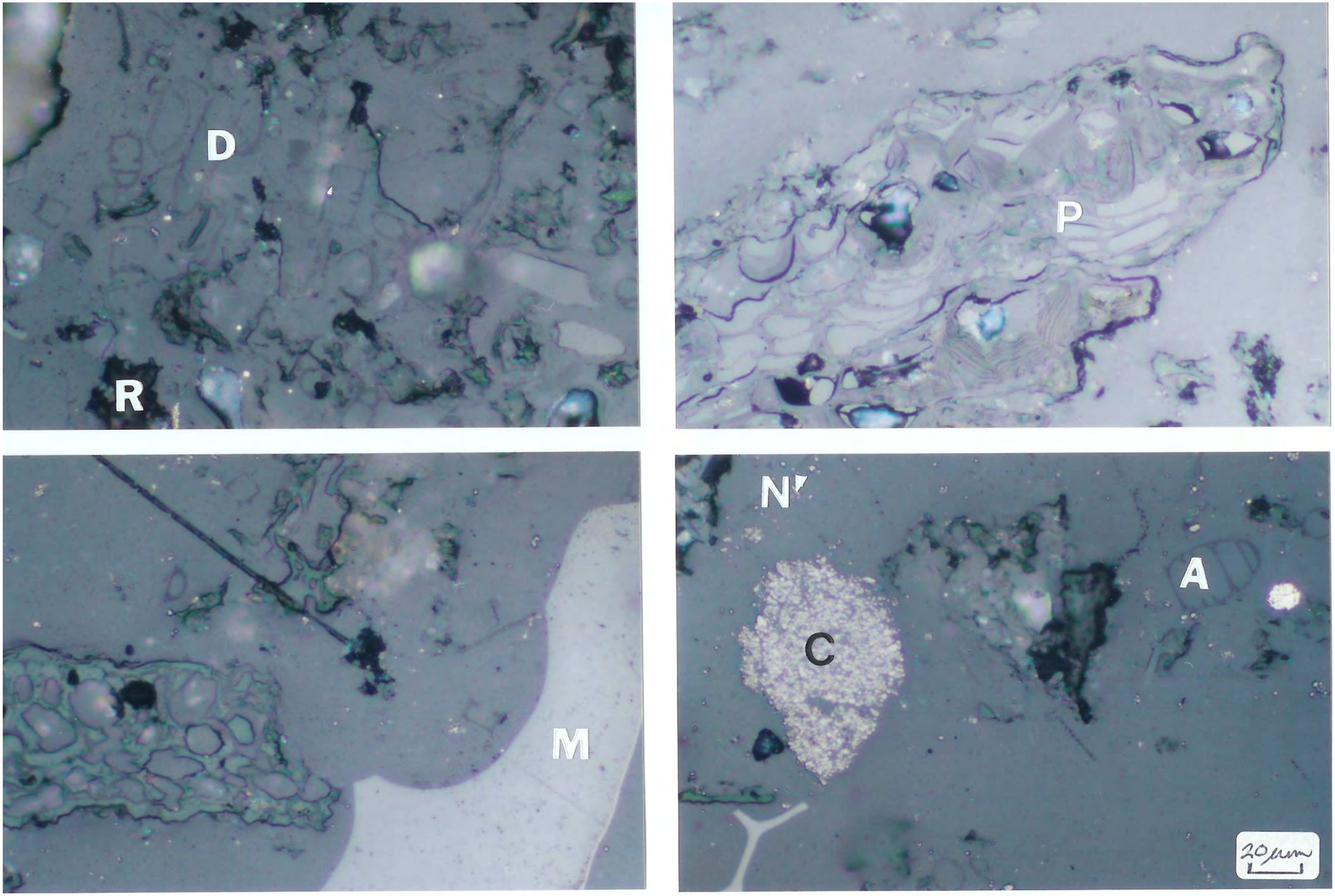


Figure 21: **Photomicrographs of Stanford's Sample Labeled NLU-64 Showing; C=Carbon Black Aggregate, N=Individual QI, M=Metallurgical Coke, P=Cellular Organic Plant Material, R=Particulate Plant, D=Diatomaceous Mass, A=Diatom and Y=Pyrite. Reflected Light In Air, X600.**

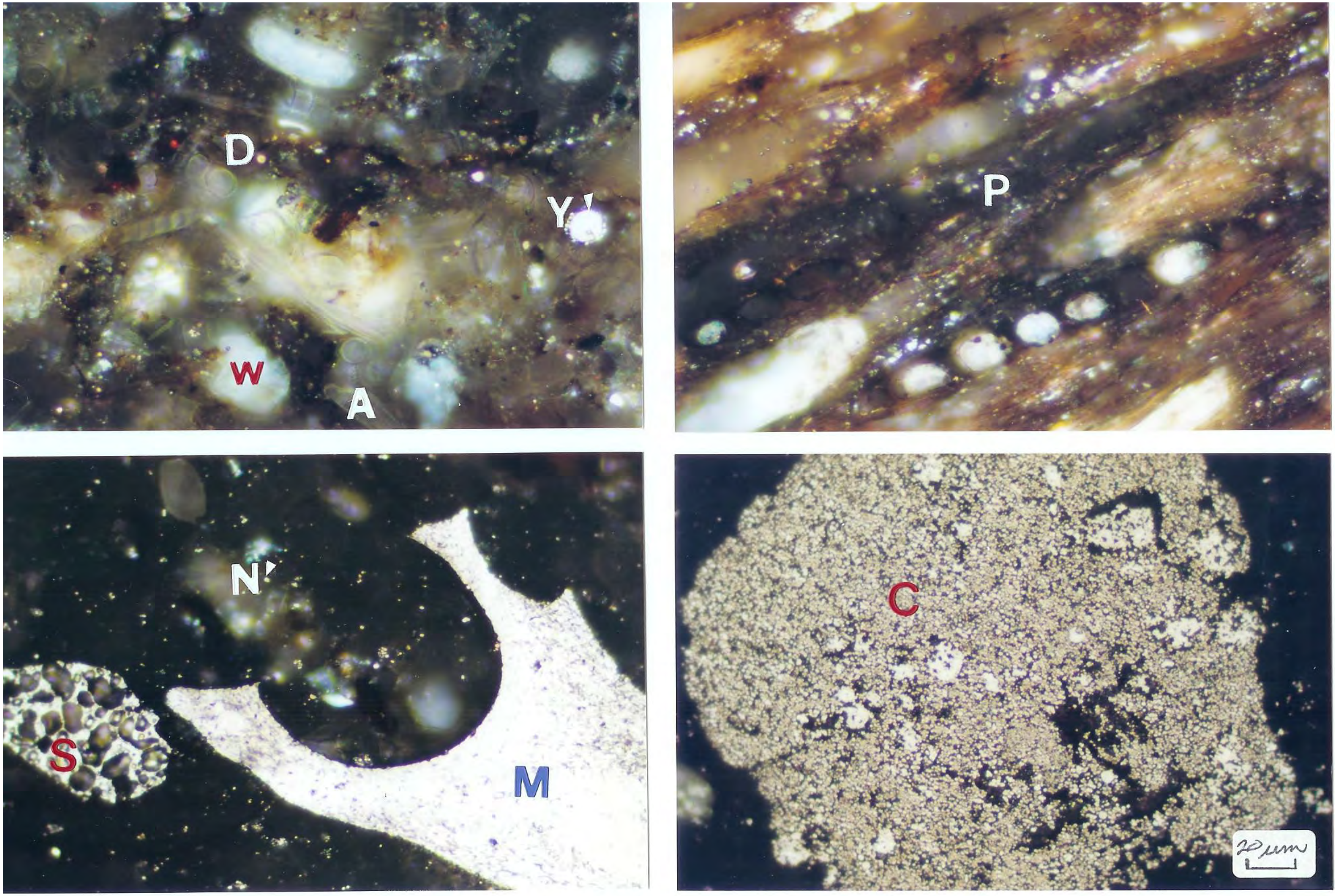


Figure 22: Photomicrographs of Stanford's Sample Labeled NLU-64 Showing; C=Carbon Black Aggregate, N=Individual QI, M=Metallurgical Coke, S=Cenosphere P=Cellular Organic Plant Material, D=Diatomaceous Mass, A=Diatom, W=White Grainy and Y=Pyrite. Reflected Light In Oil, X600.

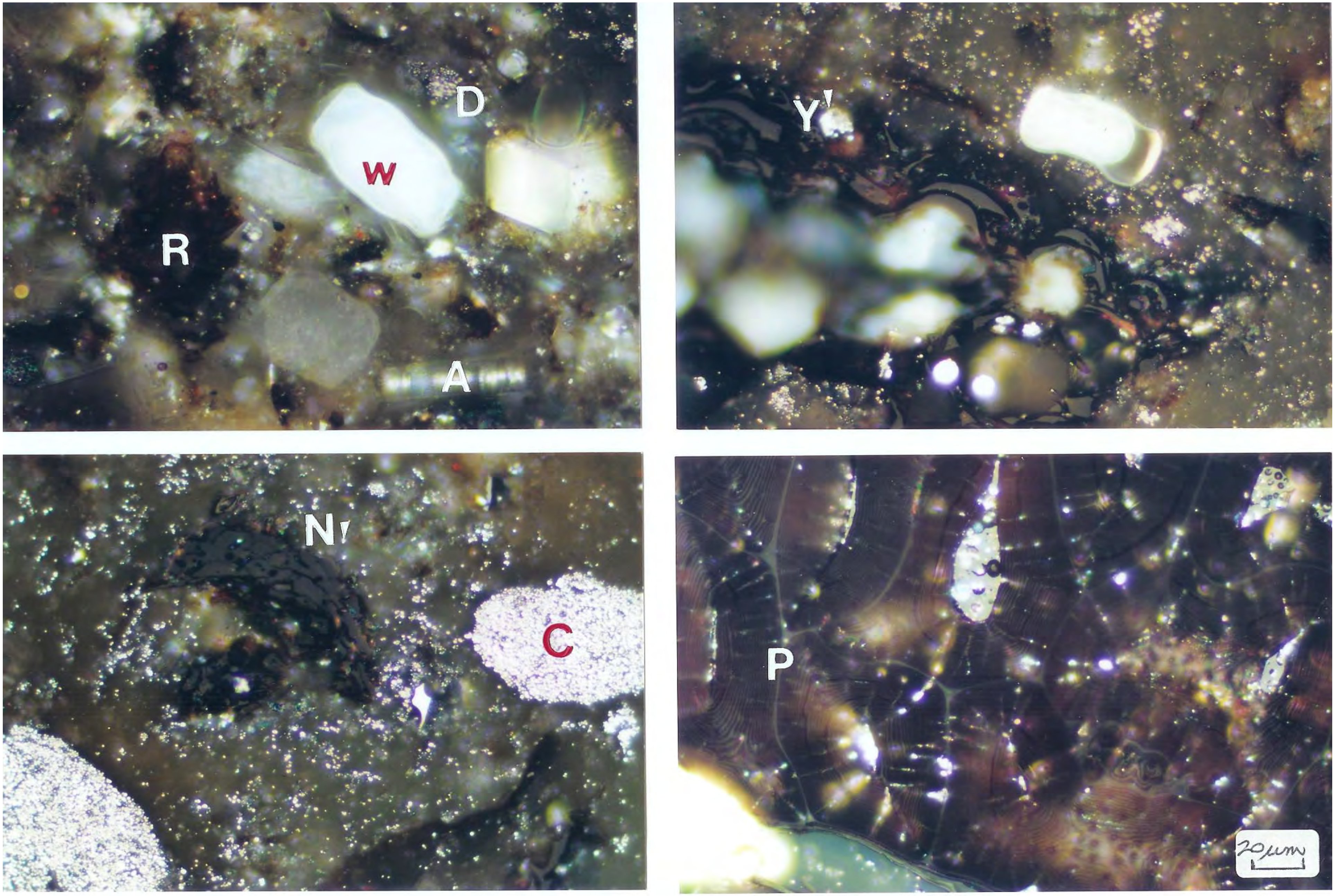


Figure 23: Photomicrographs of Stanford's Sample Labeled NLU-64 Showing; C=Carbon Black Aggregate, N=Individual QI, P=Cellular Organic Plant Material, R=Particulate Plant, D=Diatomaceous Mass, A=Diatom, W=White Grainy and Y=Pyrite. Reflected Light In Oil, X600.

R & D CARBON PETROGRAPHY
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June 8, 2005

Ms. Lei Hong
Stanford University
Civil and Environmental Engineering
380 Panama Mall Terman Engineering, B15
Stanford, CA 94305-4020

Dear Ms. Hong;

Your Purchase Order Number 14716290 of May 11, 2005 requested petrographic analysis for three samples of sediment material. The samples are identified and described as follows:

R & D NO.	***DESCRIPTION***
1124	NLU – 58
1125	NLU – 62
1126	NLU – 68-51

The solids from the three sediment samples were prepared for petrographic analysis and photographed at 250X in air and at 600X in oil with reflected light. A total of 1000 points were counted for composition. The materials were separated into four main categories which consist of carbon, organic plant material, diatoms and mineral matter. Each category is further subdivided into more specific materials.

The submicron carbon forms consist of carbon with one or two probable origins. Carbon black is a solid product of incomplete combustion. It has many commercial uses including filler in tires. In contrast QI or quinoline insolubles occur as solids in coal tar/pitch. In by-product coking the material from incomplete coal combustion and vapor phase cracking occur colloidally dispersed in the tar/pitch that are collected as by-products of carbonization. In the current work these materials are described as dense or loose aggregate, individual QI, green or less coked aggregates and very dark mattes. The related material is described as pitch, tar-like and pitch coke. Cenospheres are counted separately. They are produced when coal is heated rapidly in an unconfined condition. The rapidly heated coal becomes plastic and the internally trapped gases expand to produce very porous commonly spherical bodies of coke. Depositional carbon may be spherulitic or pyrolytic. Liquid distillation products of coal may crack to form spherulitic carbons. The high hydrogen gaseous materials from coal carbonization form pyrolytic carbon. Some red protein material may be from bacteria used to clarify or treat water in coke plants. We’ll refer to it as bug plant residue.

The organic plant material in the samples are described in terms of there degree of preservation. The portion that displays the cellular structure is counted separately from the portion that is degraded and occurs as particulate and less ordered plant structures. Much of this material that occurs in sediments and sedimentary rocks are described as kerogen. Charcoal from incompletely combusted wood also occurs in sediments and soil and when it occurs in coal it is called fusain.

Diatoms are unicellular organisms that have a variety of shapes and forms that form planktonic colonies. These plant forms are capable of photosynthesis. They contain skeletons called frustules consisting of two valves that fit together like a box. These internal skeletons consist of pure silica which has very minute fine cellular microstructures. The fossils or skeletons of diatoms have a wide variety of uses as fillers, filtering materials and from a scientific standpoint there sensitivity to temperatures and water depth are good indicators of there habitat. Some of the material that we refer to as mattes maybe associated due to specific gravity separation rather than due to natural occurrences.

The identifiable mineral matter consist of quartz SiO_2, a variety of carbonates including shells, pyrite FeS_2, brown grainy aggregates, white grainy materials, slag, metallics and other minerals. The brown stains on materials may be from humic sources. The slag is thermally altered mineral matter that has a variety of forms and shapes and ranges from glassy to crystalline. Most of the pyrite that occurs is associates with the plant material and occurs as framboids consisting of small circular aggregates of crystals. These forms are usually indicators of brackish water conditions.

In the current work we use the terms metallurgical coke and by-product coking to separate coal based coking processes from those that are based on petroleum residuals.

Stanford Sample – NLU - 58

The Stanford sample labeled NLU-58 has 12.6% by volume of total carbon. The most abundant carbon related materials are aggregates which make up 7.4% of the sample and consist of 4.3% dense aggregates, with 1.0% of loose aggregates and 2.1% of small aggregates and individual QI. The dense aggregates appear to be coked and have seen a higher degree of carbonization. Also, some of the dense aggregates appear as spherulitic carbon which is a product of vapor and gas phase cracking and the individual spherical particles are larger than those that are produced from incomplete combustion. There is 2.2% of coal tar-like or pitch related material which is the next most abundant carbon followed by 1.4% of metallurgical coke, 0.8% of coal and a small amount of depositional carbon and cenospheres. There is 27.1% of total organic plant material which is made up of 8.2% with cellular structure and 18.9% of particulate plant material. Many of the earlier samples and current samples contain spores and pollen which are the reproductive organs of plants. These materials have been included in the particulate plant material. The most abundant material in this sample is diatomaceous material which totals 52.3%. The diatom related materials consist of 16.2% of individual siliceous diatoms, with 33.4% of diatomaceous mattes and 2.7% of diatoms with mineral matter. The mattes consist of translucent and transparent siliceous materials which may or may not contain the diatom skeletons. There is 8.0% of total mineral matter which consists mostly of other mineral matter 3.1% that is not identified and 1.9% of pyrite with lesser amounts of white grainy mineral, brown grainy aggregates, quartz, carbonates and slag. The petrographic composition data is listed in Table 1 and most of the materials are illustrated in Figures 1 through 4.

The organic plant material, diatomaceous material and mineral matter make up the majority of this sample and total 87.4% by volume. The remainder of the material is carbon (12.6%) which consists of aggregates of carbon black, Normal QI, pitch-related material, coal and coke.

Stanford Sample – NLU - 62

The Stanford sample labeled NLU-62 has 15.0% by volume of total carbon. The most abundant carbon related material is carbon aggregates which makes up 8.7% of the sample and consists of 3.4% dense aggregates, with 3.7% of loose aggregates and 1.6% of small aggregates and individual QI. There is 3.5% of coal which is the next most abundant coarse carbon and lesser amounts of the other various coal and coke related carbons such as tar/pitch, pitch coke, cenospheres, metallurgical coke, spherulitic carbon and bug plant residue. The residue may be from biological water treatment. There is 31.2% of total organic plant material which consists of 8.4% with cellular structure and 22.8% of particulate plant material. The most abundant material in this sample is diatomaceous material which totals 43.6%. The diatom related material consists of 11.4% of individual siliceous diatoms, with 31.0% of diatomaceous mattes and 1.2% of diatom with mineral matter. There is 10.0% by volume of total mineral matter which consists mostly of pyrite 4.2% with 1.8% of other mineral matter that is not identified, 1.6% of white grainy mineral and lesser amounts of carbonates, quartz, brown grainy aggregates, metallics and slag. The pyrite is mostly framboidal and is generally associated with plant material. The petrographic composition data is listed in Table 1 and most of the materials are illustrated in Figures 5 through 8.

The organic plant material, diatomaceous material and mineral matter make up the majority of this sample and total 84.8% by volume. The remainder of the material is carbon (15.2%) which consists of aggregates of carbon black, Normal QI, coal, pitch-related material and coke.

Stanford Sample – NLU – 68-51

The Stanford sample labeled NLU-68-51 has 73.4% of total carbon by volume. It is very different than the other samples in this group in that it contains a large amount of coarse carbons such as metallurgical coke, coal and carbon aggregates. The most abundant material is the aggregates of carbon black, Normal QI materials 24.6% followed by metallurgical coke and oxidized coke 22.4% and coal 11.2% and charcoal 2.4%. The carbon aggregates consist mostly of dense aggregates 14.2%, with 6.2% of loose aggregates, 4.2% of small aggregates and individual QI and a small amount 0.6% of very dark QI matt. The balance of the material is coal and coke related. There is 3.0% of pitch/tar, with 1.6% of pitch coke, 0.8% of depositional carbon, 0.4% of cenospheres and 6.4% of bug plant residue. The residue may be from biological water treatment. There is 10.2% of total organic plant material which consists of 7.4% with cellular structure and 2.8% of particulate plant material. There is 7.0% of total diatomaceous material which consists of 4.2% of individual siliceous diatoms, with 2.0% of diatomaceous mattes and 0.8% of diatom with mineral matter. There is 9.4% of total mineral matter which consists mostly of slag 5.8% with lesser amounts of the white grainy mineral, other mineral matter that is not identified, carbonates, pyrite and metallics. The petrographic composition data is listed in Table 1 and most of the materials are illustrated in Figures 9 through 13.

The NLU-68-51 sediment sample has the most and widest variety of carbons in the current group of samples most of which are coarse carbon black/QI aggregates, metallurgical coke and coal. Most of the mineral matter is slag 5.8%. The balance of the material is plant 10.2% and diatom related 7.0%.

Please do not hesitate to call us at (724) 327-5019 or e-mail us at ralphgray@aol.com if you have any questions or wish to discuss this work.

Sincerely,

Ra1ph J Gray
Daniel P. Gray

Table 1

Petrographic Composition Analysis of Sediment Sample from Stanford University

R & D No.	**1124**	**1125**	**1126**
Stanford Sample ID	**NLU - 58**	**NLU - 62**	**NLU – 68-51**
Carbon:			
Carbon Black: / Normal QI			
Dense Aggregates	**4.3**	**3.4**	**14.2**
Loose Aggregates	**1.0**	**3.7**	**6.2**
Small Aggregates and Individual QI	**2.1**	**1.6**	**4.2**
Green Aggregates	---	---	---
Very Dark QI Matt	---	---	**0.6**
Pitch - Normal	**1.8**	**1.0**	**2.4**
Pitch – High Reflecting (thermally altered)	---	---	---
Tar-Like	**0.4**	**0.4**	**0.6**
Pitch Coke	---	**0.6**	**1.6**
Cenospheres	**0.2**	**0.4**	**0.4**
Petroleum Coke	---	---	---
Metallurgical Coke – coal related	**1.4**	**0.2**	**19.4**
Oxidized Coke or Burnt	---	---	**3.0**
Depositional carbon –spherulytic	**0.2**	**0.2**	**0.2**
Pyrolytic	**0.4**	---	**0.6**
Bug Plant Residue	---	**0.2**	**6.4**
Charcoal	---	---	**2.4**
Coal	**0.8**	**3.5**	**11.2**
Total Carbon	**12.6**	**15.2**	**73.4**
Organic Plant Material (Kerogen-Like)			
Cellular	**8.2**	**8.4**	**7.4**
Particulate	**18.9**	**22.8**	**2.8**
Total Plant	**27.1**	**31.2**	**10.2**
Diatom - Individual	**16.2**	**11.4**	**4.2**
Diatom - Mattes	**33.4**	**31.0**	**2.0**
Diatom Related - with Mineral Matter	**2.7**	**1.2**	**0.8**
Total Diatom	**52.3**	**43.6**	**7.0**
Mineral Matter			
Quartz	**0.4**	**0.6**	---
Carbonates	**0.4**	**1.0**	**0.2**
Pyrite	**1.9**	**4.2**	**0.2**
Brown grainy aggregate	**0.8**	**0.2**	**0.2**
White Grainy	**1.2**	**1.6**	**1.0**
Slag	**0.2**	**0.2**	**5.8**
Metallics	---	**0.4**	**0.8**
Other mineral matter:	**3.1**	**1.8**	**1.2**
Total Mineral Matter	**8.0**	**10.0**	**9.4**
Grand Total	**100.0**	**100.0**	**100.0**

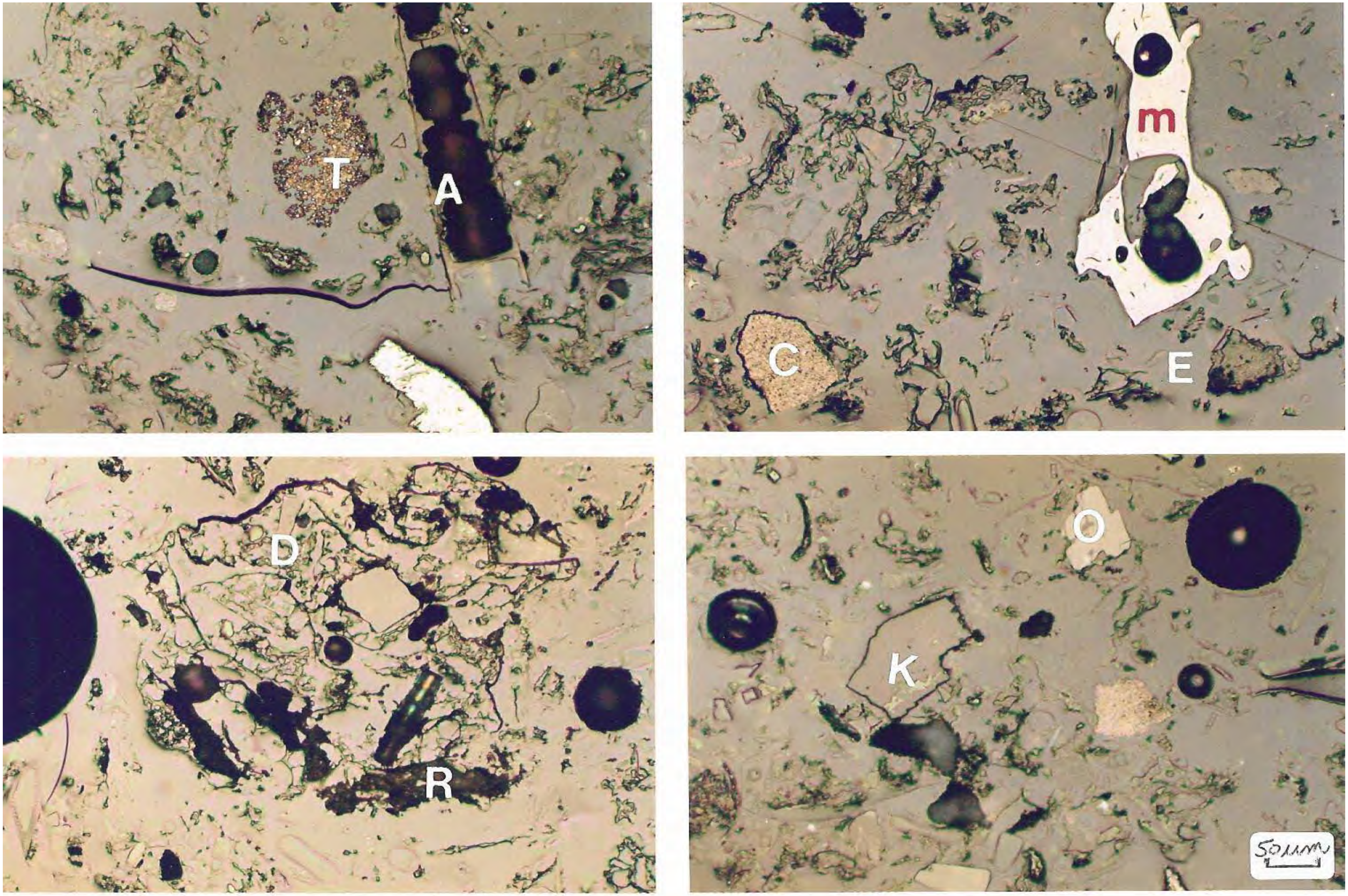

Figure 1: **Photomicrographs of Stanford's Sample Labeled NLU-58 Showing; C=Carbon Aggregate, T=Pitch with QI, R=Particulate Plant, D=Diatomaceous Mass, A=Diatom, K=Coal, M=Coke, O=Other Mineral and E=Epoxy Mounting Media. Reflected Light In Air, X250.**

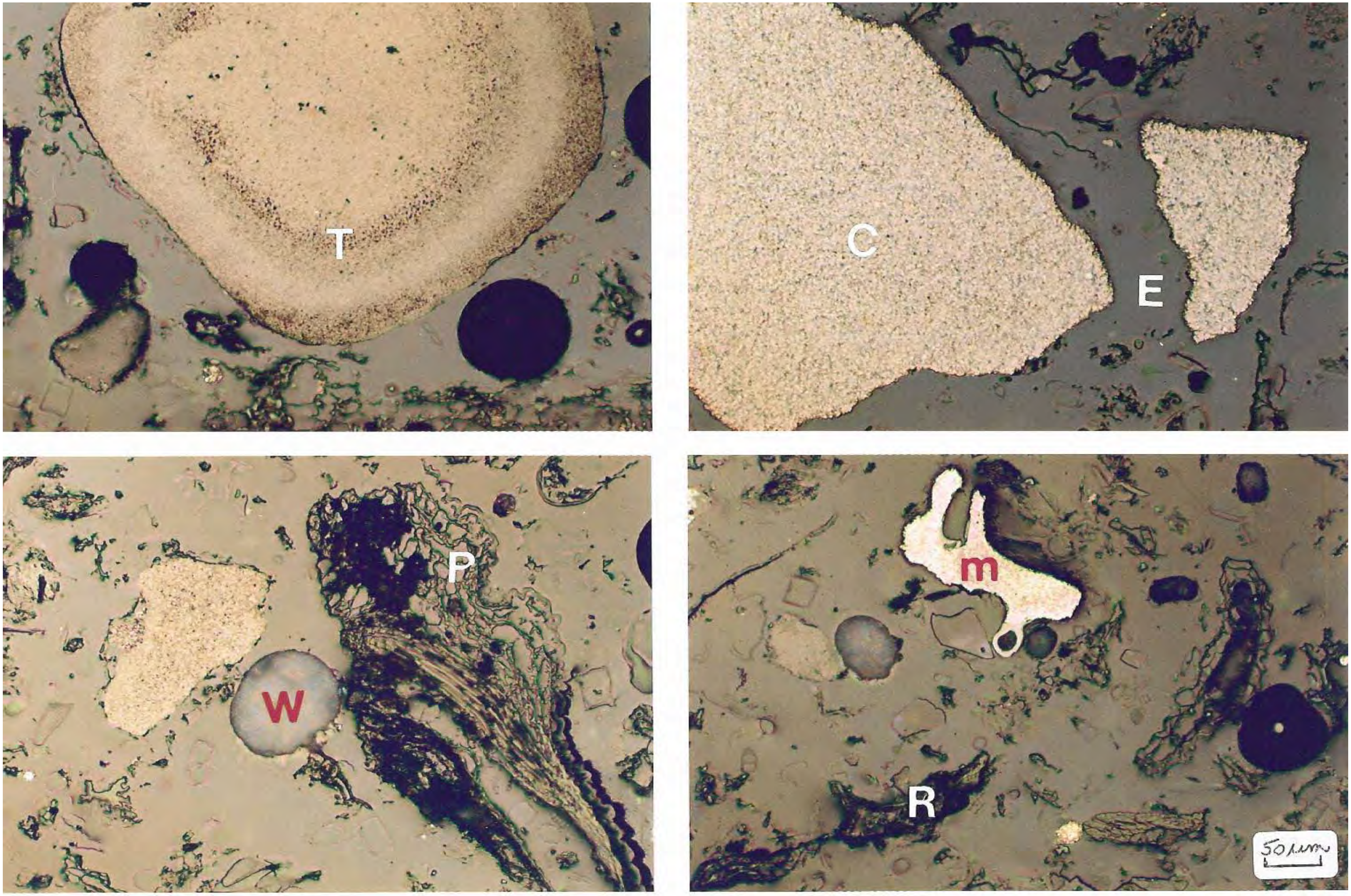

Figure 2: Photomicrographs of Stanford's Sample Labeled NLU-58 Showing; C=Carbon Black Aggregate (dense aggregate), T=Pitch with QI, P=Cellular Plant Material, R=Particulate Plant, M=Metallurgical Coke, W=White Grainy Mineral and E=Epoxy Mounting Media. Reflected Light In Air, X250.

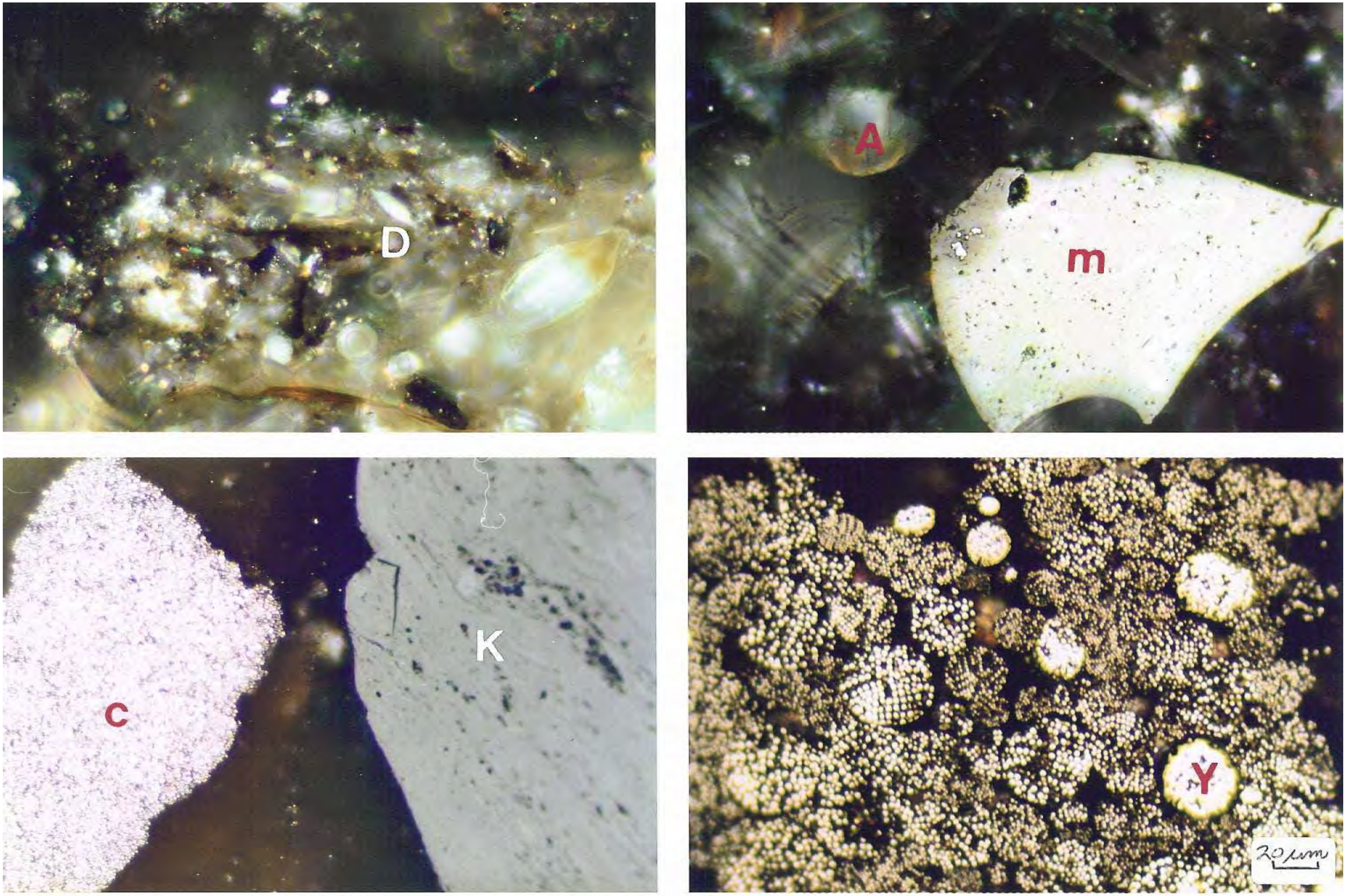

Figure 3: Photomicrographs of Stanford's Sample Labeled NLU-58 Showing; C=Carbon Aggregate (dense), D=Diatomaceous Mass, A=Diatom, K=Coal, M=Coke (oxidized) and Y=Pyrite (colony). Reflected Light In Oil, X600.

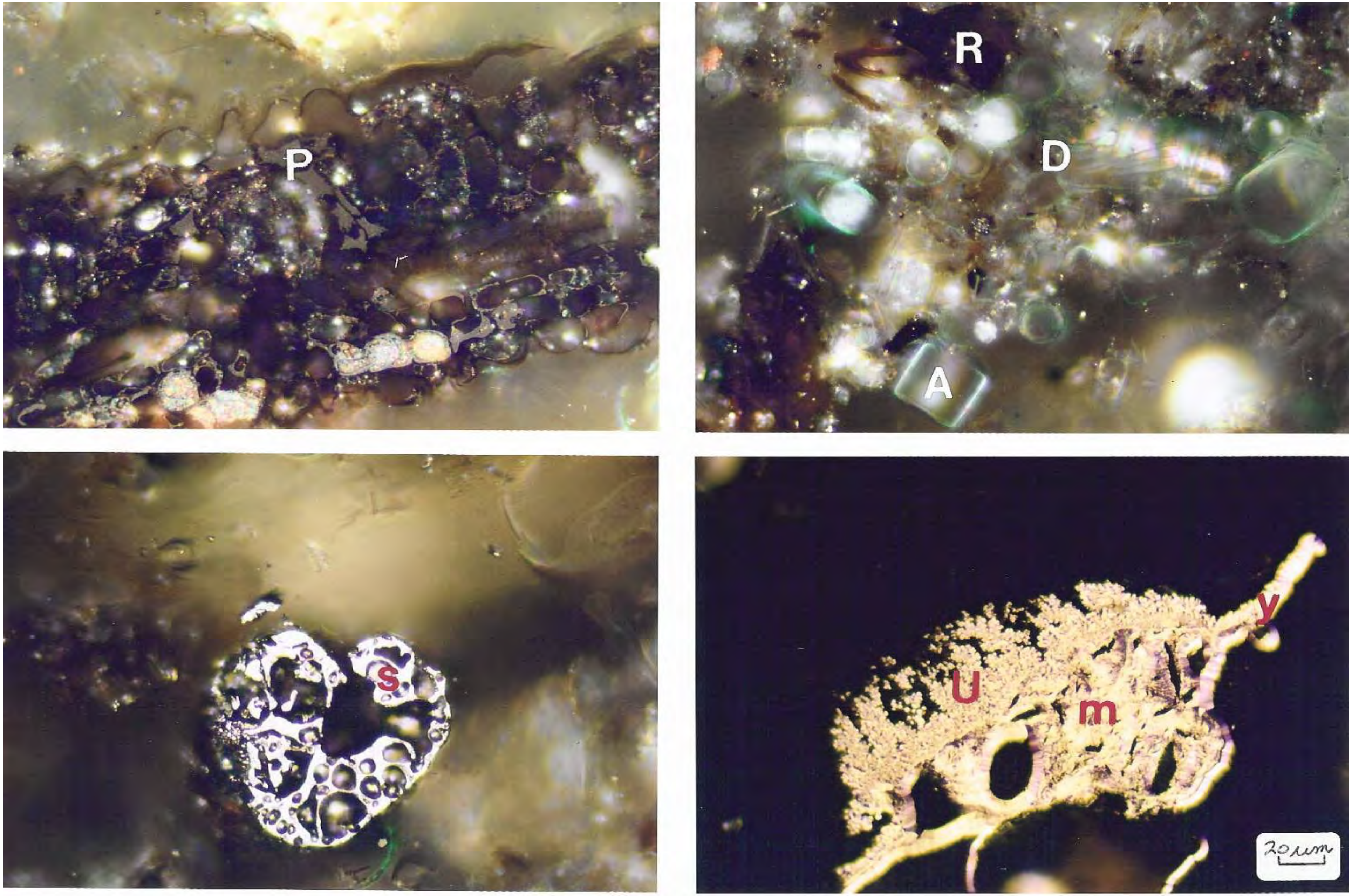

Figure 4: Photomicrographs of Stanford's Sample Labeled NLU-58 Showing; P=Cellular Organic Plant Material, R=Particulate Plant, D=Diatomaceous Mass, A=Diatom, S=Cenosphere and M=Metallurgical Coke with Depositional Carbon (X=Pyrolytic and U=Spherulytic Carbon) Coating. Reflected Light in Oil, 600X.

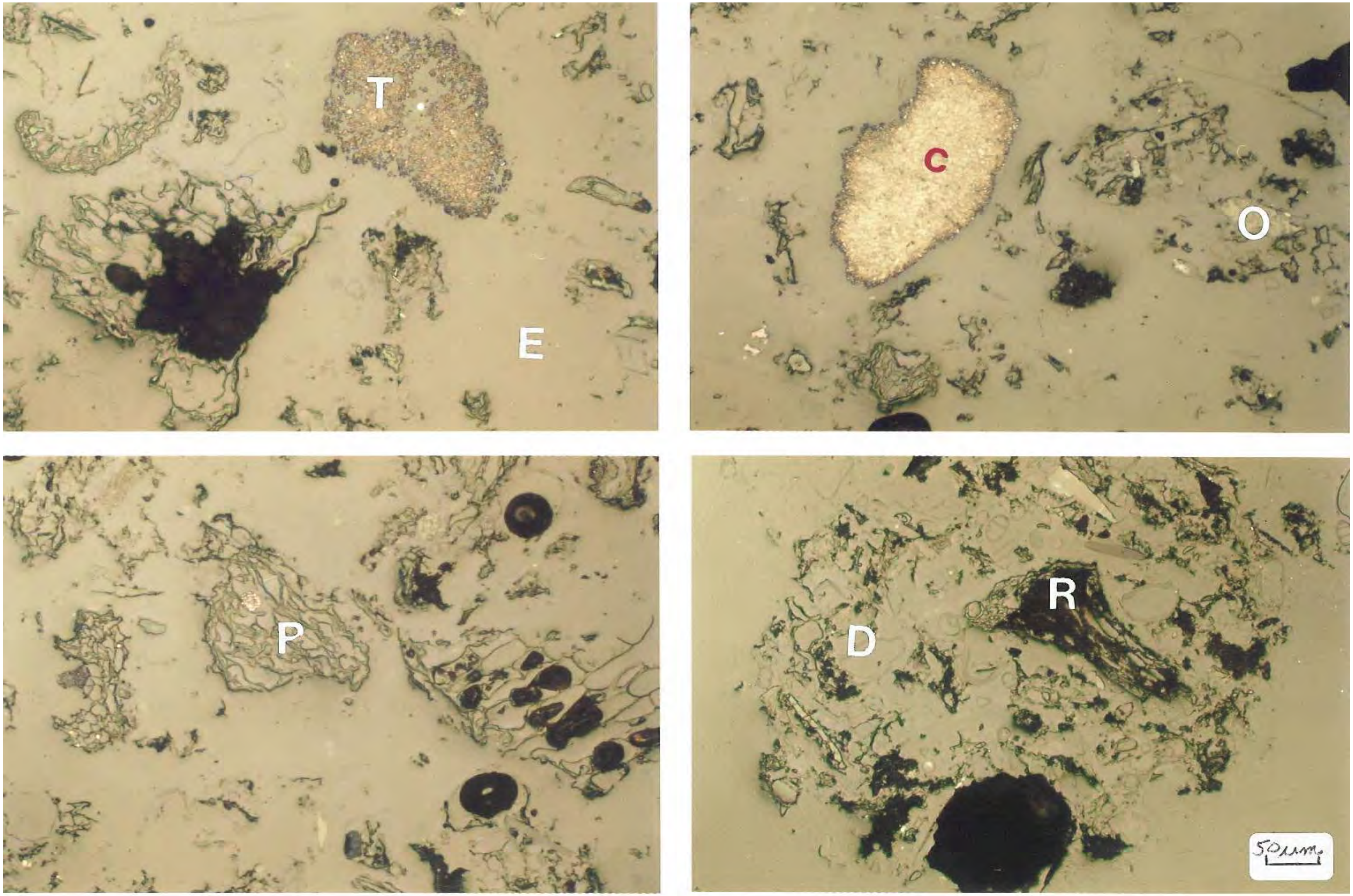

Figure 5: Photomicrographs of Stanford's Sample Labeled NLU-62 Showing; C=Carbon Aggregate (dense), T=Pitch with QI, P=Cellular Plant Tissue, R=Particulate Plant, D=Diatomaceous Mass, O=Other Mineral and E=Epoxy Mounting Media. Reflected Light In Air, X250.

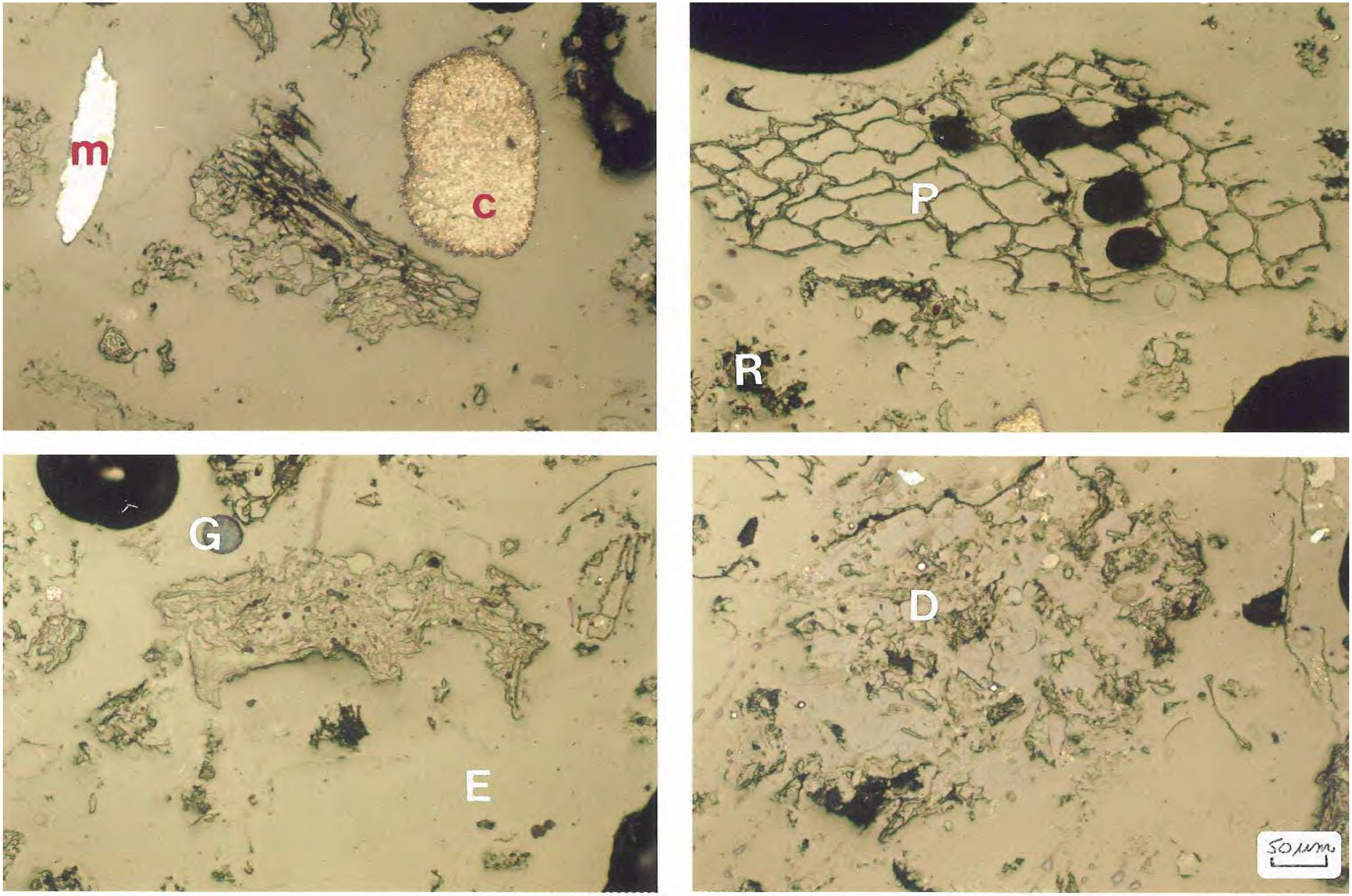

Figure 6: Photomicrographs of Stanford's Sample Labeled NLU-62 Showing; C=Carbon Aggregate (dense), P=Cellular Plant Tissue, R=Particulate Plant, D=Diatomaceous Mass, M=Coke, G=Grainy Mineral and E=Epoxy Mounting Media. Reflected Light In Air, X250.

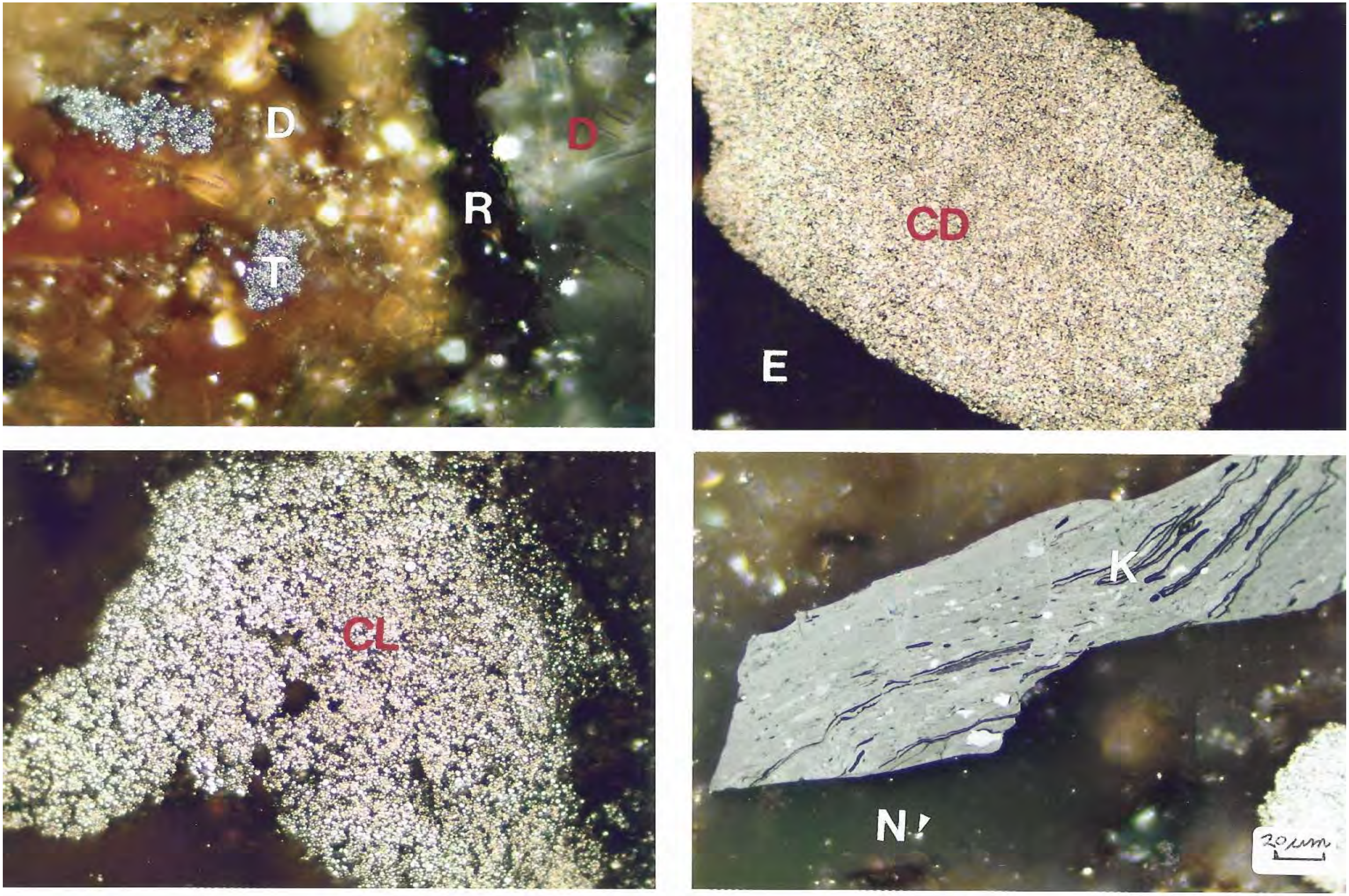

Figure 7: Photomicrographs of Stanford's Sample Labeled NLU-62 Showing; CD=Carbon Aggregate (dense), CL=Carbon Aggregate (loose), T=Pitch with QI, N=Individual Normal QI, K=Coal, R=Particulate Plant, D=Diatomaceous Mass and E=Epoxy Mounting Media. Reflected Light In Oil, X600.

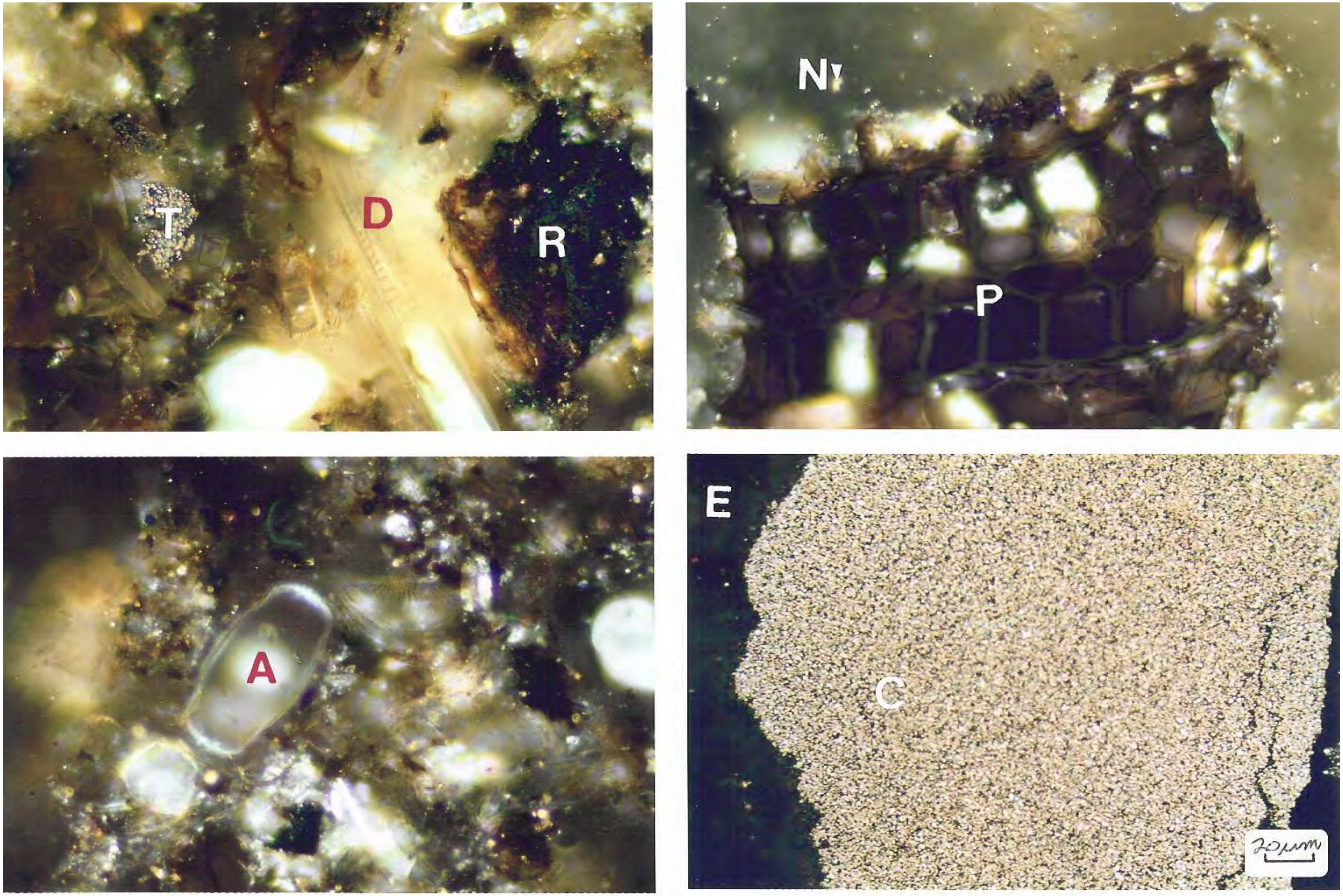

Figure 8: Photomicrographs of Stanford's Sample Labeled NLU-62 Showing; C=Carbon Aggregate (dense), T=Pitch with QI, N=Individual Normal QI, P=Cellular Plant Material, R=Particulate Plant, D=Diatomaceous Mass, A=Diatom and E=Epoxy Mounting Media. Reflected Light In Oil, X600.

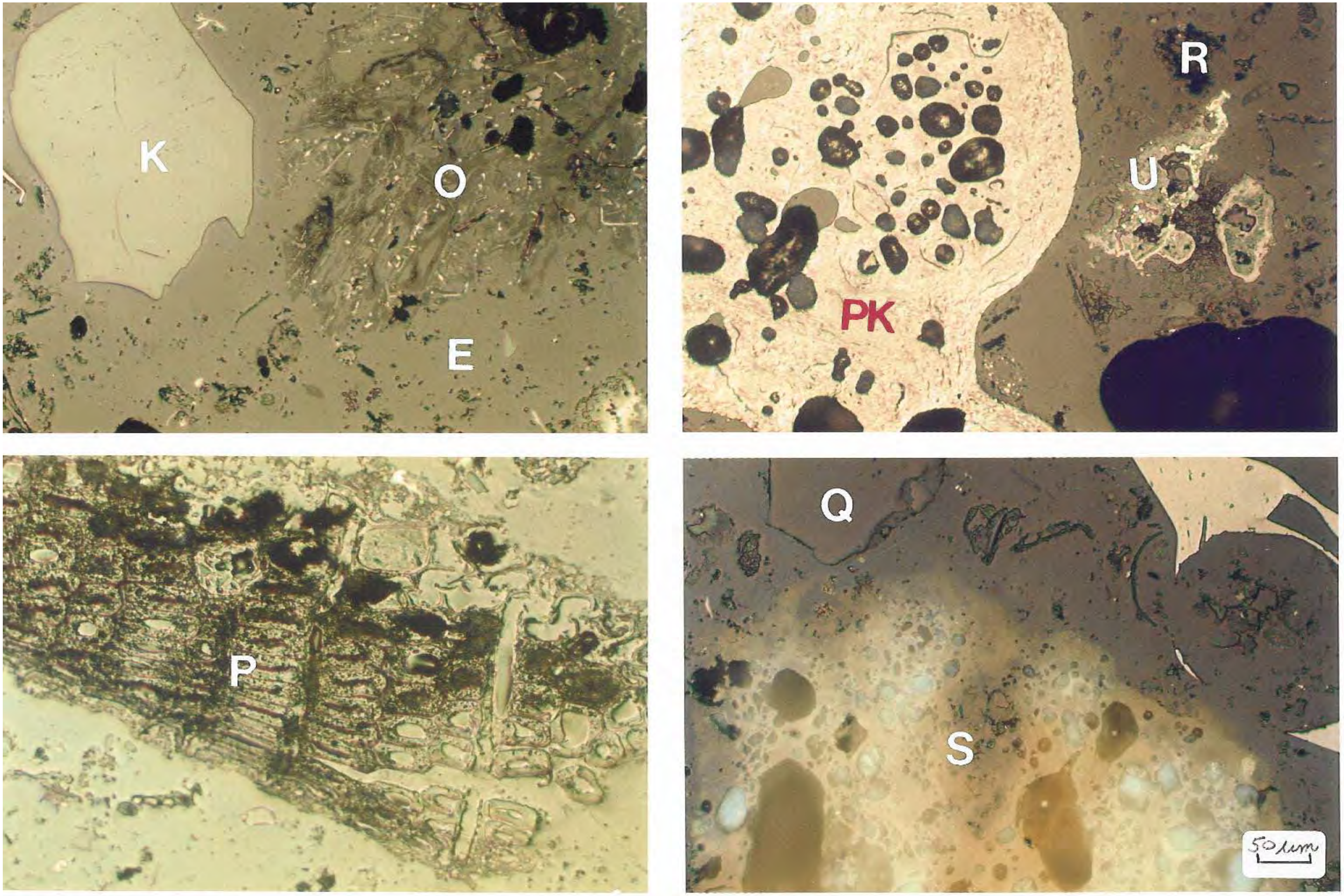

Figure 9: Photomicrographs of Stanford's Sample Labeled NLU-68-51 Showing; P=Cellular Plant Material, R=Particulate Plant, PK=Pitch Coke, K=Coal, S=Slag, Q=Quartz, O=Odd Mineral, U=Rust and E=Epoxy Mounting Media. Reflected Light In Air, X250.

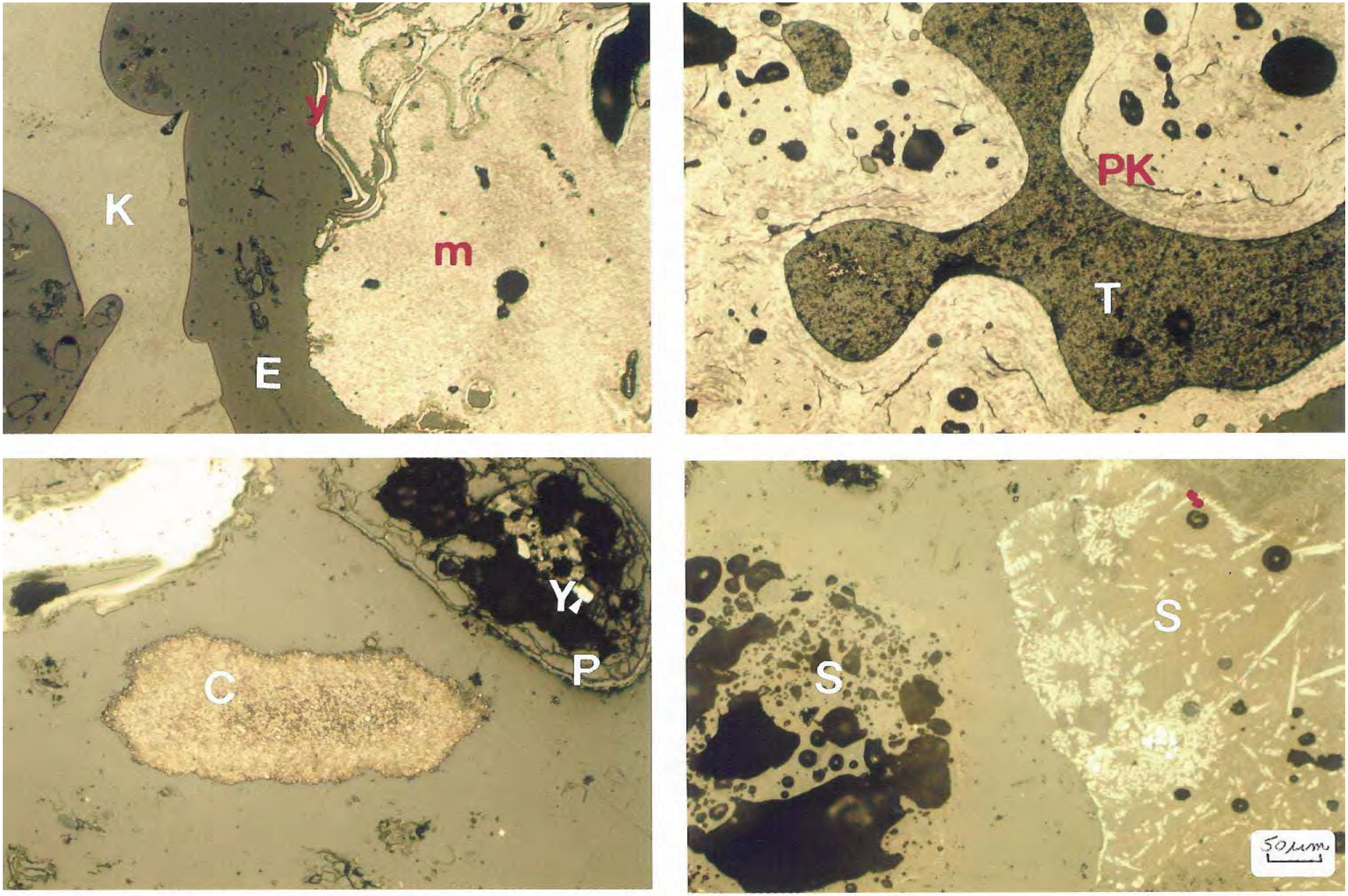

Figure 10: Photomicrographs of Stanford's Sample Labeled NLU-68-51 Showing; C=Carbon Aggregate (dense), P=Cellular Plant Material, PK=Pitch Coke, T=Pitch with Low QI, K=Softened Coal, M=Met Coke, Y=Pyrolytic Carbon Coating, S=Slag and E=Epoxy Mounting Media. Reflected Light In Air, X250.

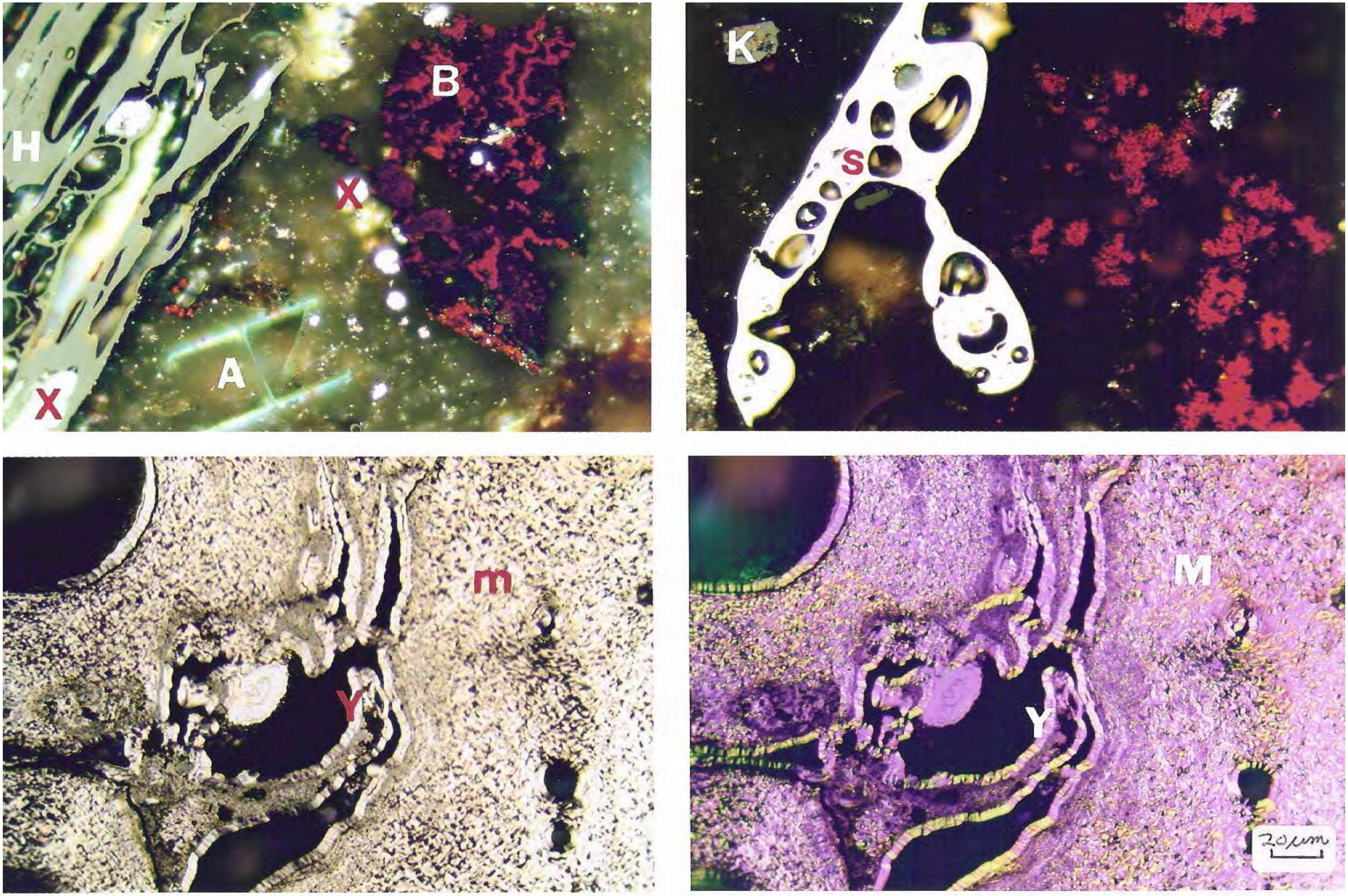

Figure 11: Photomicrographs of Stanford's Sample Labeled NLU-68-51 Showing; K-Coal, H=Charcoal, S=Cenosphere Fragment M=Metallurgical Coke, Y=Pyrolytic Carbon Coating, B=Bug Plant Residue, A=Diatom and X=Pyrite. Reflected Light In Oil, X600. Bottom Right Photo in Polarized Light.

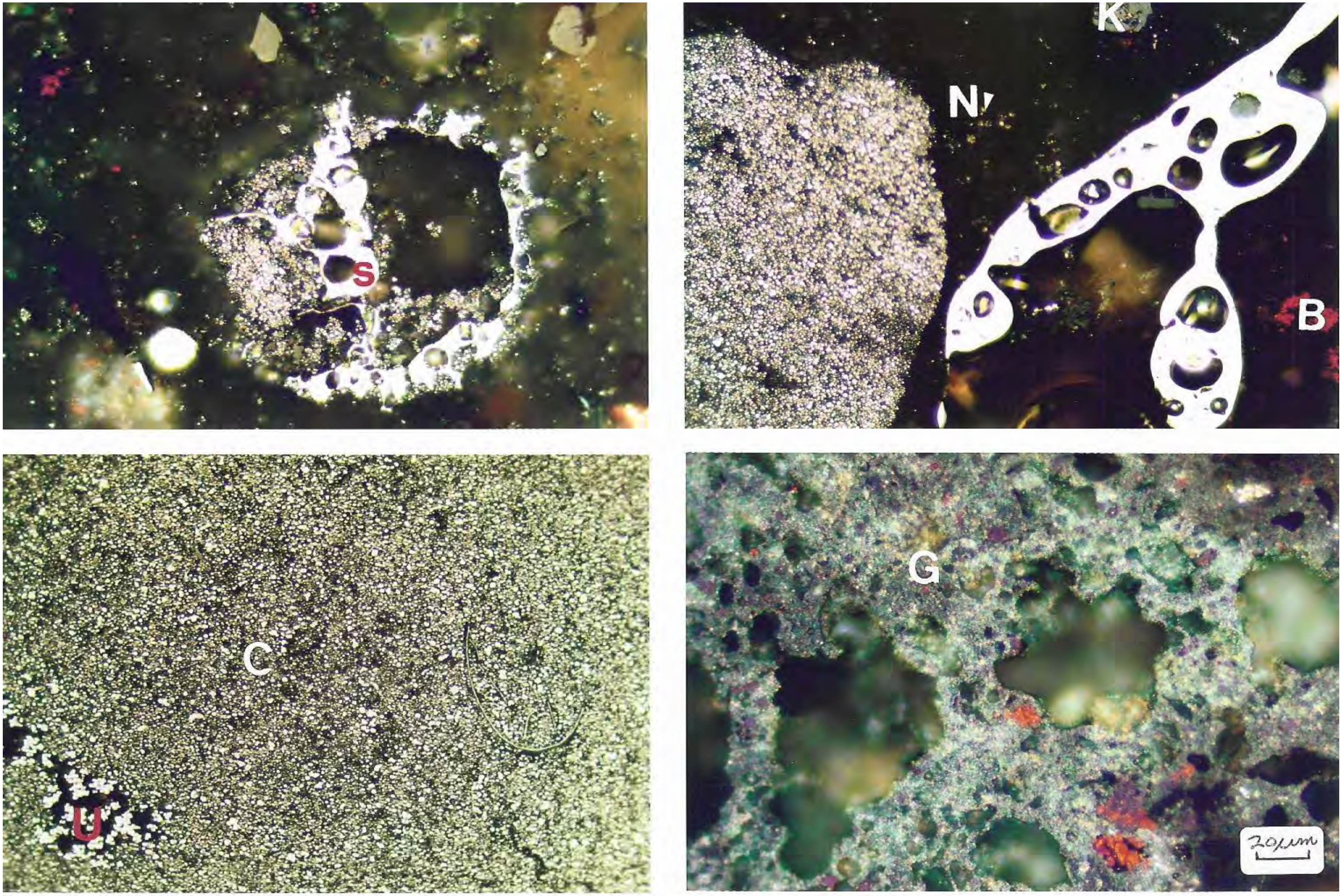

Figure 12: **Photomicrographs of Stanford's Sample Labeled NLU-68-51 Showing; C=Carbon Aggregate (loose or pitch), N=Individual QI, K=Coal, S=Cenosphere Coated with Normal QI, U=Spherulytic Carbon, B=Bug Plant Residue and G=Slag. Reflected Light In Oil, X600.**

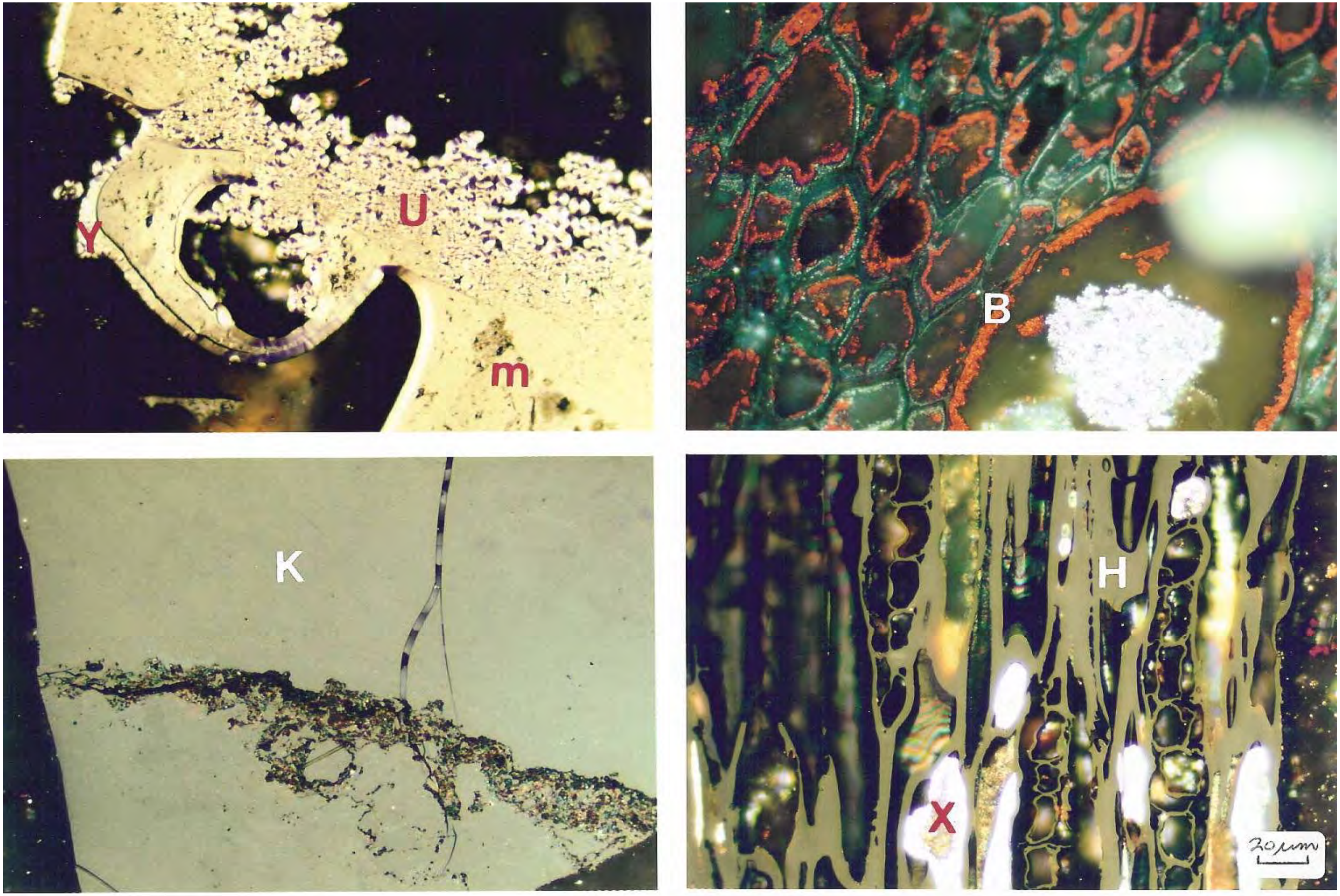

Figure 13: **Photomicrographs of Stanford's Sample Labeled NLU-68-51 Showing; K=Coal, H=Charcoal, M=Metallurgical Coke with Coating of depositional Carbon (Y= pyrolytic and U=spherulitic), B=Bug Plant Residue and X=Pyrite. Reflected Light In Oil, X600.**

R & D CARBON PETROGRAPHY
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June 7, 2005

Ms. Lei Hong
Stanford University
Civil and Environmental Engineering
380 Panama Mall Terman Engineering, B15
Stanford, CA 94305-4020

Dear Ms. Hong;

Your Purchase Order Number 14716370 of May 11, 2005 requested petrographic analysis for three samples of sediment material. The samples are identified and described as follows:

R & D NO.	*DESCRIPTION*
1127	NLU – 68-52
1128	NLU – 72
1126	NLU – 73-55

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The submicron carbon forms consist of carbon with one or two probable origins. Carbon black is a solid product of incomplete combustion. It has many commercial uses including filler in tires. In contrast QI or quinoline insolubles occur as solids in coal tar/pitch. In by-product coking the material from incomplete coal combustion and vapor phase cracking occur colloidally dispersed in the tar/pitch that are collected as by-products of carbonization. In the current work these materials are described as dense or loose aggregate, individual QI, green or less coked aggregates and very dark mattes. The related material is described as pitch, tar-like and pitch coke. Cenospheres are counted separately. They are produced when coal is heated rapidly in an unconfined condition. The rapidly heated coal becomes plastic and the internally trapped gases expand to produce very porous commonly spherical bodies of coke. Depositional carbon may be spherulitic or pyrolytic. Liquid distillation products of coal may crack to form spherulitic carbons. The high hydrogen gaseous materials from coal carbonization form pyrolytic carbon. Some red protein material may be from bacteria used to clarify or treat water in coke plants. We'll refer to it as bug plant residue.

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In the current work we use the terms metallurgical coke and by-product coking to separate coal based coking processes from those that are based on petroleum residuals.

Stanford Sample – NLU – 68-52

The Stanford sample labeled NLU-68-52 has 35.6% by volume of total carbon. The most abundant carbon related material is coal and metallurgical coke. The coal makes up 14.4% of the sample and includes softened or thermally altered particles. There is 15.3% of metallurgical coke and oxidized coke. The remaining carbon consists of lesser amounts of bug plant residue, tar/pitch, QI aggregates, depositional carbon, pitch coke, charcoal and cenospheres. There is only 6.7% of total organic plant material which is made up of 4.0% with cellular structure and 2.7% of particulate plant material. There is only 2.6% of diatomaceous material which consists of 0.7% of individual siliceous diatoms and 1.9% of diatomaceous mattes. The mineral matter is the most abundant material in this sample and consists mostly of slag 51.2%,with lesser amounts of other mineral matter that is not identified, brown grainy aggregates, metallics and pyrite. The slag is probably the residue from mineral impurities from coal combustion. The petrographic composition data is listed in Table 1 and most of the materials are illustrated in Figures 1 through 5.

The most abundant material in this sample is mineral matter which is mostly slag 51.2%. The next most common material is carbon 35.6% which is predominantly coal or altered coal and coke. There is a relatively small amount of plant material 6.7% and diatomaceous material 2.6%.

Stanford Sample – NLU - 72

The Stanford sample labeled NLU-72 has only 6.5% by volume of total carbon. The most abundant carbon related material is coal 2.5% followed by carbon aggregates which makes up only 2.4% of the sample. There is a small amount of other carbons which consist of pitch, pitch coke, tar-like material and bug plant residue. The bug plant residue may be from biological water treatment. There is 26.8% of total organic plant material which consists of 7.9% with cellular structure and 18.9% of particulate plant material. The most abundant material in this sample is diatomaceous material which totals 63.9%. The diatom related material consists of 11.5% of individual siliceous diatoms, with 50.1% of diatomaceous mattes and 2.3% of diatoms with mineral matter. There is only 2.8% of total mineral matter which consists of small amounts of pyrite, carbonates, quartz, white grainy mineral and slag. The petrographic composition data is listed in Table 1 and most of the materials are illustrated in Figures 6 through 9.

The diatomaceous material and organic plant material make up the majority of this sample and total 90.7% by volume. The remainder of the material is carbon (6.5%) which is consists mostly of coal and coke. The mineral matter is relatively low in the NLU-72 sample.

Stanford Sample – NLU – 73-55

The Stanford sample labeled NLU-73-55 has 14.9% of total carbon by volume. The most abundant carbon material is the aggregates of QI which total 7.1% and consist of loose aggregates 3.4%, with 2.4% of small aggregates and individual QI and 1.7% of dense aggregates. The remaining carbon is mostly coal and coke related and consists of 2.6% of coal, with 1.8% of metallurgical coke and oxidized coke, 2.0% of tar or pitch and lesser amounts of cenospheres, pitch coke and charcoal. There is 25.1% of total organic plant material which consists of 5.8% with cellular structure and 19.3% of particulate plant material. The most abundant material in this sample is diatomaceous material which totals 53.8%. The diatom related material consists of 17.2% of individual siliceous diatom frustules, with 36.4% of diatomaceous mattes and 0.2% of diatoms with mineral matter. There is 6.2% of total mineral matter which consists of small amounts of white grainy mineral, slag, carbonates, quartz, and pyrite, carbonates, quartz, white grainy mineral and white grainy mineral. The petrographic composition data is listed in Table 1 and most of the materials are illustrated in Figures 10 through 13.

The diatomaceous material and organic plant material make up the majority of this sample and total 78.9% by volume. The carbon is the next most common material and makes up 14.9% of the sample. The mineral matter is the least frequent material and consists of small amounts of various mineral forms.

Please do not hesitate to call us at (724) 327-5019 or e-mail us at ralphgray@aol.com if you have any questions or wish to discuss this work.

Sincerely,

Ra1ph J. Gray
Daniel P. Gray

Table 1

Petrographic Composition Analysis of Sediment Sample from Stanford University

R & D No.	**1127**	**1128**	**1129**
Stanford Sample ID	**NLU – 68-52**	**NLU - 72**	**NLU – 73-55**
Carbon:			
Carbon Black: / Normal QI			
Dense Aggregates	**0.4**	**---**	**1.7**
Loose Aggregates	**0.2**	**1.4**	**3.0**
Small Aggregates and Individual QI	**0.2**	**1.0**	**2.4**
Green Aggregates	**---**	**---**	**---**
Very Dark QI Matt	**---**	**---**	**---**
Pitch - Normal	**0.6**	**0.8**	**0.6**
Pitch – High Reflecting (thermally altered)	**---**	**---**	**---**
Tar-Like	**0.2**	**0.2**	**1.4**
Pitch Coke	**0.5**	**0.4**	**0.4**
Cenospheres	**0.3**	**---**	**0.6**
Petroleum Coke	**---**	**---**	**---**
Metallurgical Coke – coal related	**11.1**	**---**	**0.8**
Oxidized Coke or Burnt	**4.2**	**---**	**1.0**
Depositional carbon –spherulytic	**0.1**	**---**	**---**
Pyrolytic	**0.8**	**---**	**---**
Bug Plant Residue	**2.2**	**0.2**	**---**
Charcoal	**0.4**	**---**	**0.4**
Coal – *includes softened coal (thermal)	***14.4**	**2.5**	**2.6**
Total Carbon	**35.6**	**6.5**	**14.9**
Organic Plant Material (Kerogen-Like)			
Cellular	**4.0**	**7.9**	**5.8**
Particulate	**2.7**	**18.9**	**19.3**
Total Plant	**6.7**	**26.8**	**25.1**
Diatom - Individual	**0.7**	**11.5**	**17.2**
Diatom - Mattes	**1.9**	**50.1**	**36.4**
Diatom Related - with Mineral Matter	**---**	**2.3**	**0.2**
Total Diatom	**2.6**	**63.9**	**53.8**
Mineral Matter			
Quartz	**---**	**0.4**	**0.8**
Carbonates	**---**	**0.8**	**1.0**
Pyrite	**0.2**	**0.8**	**0.8**
Brown grainy aggregate	**0.7**	**0.4**	**---**
White Grainy	**---**	**0.2**	**1.8**
Slag	**51.2**	**0.2**	**1.2**
Metallics	**0.8**	**---**	**---**
Other mineral matter:	**2.2**	**---**	**0.6**
Total Mineral Matter	**55.1**	**2.8**	**6.2**
Grand Total	**100.0**	**100.0**	**100.0**

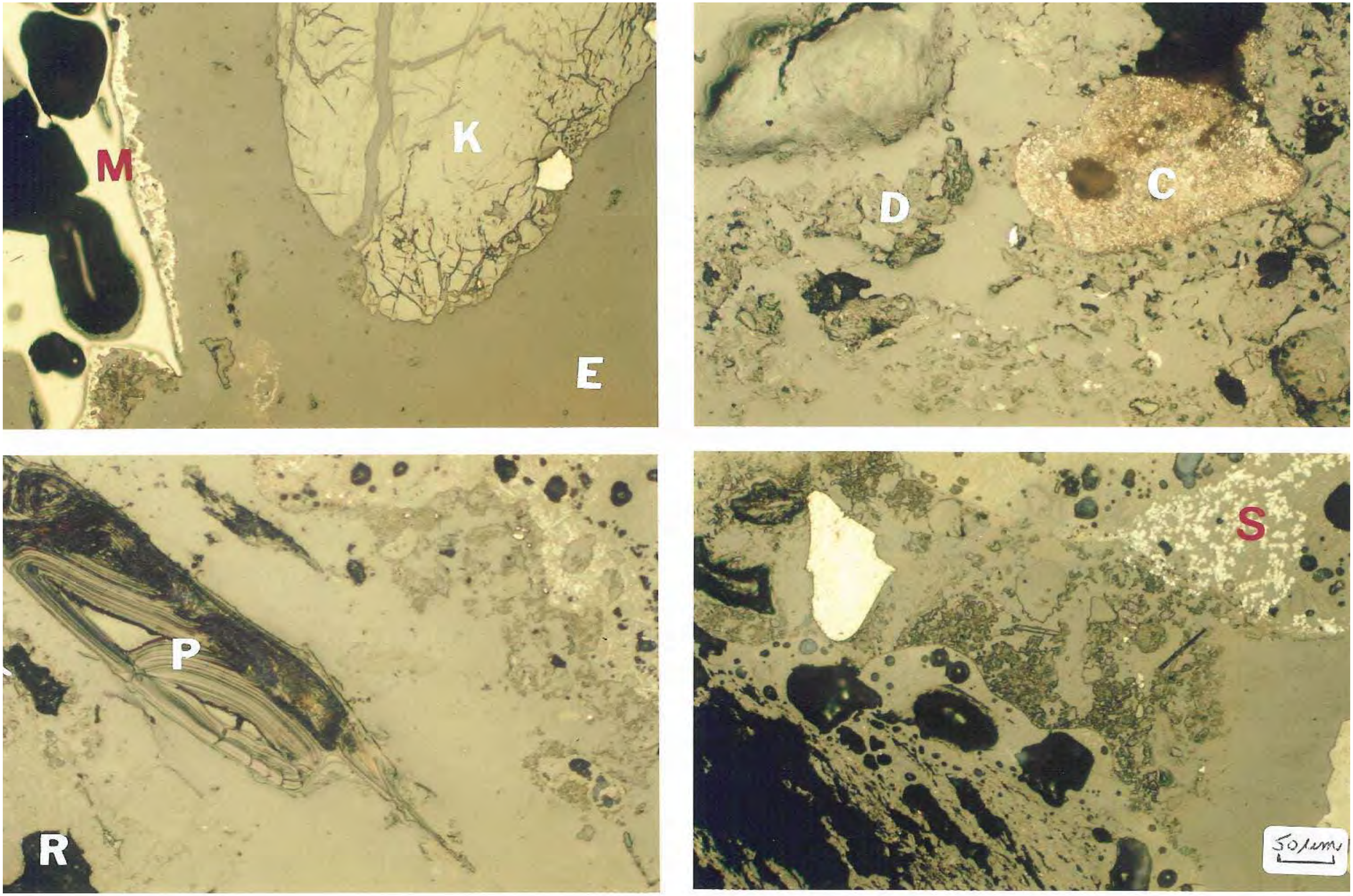

Figure 1: Photomicrographs of Stanford's Sample Labeled NLU-68-52 Showing; C=Carbon Aggregate (loose) P=Cellular Plant Material, R=Particulate Plant, D=Diatomaceous Mass, K=Coal, M=Metallurgical Coke with Pyrolytic Coating, S=Slag, and E=Epoxy Mounting Media. Reflected Light In Air, X250.

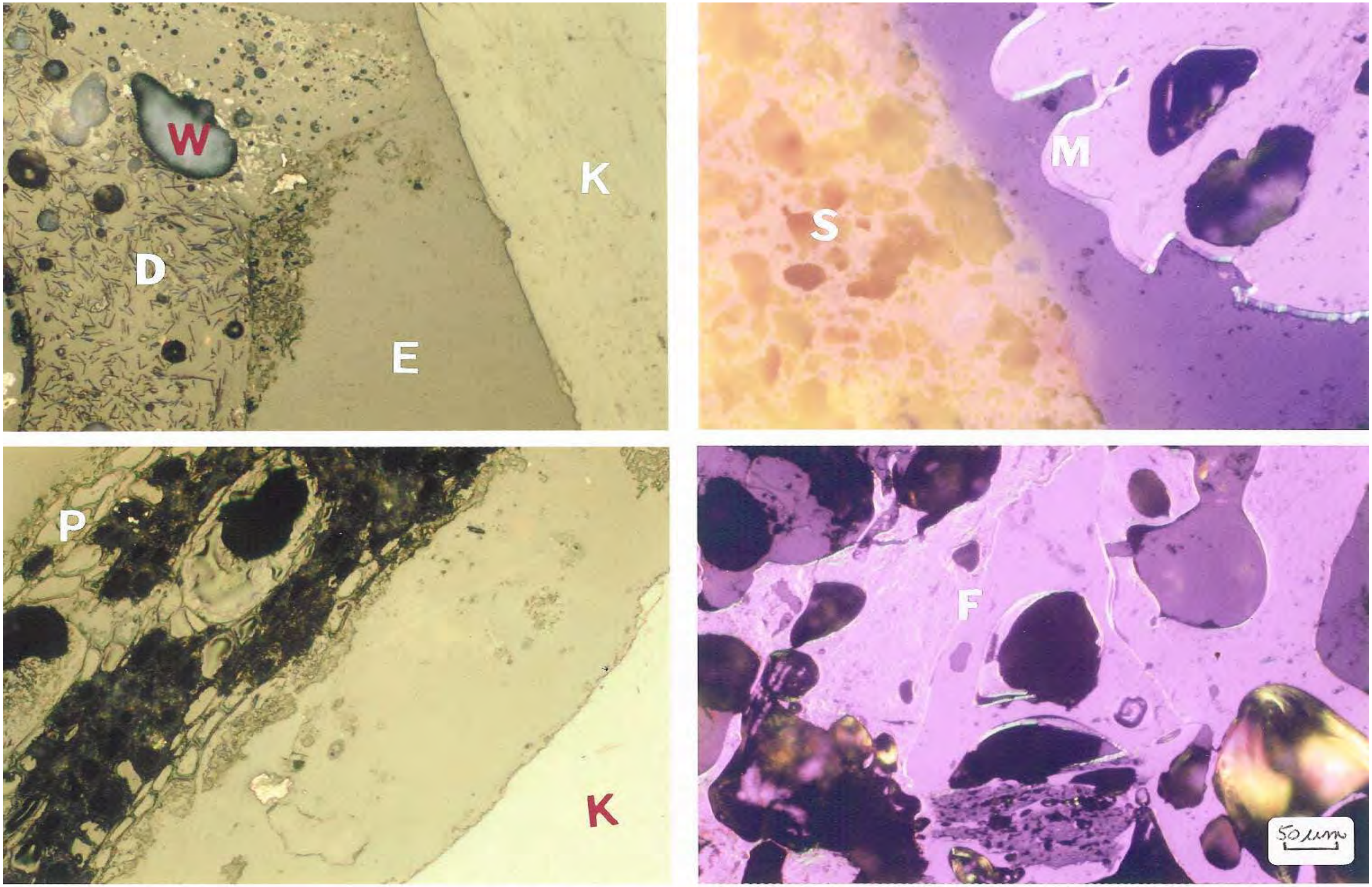

Figure 2: Photomicrographs of Stanford's Sample Labeled NLU-68-52 Showing; P=Cellular Plant Material, D=Diatomaceous Mass, K=Coal, M=Metallurgical Coke with Pyrolytic Coating, F=Foundary Coke, S=Slag, W=White Grainy Mineral and E=Epoxy Mounting Media. Reflected Light In Air, X250. Top and Bottom Photos on Right in Polarized Light.

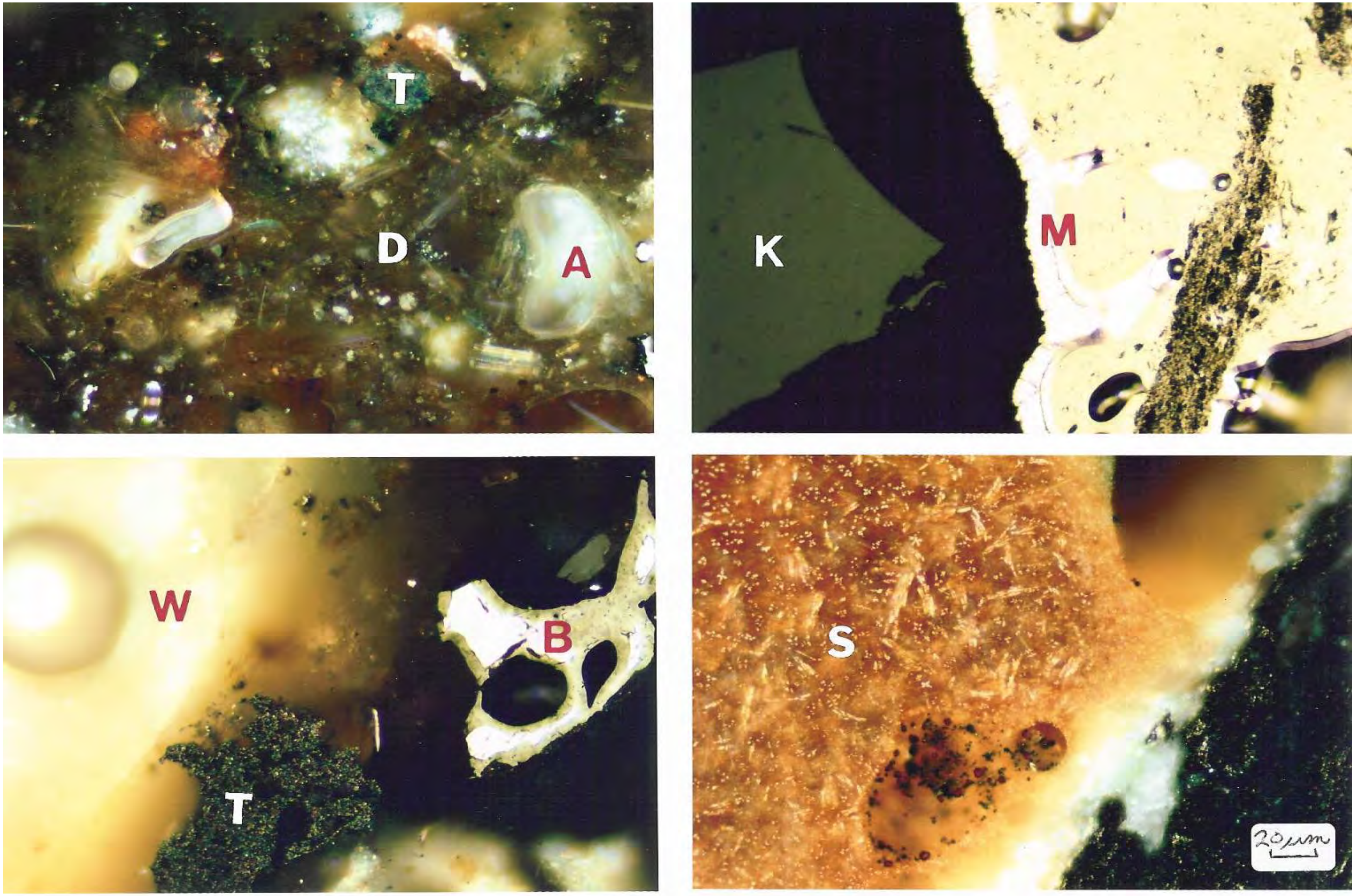

Figure 3: Photomicrographs of Stanford's Sample Labeled NLU-68-52 Showing; D=Diatomaceous Mass, A=Diatom, T=Tar-Like to Pitch, K=Coal, M=Metallurgical Coke with Pyrolytic Coating, B=Burnt Coke, S=Slag and W=White to Glassy Slag. Reflected Light In Oil, X600.

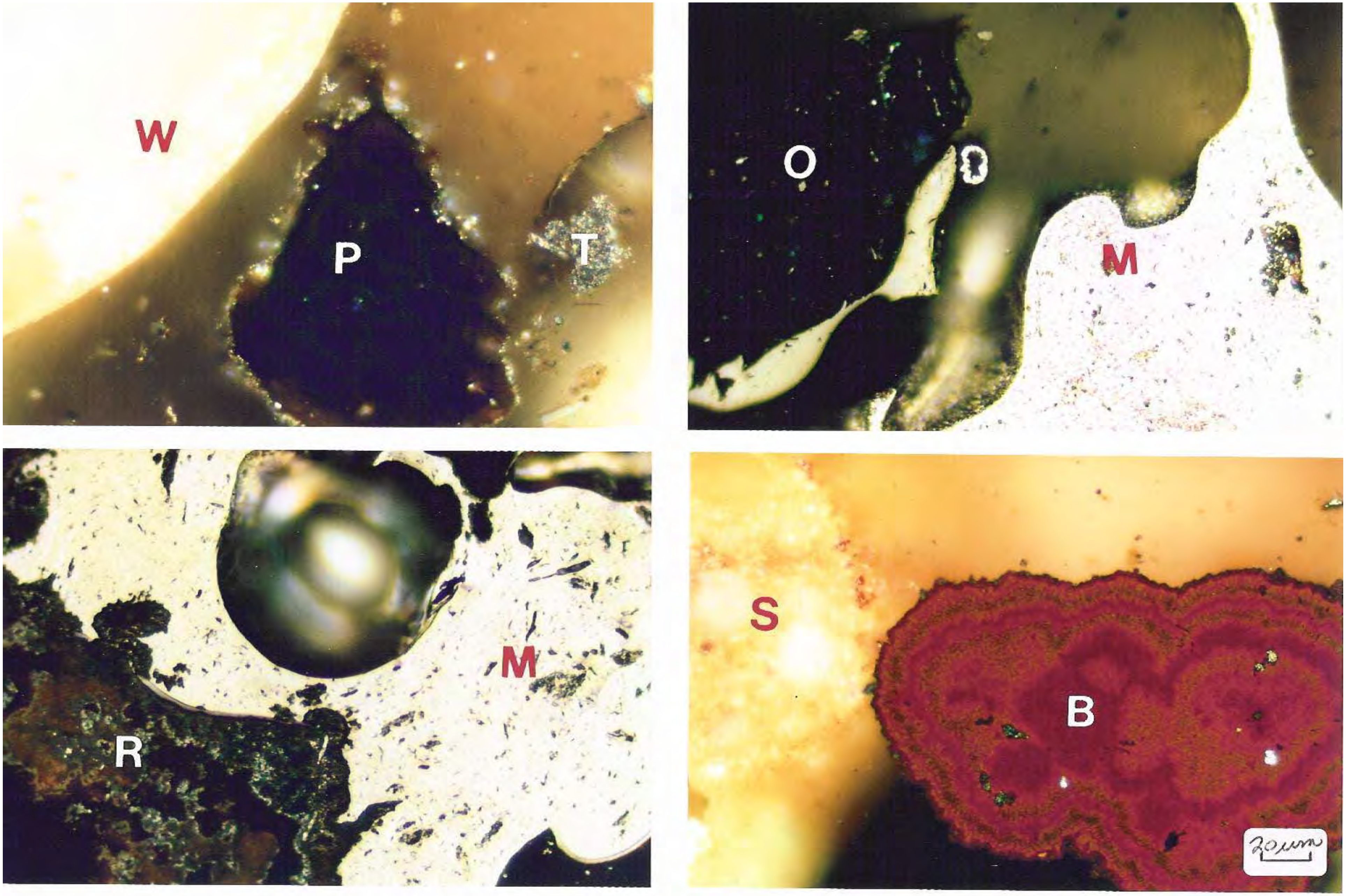

Figure 4: Photomicrographs of Stanford's Sample Labeled NLU-68-52 Showing; P=Cellular Plant Material with QI at the Outer Surface, T=Tar-Like to Pitch, O=Carbonaceous Shale, M=Metallurgical Coke, B=Bug Plant Residue, S=Slag, R=Rust and W=White to Glassy Slag. Reflected Light In Oil, X600.

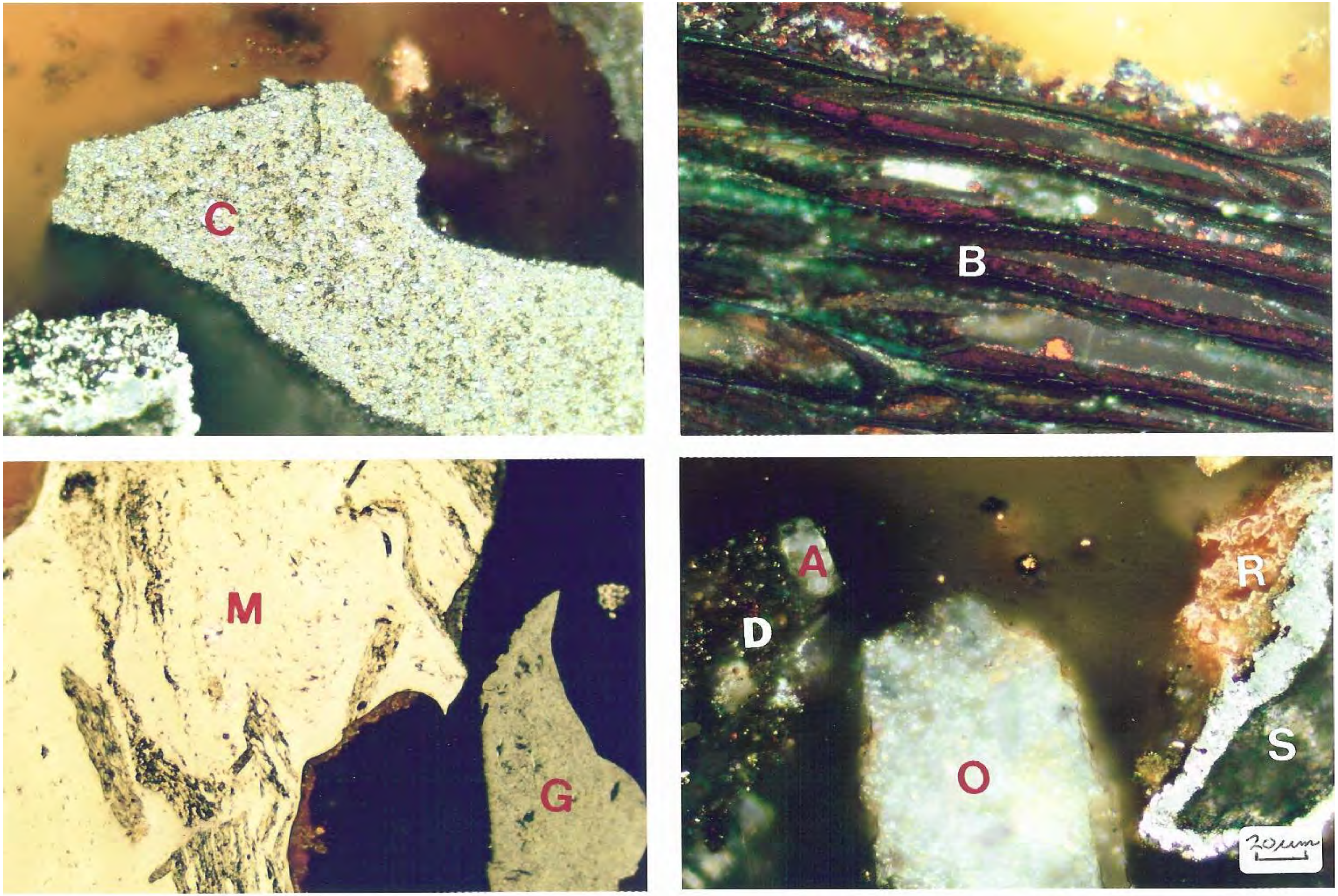

Figure 5: **Photomicrographs of Stanford's Sample Labeled NLU-68-52 Showing; C=Carbon Aggregate (dense), D=Diatomaceous Mass, A=Diatom, M=Coke, G=Semi-Coke (green), B=Bug Plant Residue, S=Slag, R=Rust and O=Other Mineral. Reflected Light In Oil, X600.**

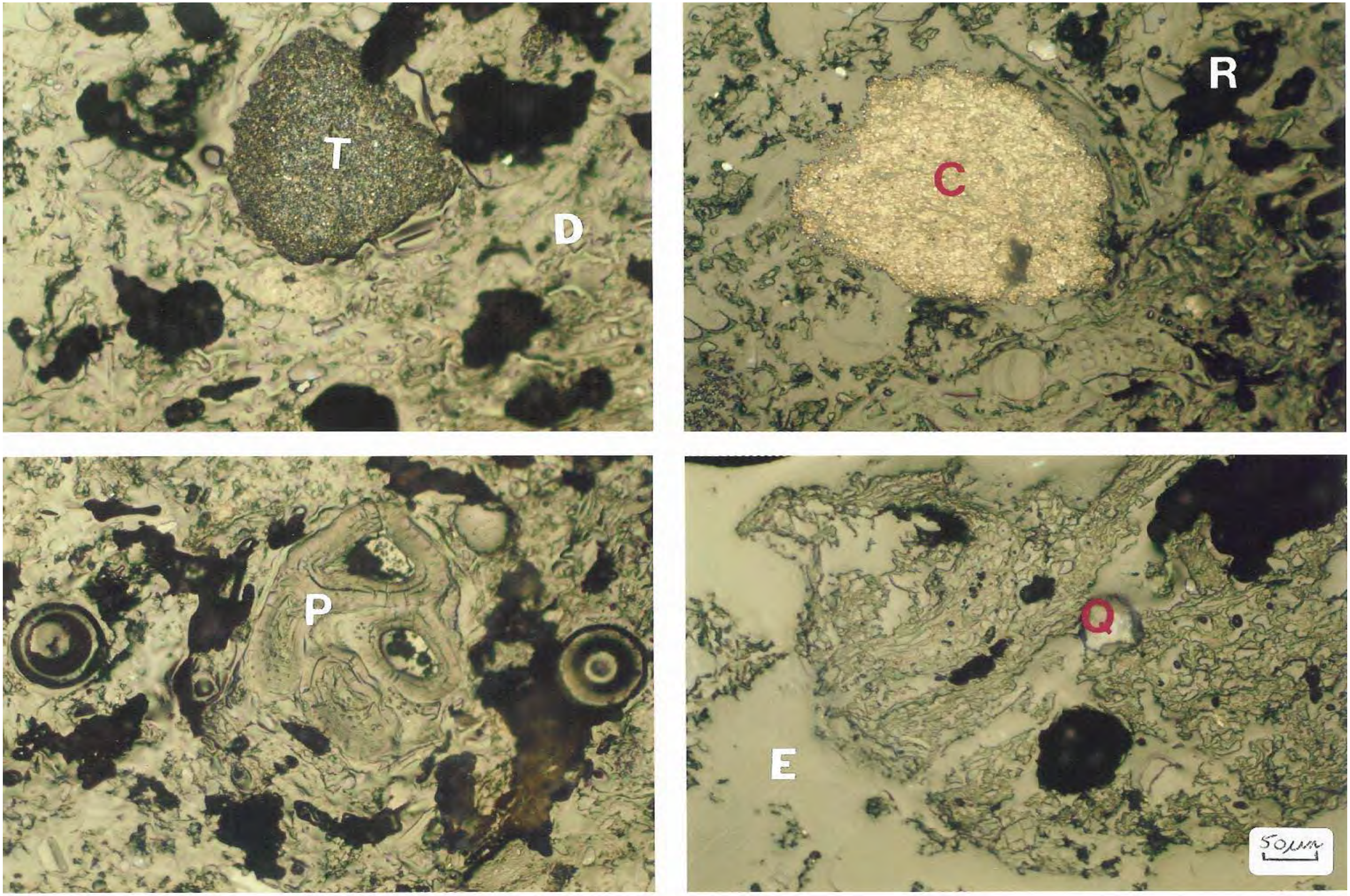

Figure 6: Photomicrographs of Stanford's Sample Labeled NLU-72 Showing; C=Carbon Aggregate (loose), T=Pitch, P=Cellular Plant Material, R=Particulate Plant, D=Diatomaceous Mass, Q=Quartz and E=Epoxy Mounting Media. Reflected Light In Air, X250.

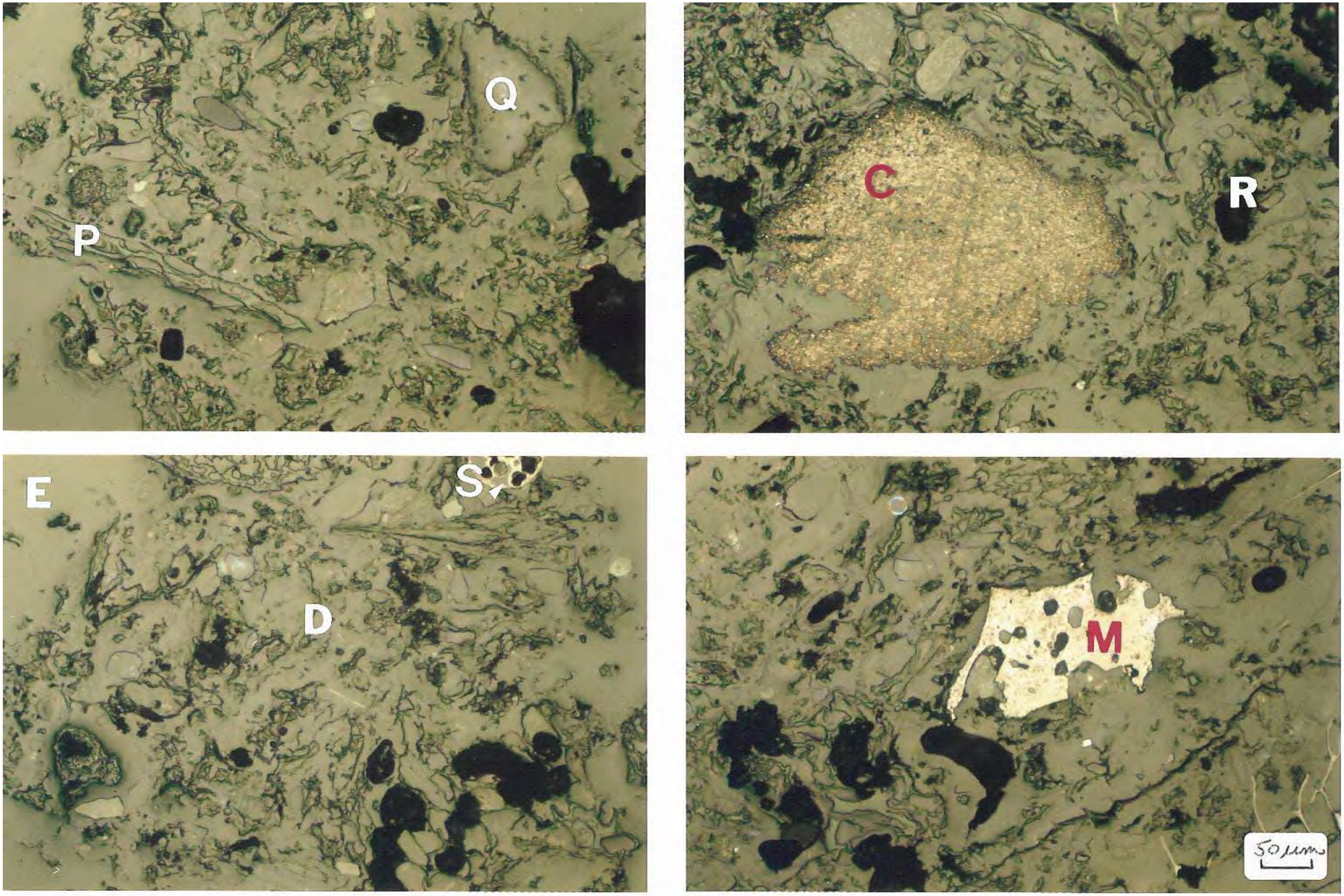

Figure 7: Photomicrographs of Stanford's Sample Labeled NLU-72 Showing; C=Carbon Aggregate (loose), M=Coke, P=Cellular Plant Material, D=Diatomaceous Mass, S=Cenosphere, Q=Quartz and E=Epoxy Mounting Media. Reflected Light In Air, X250.

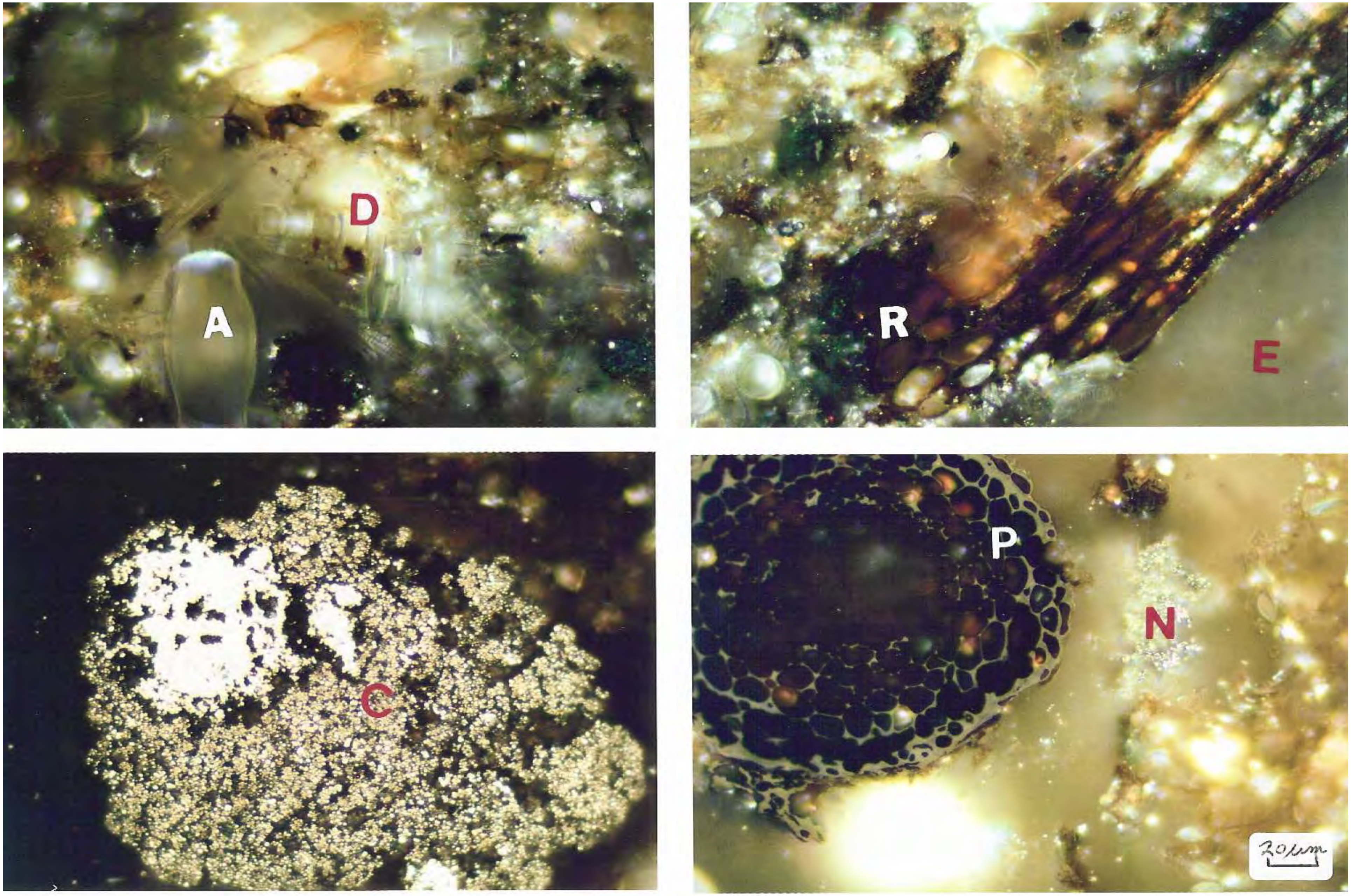

Figure 8: Photomicrographs of Stanford's Sample Labeled NLU-72 Showing; C=Carbon Aggregate (dense and loose), N=Small QI Aggregate, P=Cellular Plant Material, R=Particulate Plant, D=Diatomaceous Mass, A=Diatom and E=Epoxy Mounting Media. Reflected Light In Oil, X600.

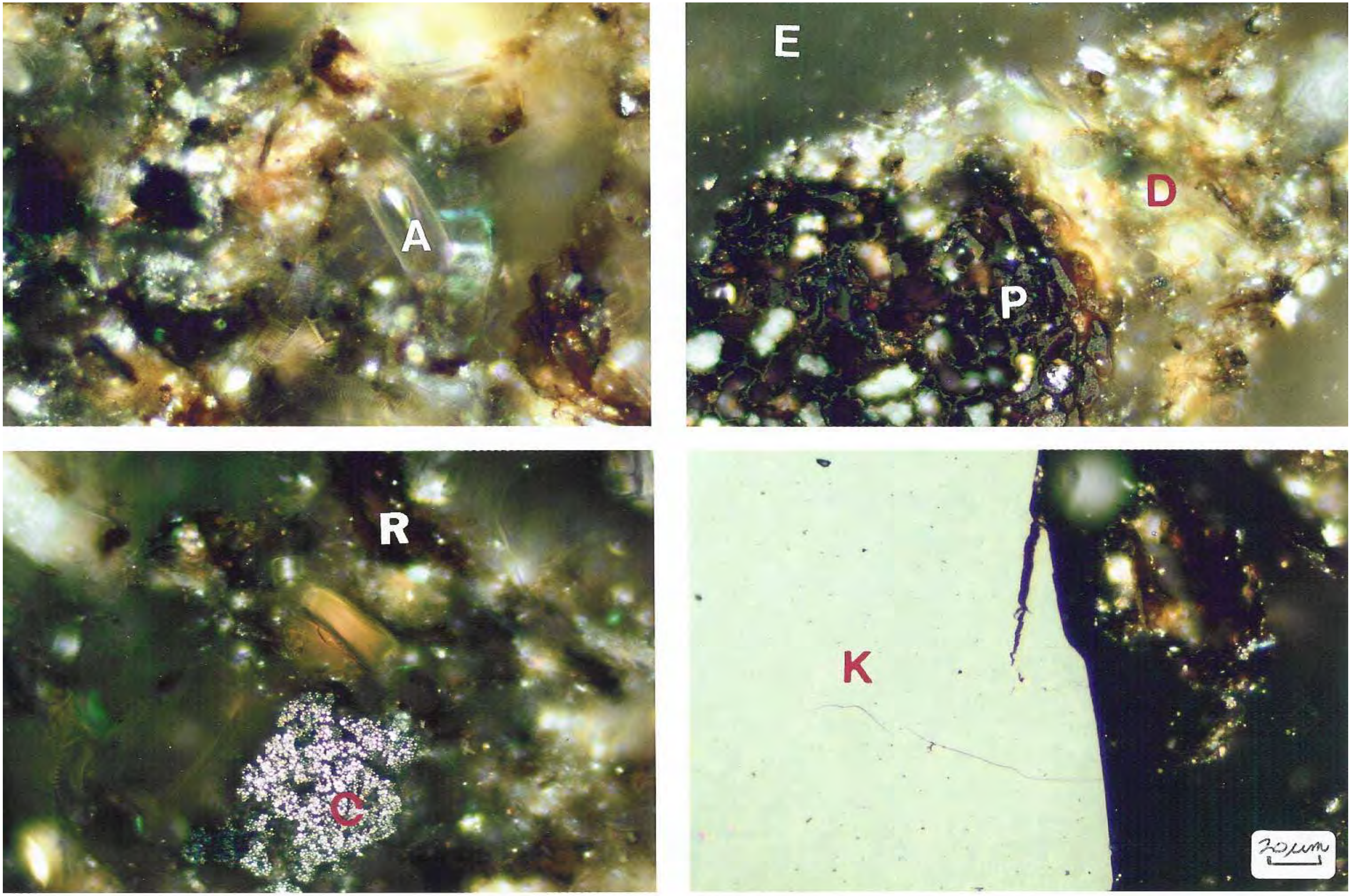

Figure 9: Photomicrographs of Stanford's Sample Labeled NLU-72 Showing; C=Carbon Aggregate (loose), N=Individual QI, K=Coal, P=Cellular Plant Material, R=Particulate Plant, D=Diatomaceous Mass, A=Diatom and E=Epoxy Mounting Media. Reflected Light In Oil, X600.

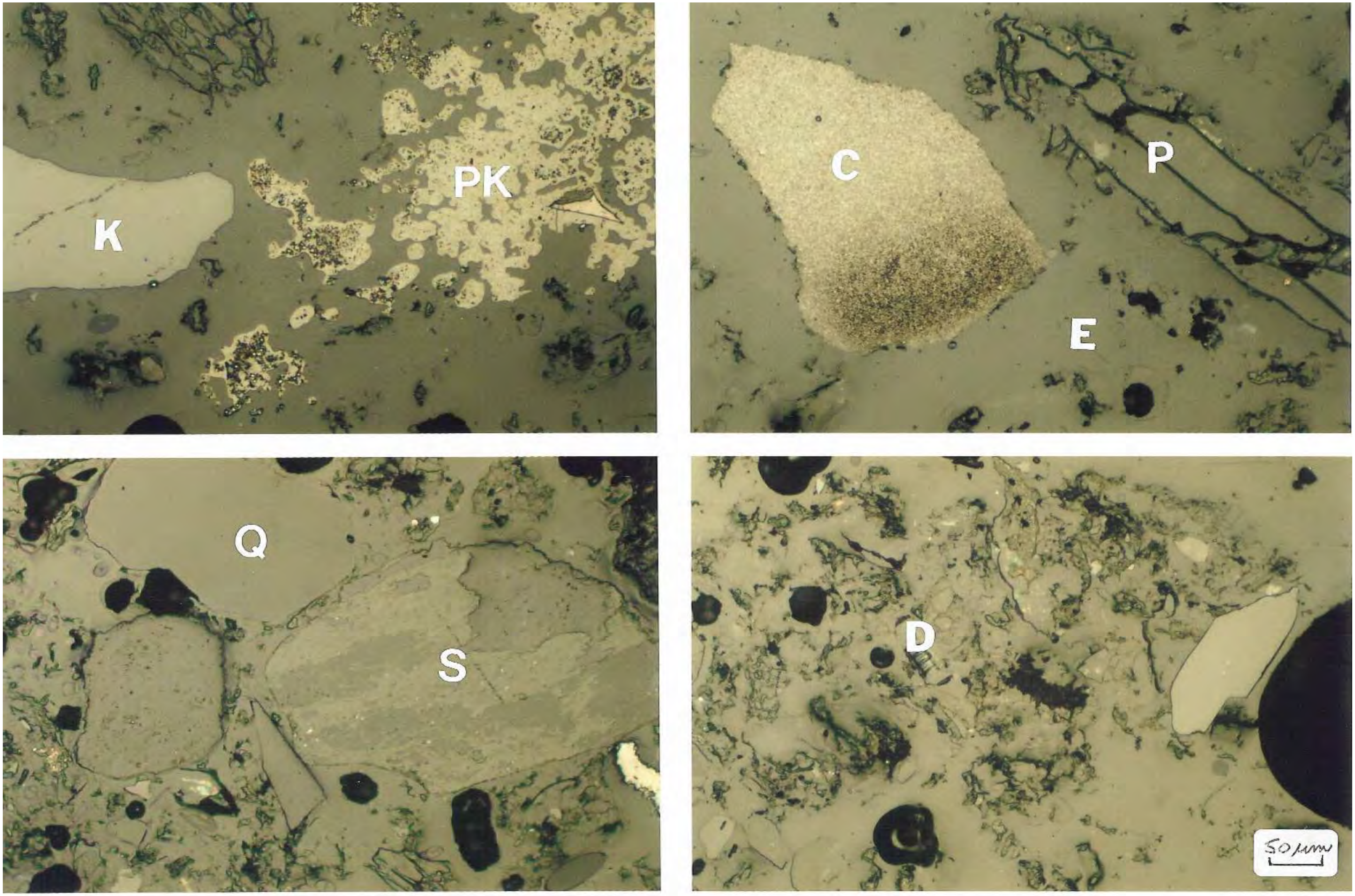

Figure 10: Photomicrographs of Stanford's Sample Labeled NLU-73-55 Showing; C=Carbon Aggregate (dense and loose), K=Coal, PK=Pitch Coke, P=Cellular Plant Material, R=Particulate Plant, D=Diatomaceous Mass, Q=Quartz, S=Slag and E=Epoxy Mounting Media. Reflected Light In Air, X250.

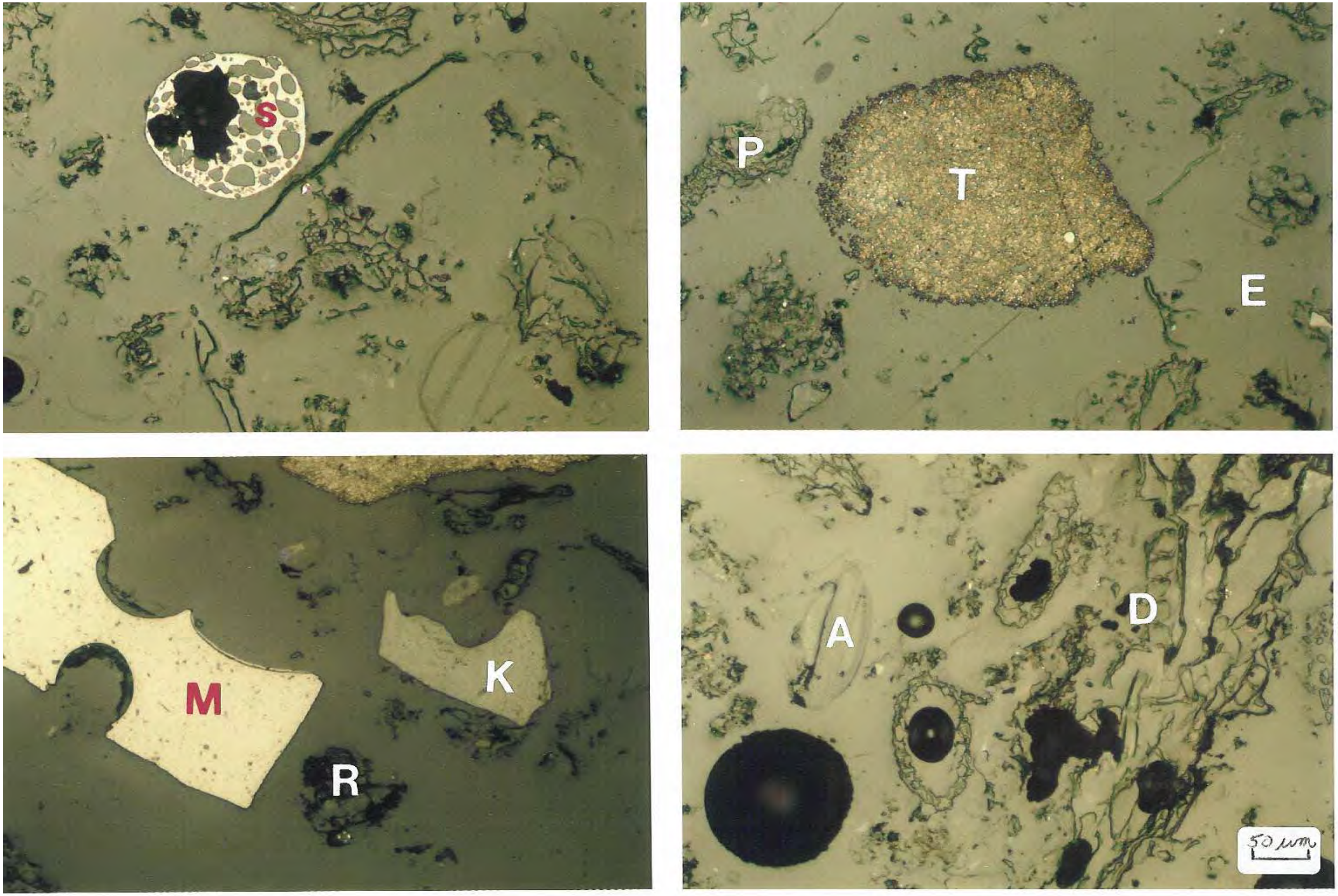

Figure 11: **Photomicrographs of Stanford's Sample Labeled NLU-73-55 Showing; T=Pitch with High QI, K=Coal, M=Metallurgical Coke, S=Cenosphere, P=Cellular Plant Material, R=Particulate Plant, D=Diatomaceous Mass, A=Diatom and E=Epoxy Mounting Media. Reflected Light In Air, X250.**

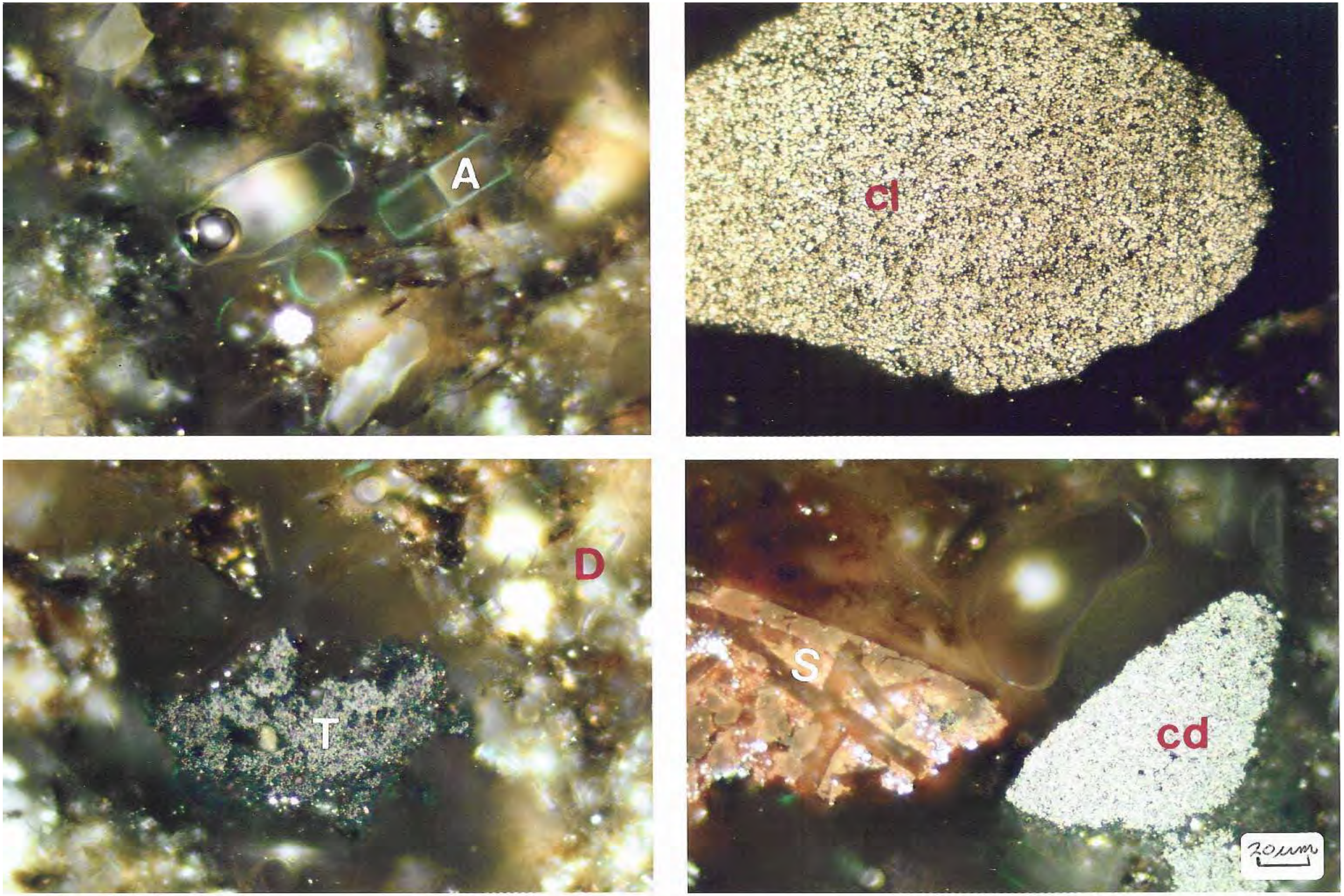

Figure 12: Photomicrographs of Stanford's Sample Labeled NLU-73-55 Showing; CL=Carbon Aggregate (loose), CD=Carbon Aggregate (dense), T=Tar-Like, D=Diatomaceous Mass, A=Diatom, S=Slag, E=Epoxy Mounting Media. Reflected Light In Oil, X600.

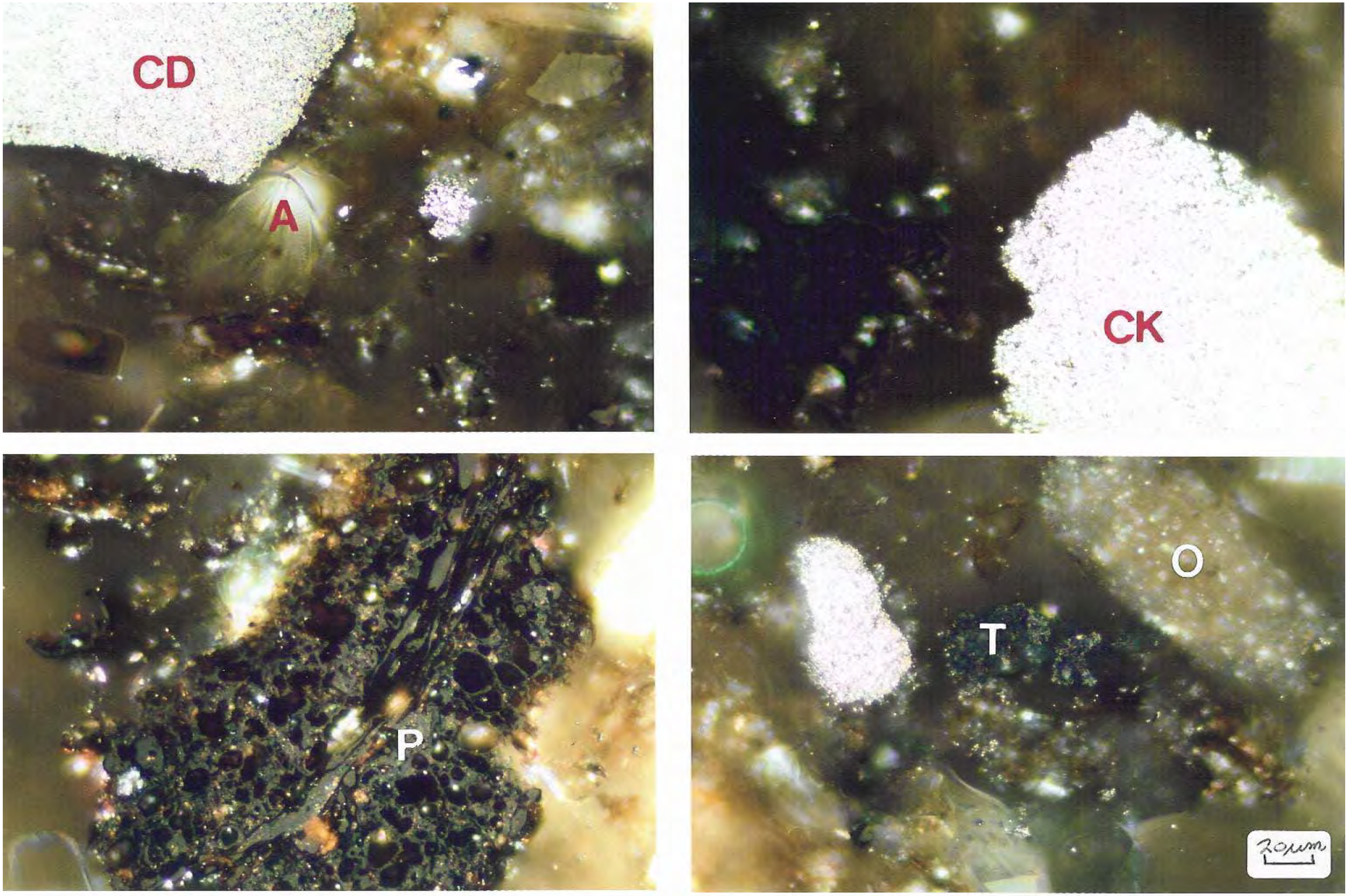

Figure 13: Photomicrographs of Stanford's Sample Labeled NLU-73-55 Showing; CK=Coked Carbon Aggregate, CD=Carbon Aggregate (dense), T=Tar-Like, P=Cellular Plant Material, A=Diatom and O=Other Mineral. Reflected Light In Oil, X600.

R & D CARBON PETROGRAPHY
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June 7, 2005

Ms. Lei Hong
Stanford University
Civil and Environmental Engineering
380 Panama Mall Terman Engineering, B15
Stanford, CA 94305-4020

Dear Ms. Hong;

Your Purchase Order Number 14716270 of May 12, 2005 requested petrographic analysis for five samples of sediment material. The samples are identified and described as follows:

R & D NO.	***DESCRIPTION***
1119	NLU – 402
1120	NLU - 45DC
1121	NLU – 54
1122	NLU – 55
1123	NLU – 57

The solids from the five sediment samples were prepared for petrographic analysis and photographed at 250X in air and at 600X in oil with reflected light. A total of 1000 points were counted for composition. The materials were separated into four main categories which consist of carbon, organic plant material, diatoms and mineral matter. Each category is further subdivided into more specific materials.

The submicron carbon forms consist of carbon with one or two probable origins. Carbon black is a solid product of incomplete combustion. It has many commercial uses including filler in tires. In contrast QI or quinoline insolubles occur as solids in coal tar/pitch. In by-product coking the material from incomplete coal combustion and vapor phase cracking occur colloidally dispersed in the tar/pitch that are collected as by-products of carbonization. In the current work these materials are described as dense or loose aggregate, individual QI, green or less coked aggregates and very dark mattes. The related material is described as pitch, tar-like and pitch coke. Cenospheres are counted separately. They are produced when coal is heated rapidly in an unconfined condition. The rapidly heated coal becomes plastic and the internally trapped gases expand to produce very porous commonly spherical bodies of coke. Depositional carbon may be spherulitic or pyrolytic. Liquid distillation products of coal may crack to form spherulitic carbons. The high hydrogen gaseous materials from coal carbonization form pyrolytic carbon.

The organic plant material in the samples are described in terms of there degree of preservation. The portion that displays the cellular structure is counted separately from the portion that is degraded and occurs as particulate and less ordered plant structures. Much of this material that occurs in sediments and sedimentary rocks are described as kerogen.

Diatoms are unicellular organisms that have a variety of shapes and forms that form planktonic colonies. These plant forms are capable of photosynthesis. They contain skeletons called frustules consisting of two valves that fit together like a box. These internal skeletons consist of pure silica which has very minute fine cellular microstructures. The fossils or skeletons of diatoms have a wide variety of uses as fillers, filtering materials and from a scientific standpoint there sensitivity to temperatures and water depth are good indicators of there habitat. Some of the material that we refer to as mattes maybe associated due to specific gravity separation rather than due to natural occurrences.

The identifiable mineral matter consist of quartz SiO_2, a variety of carbonates including shells, pyrite FeS_2, brown grainy aggregates, white grainy materials, slag, metallics and other minerals. The brown stains on materials may be from humic sources. The slag is thermally altered mineral matter that has a variety of forms and shapes and ranges from glassy to crystalline. Most of the pyrite that occurs is associates with the plant material and occurs as framboids consisting of small circular aggregates of crystals. These forms are usually indicators of brackish water conditions.

In the current work we use the terms metallurgical coke and by-product coking to separate coal based coking processes from those that are based on petroleum residuals.

Stanford Sample – NLU - 402

The Stanford sample labeled NLU - 402 has 8.2% by volume of total carbon. The most abundant carbon related material is coal tar pitch which makes up 3.8% of the sample and consists of 3.4% of pitch and 0.4% of a tar-like material. The next most common carbon is charcoal (1.0%) and coal (0.8%). A very small amount of charcoal has been noted in these samples. There is 1.6% of total carbon aggregates and individual micron and submicron sized spherical solids which consist of dense (0.2%) and loose aggregates (0.8%) and small aggregates and individual QI (0.6%). The remainder of the carbon is related to by-product coke oven products or petroleum coke. There is 0.6% of metallurgical coke, 0.2% of 'Carry-Over' cenospheres and 0.2% of petroleum coke. There is 21.8% of total organic plant material which consists of 8.6% with cellular structure and 13.2% of particulate plant material. Many of the previous samples and current samples contain spores and pollen which are the reproductive organs of plants. These materials have been included in the particulate plant material. The most abundant material in this sample is diatomaceous material which totals 54.8%. The diatom related material consists of 12.8% of individual siliceous diatoms and 42.0% of diatomaceous mattes. There is 15.2% of total mineral matter which consists mostly of quartz (4.0%) and other siliceous minerals (6.6%), with lesser amounts of carbonates, slag white grainy mineral, pyrite, brown grainy aggregate and metallics. The petrographic composition data is listed in Table 1 and most of the materials are illustrated in Figures 1 through 5.

The diatomaceous material and the organic plant material make up the majority of this sample and totals 76.6% by volume. The remainder of the material is various types of mineral matter and carbon related material. The carbon related material is the least common material in the LUI-402 sample.

Stanford Sample – NLU – 45DC

The Stanford sample labeled NLU – 45DC has 5.5% by volume of total carbon. The most abundant carbon related material is aggregate which makes up 3.8% of the sample and consists of 2.5% of green aggregates and 1.3% of small aggregates and individual QI. The remaining individual carbon categories have less than 1.0% of material and total 1.7%. There is 27.4% of total organic plant material which consists of 7.8% with cellular structure and 19.6% of particulate plant material. As previously noted for the earlier samples and current samples contain spores and pollen which are the reproductive organs of plants. These materials have been included in the particulate plant material. The most abundant material in this sample is diatomaceous material which totals 62.7%. The diatom related material consists of 27.0% of individual siliceous diatoms, with 34.3% of diatomaceous mattes and 1.4% diatom related with mineral matter. These mattes consist of translucent and transparent siliceous materials which may or may not contain the diatom skeletons. There is 4.4% of total mineral matter which consists mostly of pyrite 1.6% and other mineral matter 1.1% that is not identified, with lesser amounts of carbonates, slag and quartz. The quartz content is unusually low. The pyrite is mostly framboidal and is generally associated with plant material. The petrographic composition data is listed in Table 1 and most of the materials are illustrated in Figures 6 through 9.

The diatomaceous material and the organic plant material make up the majority of this sample and totals 90.1% by volume. The remainder of the material is various types of mineral matter and carbon related material. The carbon related material is relatively low in the LUI-45DC sample.

Stanford Sample – NLU – 54

The Stanford sample labeled NLU – 54 is very low in carbon related material and has 1.4% by volume of total carbon. There is small amount tar-like material, loose aggregates, small aggregates and individual QI and coal. There is an unusually high amount of total organic plant material 33.2% which consists of 13.2% with cellular structure and 20.0% of particulate plant material. As previously noted spores and pollen have been included in the particulate plant material. The most abundant material in this sample is diatomaceous material which totals 60.6%. The diatom related materials which are silicates of plant origin consists of 23.4% of individual siliceous diatoms, with 34.2% of diatomaceous mattes and 3.0% diatom related with mineral matter. The mattes consist of translucent and transparent siliceous materials which may or may not contain the diatom skeletons. There is 4.8% of total mineral matter which consists mostly of other mineral matter 1.8% that is not identified as well as 1.2% of white grainy minerals, with lesser amounts of quartz, pyrite, slag and metallics. The petrographic composition data is listed in Table 1 and most of the materials are illustrated in Figures 10 through 14.

The diatomaceous material and the organic plant material make up the majority of this sample and totals 93.8% by volume, with 4.8% of mineral matter and only 1.4% of total carbon.

Stanford Sample – NLU - 55

The Stanford sample NLU-55 is very different than the other samples in this group in that it contains a large amount of coarse carbons such as coal, coke and carbon aggregates and they total 75.4% by volume. The most abundant material is metallurgical coke and oxidized coke 25.8%, with 19.9% of coal and 20.7% of total carbon black/Normal QI materials. The carbon aggregates consist of 9.3% of loose aggregates, with 5.4% of dense aggregates, 3.3% of small aggregates and individual QI and 2.7% of very dark QI matt. The balance of the material is coal and coke related. There is 4.7% of pitch, with 4.4% of pitch coke, 3.3% of depositional carbon and a small amount of cenospheres and bug plant residue. The residue is from biological water treatment. There is 5.3% of total organic plant material which consists of 3.6% with cellular structure and 1.7% of particulate plant material. There is a relatively small amount 1.5% of diatomaceous material which consists of small clusters or mattes of diatoms and individual siliceous diatoms. There is 17.8% of total mineral matter which consists mostly of slag 14.3% with lesser amounts of the white grainy mineral, other mineral matter that is not identified, carbonates, pyrite, metallics and brown grainy aggregates. The petrographic composition data is listed in Table 1 and most of the materials are illustrated in Figures 15 through 20.

The NLU-55 sediment sample has the most and widest variety of carbons most of which are coarse coal and metallurgical coke. There is also a relatively large amount of mineral matter that is mostly slag 14.3%. The balance of the material is plant 5.3% and diatom related 1.5%.

Stanford Sample – NLU – 57

The Stanford sample labeled NLU – 57 is similar to the other samples that are dominantly plant related and has only 4.4% by volume of total carbon. This carbon is mostly disseminated QI material 1.8%, with 1.6% of coal and the remaining 1.0% is tar/pitch related. There is 23.8% of total organic plant material which consists of 4.2% with cellular structure and 19.6% of particulate plant material. The most abundant material in this sample is diatomaceous material which totals 66.4%. The diatom related material consists of 11.8% of individual siliceous diatoms, with 52.4% of diatomaceous mattes and 2.2% of diatom with mineral matter. The mattes consist of translucent and transparent siliceous materials which may or may not contain the diatom skeletons. There is 5.4% of total mineral matter which consists mostly of white grainy mineral 2.6%, with lesser amounts of other mineral matter that is not identified, quartz, carbonates, pyrite and brown grainy aggregates. The petrographic composition data is listed in Table 1 and most of the materials are illustrated in Figures 21 through 25.

The diatomaceous material and the organic plant material make up the majority of this sample and total 90.2% by volume. The remainder of the material is various types of mineral matter and carbon related materials. The carbon related material totals 4.4% which is mostly QI and coal. The mineral matter is only 5.4% which is mostly white grainy mineral and the balance occurs in five other mineral forms.

Please do not hesitate to call us at (724) 327-5019 or e-mail us at ralphgray@aol.com if you have any questions or wish to discuss this work.

Sincerely,

Ra1ph J Gray
Daniel P. Gray

Table 1

Petrographic Composition Analysis of Soil Sample from Stanford University

R & D No.	**1119**	**1120**	**1121**	**1122**	**1123**
Stanford Sample ID	**NLU - 402**	**NLU 45DC**	**NLU - 54**	**NLU - 55**	**NLU - 57**
Carbon:					
Carbon Black: / Normal QI					
Dense Aggregates	0.2	---	---	5.4	---
Loose Aggregates	0.8		0.4	9.3	---
Small Aggregates and Individual QI	0.6	1.3	0.2	3.3	1.8
Green Aggregates	---	2.5	---	---	---
Very Dark QI Matt	---	---	---	2.7	---
Pitch - Normal	3.4	0.7	---	4.7	0.6
Pitch – High Reflecting (thermally altered)	---	---	---	---	---
Tar-Like	0.4	0.6	0.6	---	0.2
Pitch Coke	---	0.2	---	4.4	---
Cenospheres	0.2	0.1	---	0.3	0.2
Petroleum Coke	0.2	---	---	---	---
Metallurgical Coke – coal related	0.6	0.1	---	20.3	---
Oxidized Coke	---	---	---	1.5	---
Depositional carbon –spherulytic	---	---	---	1.2	---
Pyrolytic	---	---	---	2.1	---
Bug Plant Residue	---	---	---	0.3	---
Charcoal	1.0	---	---	---	---
Coal	0.8	---	0.2	19.9	1.6
Total Carbon	8.2	5.5	1.4	75.4	4.4
Organic Plant Material (Kerogen-Like)					
Cellular	8.6	7.8	13.2	3.6	4.2
Particulate	13.2	19.6	20.0	1.7	19.6
Total Plant	21.8	27.4	33.2	5.3	23.8
Diatom - Individual	12.8	27.0	23.4	0.9	11.8
Diatom - Mattes	42.0	34.3	34.2	0.6	52.4
Diatom Related - with Mineral Matter	---	1.4	3.0	---	2.2
Total Diatom	54.8	62.7	60.6	1.5	66.4
Mineral Matter					
Quartz	4.0	0.1	0.8	---	0.8
Carbonates	1.2	0.9	---	0.6	0.4
Pyrite	0.6	1.6	0.4	0.2	0.4
Brown grainy aggregate	0.4	---	---	0.3	0.2
White Grainy	1.0	0.3	1.2	1.3	2.6
Slag	1.2	0.4	0.4	14.3	---
Metallics	0.2	---	0.2	0.4	---
Other mineral matter:	6.6	1.1	1.8	0.7	1.0
Total Mineral Matter	15.2	4.4	4.8	17.8	5.4
Grand Total	100.0	100.0	100.0	100.0	100.0

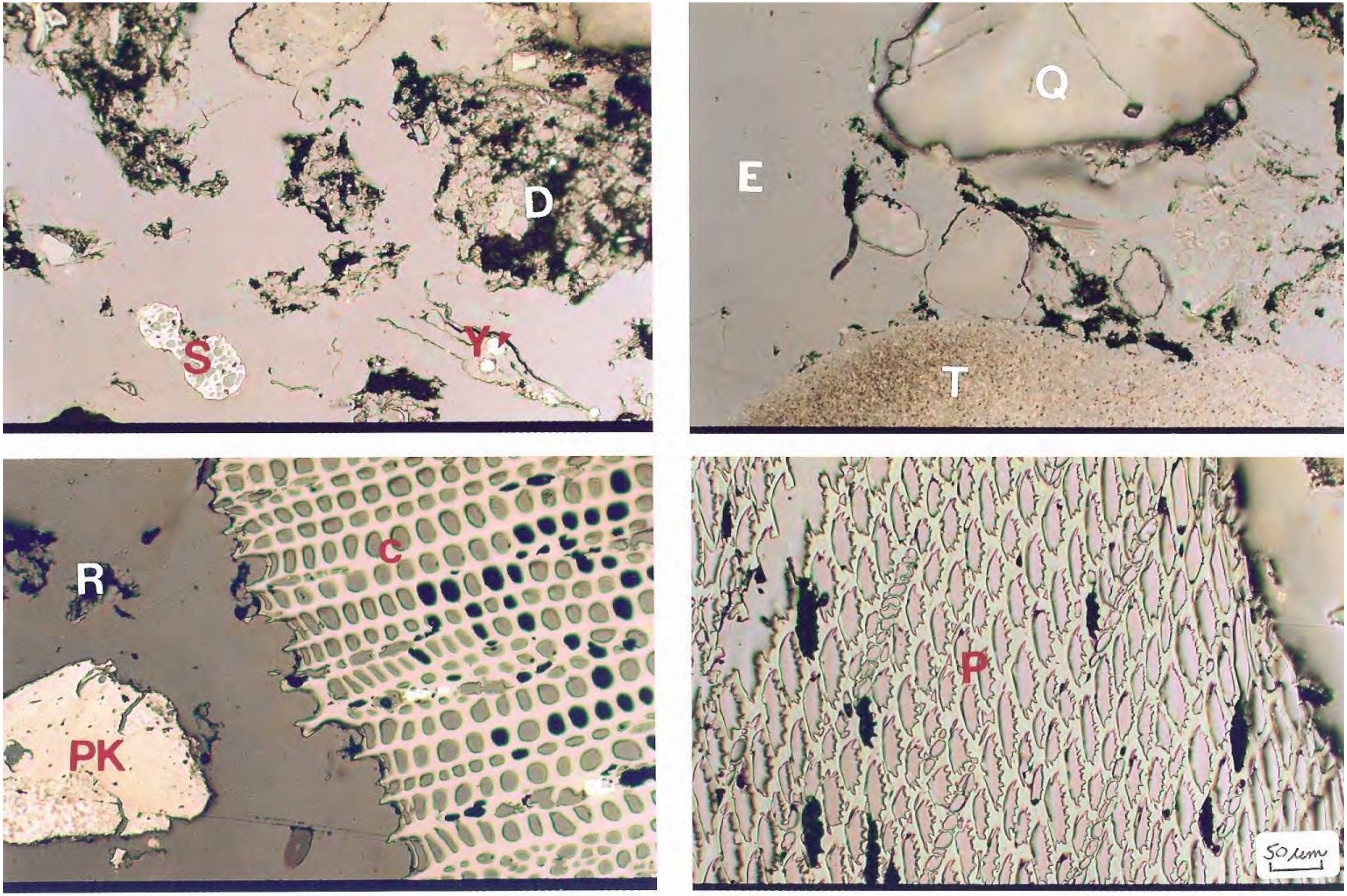

Figure 1: Photomicrographs of Stanford's Sample Labeled NLU-402 Showing; C=Charcoal, T=Pitch-Like, P=Cellular Organic Plant Tissue, R=Particulate Plant, D=Diatom Aggregate (matt), PK=Pitch Coke, Q=Quartz, Y=Pyrite and E=Epoxy Mounting Media. Reflected Light In Air, X250.

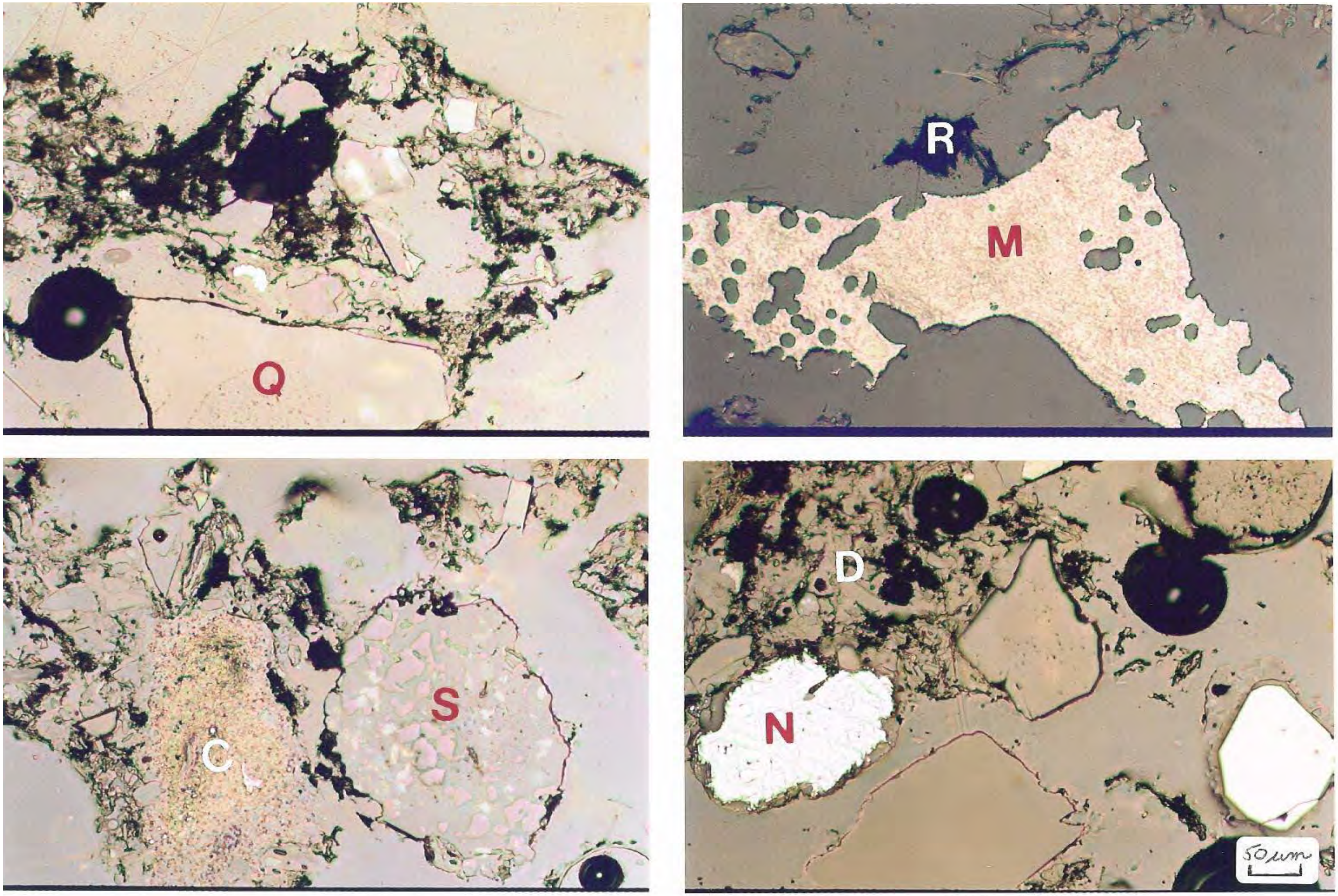

Figure 2: Photomicrographs of Stanford's Sample Labeled NLU-402 Showing; C=Carbon Black Aggregate, R=Particulate Plant, D=Diatom Aggregate (matt), M=Metallurgical Coke, Q=Quartz, S=Slag and N=Metallic. Reflected Light In Air, X250.

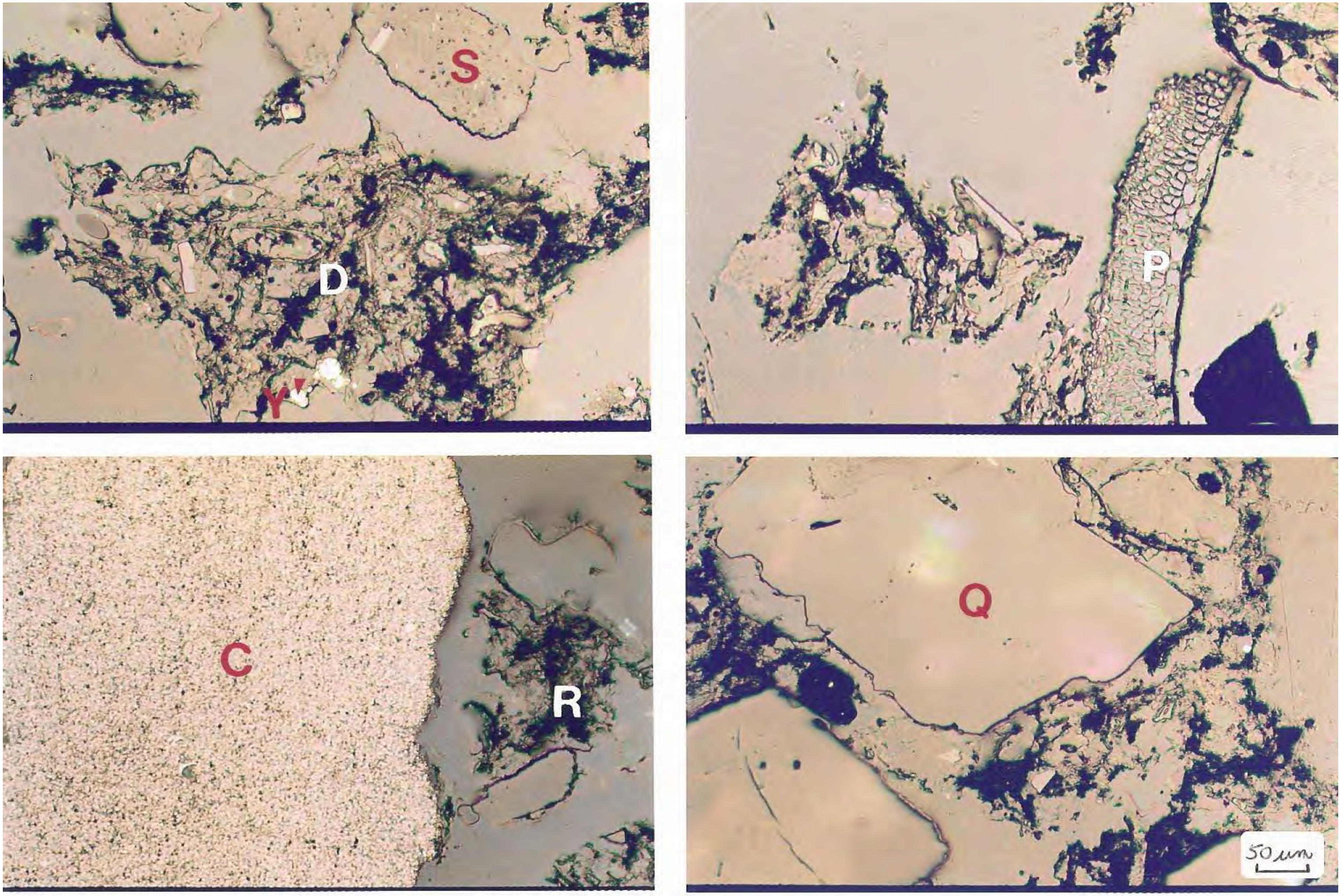

Figure 3: **Photomicrographs of Stanford's Sample Labeled NLU-402 Showing; C=Carbon Black Aggregate, P=Cellular Organic Plant Material, R=Particulate Plant, D=Diatom Aggregate (matt), Q=Quartz, S=Slag and Y=Pyrite. Reflected Light In Air, X250.**

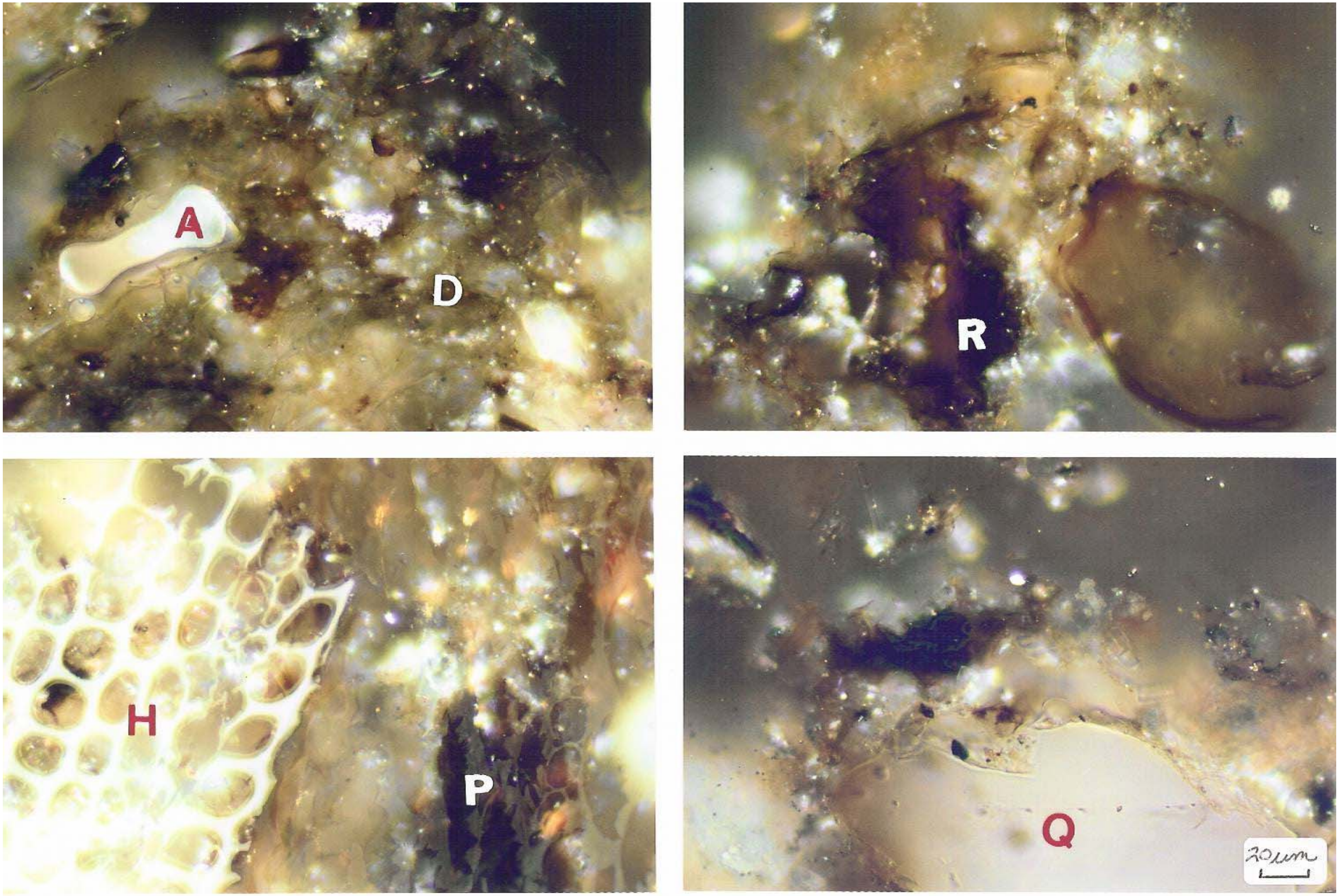

Figure 4: Photomicrographs of Stanford's Sample Labeled NLU-402 Showing; H=Charcoal, P=Cellular Organic Plant Material, R=Particulate Plant, D=Diatom Aggregate (matt), A=Diatom and Q=Quartz. Reflected Light In Oil, X600.

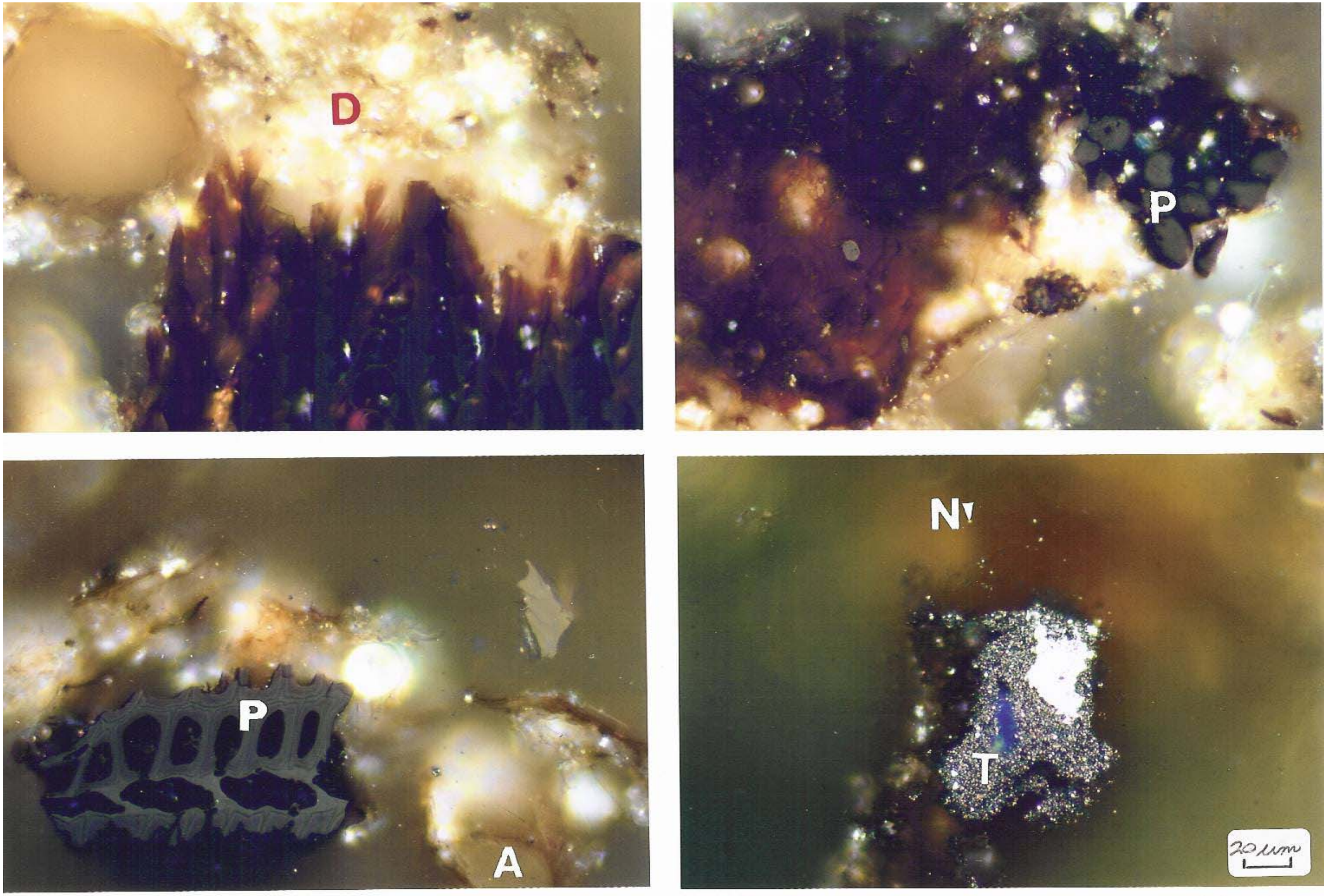

Figure 5: Photomicrographs of Stanford's Sample Labeled NLU-402 Showing; T=Pitch with QI, N=Individual QI, P=Cellular Organic Plant Material, D=Diatom Aggregate (matt) and A=Diatom. Reflected Light In Oil, X600.

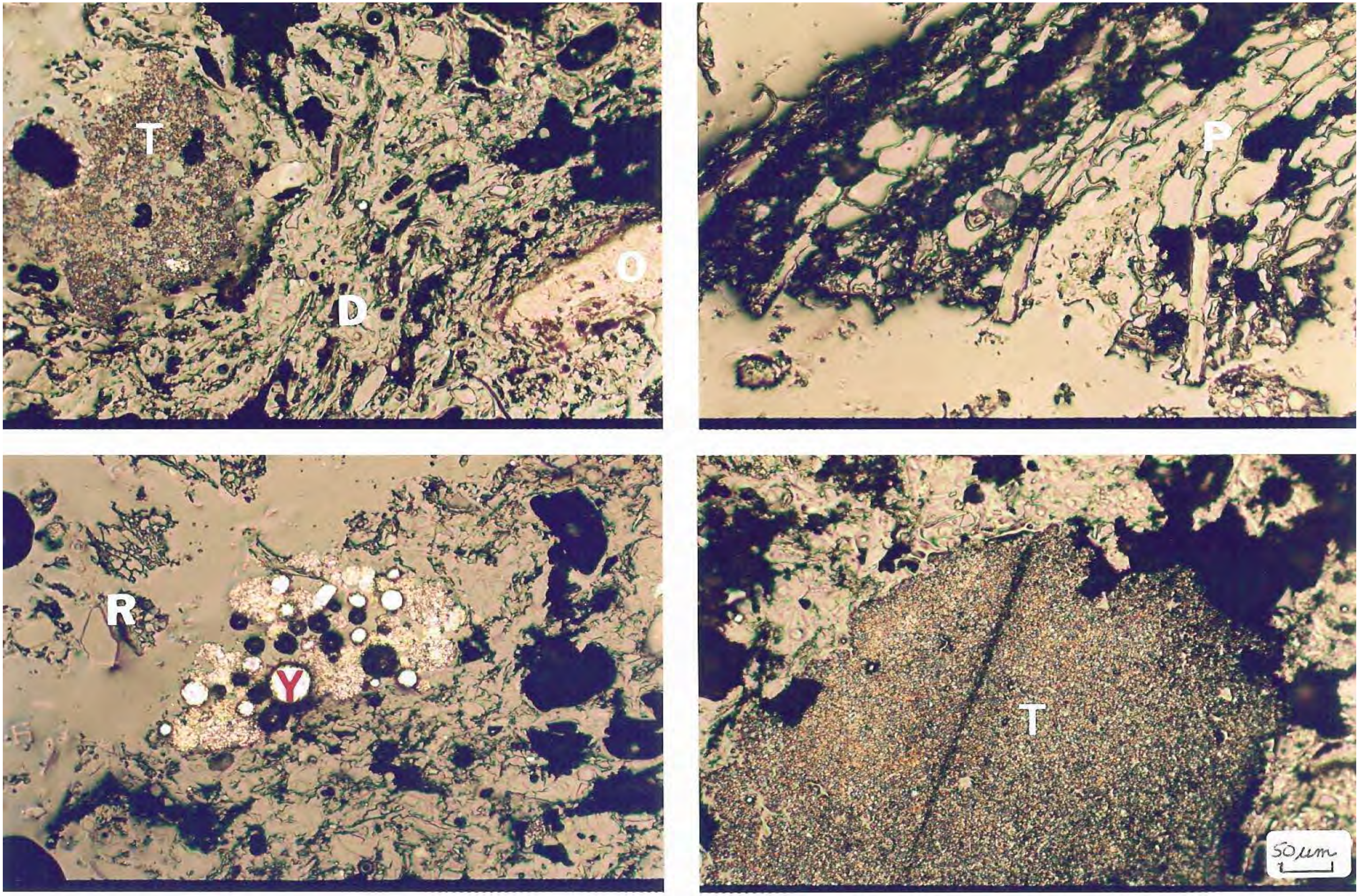

Figure 6: Photomicrographs of Stanford's Sample Labeled NLU-45DC Showing; T=Pitch with QI, P=Cellular Organic Plant Material, R=Particulate Plant, D=Diatomaceous Mass, O=Other Mineral and Y=Pyrite. Reflected Light In Air, X250.

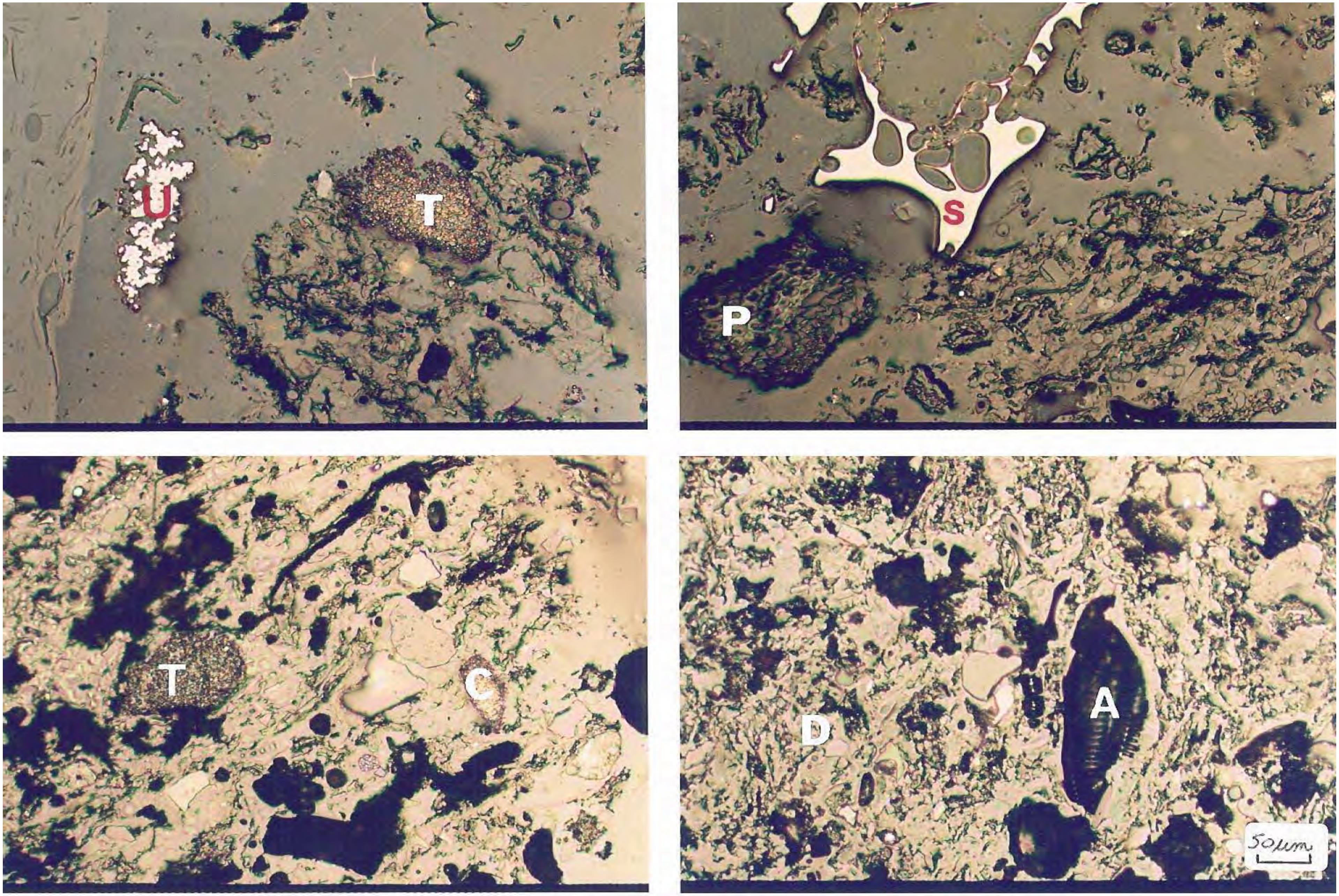

Figure 7: Photomicrographs of Stanford's Sample Labeled NLU-45DC Showing; C=Carbon Black Aggregate (small), T=Pitch with Normal QI, P=Cellular Organic Plant Material, D=Diatomaceous Mass, A=Diatom, S=Cenosphere and U=Spherulytic Carbon. Reflected Light In Air, X250.