



Particulado Volátil e Aerotransportado

AGG 0201 Geoquímica de Ambientes Superficiais
Profª. Andréa Teixeira Ustra

Material particulado sólido na atmosfera

- Partículas emitidas ou formadas na atmosfera
- Partículas geradas por processos naturais e antropogênicos

Material Particulado (MP): Partículas sólidas e líquidas na atmosfera

≠

Aerosol : MP em suspensão e gás no ar

Propriedades físico-químicas e mineralógicas,
além da sua distribuição espacial e temporal

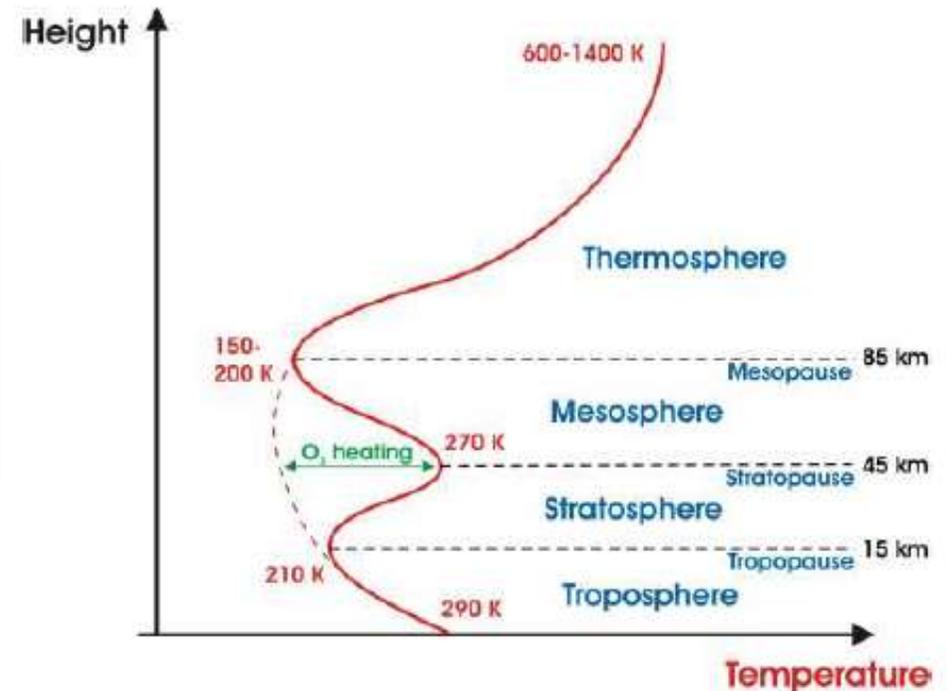
- impacto ambiental local ou planetário
- componente de maior incerteza nos modelos de mudanças climáticas

O estudo de MP atmosférico busca o entendimento de interações entre a Terra sólida e sua hidrosfera, biosfera, atmosfera e antroposfera.

Tipos e fontes

- Partículas primárias: emitidas diretamente na atmosfera (e.g. poeira mineral)
- Partículas secundárias: formadas na atmosfera pela conversão gás-partícula (e.g. nitrato de amônia).

MP ocorrem tanto na troposfera quanto na estratosfera



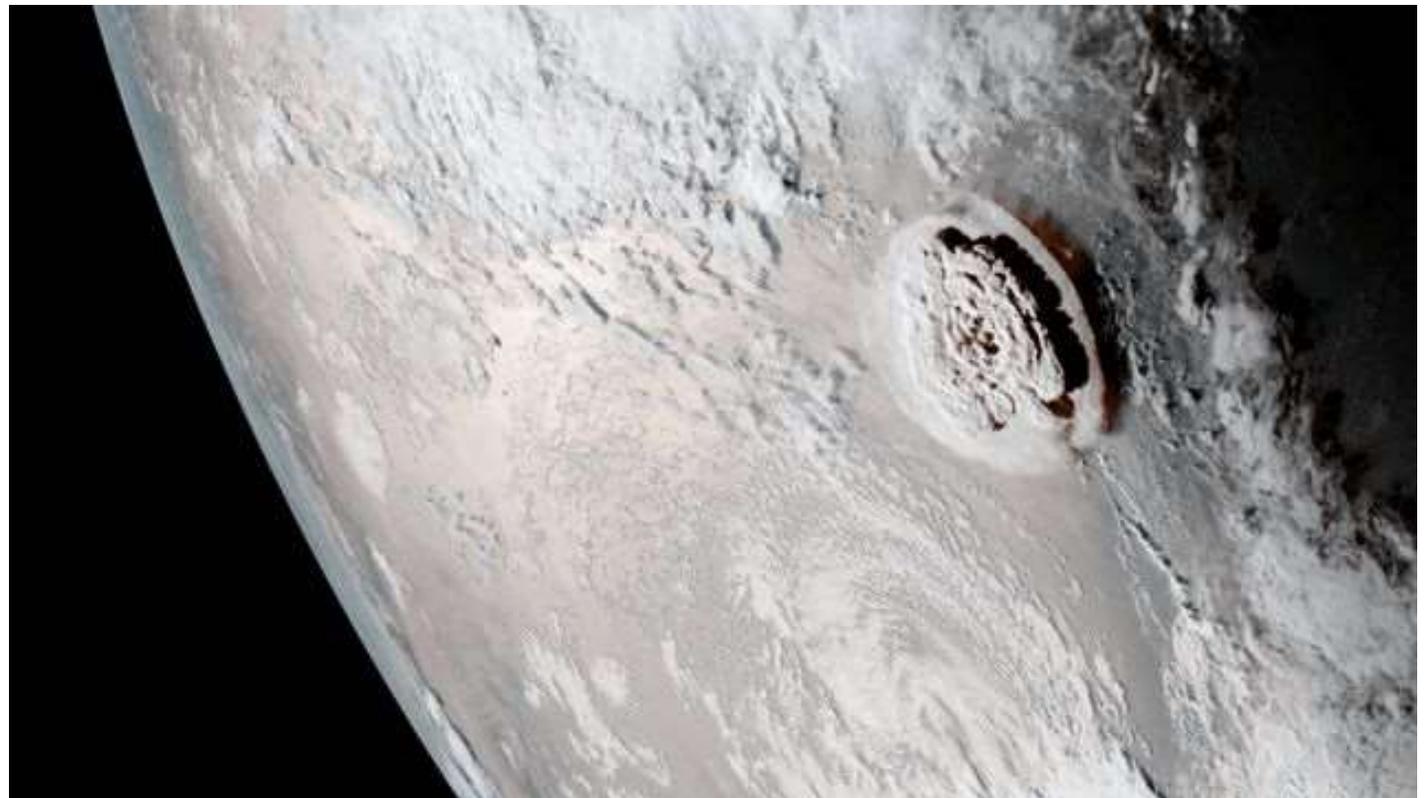
MP naturais na troposfera:
erupções vulcânicas, bolhas na
superfície do mar, tempestades
de poeira e queimadas



MP naturais na troposfera:
erupções vulcânicas, bolhas na
superfície do mar, tempestades
de poeira e queimadas



Janeiro de 2022 – Erupção do vulcão Tonga



Nuvem de cinza se espalha por ilhas de Tonga



Fonte: USGS

BBC

Erupção deixa poucos rastros acima da água em Hunga-Tonga e Hunga Ha'apai

7 Jan 2022
Duas ilhas estavam ligadas por uma cratera vulcânica



15 Jan 2022
Duas horas antes da erupção, a cratera é coberta pelo mar



15 Jan 2022
Depois da explosão, radar mostra apenas terreno elevado acima da água



Fonte: Copernicus/ESA/Sentinel Hub, Planet Labs

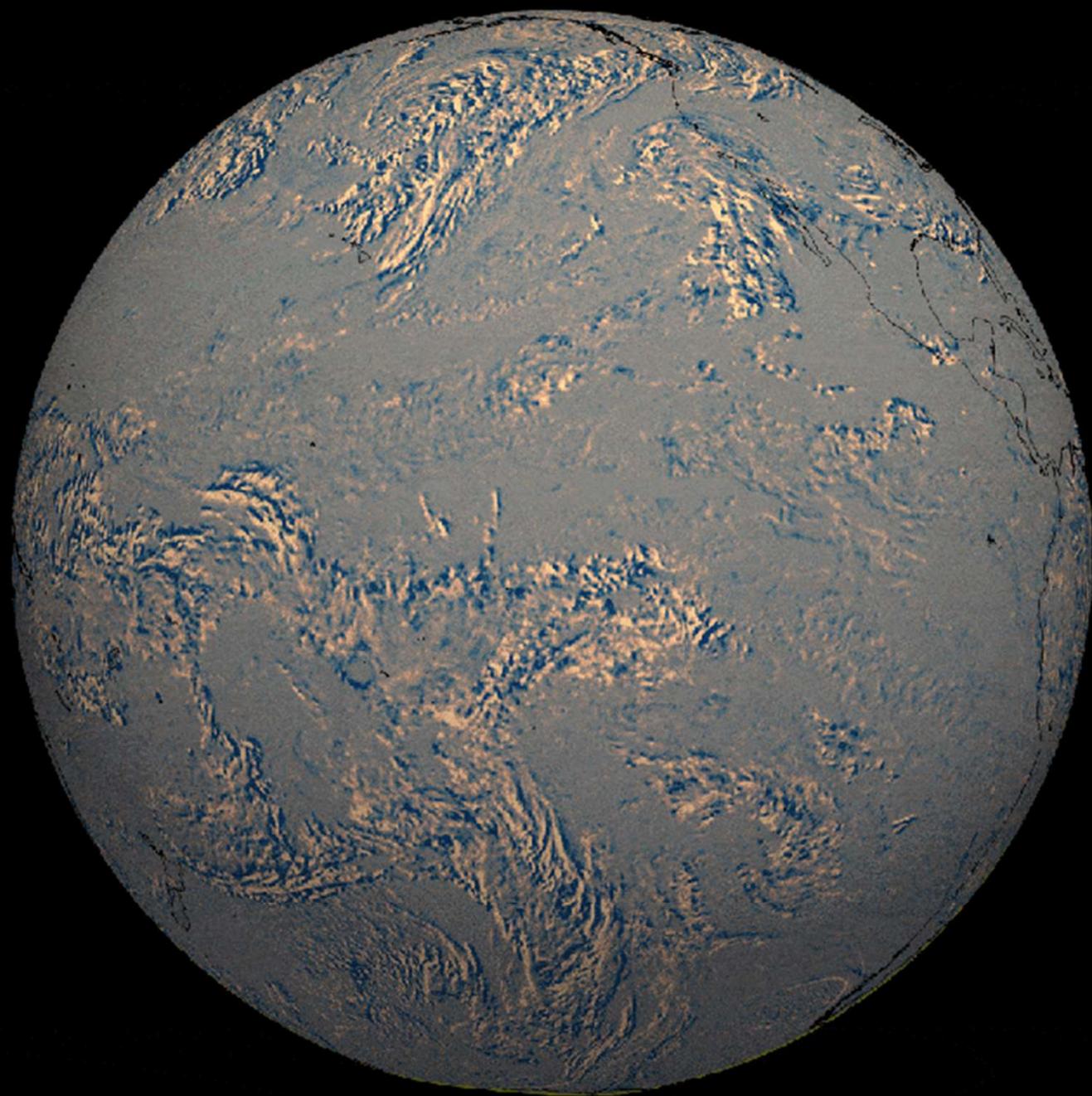
BBC



Violência do vulcão explicada

<https://www.bbc.com/portuguese/internacional-60008124>







MP naturais na troposfera:
erupções vulcânicas, bolhas na
superfície do mar, tempestades
de poeira e queimadas



Partículas biogênicas: detritos vegetais, fragmentos
animais, pólen, esporos, algas, fungos, bactérias e
vírus, além de partículas orgânicas secundárias
formadas por compostos orgânicos voláteis biogênicos

MP naturais na troposfera:
erupções vulcânicas, bolhas na superfície do mar, tempestades de poeira e queimadas



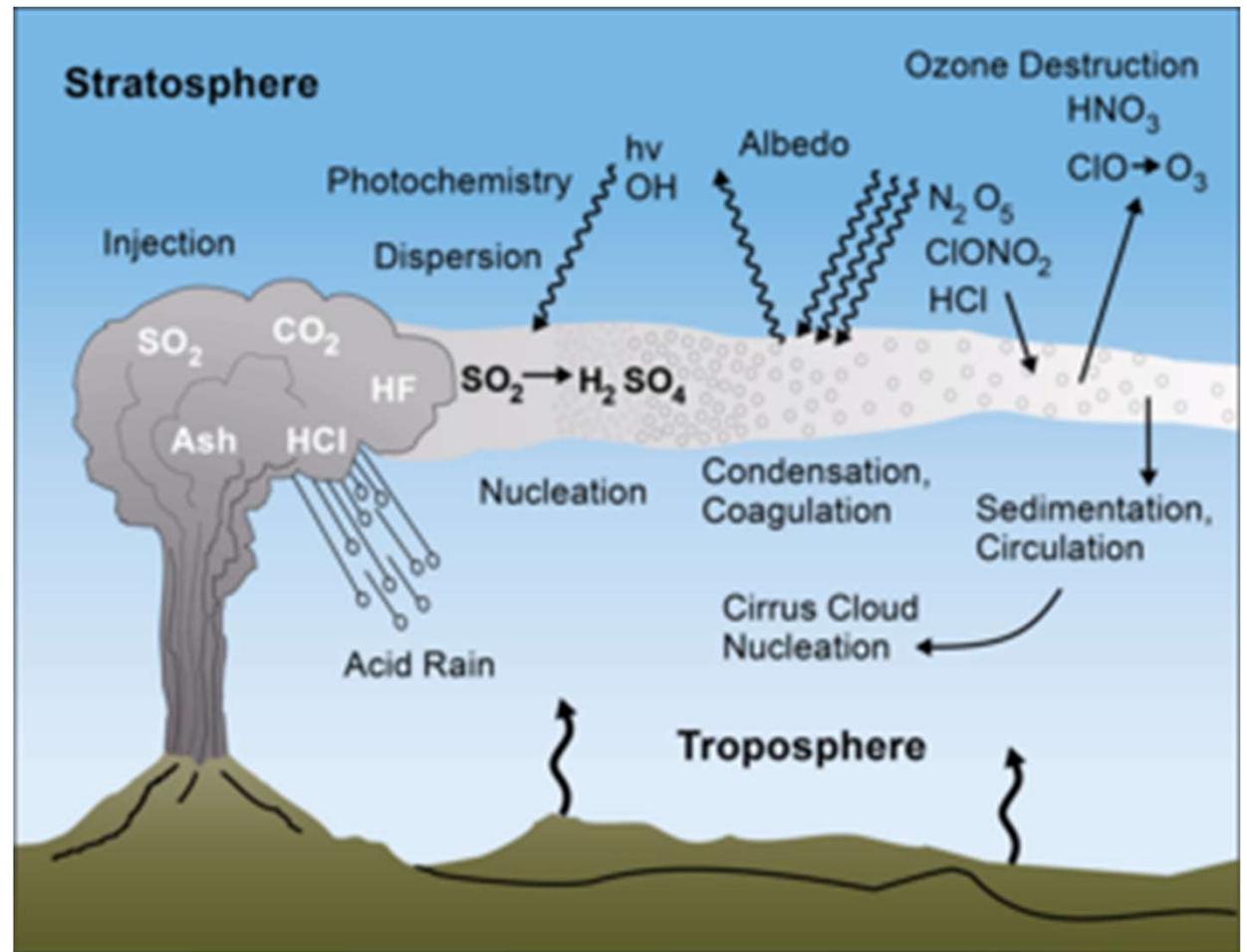
Partículas biogênicas: detritos vegetais, fragmentos animais, pólen, esporos, algas, fungos, bactérias e vírus, além de partículas orgânicas secundárias formadas por compostos orgânicos voláteis biogênicos

Partículas antropogênicas
resultantes de atividade industrial, construção civil, tráfego, mineração, incineração e combustão de combustíveis fósseis e biomassa



MP na estratosfera: material extraterrestre e grandes erupções vulcânicas. Ocorrem também partículas de ácido sulfúrico (H_2SO_4) produzidas pela oxidação de sulfeto de carbono (COS) (oceanos) e dióxido de enxofre (SO_2) (vulcões)

MP na estratosfera é caracterizado por baixas concentrações de partículas, menor diversidade de partículas e maiores tempos de residência do que o MP na troposfera



Tamanho das partículas

Diâmetros variam desde poucos nanômetros (nm)
até dezenas de micrometros (μm)

$d < 2.5 \mu\text{m}$ (MP 2.5) - *finas*

$d > 2.5 \mu\text{m}$ - *grossas*



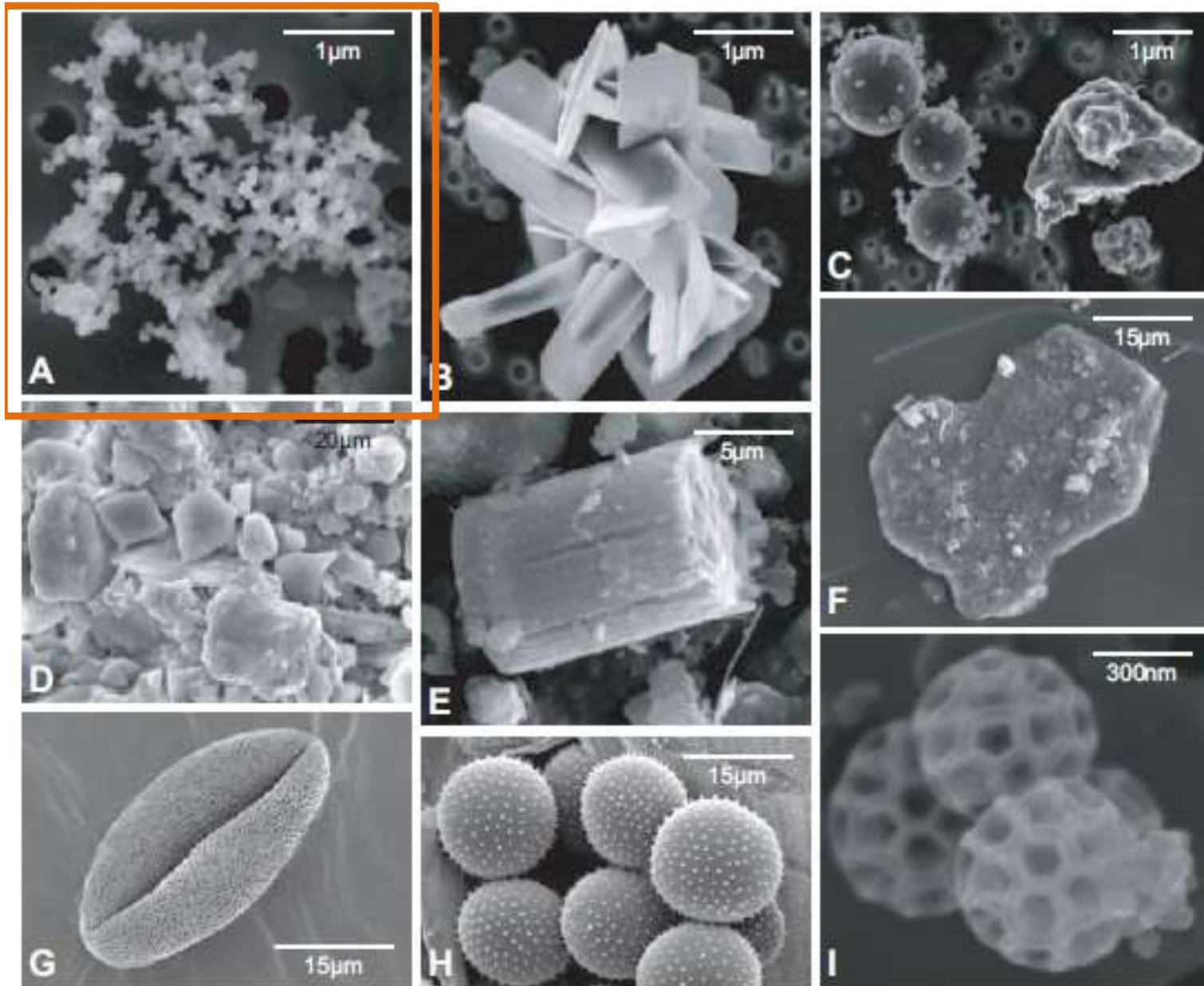


FIGURE 4 Scanning electron microscope images of anthropogenic (A–C) and natural (D–I) particles. (A) Typical aggregate of soot particles, Strasbourg; (B) combustion-derived Ca-sulfate crystals, Strasbourg; (C) plagioclase and spheres of combustion-derived magnetite, Strasbourg; (D) calcite and clays in Saharan dust, collected in Barcelona; (E) diatom in Saharan dust, collected at Santa Cruz de Tenerife (Canary Islands); (F) illite with attached halite crystals (small bright cubes) in Saharan dust, collected at Santa Cruz de Tenerife (Canary Islands); (G) firebush pollen (*Hamelia patens*); (H) spores of wheat leaf rust (*Puccinia triticina*); (I) agglomerate of three brochosomes (carbon-rich particles produced by leaf-hopping insects as a water-repellent body coat), Strasbourg. IMAGES COURTESY OF THE ELECTRON MICROSCOPY GROUP AT THE UNIVERSITY OF BASEL (G, H) AND THE RESEARCH GROUPS OF THE AUTHORS.

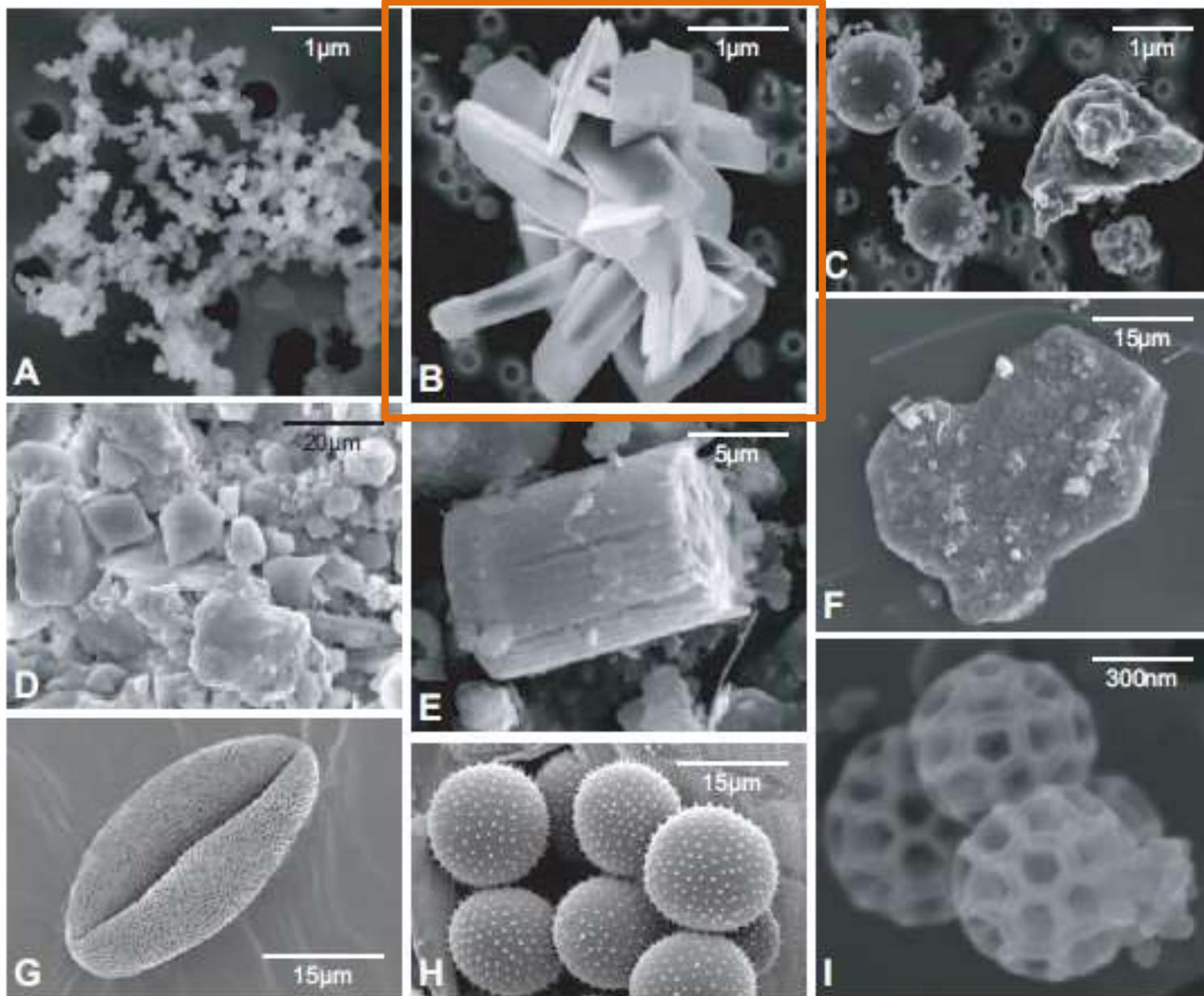


FIGURE 4 Scanning electron microscope images of anthropogenic (A–C) and natural (D–I) particles. (A) Typical aggregate of soot particles, Strasbourg; (B) combustion-derived Ca-sulfate crystals, Strasbourg; (C) plagioclase and spheres of combustion-derived magnetite, Strasbourg; (D) calcite and clays in Saharan dust, collected in Barcelona; (E) diatom in Saharan dust, collected at Santa Cruz de Tenerife (Canary Islands); (F) illite with attached halite crystals (small bright cubes) in Saharan dust, collected at Santa Cruz de Tenerife (Canary Islands); (G) firebush pollen (*Hamelia patens*); (H) spores of wheat leaf rust (*Puccinia triticina*); (I) agglomerate of three brochosomes (carbon-rich particles produced by leaf-hopping insects as a water-repellent body coat), Strasbourg. IMAGES COURTESY OF THE ELECTRON MICROSCOPY GROUP AT THE UNIVERSITY OF BASEL (G, H) AND THE RESEARCH GROUPS OF THE AUTHORS.

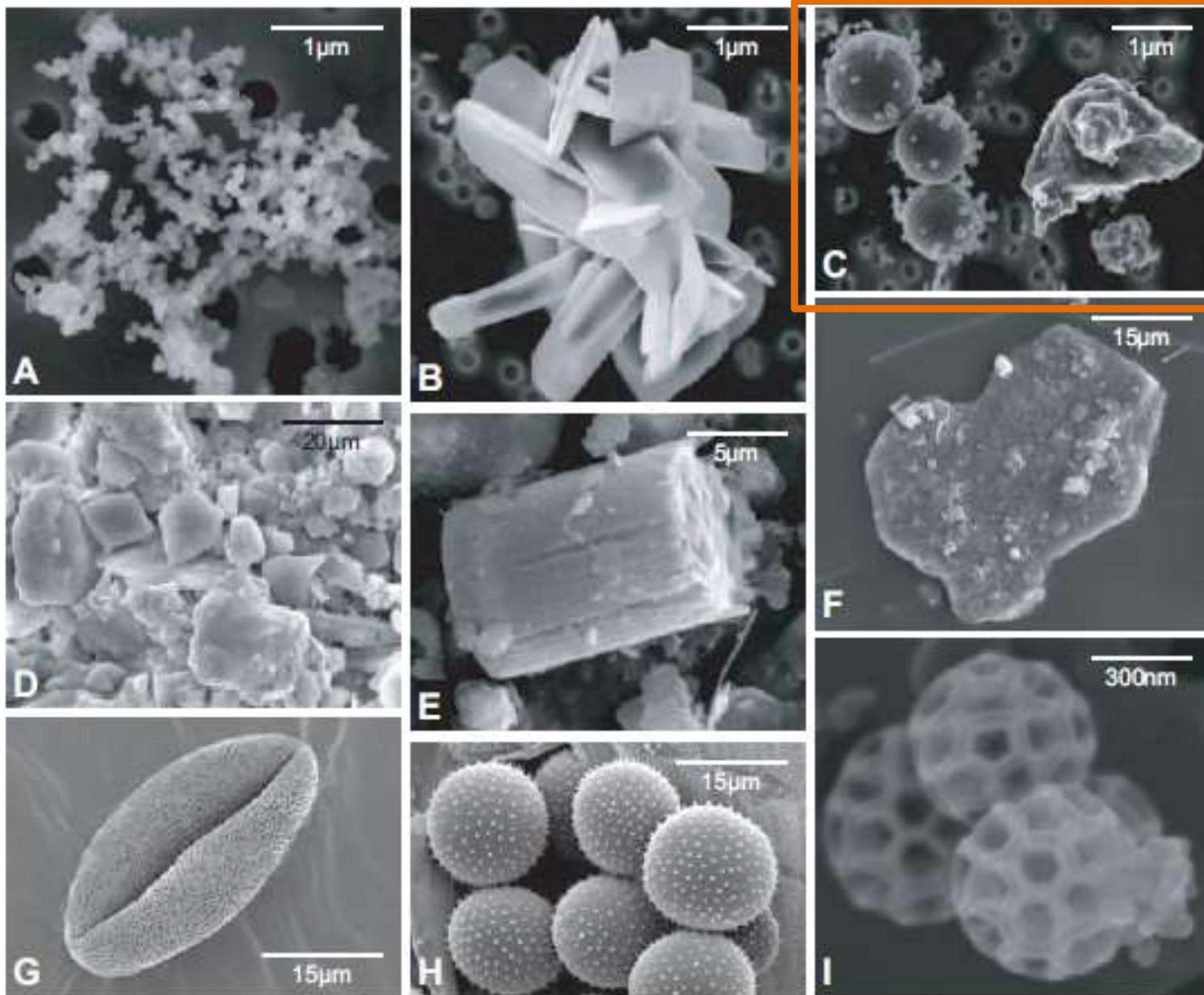


FIGURE 4 Scanning electron microscope images of anthropogenic (A–C) and natural (D–I) particles. (A) Typical aggregate of soot particles, Strasbourg; (B) combustion-derived Ca-sulfate crystals, Strasbourg; (C) plagioclase and spheres of combustion-derived magnetite, Strasbourg; (D) calcite and clays in Saharan dust, collected in Barcelona; (E) diatom in Saharan dust, collected at Santa Cruz de Tenerife (Canary Islands); (F) illite with attached halite crystals (small bright cubes) in Saharan dust, collected at Santa Cruz de Tenerife (Canary Islands); (G) firebush pollen (*Hamelia patens*); (H) spores of wheat leaf rust (*Puccinia triticina*); (I) agglomerate of three brochosomes (carbon-rich particles produced by leaf-hopping insects as a water-repellent body coat), Strasbourg. IMAGES COURTESY OF THE ELECTRON MICROSCOPY GROUP AT THE UNIVERSITY OF BASEL (G, H) AND THE RESEARCH GROUPS OF THE AUTHORS.

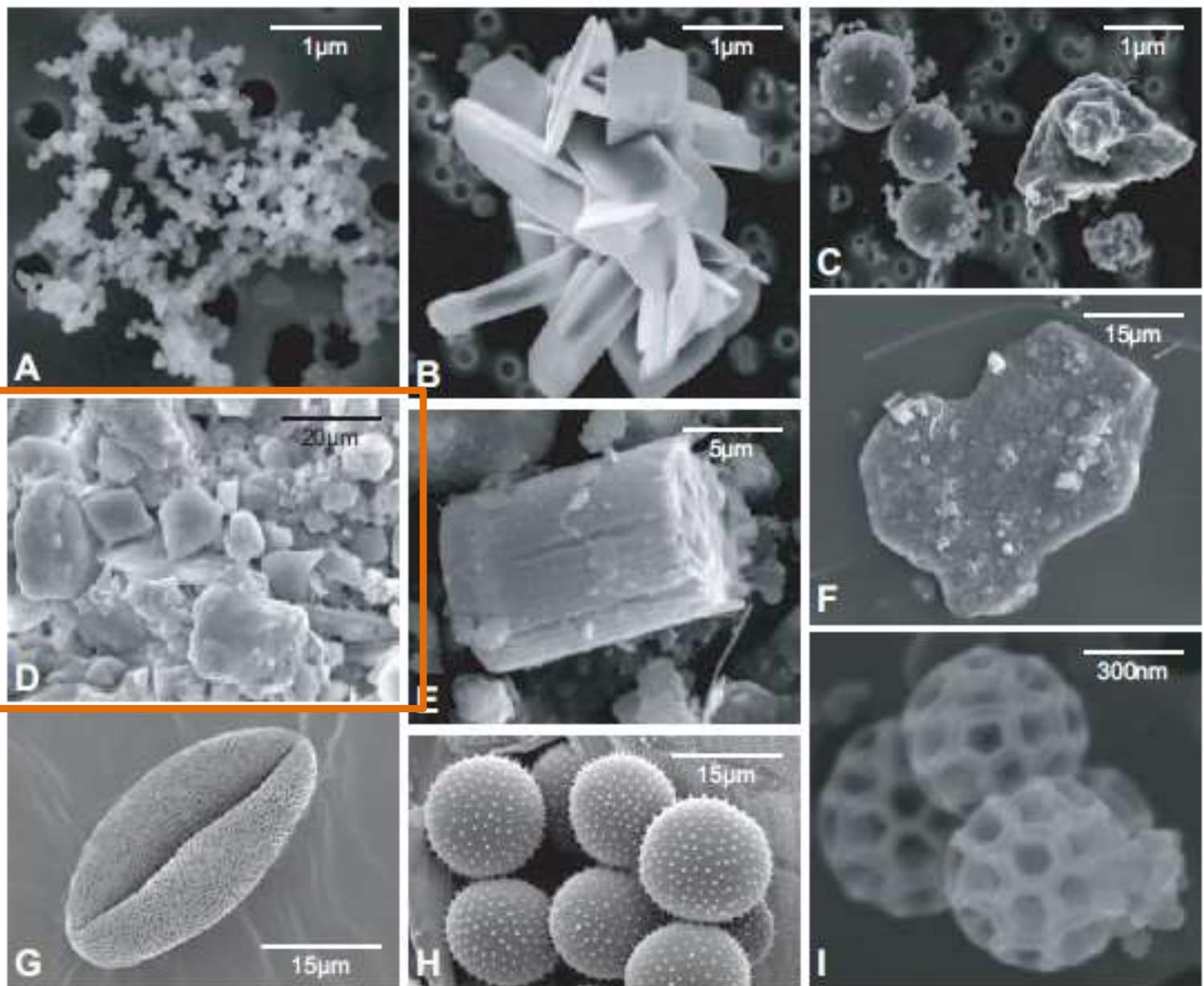


FIGURE 4 Scanning electron microscope images of anthropogenic (A–C) and natural (D–I) particles. (A) Typical aggregate of soot particles, Strasbourg; (B) combustion-derived Ca-sulfate crystals, Strasbourg; (C) plagioclase and spheres of combustion-derived magnetite, Strasbourg; (D) calcite and clays in Saharan dust, collected in Barcelona; (E) diatom in Saharan dust, collected at Santa Cruz de Tenerife (Canary Islands); (F) illite with attached halite crystals (small bright cubes) in Saharan dust, collected at Santa Cruz de Tenerife (Canary Islands); (G) firebush pollen (*Hamelia patens*); (H) spores of wheat leaf rust (*Puccinia triticina*); (I) agglomerate of three brochosomes (carbon-rich particles produced by leaf-hopping insects as a water-repellent body coat), Strasbourg. IMAGES COURTESY OF THE ELECTRON MICROSCOPY GROUP AT THE UNIVERSITY OF BASEL (G, H) AND THE RESEARCH GROUPS OF THE AUTHORS.

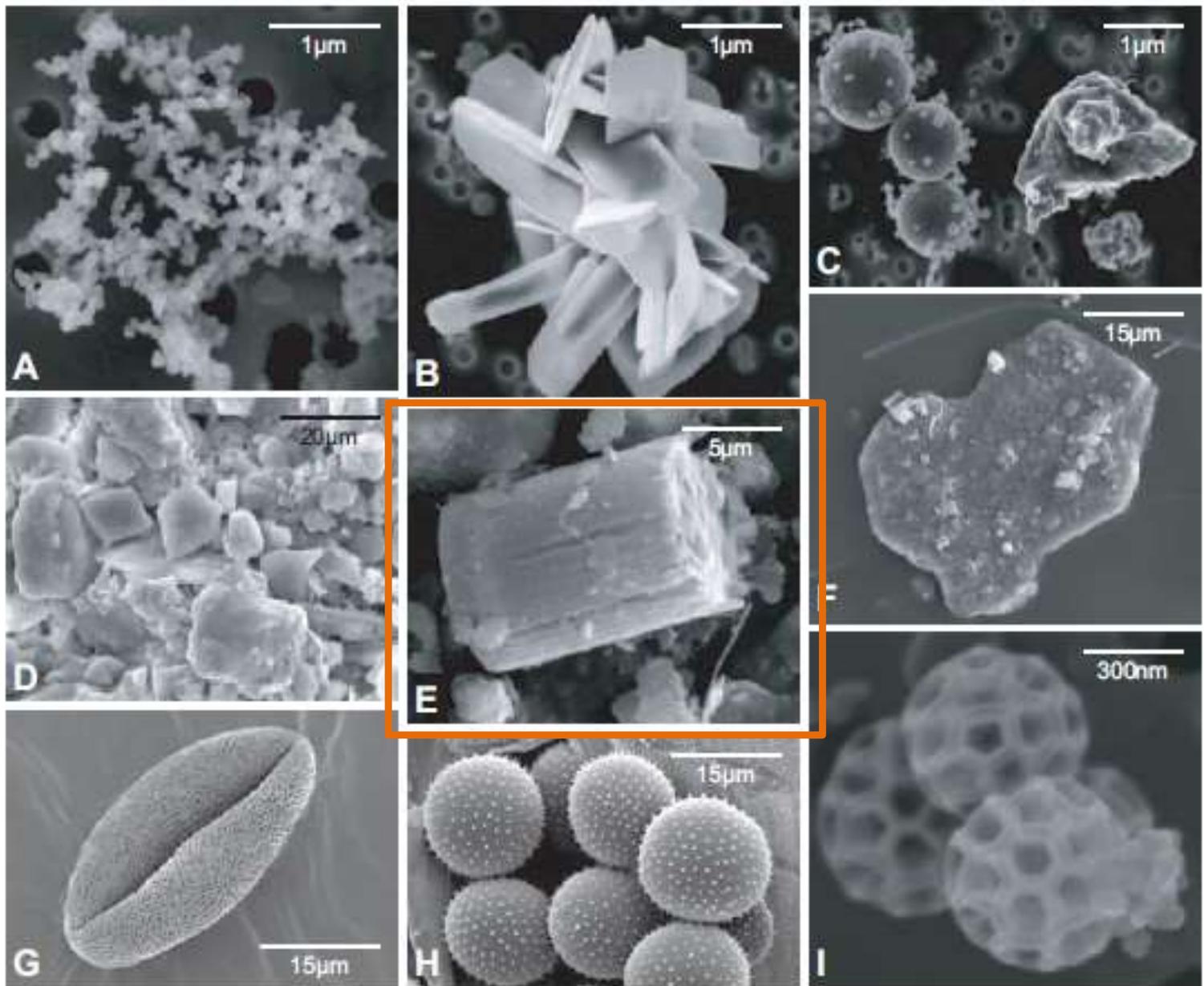


FIGURE 4 Scanning electron microscope images of anthropogenic (A–C) and natural (D–I) particles. (A) Typical aggregate of soot particles, Strasbourg; (B) combustion-derived Ca-sulfate crystals, Strasbourg; (C) plagioclase and spheres of combustion-derived magnetite, Strasbourg; (D) calcite and clays in Saharan dust, collected in Barcelona; (E) diatom in Saharan dust, collected at Santa Cruz de Tenerife (Canary Islands); (F) illite with attached hematite crystals (small bright cubes) in Saharan dust, collected at Santa Cruz de Tenerife (Canary Islands); (G) firebush pollen (*Hamelia patens*); (H) spores of wheat leaf rust (*Puccinia triticina*); (I) agglomerate of three brochosomes (carbon-rich particles produced by leaf-hopping insects as a water-repellent body coat), Strasbourg. IMAGES COURTESY OF THE ELECTRON MICROSCOPY GROUP AT THE UNIVERSITY OF BASEL (G, H) AND THE RESEARCH GROUPS OF THE AUTHORS.

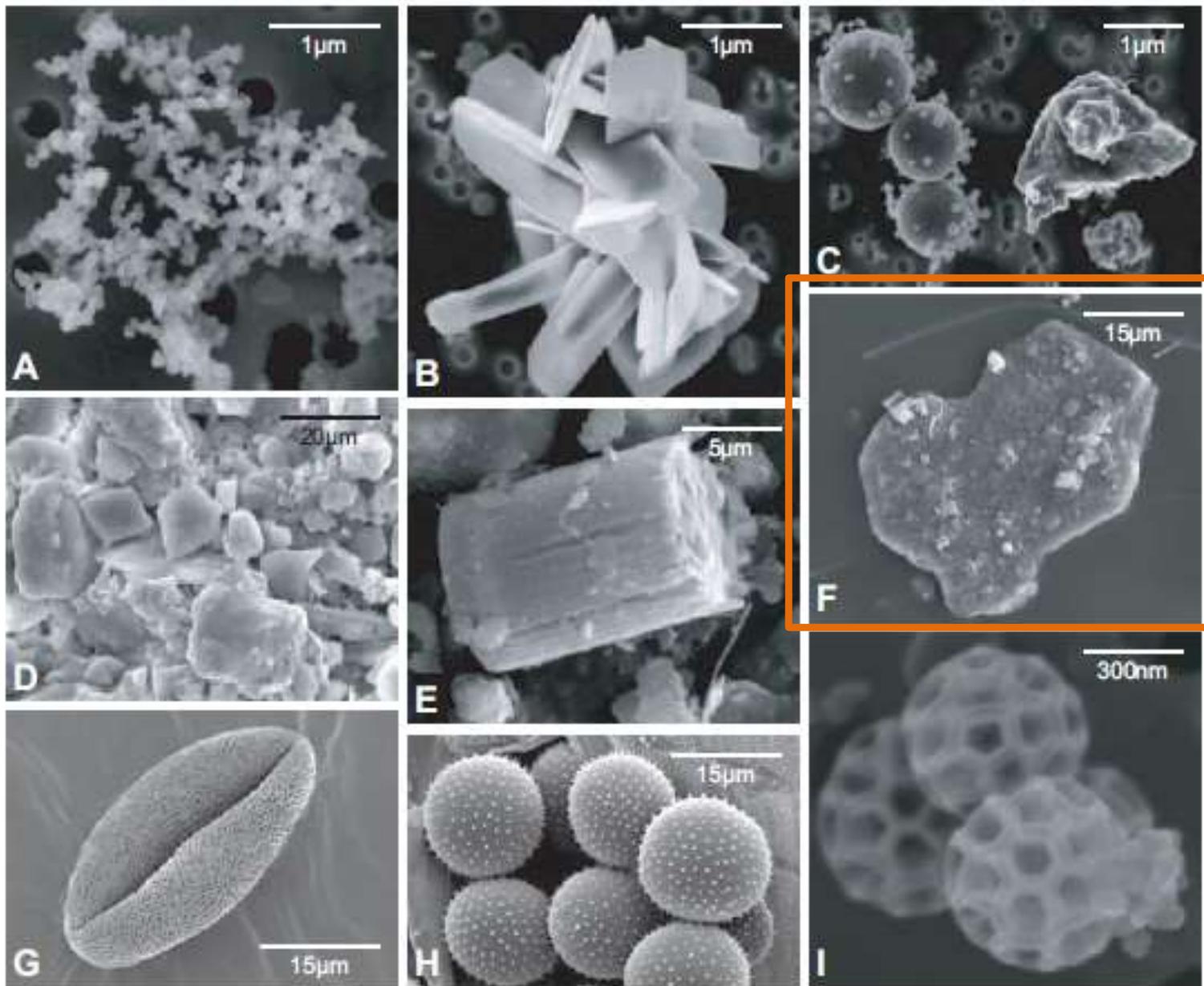


FIGURE 4 Scanning electron microscope images of anthropogenic (A–C) and natural (D–I) particles. (A) Typical aggregate of soot particles, Strasbourg; (B) combustion-derived Ca-sulfate crystals, Strasbourg; (C) plagioclase and spheres of combustion-derived magnetite, Strasbourg; (D) calcite and clays in Saharan dust, collected in Barcelona; (E) diatom in Saharan dust, collected at Santa Cruz de Tenerife (Canary Islands); (F) illite with attached halite crystals (small bright cubes) in Saharan dust, collected at Santa Cruz de Tenerife (Canary Islands); (G) firebush pollen (*Hamelia patens*); (H) spores of wheat leaf rust (*Puccinia triticina*); (I) agglomerate of three brochosomes (carbon-rich particles produced by leaf-hopping insects as a water-repellent body coat), Strasbourg. IMAGES COURTESY OF THE ELECTRON MICROSCOPY GROUP AT THE UNIVERSITY OF BASEL (G, H) AND THE RESEARCH GROUPS OF THE AUTHORS.

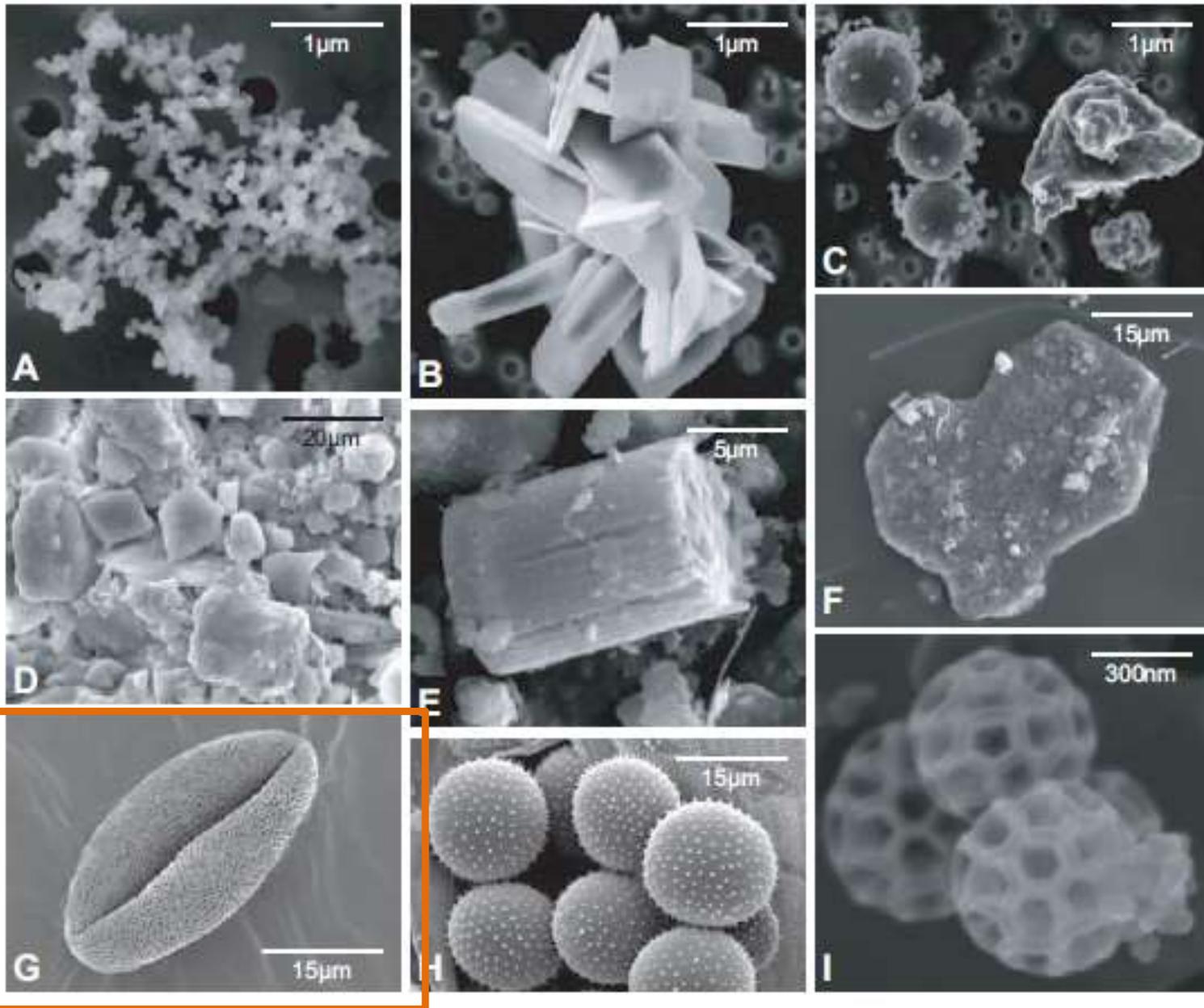


FIGURE 4 Scanning electron microscope images of anthropogenic (A–C) and natural (D–I) particles. (A) Typical aggregate of soot particles, Strasbourg; (B) combustion-derived Ca-sulfate crystals, Strasbourg; (C) plagioclase and spheres of combustion-derived magnetite, Strasbourg; (D) calcite and clays in Saharan dust, collected in Barcelona; (E) diatom in Saharan dust, collected at Santa Cruz de Tenerife (Canary Islands); (F) illite with attached halite crystals (small bright cubes) in Saharan dust, collected at Santa Cruz de Tenerife (Canary Islands); (G) firebush pollen (*Hamelia patens*); (H) spores of wheat leaf rust (*Puccinia trancina*); (I) agglomerate of three brochosomes (carbon-rich particles produced by leaf-hopping insects as a water-repellent body coat), Strasbourg. IMAGES COURTESY OF THE ELECTRON MICROSCOPY GROUP AT THE UNIVERSITY OF BASEL (G, H) AND THE RESEARCH GROUPS OF THE AUTHORS.

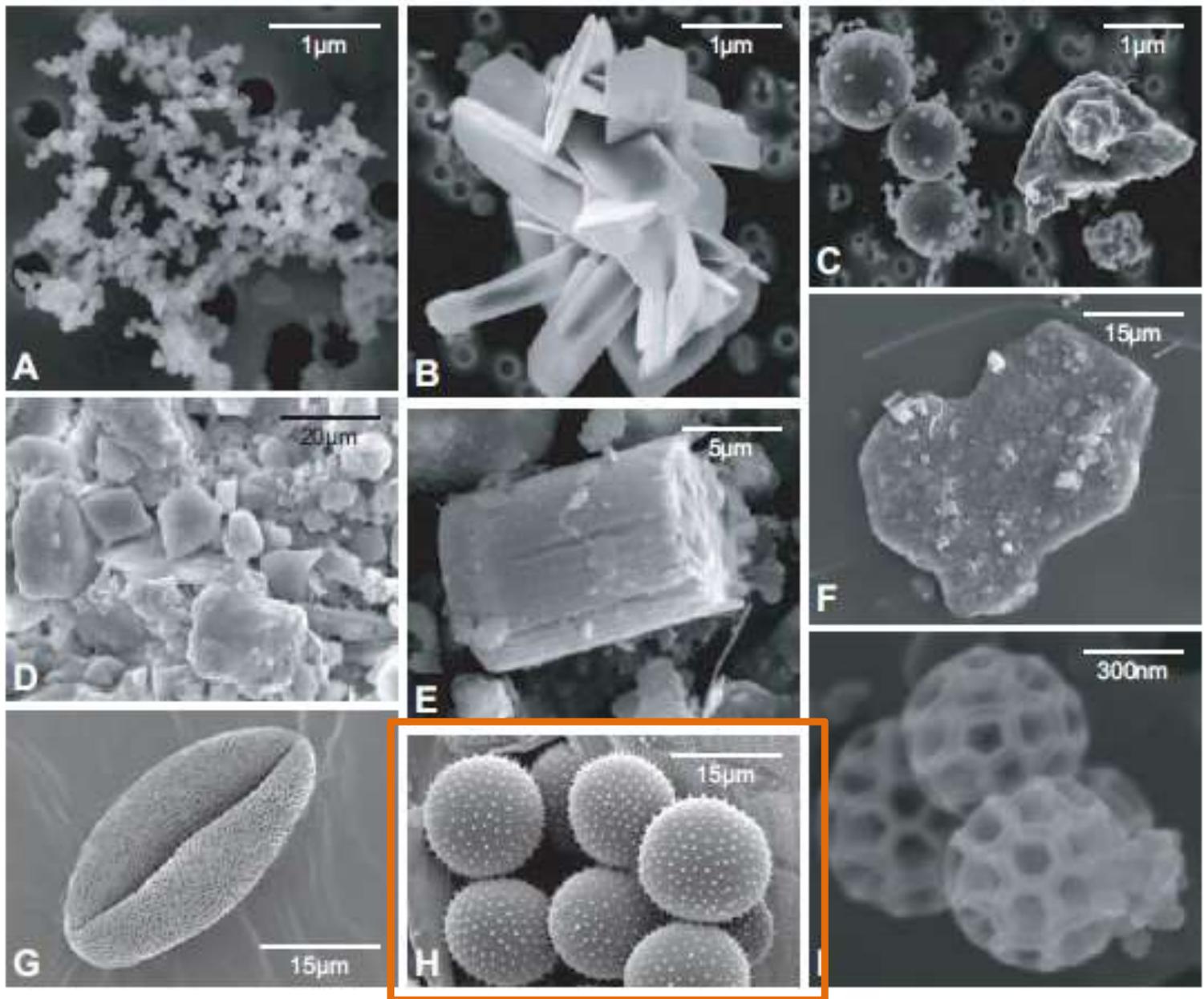


FIGURE 4 Scanning electron microscope images of anthropogenic (A–C) and natural (D–I) particles. (A) Typical aggregate of soot particles, Strasbourg; (B) combustion-derived Ca-sulfate crystals, Strasbourg; (C) plagioclase and spheres of combustion-derived magnetite, Strasbourg; (D) calcite and clays in Saharan dust, collected in Barcelona; (E) diatom in Saharan dust, collected at Santa Cruz de Tenerife (Canary Islands); (F) illite with attached halite crystals (small bright cubes) in Saharan dust, collected at Santa Cruz de Tenerife (Canary Islands); (G) firebush pollen (*Hamelia patens*); (H) spores of wheat leaf rust (*Puccinia triticina*); (I) agglomerate of three brochosomes (carbon-rich particles produced by leaf-hopping insects as a water-repellent body coat), Strasbourg. IMAGES COURTESY OF THE ELECTRON MICROSCOPY GROUP AT THE UNIVERSITY OF BASEL (G, H) AND THE RESEARCH GROUPS OF THE AUTHORS.

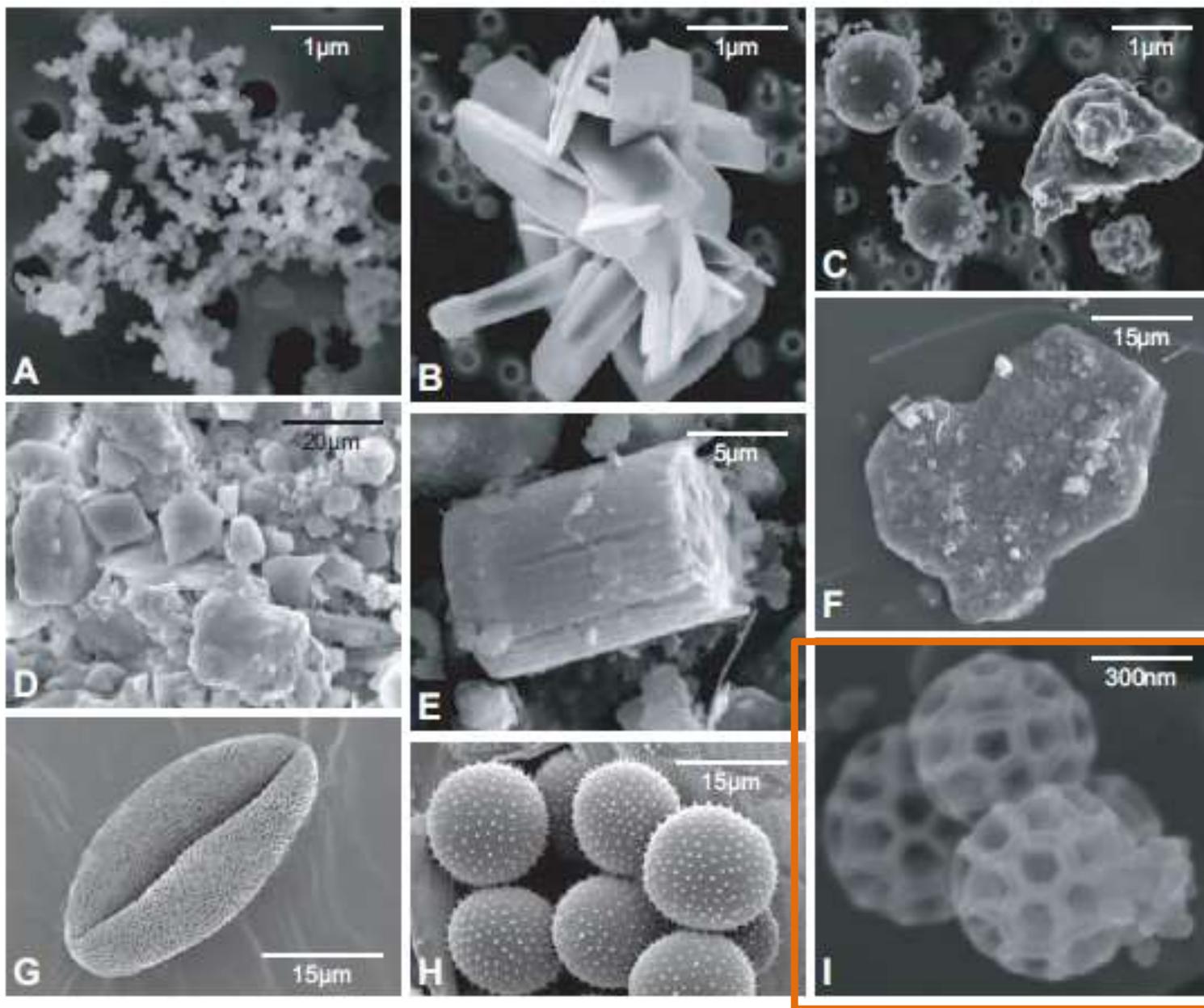


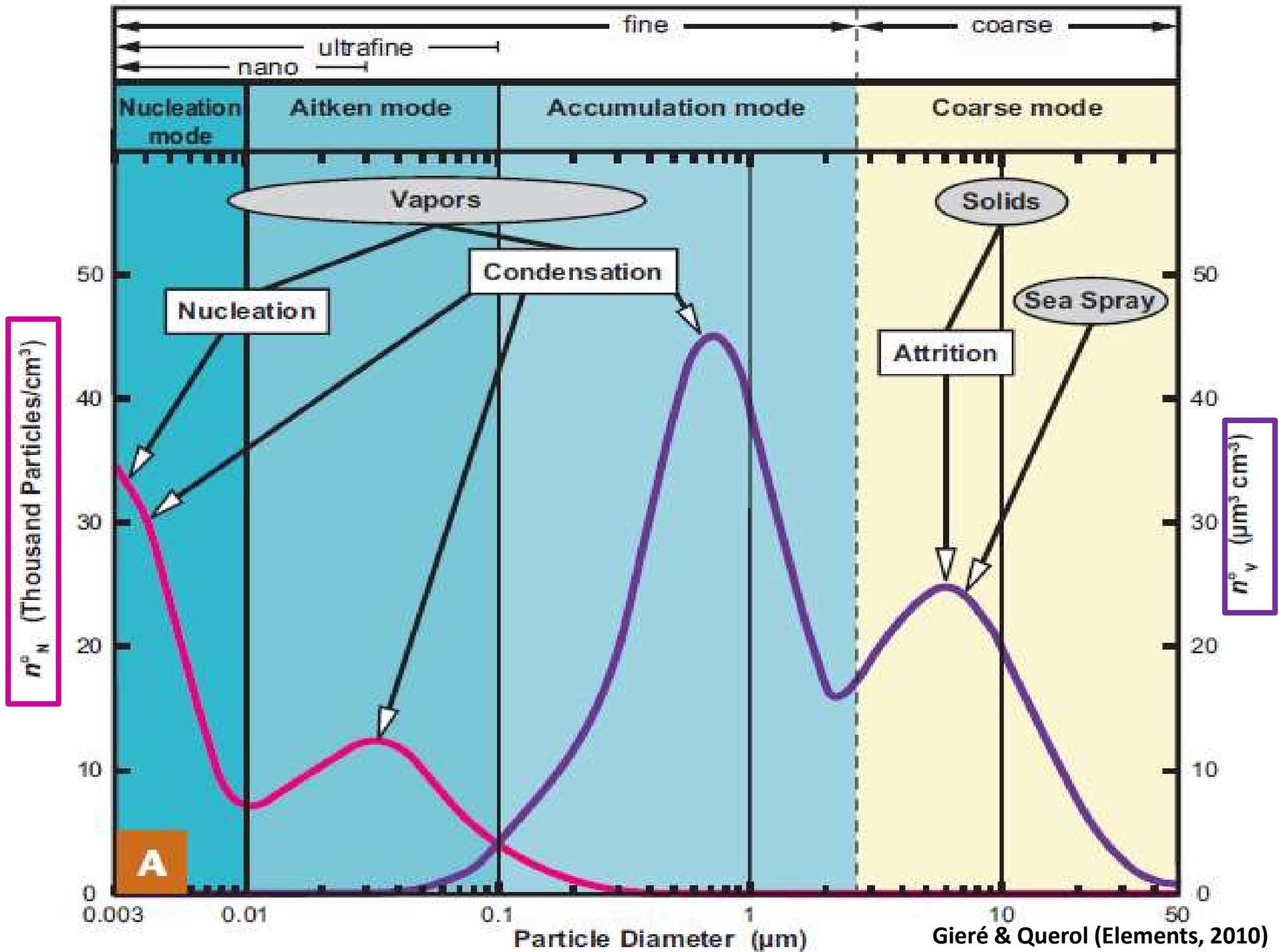
FIGURE 4 Scanning electron microscope images of anthropogenic (A–C) and natural (D–I) particles. (A) Typical aggregate of soot particles, Strasbourg; (B) combustion-derived Ca-sulfate crystals, Strasbourg; (C) plagioclase and spheres of combustion-derived magnetite, Strasbourg; (D) calcite and clays in Saharan dust, collected in Barcelona; (E) diatom in Saharan dust, collected at Santa Cruz de Tenerife (Canary Islands); (F) illite with attached halite crystals (small bright cubes) in Saharan dust, collected at Santa Cruz de Tenerife (Canary Islands); (G) firebush pollen (*Hamelia patens*); (H) spores of wheat leaf rust (*Puccinia triticina*); (I) agglomerate of three brochosomes (carbon-rich particles produced by leaf-hopping insects as a water-repellent body coat), Strasbourg. IMAGES COURTESY OF THE ELECTRON MICROSCOPY GROUP AT THE UNIVERSITY OF BASEL (G, H) AND THE RESEARCH GROUPS OF THE AUTHORS.

$d = 10-100 \text{ nm}$ range Aitken,
formadas principalmente por
coagulação de partículas no
range Nucleação ou
condensação destas

Apesar de serem as mais
abundantes, devido ao seus
tamanhos, contribuem com
pequena proporção no volume
ou massa total

Range Acumulação: partículas
geradas diretamente por
emissões primárias, pela
condensação de vapores de baixa
volatilidade no MP existente e
por coagulação de partículas
menores

O processo de
coagulação é
relativamente lento e
geralmente previne que
partículas finas cresçam
mais do que $\sim 1 \mu\text{m}$



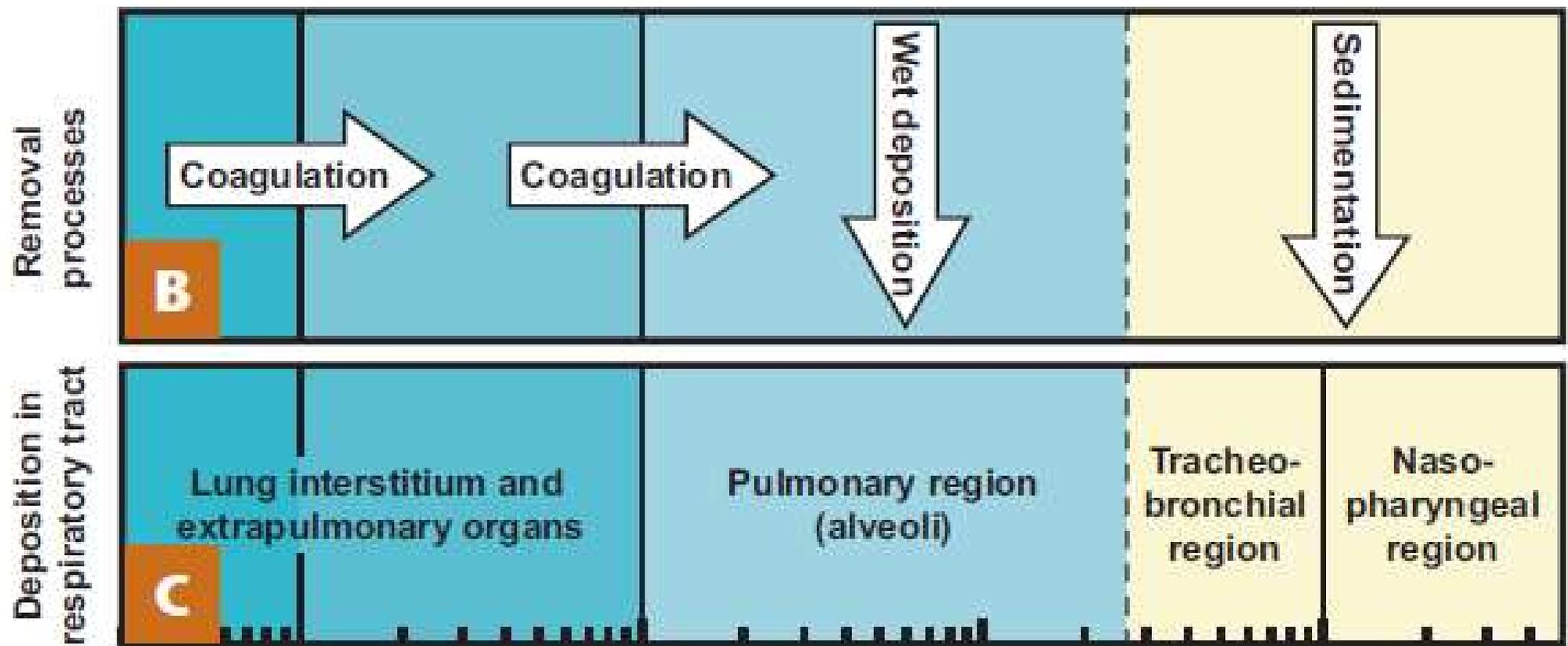
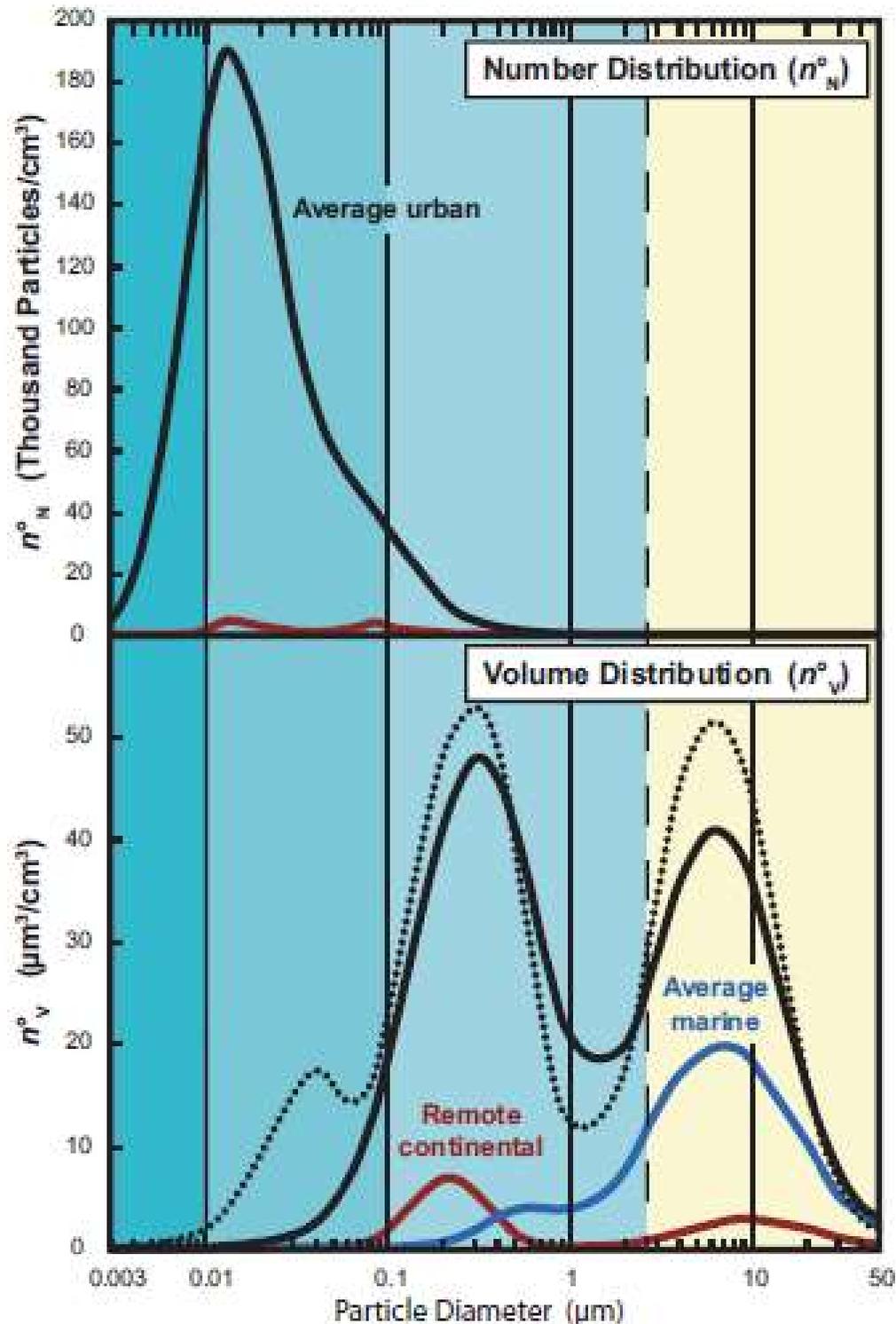


FIGURE 5 (A) Typical size distributions of the number (n^0_N , magenta line) and the volume (n^0_V , purple line) of atmospheric particles per cubic centimeter of air. Source materials of particles shown in grey ellipses; formation processes of particles shown in white rectangles and associated arrows. (B) Particle removal processes. (C) Areas in the respiratory tract where inhaled PM is deposited preferentially. COMPILED FROM WHITBY (1978), SEINFELD AND PANDIS (2006), AND NEWMAN (2001)

MP grosso – gerado por processos mecânicos, como abrasão e fragmentação. Incluem poeira mineral de ambientes áridos, sal marinho e partículas biogênicas e antropogênicas (e.g. abrasão dos pneus e freios de veículos).

Devido ao seu volume e massa, essa fração é relevante para o MP total

Partículas maiores têm menor tempo de residência na atmosfera



Número de partículas por unidade de volume = n^o_N

Volume das partículas por unidade de volume = n^o_V

Ambiente **urbano**, **marinho** e **continental**

Curva tracejada – estrada: n^o_V para partículas finas (combustão) e grossas (abrasão e resuspensão)

Composição química

- **Ambiente marinho:** principalmente Cl^- , Na^+ , e SO_4^{2-} e algum Mg^{2+} .
- **Poeira mineral, cinzas vulcânicas, poeira industrial:** bastante variável (e.g. silicatos, óxidos, sulfatos, carbonatos, ligas, vidro) devido aos diferentes mecanismos de formação e composição das fontes.
- **Partículas aerossóis primárias biogênicas (PBAP)** – teor biológico (e.g. pólen, esporos, fragmentos de plantas: Carbono e elementos secundários (e.g. potássio, fósforo).
- **Partículas carbonáticas derivadas de combustão:** Matéria orgânica e Carbono elementar
- **Compostos inorgânicos secundários:** sais (principalmente de NO_3^- , SO_4^{2-} , and NH_4^+)
- **Aerosol orgânico secundário:** emitidos pela biosfera e fontes antropogênicas (e.g. VOCs).

EC – Elemental carbon. This is a poorly defined term, used in the atmospheric sciences to describe mostly elemental carbon in aerosol particles. EC refers to the most refractory part of carbonaceous aerosol particles, the part that oxidizes above a certain threshold value (established in combustion experiments). It is determined by thermal or thermo-optical methods.

OM – Organic matter. This is a collective term describing thousands of individual organic compounds, which vary widely in regard to physical and chemical properties.

Fluxos

MP atmosférico é predominantemente natural (98 wt%) e não antropogênico (2 wt%)

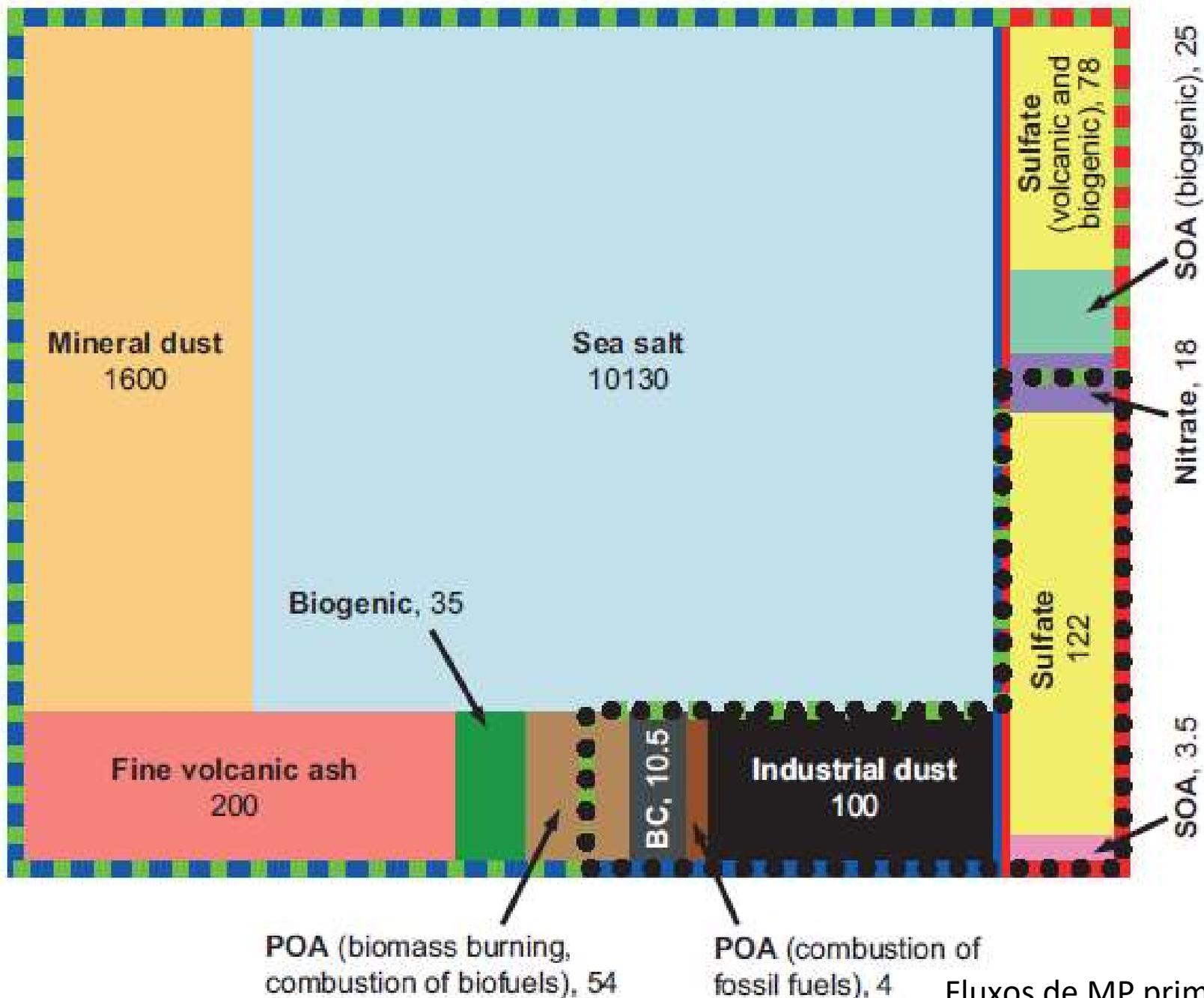
Sal marinho e poeira mineral são os maiores contribuintes para o fluxo global de massa

Das emissões naturais, 3 wt% são provenientes de cinzas vulcânicas

De acordo com estimativas, ~99 wt% do fluxo NATURAL total consiste em partículas primárias, enquanto ~50 wt% do fluxo ANTROPOGÊNICO consiste em aerossóis secundários

Para melhorar a qualidade do ar, é crucial reduzir emissões de gases precursores e não apenas emissões primárias!

■ Natural
 ●●● Anthropogenic
 ▬ Primary
 ▬ Secondary



Fluxos de MP primário e secundário, em Tg/ano (Tg = 10¹² g = 1 Mt), mostrados como uma fração da área do retângulo

- Os **padrões de qualidade do ar estaduais** foram inicialmente estabelecidos em **1976**, pelo **Decreto Estadual nº 8468/76**, e os **padrões nacionais** foram estabelecidos **pelo IBAMA** – Instituto Brasileiro de Meio Ambiente e aprovados pelo **CONAMA** – Conselho Nacional de Meio Ambiente, por meio da Resolução CONAMA nº 03/90.
- Em 2005, a Organização Mundial de Saúde – OMS publicou documento com uma revisão dos valores-guia para os poluentes atmosféricos visando à proteção da saúde da população, à luz dos conhecimentos científicos adquiridos até então.
- Segundo essa publicação, os **padrões de qualidade do ar (PQAr)** variam de acordo com a abordagem adotada para balancear riscos à saúde, viabilidade técnica, considerações econômicas e vários outros fatores políticos e sociais, que, por sua vez, dependem, entre outras coisas, do nível de desenvolvimento e da capacidade do Estado de gerenciar a qualidade do ar. As diretrizes recomendadas pela OMS levam em conta esta heterogeneidade e, em particular, reconhecem que, ao formularem políticas de qualidade do ar, os governos devem considerar cuidadosamente suas circunstâncias locais antes de adotarem os valores propostos como padrões nacionais. A OMS também preconiza que o processo de estabelecimento de padrões visa atingir as menores concentrações possíveis no contexto de limitações locais, capacidade técnica e prioridades em termos de saúde pública.

Decreto Estadual nº 59113/2013

A administração da qualidade do ar no território do Estado de São Paulo será efetuada através de Padrões de Qualidade do Ar, observados os seguintes critérios:

- **Metas Intermediárias – (MI)** estabelecidas como valores temporários a serem cumpridos em etapas, visando à melhoria gradativa da qualidade do ar no Estado de São Paulo, baseada na busca pela redução das emissões de fontes fixas e móveis, em linha com os princípios do desenvolvimento sustentável;
- **Padrões Finais (PF)** – Padrões determinados pelo melhor conhecimento científico para que a saúde da população seja preservada ao máximo em relação aos danos causados pela poluição atmosférica.

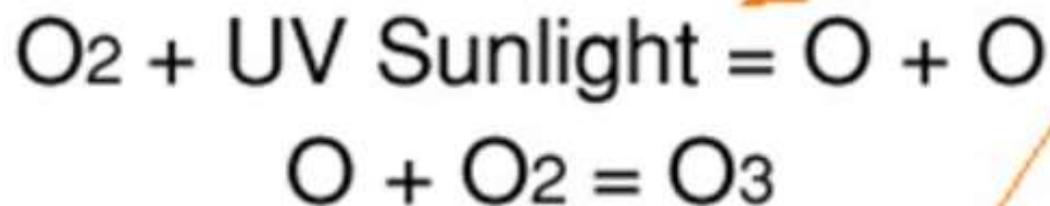
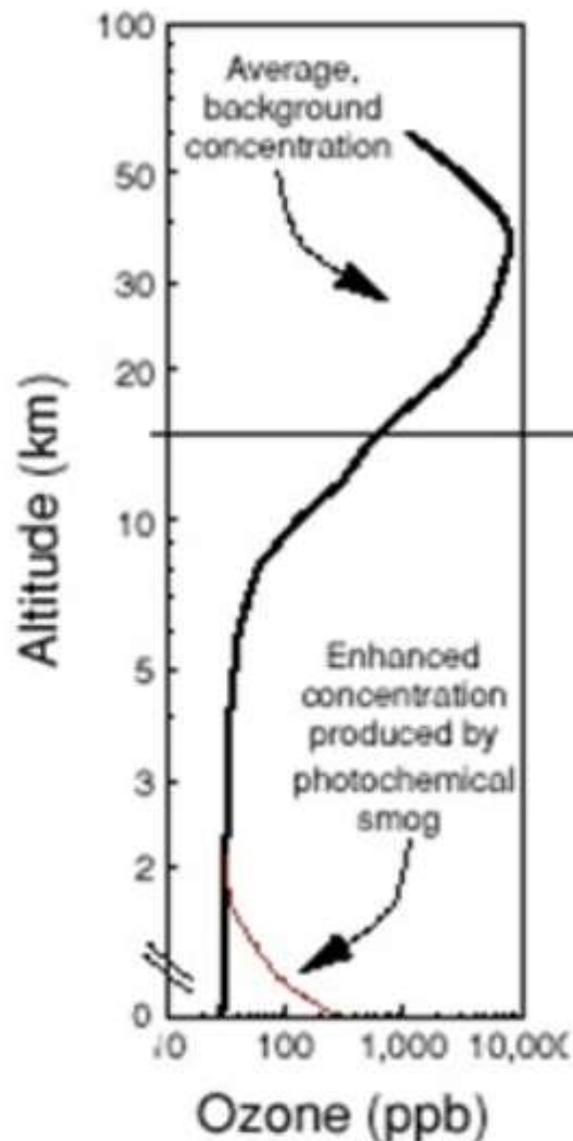
Padrões Estaduais de Qualidade do Ar (Decreto Estadual nº 59113 de 23/04/2013)

Poluente	Tempo de Amostragem	MI1 ($\mu\text{g}/\text{m}^3$)	MI2 ($\mu\text{g}/\text{m}^3$)	MI3 ($\mu\text{g}/\text{m}^3$)	PF ($\mu\text{g}/\text{m}^3$)
partículas inaláveis (MP ₁₀)	24 horas	120	100	75	50
	MAA ₁	40	35	30	20
partículas inaláveis finas (MP _{2,5})	24 horas	60	50	37	25
	MAA ₁	20	17	15	10
dióxido de enxofre (SO ₂)	24 horas	60	40	30	20
	MAA ₁	40	30	20	–
dióxido de nitrogênio (NO ₂)	1 hora	260	240	220	200
	MAA ₁	60	50	45	40
Ozônio (O ₃)	8 horas	140	130	120	100
monóxido de carbono (CO)	8 horas	–	–	–	9 ppm
fumaça* (FMC)	24 horas	120	100	75	50
	MAA ₁	40	35	30	20
partículas totais em suspensão* (PTS)	24 horas	–	–	–	240
	MGA ₂	–	–	–	80

Padrões Estaduais de Qualidade do Ar (Decreto Estadual nº 59113 de 23/04/2013)

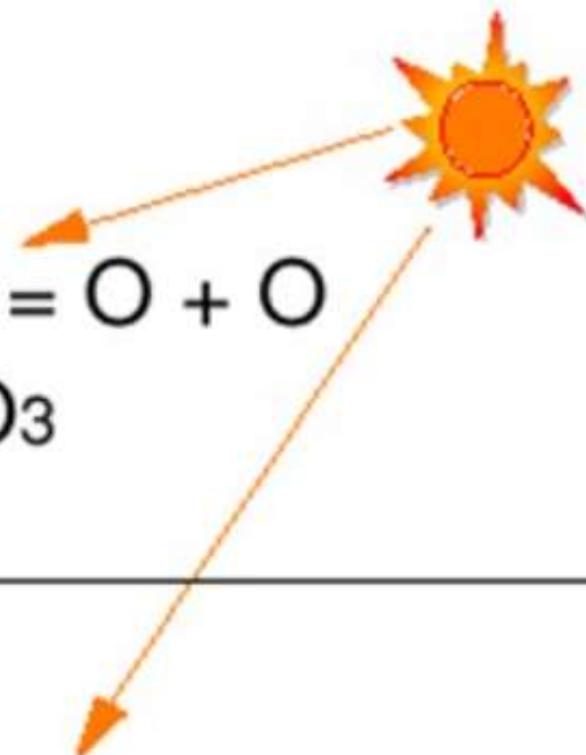
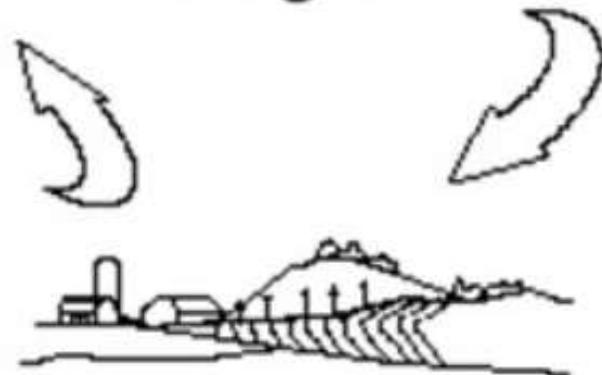
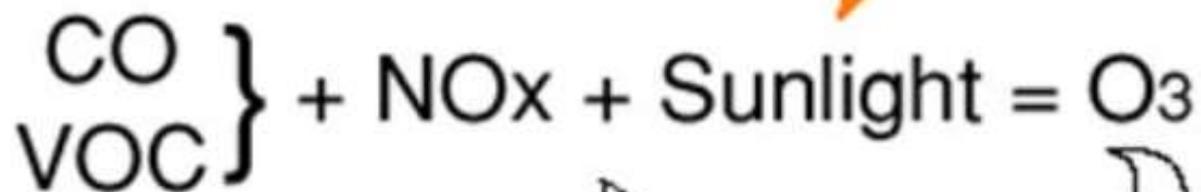
Poluente	Tempo de Amostragem	MI1 ($\mu\text{g}/\text{m}^3$)	MI2 ($\mu\text{g}/\text{m}^3$)	MI3 ($\mu\text{g}/\text{m}^3$)	PF ($\mu\text{g}/\text{m}^3$)
partículas inaláveis (MP ₁₀)	24 horas MAA ₁	120	100	75	50
		40	35	30	20
partículas inaláveis finas (MP _{2,5})	24 horas MAA ₁	60	50	37	25
		20	17	15	10
dióxido de enxofre (SO ₂)	24 horas MAA ₁	60	40	30	20
		40	30	20	–
dióxido de nitrogênio (NO ₂)	1 hora MAA ₁	260	240	220	200
		60	50	45	40
Ozônio (O ₃)	8 horas	140	130	120	100
monóxido de carbono (CO)	8 horas	–	–	–	9 ppm
fumaça* (FMC)	24 horas MAA ₁	120	100	75	50
		40	35	30	20
partículas totais em suspensão* (PTS)	24 horas MGA ₂	–	–	–	240
		–	–	–	80

OZÔNIO TROPOSFÉRICO

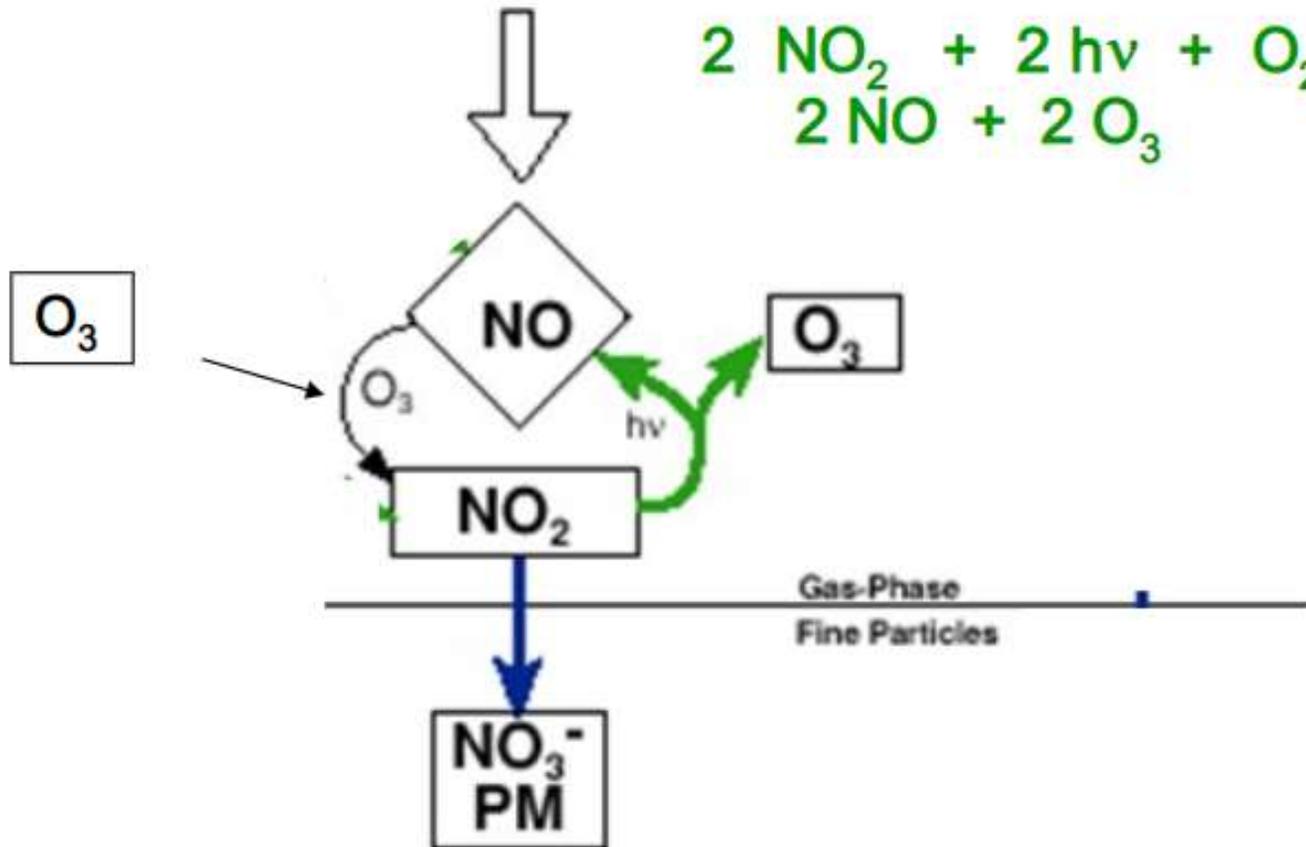
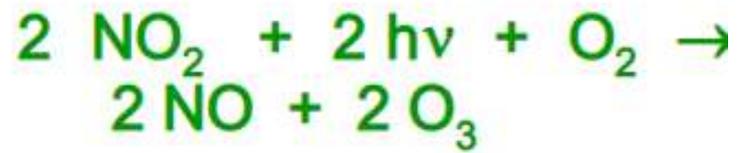


Stratosphere

Troposphere



**PRIMARY
SOURCES**



Estrutura do índice de qualidade do ar

Qualidade	Índice	MP ₁₀ (µg/m ³) 24h	MP _{2,5} (µg/m ³) 24h	O ₃ (µg/m ³) 8h	CO (ppm) 8h	NO ₂ (µg/m ³) 1h	SO ₂ (µg/m ³) 24h
N1 – Boa	0 – 40	0 – 50	0 – 25	0 – 100	0 – 9	0 – 200	0 – 20
N2 – Moderada	41 – 80	>50 – 100	>25 – 50	>100 – 130	>9 – 11	>200 – 240	>20 – 40
N3 – Ruim	81 – 120	>100 – 150	>50 – 75	>130 – 160	>11 – 13	>240 – 320	>40 – 365
N4 – Muito Ruim	121 – 200	>150 – 250	>75 – 125	>160 – 200	>13 – 15	>320 – 1130	>365 – 800
N5 – Péssima	>200	>250	>125	>200	>15	>1130	>800

Qualidade do ar e efeitos à saúde

Qualidade	Índice	Significado
N1 – Boa	0 – 40	
N2 – Moderada	41 – 80	Pessoas de grupos sensíveis (crianças, idosos e pessoas com doenças respiratórias e cardíacas) podem apresentar sintomas como tosse seca e cansaço. A população, em geral, não é afetada.
N3 – Ruim	81 – 120	Toda a população pode apresentar sintomas como tosse seca, cansaço, ardor nos olhos, nariz e garganta. Pessoas de grupos sensíveis (crianças, idosos e pessoas com doenças respiratórias e cardíacas) podem apresentar efeitos mais sérios na saúde.
N4 – Muito Ruim	121 – 200	Toda a população pode apresentar agravamento dos sintomas como tosse seca, cansaço, ardor nos olhos, nariz e garganta e ainda falta de ar e respiração ofegante. Efeitos ainda mais graves à saúde de grupos sensíveis (crianças, idosos e pessoas com doenças respiratórias e cardíacas).
N5 – Péssima	>200	Toda a população pode apresentar sérios riscos de manifestações de doenças respiratórias e cardiovasculares. Aumento de mortes prematuras em pessoas de grupos sensíveis.

Impactos globais – clima

Apesar de permanecerem menos tempo na atmosfera do que os gases do efeito estufa, o MP modifica o equilíbrio radiativo do sistema Terra – atmosfera, contribuindo para mudanças climáticas.

Radiative forcing (RF): quantifica como um composto ou processo influencia o balanço energético na tropopausa (IPCC 2007).

$RF > 0 \rightarrow$ superfície global média aquece

$RF < 0 \rightarrow$ superfície global média resfria

Efeitos diretos: espalhamento e absorção de radiação pelo MP atmosférico, onde partículas escuras (e.g. BC, soot) absorvem radiação e aquecem a atmosfera (RF > 0). Quando depositados sobre neve ou gelo, essas partículas reduzem a sua refletância, ou albedo.

Algumas espécies de MP como sulfatos e CO, refletem a radiação solar, atuando na direção oposta do aquecimento causado pelas partículas escuras e gases do efeito estufa.

Soot – A primary combustion-derived particle type with a characteristic and well-defined structure consisting of graphene-like layers, which are wrapped into spherules with diameters of 20–50 nm. These spherules aggregate into clusters that typically have a chain-like fractal appearance (FIG. 4A). Soot strongly absorbs solar radiation and reemits it as heat, thus exerting a strong positive RF.

OC – Organic carbon. The term describes the mass of carbon contained in all organic compounds present in an aerosol particle. OC is typically determined by thermo-optical methods, along with EC.

BC – Black carbon. This collective term is used in the atmospheric sciences to describe a range of carbonaceous particles that strongly absorb shortwave solar radiation. BC is formed during combustion of fossil fuels, biofuels, and biomass and consists of various materials, including char particles, soot, and a mixture of partially burned and pyrolyzed plant materials. Most commonly, BC is determined by measuring light attenuation (e.g. by using an aethalometer)

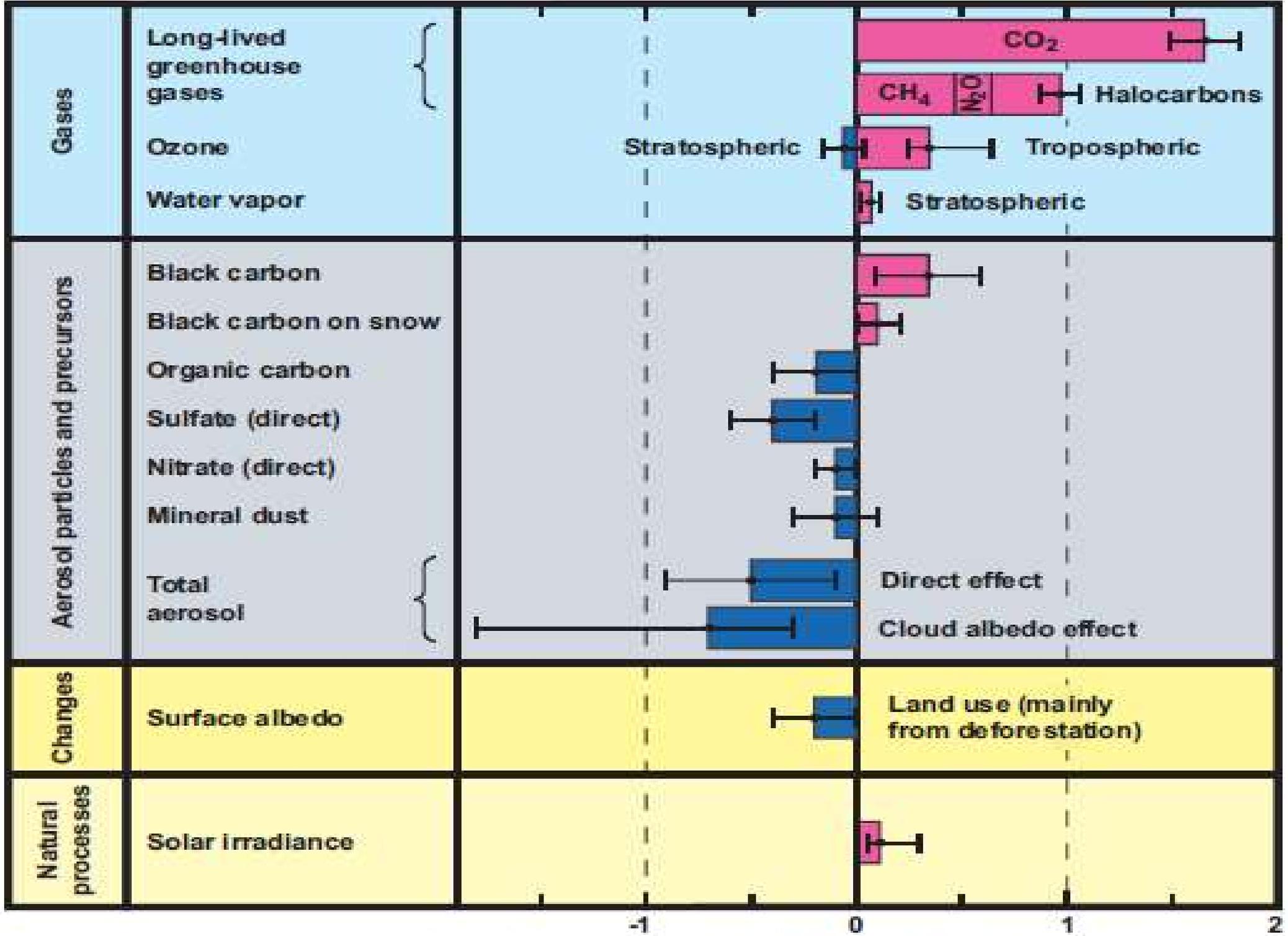
Efeitos indiretos: partículas aerossóis higroscópicas atuam como condensadoras de nuvens ou gelo

Albedo – A measure of how strongly an object (e.g. ice) reflects radiation. It is quantified as the proportion of incident solar radiation (of all wavelengths) that is reflected.

Hygroscopicity – A term describing the tendency of a substance to absorb moisture from the air (but not necessarily to the point of dissolution)

1991 Erupção do Monte Pinatubo – camada aerosol de sulfato se formou pela oxidação do SO_2 injetado na atmosfera, causando $\text{RF} < 0$ e resfriamento substancial do hemisfério Norte no verão de 1992.





Gieré & Querol (Elements, 2010)

Radiative Forcing (W/m²)

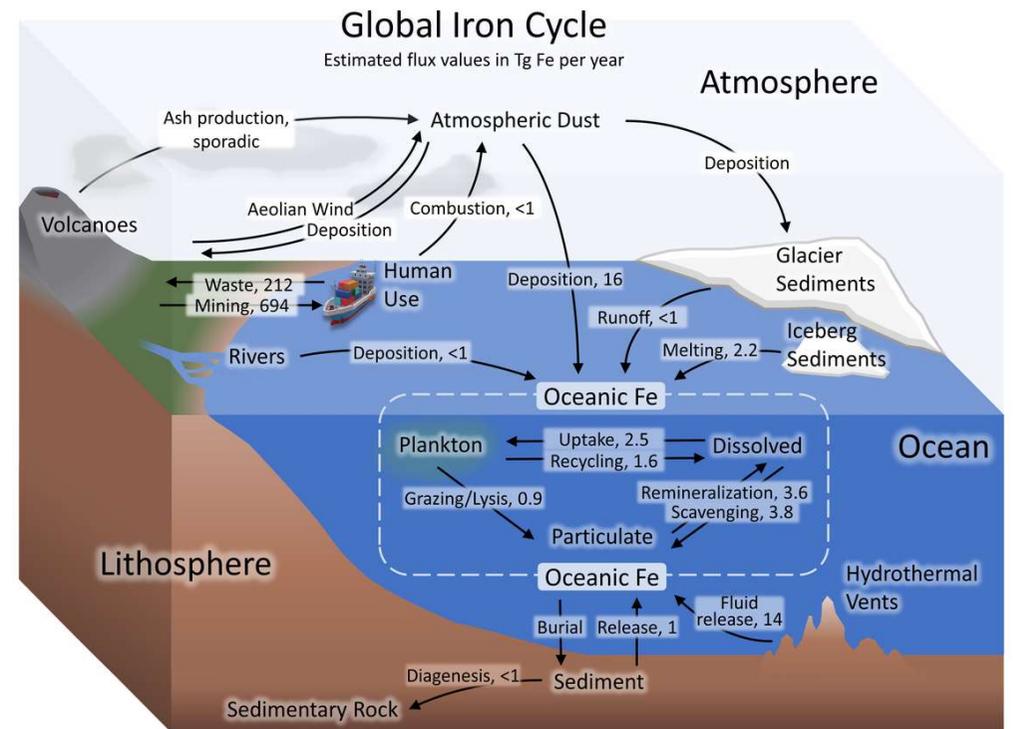
Impactos globais – ecossistemas

O crescimento de fitoplacton requer ferro para as enzimas que realizam a fotossíntese

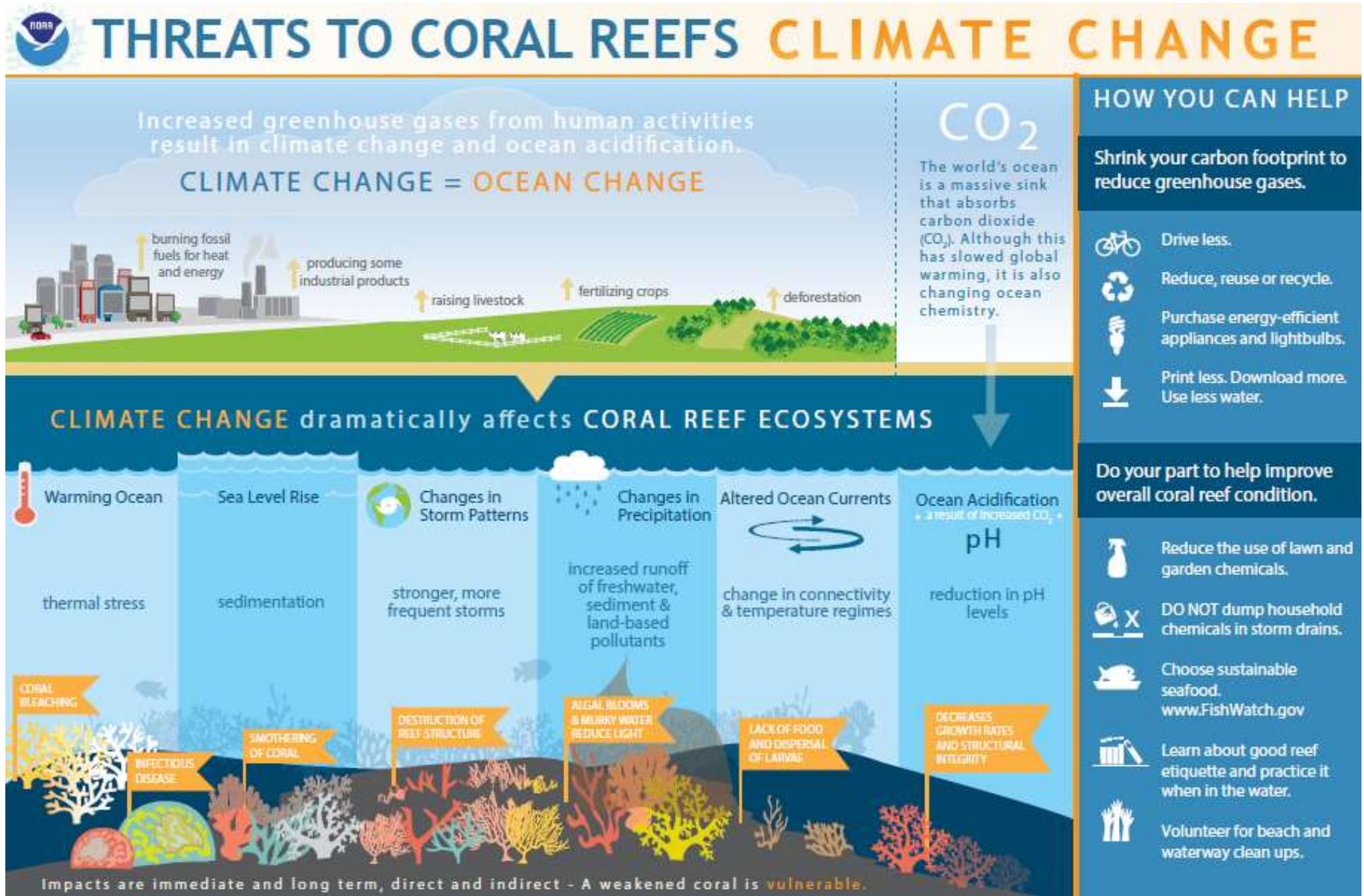
Sedimentos fluviais e glaciais representam o maior fluxo de ferro para as regiões costeiras. No mar aberto, a fonte de ferro dominante é a poeira eólica, que também fornece outros nutrientes.

Crescimento de fitoplancton → aumento de sequestro de CO₂ da atmosfera através de sua conversão em biomassa.

Mudanças no fornecimento de ferro podem modificar a emissão de gases e consequentemente influenciar o pH e afetar a disponibilidade do ferro.



O aumento da deposição de poeira também pode ter um efeito negativo nos ecossistemas marinhos. A diminuição dos recifes de corais do Caribe pode ser parcialmente relacionada ao aumento do fluxo de poeira da África, que aumenta a turbidez da água. Outros fatores também podem contribuir para essa perturbação ambiental (fungos e bactérias).



Impactos globais – *visibilidade*

Episódios de poluição, erupções vulcânicas, queimadas e tempestades de poeira

London's Great Smog, 1950



Dust storm in Sydney, 2009



U.S. Dust Bowl, 1930



Eyjafjallajökull eruption, 2010



São Paulo, 2019 – Smoke from Amazon Rain Forest



Impactos globais – *visibilidade*

Episódios de poluição, erupções vulcânicas e tempestades

London's Great Smog, 1950



Dust storm



Dust Bowl, 1930



Eyjafjallajökull eruption, 2010



São Paulo, 2019 – Smoke from Amazon Rain Forest



Impactos globais – *visibilidade*

Episódios de poluição, erupções vulcânicas, queimadas e tempestades de poeira

London's Great Smog, 1950



Dust storm in Sydney, 2009



U.S. Dust Bowl, 1930



Eyjafjallajökull eruption, 2010



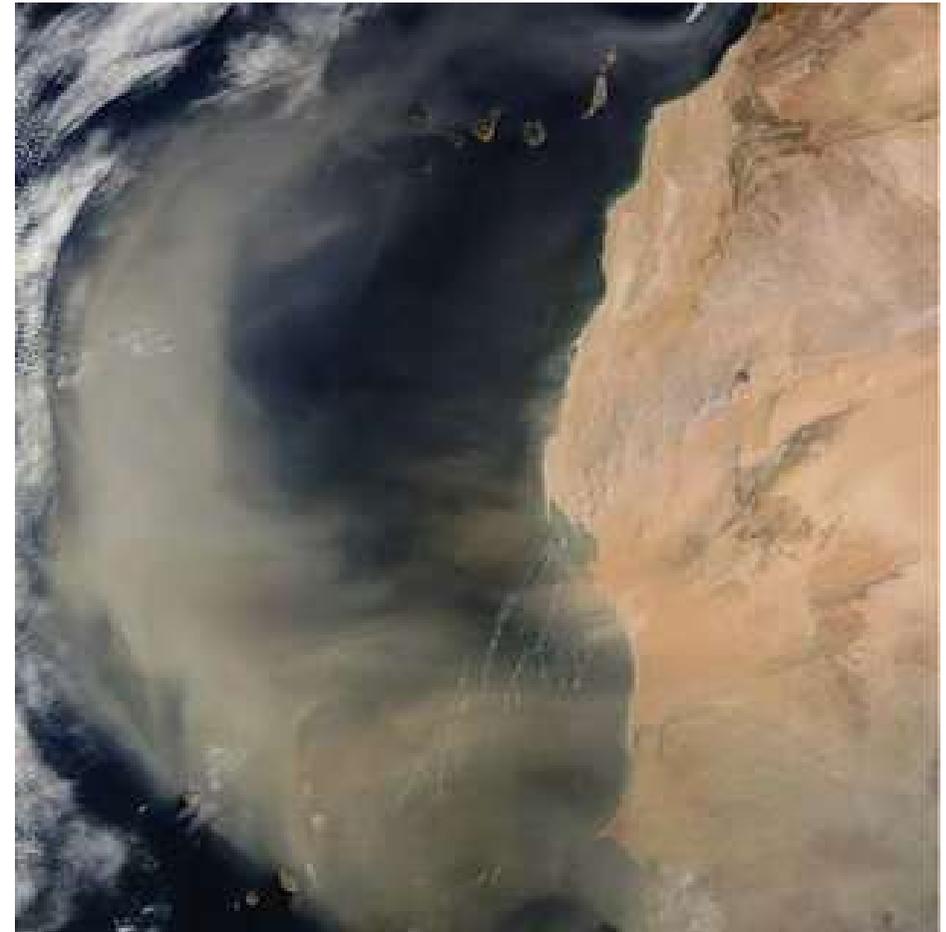
São Paulo, 2019 – Smoke from Amazon Rain Forest



Tempestades na Ásia oriental (*Kosa events, Hwangsa*) transportam grandes quantidades de poeira da fonte (Taklamakan e deserto Gobi, Chinese Loess Plateau) através da Coreia e Japão até locais distantes como a Groelândia



Poeira do Saara é observada regularmente nas Ilhas Canárias e na Europa



Poeira mineral

Principais fontes são as regiões áridas e semi-áridas do planeta – Saara, Oriente Médio e Ásia Oriental

Composição geral: quartzo, feldspato, micas, argilominerais, óxidos e evaporitos.

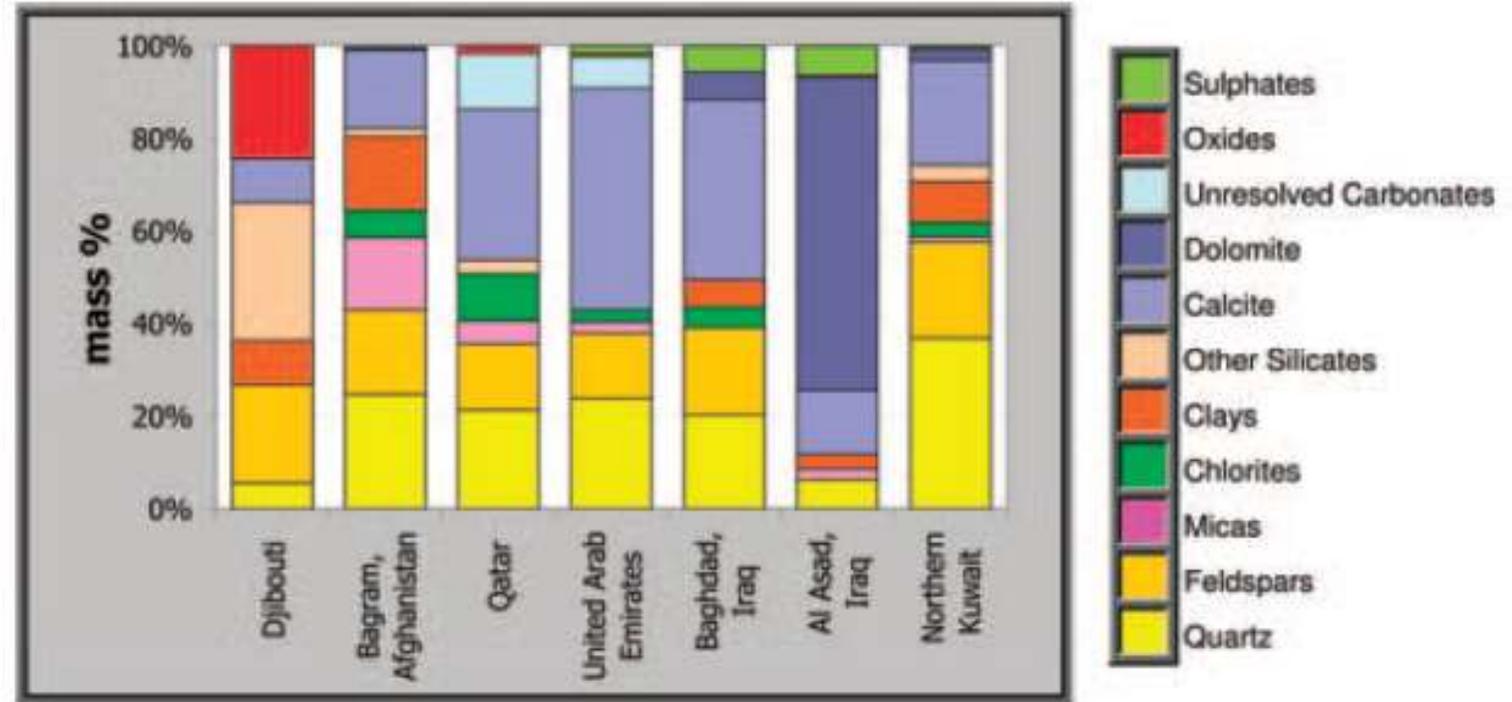


FIGURE 1 Quantitative XRD results for seven <math><38\ \mu\text{m}</math> sieved dust samples from the Middle East. Dust samples are often chemically similar (SEE FIG. 4 TOP) but mineralogically different (Engelbrecht et al. 2009b). The Djibouti sample (African Rift Valley) contains substantial mafic silicate minerals and iron-titanium oxides; the United Arab Emirates and Al Asad samples contain abundant calcite and dolomite, respectively. Kuwaiti samples are rich in silt-sized quartz. Mineralogical differences in regional soils are reflected in the airborne dust transported aloft.

Fontes, caminhos e fluxos

A caracterização do MP fornece informações valiosas sobre a fonte e o caminho percorrido pelas partículas.

As concentrações dos elementos traçadores variam com o tamanho da partícula → análise conjunta aumenta a acurácia da determinação da fonte

A composição do MP é dominada por óxidos de Si, Al, Fe e Ca, e por carbonatos e suas proporções são as mesmas da crosta superior, mas variam entre os continentes.

Do ponto de vista mineralógico e composição química, a poeira do gelo Antártico é atribuída a fontes da América do Sul, mas também apresenta contribuição da Austrália

Alguns depósitos de loess (poeira mineral eólica) na Argentina são pobres em quartzo e ricos em plagioclásio, fragmentos de vidro e outros materiais piroclásticos, devido aos vulcões Andinos.

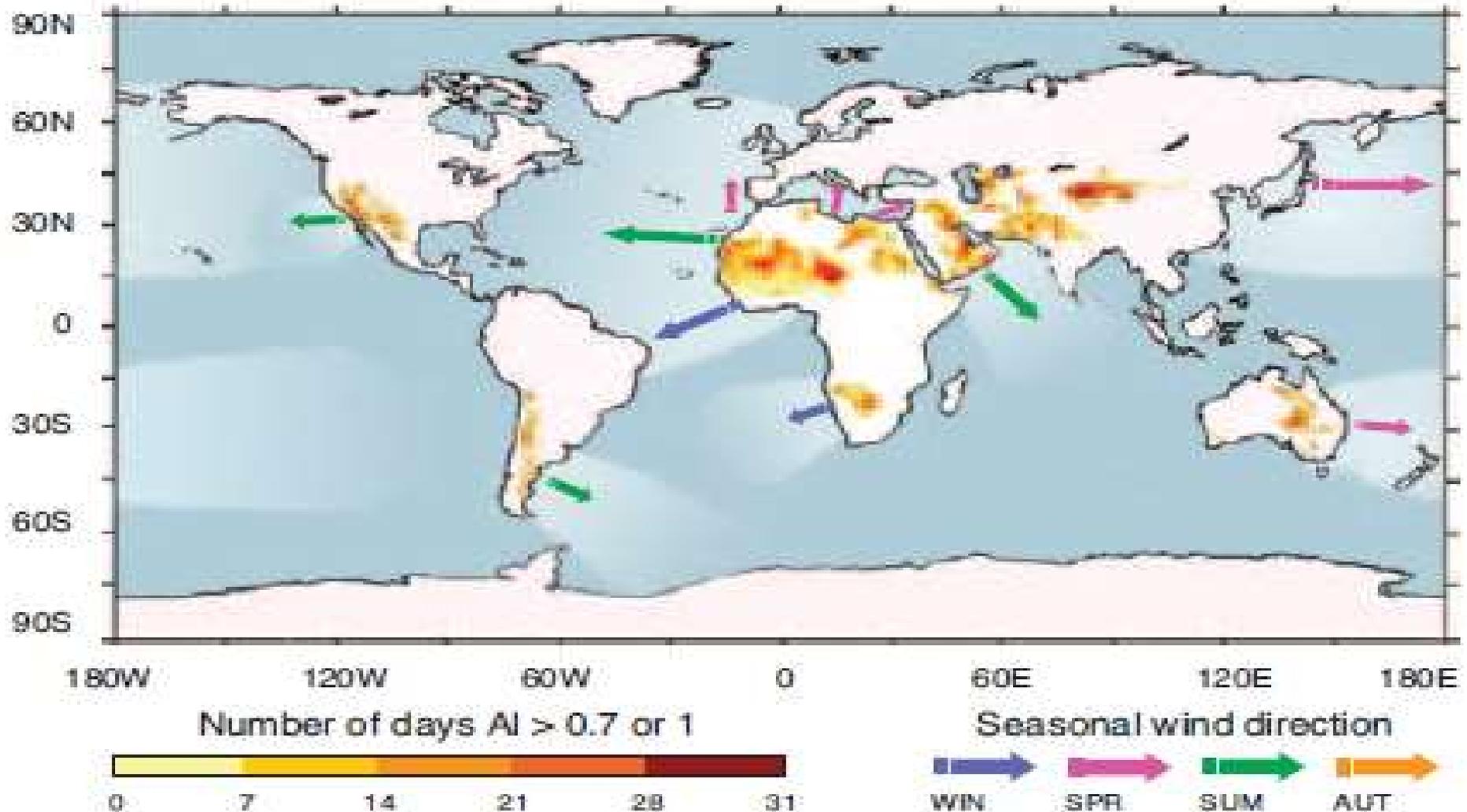


FIGURE 2 Global distribution of dust sources (after Prospero et al. 2002). The number of days exceeding the absorbing aerosol index (AI) is shown in shades of yellow and brown. Distributions were computed using a threshold AI of 1.0 in the dust belts and 0.7 elsewhere. Note that the seasons are six months apart in the Northern and Southern Hemispheres. Arrows indicate the general direction of dust storms (no significant storms in autumn), and major impacted areas over the ocean are shown in paler shades of blue.

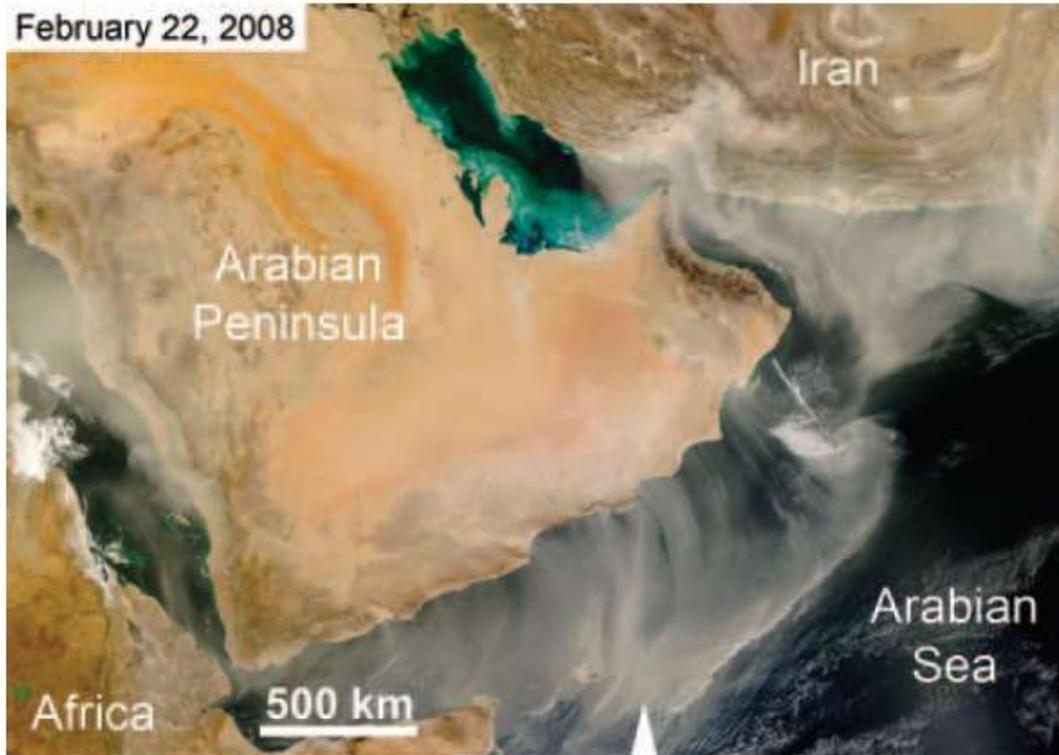


FIGURE 3 Satellite image of a dust storm, generated by north-westerly *shamal* winds, extending from the horn of Africa to India. Visible dust sheets blow from the Arabian Peninsula, as well as from Iran and Pakistan (top right). Dust streamers extend across the waters of the Red Sea (left), Persian Gulf (centre) and Arabian Sea. SATELLITE IMAGE COURTESY OF NASA



FIGURE 5 Satellite image of dust plumes streaming westward off the coast of Angola and Namibia. Green hues along the coastline indicate the presence of phytoplankton in surface waters. Note that, due to the coarse nature of sand grains, no dust is coming off the dune field along the southern coastline. SATELLITE IMAGE COURTESY OF NASA

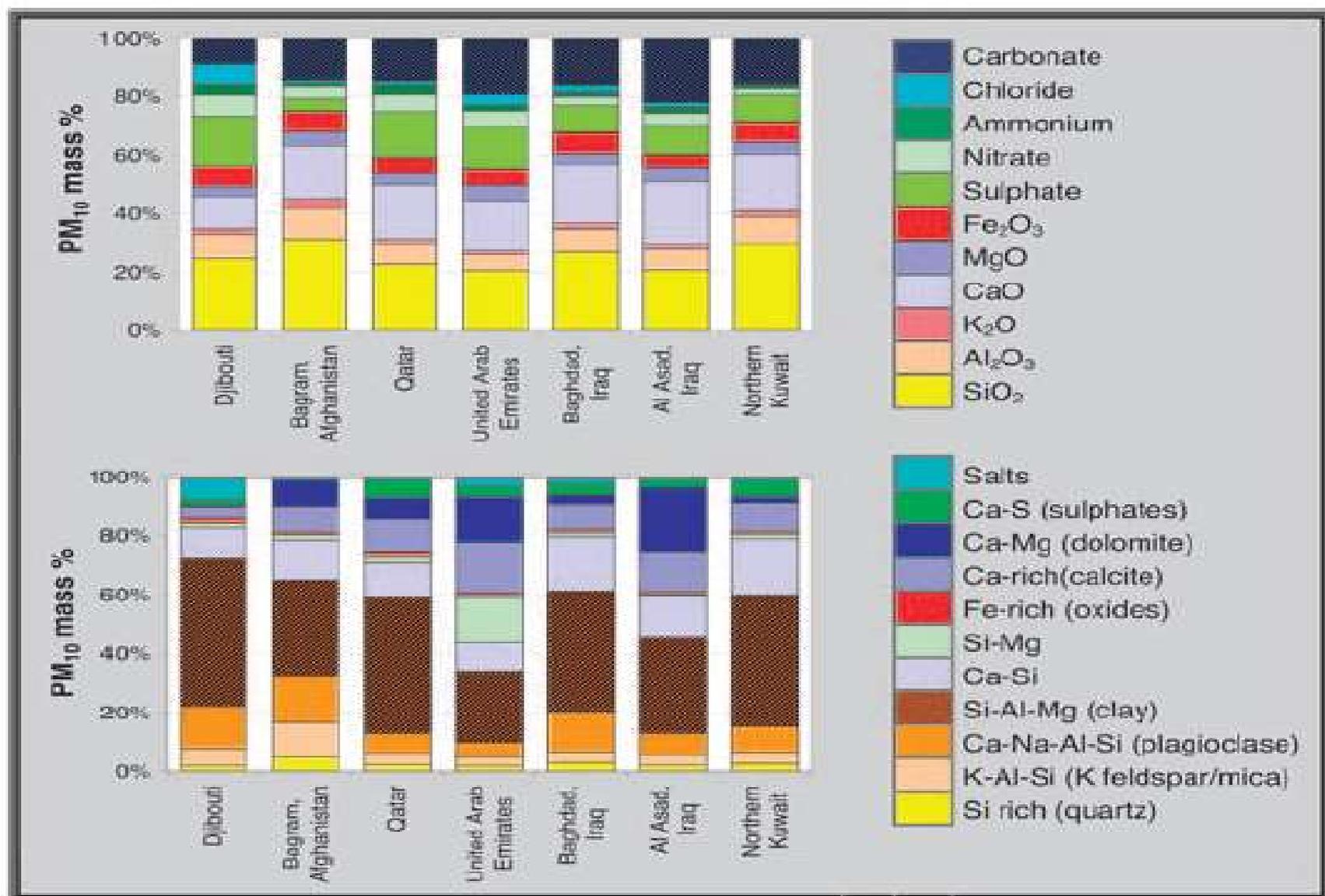
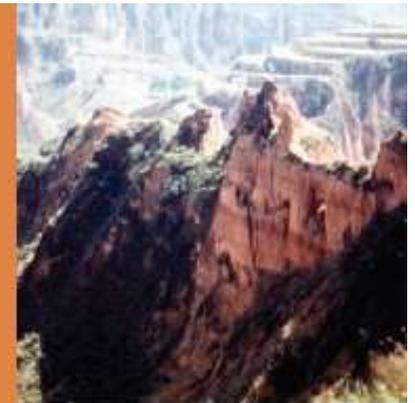


FIGURE 4 Chemical and electron microscope analyses for Middle East PM₁₀ dust sample. **(Top)** Concentrations (in mass %) of oxides, sulphate (in gypsum), chloride (in salt), nitrate, ammonium, and carbonates. **(Bottom)** Elemental compositions obtained by single-particle electron microscopy. Clay (Si–Al–Mg) minerals, generally occurring as coatings on other silicates, form the largest fraction of particles when analyzed by this method (Engelbrecht et al. 2009a).

Rain and Dust: Magnetic Records of Climate and Pollution

Barbara A. Maher*

1811-5209/09/0005-0229\$2.50 DOI: 10.2113/gselements.5.4.229



The alternating light-coloured loess layers and reddish brown palaeosols, revealed in the walls of erosional gullies, provide a stunning visual record of past changes in the strength of the East Asian summer and winter monsoons.

Registros magnéticos do clima do passado

Registros do clima nos sedimentos: regiões muito antigas ou geleiras.

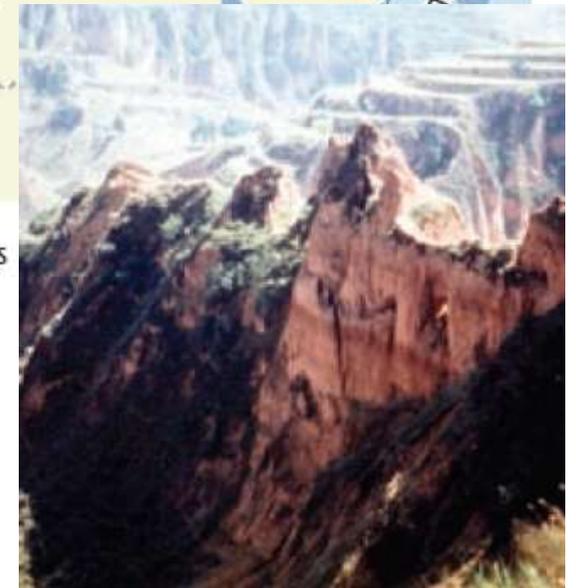
Um dos maiores registros climáticos nos sedimentos é o Platô de Loess Chinês – extenso e espesso (~350 m) depósito de sedimentos carregados pelo vento por pelo menos 2 Ma.

É o registro climático do Período Quaternário mais detalhado do planeta!



FIGURE 1

The East Asian monsoon systems



O loess é formado de baixo para cima, de forma quase contínua, conforme os ventos carregam sedimentos.



FIGURE 1 The East Asian monsoon systems

Composição extremamente homogênea:
quartzo (~35%), filosilicatos (~25%),
plagioclase (10–15%), calcita (~10–15%), K-
feldspato (~5%), dolomita e amphibolio (\leq
5%), com teor mínimo de hematita e goethita
e traços de magnetita e maghemita.

Durante os estágios glaciais, quando as monções de inverno eram intensas e frias, ventos com poeiras secas assopravam do interior da Ásia para o Pacífico. A taxa de deposição de loess era maior e o loess depositado previamente era rapidamente soterrado por mais loess.

Durante os estágios interglaciais, quando as monções de verão eram fortes e quentes, o ar úmido assoprava do Pacífico para a China. As superfícies do terreno se tornavam mais vegetadas e o loess era intemperizado por uma camada de solo superficial (paleosolo).



FIGURE 1 The East Asian monsoon systems



As alternâncias glacial/interglacial entre o loess pálido e o paleosolo marrom avermelhado forma esse belo e fascinante registro dos sistemas de monções de inverno e verão durante o período Quaternário.

As sequências verticais de loess/palaeosolos do Platô de Loess carregam um registro magnético detalhado do tempo e mudanças climáticas.

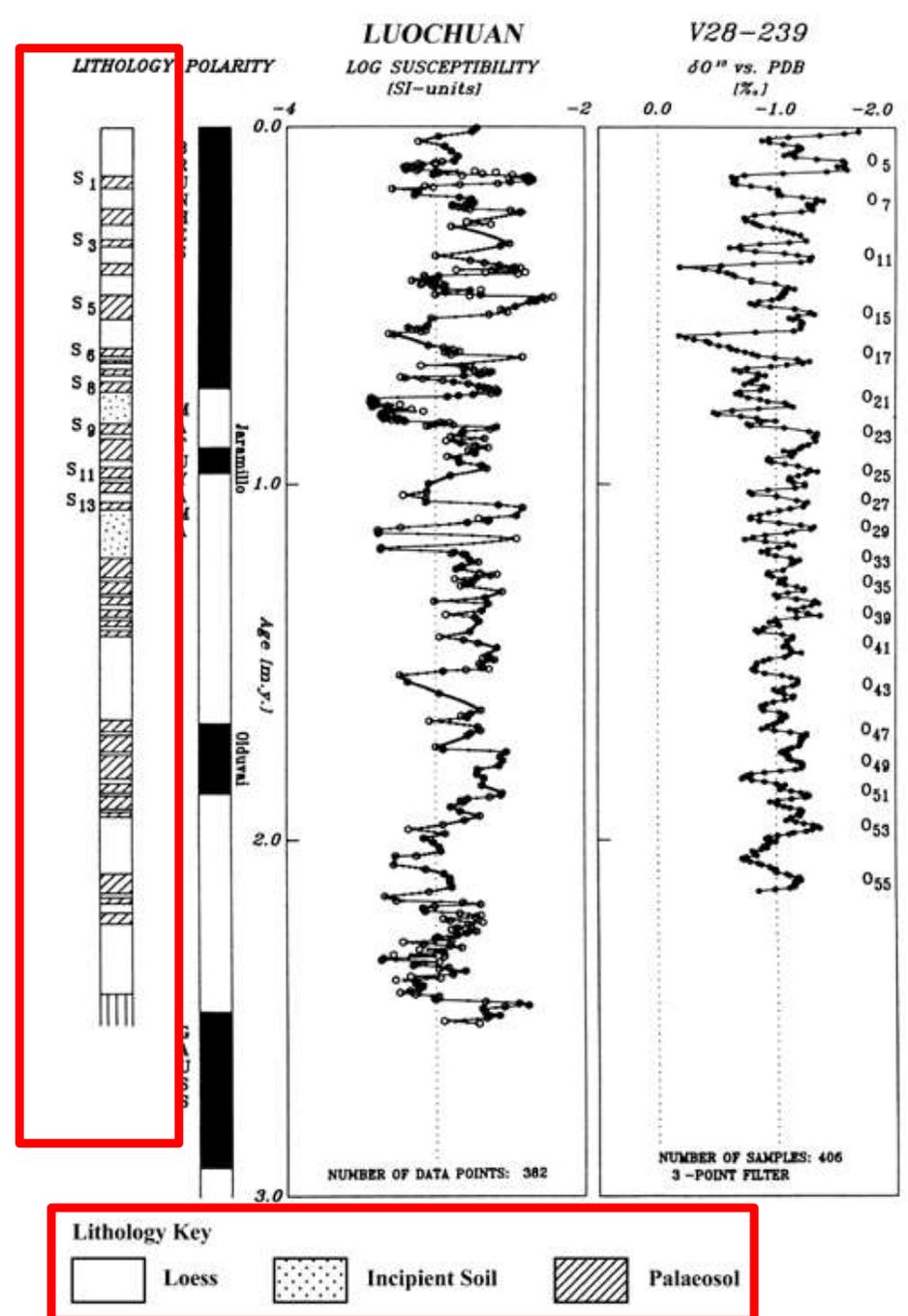


FIGURE 2 Left to right: loess/palaeosol stratigraphy at Luochuan (central Plateau) (S1-S13 = palaeosol 1 to palaeosol 13); palaeomagnetic stratigraphy and dating (black = period of normal polarity; white = reverse polarity); magnetic susceptibility; deep-sea oxygen isotope record (O_n = oxygen isotope stage, odd numbers = interglacials). FROM HELLER AND LIU (1986)

Registro de seis eventos de reversão geomagnética durante pelo menos 2.5 My.

Paleosolos contém mais minerais magnéticos (magnetita–maghemita) na fração ultrafina ($d \leq 0.05 \mu\text{m}$). O Loess menos intemperizado contém concentrações muito menores desses minerais magnéticos.

Susceptibilidade magnética maior nos paleosolos do que no Loess.

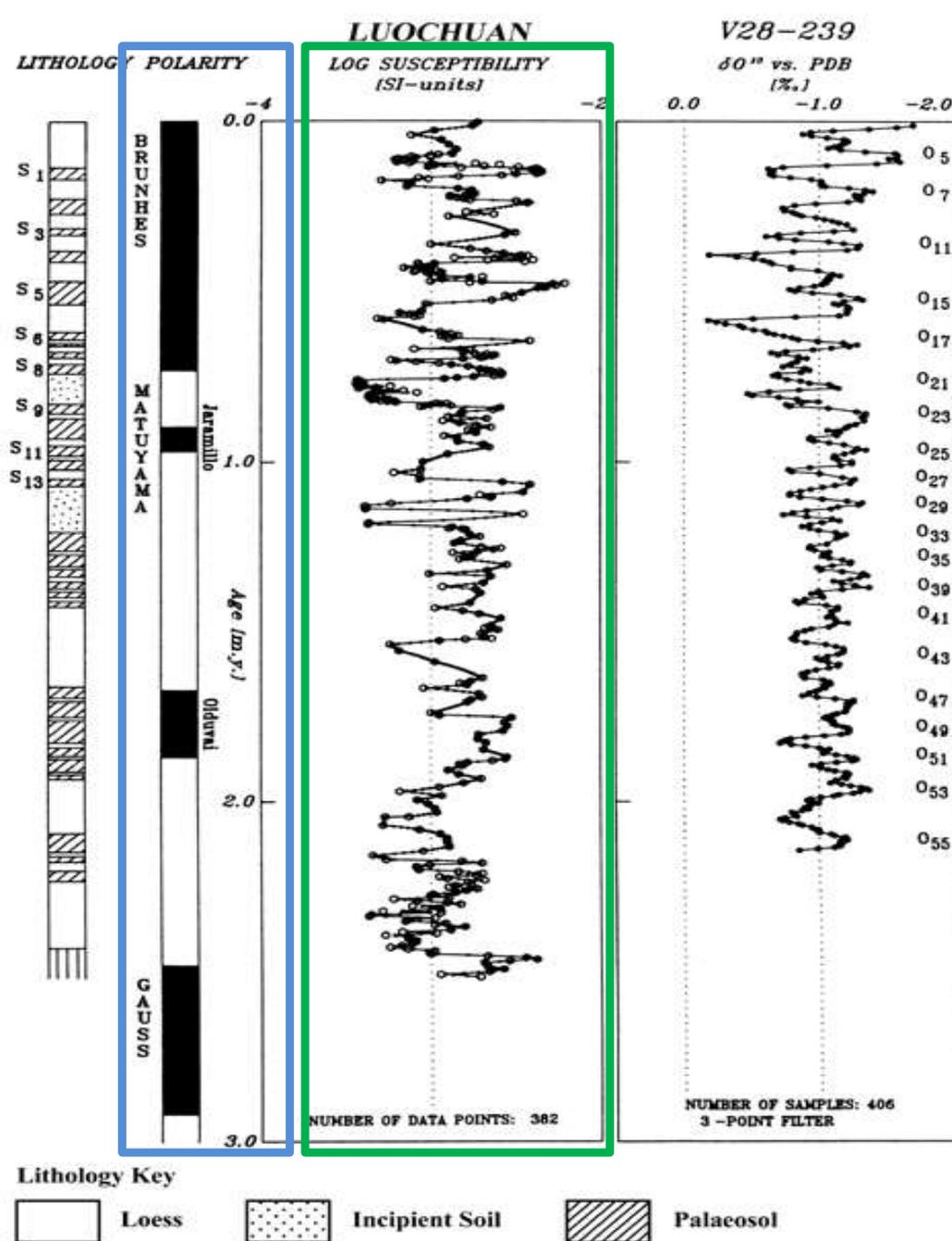


FIGURE 2 Left to right: loess/palaeosol stratigraphy at Luochuan (central Plateau) (S1–S13 = palaeosol 1 to palaeosol 13); palaeomagnetic stratigraphy and dating (black = period of normal polarity; white = reverse polarity); magnetic susceptibility; deep-sea oxygen isotope record (O_n = oxygen isotope stage, odd numbers = interglacials). FROM HELLER AND LIU (1986)

As variações da susceptibilidade podem ser comparadas com as variações do isótopo de oxigênio do assoalho oceânico.

Nos estágios glaciais passados, o gelo no continente retinha grandes quantidades de ^{16}O , deixando os oceanos ricos em ^{18}O .

Forte correlação entre loess/palaeosol \times MS \times $\delta^{18}\text{O}$ \rightarrow acoplamento das monções asiáticas com os ciclos de glaciação e deglaciação da Terra.

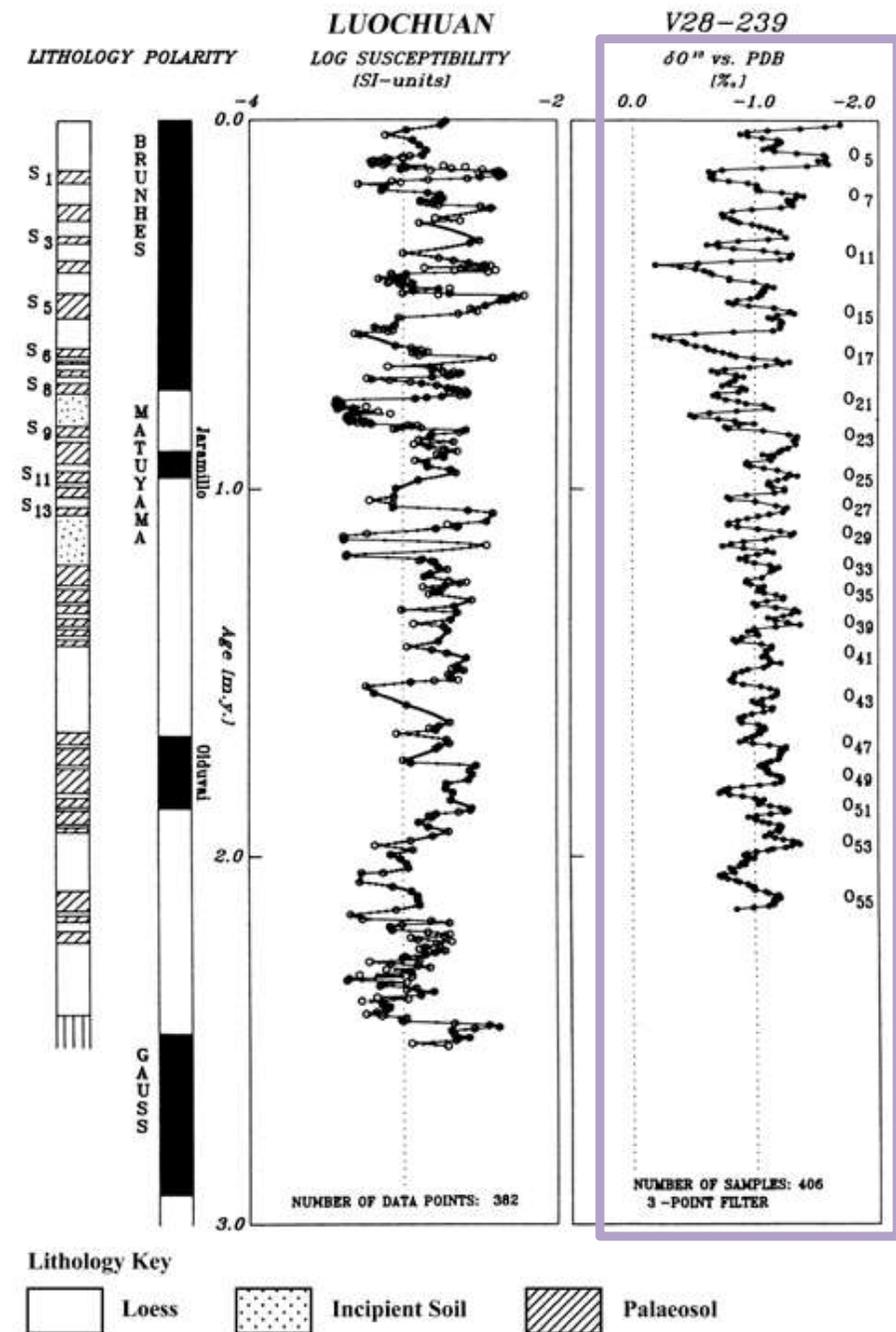


FIGURE 2 Left to right: loess/palaeosol stratigraphy at Luochuan (central Plateau) (S1-S13 = palaeosol 1 to palaeosol 13); palaeomagnetic stratigraphy and dating (black = period of normal polarity; white = reverse polarity); magnetic susceptibility; deep-sea oxygen isotope record (O_n = oxygen isotope stage, odd numbers = interglacials). FROM HELLER AND LIU (1986)

Comparação com solos modernos:

Magnetita/maghemita ultrafina são formadas em solos bem drenados de pH neutro. Solos ácidos ou permanentemente molhados esses minerais não são formados ou são transformados em minerais não magnéticos.

Solos modernos no Platô de Loess Chinês, e outros no planeta, apresentam boa correlação entre a quantidade de minerais magnéticos formados e a precipitação annual.

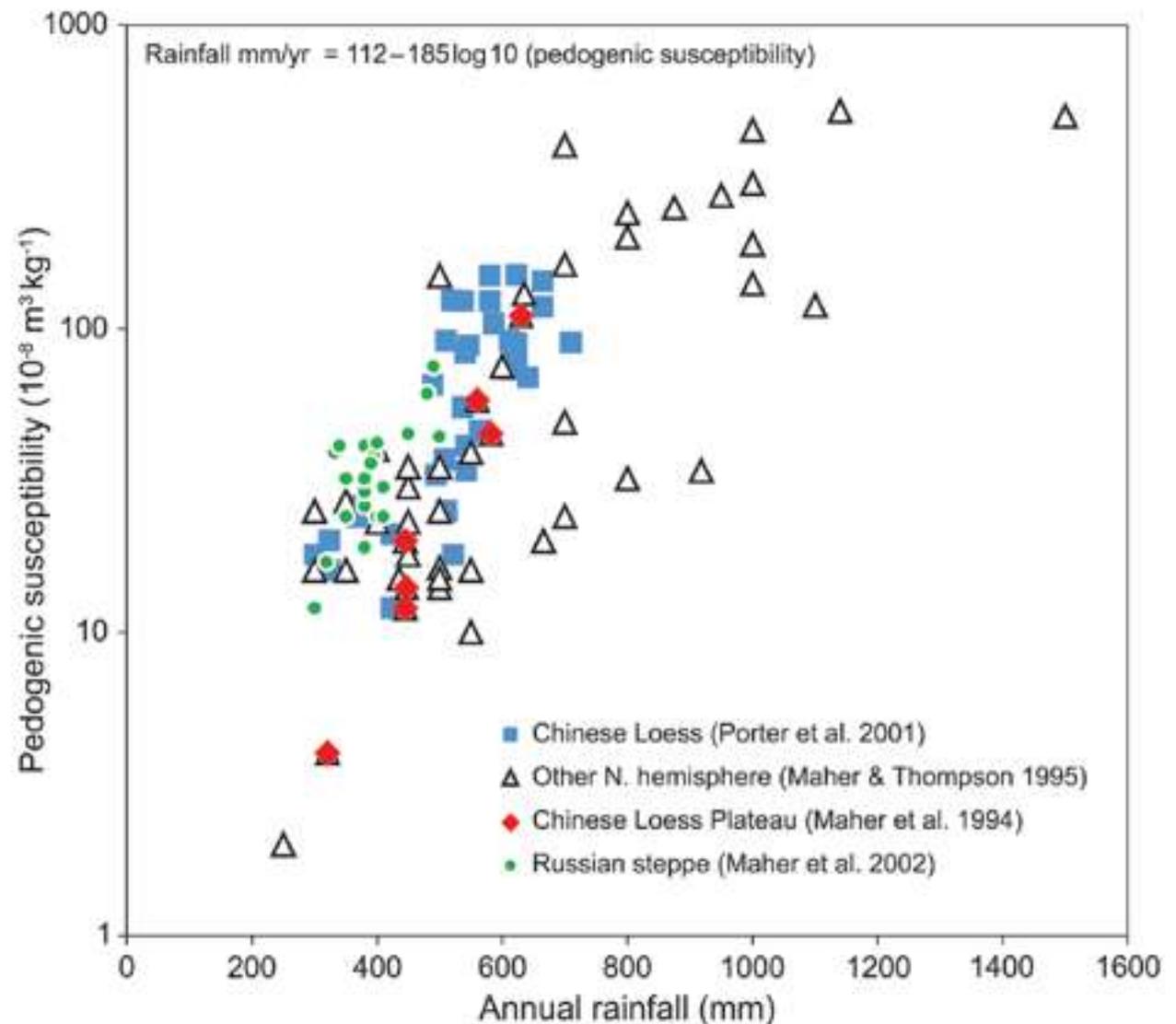


FIGURE 5 Relationship between pedogenic (soil-formed) magnetic susceptibility and annual rainfall for modern loessic soils and modern (last 30-year averages) rainfall. Statistical examination of the relationships between the soil magnetic properties and major climate variables (temperature, rainfall, etc.) identifies annual rainfall as the most significant factor ($R^2 = 0.88$). The relationship between soil magnetism and rainfall can thus be expressed as the equation shown in the figure. FROM MAHER ET AL. 2002

Quando o oxigênio disponível para as bactérias diminui pela entrada de água, bactérias ferro-redutoras, que usam ferro ao invés de oxigênio em seu metabolismo, liberam Fe^{2+} no solo. Quando a quantidade de oxigênio aumenta no solo, essas partículas reagem com óxidos de Fe^{3+} e formam magnetita.

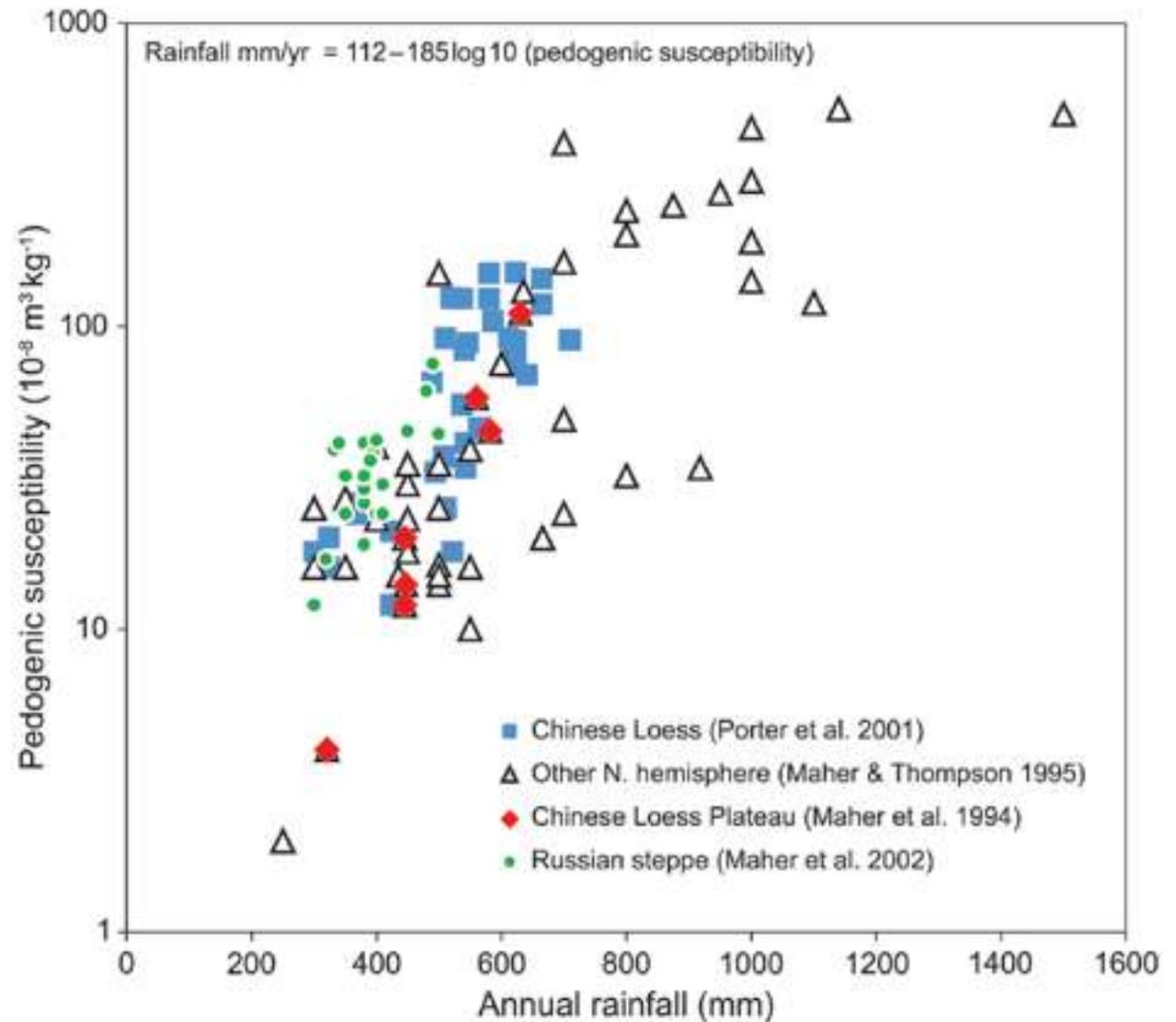
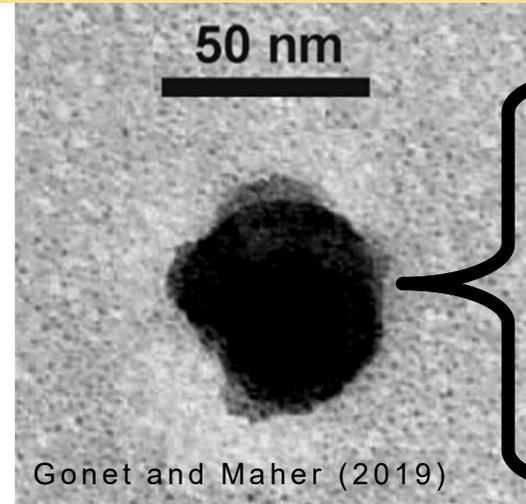


FIGURE 5 Relationship between pedogenic (soil-formed) magnetic susceptibility and annual rainfall for modern loessic soils and modern (last 30-year averages) rainfall. Statistical examination of the relationships between the soil magnetic properties and major climate variables (temperature, rainfall, etc.) identifies annual rainfall as the most significant factor ($R^2 = 0.88$). The relationship between soil magnetism and rainfall can thus be expressed as the equation shown in the figure. FROM MAHER ET AL. 2002

Aplicação do magnetismo na poluição

Fe-bearing particles in
particulate matter



Which minerals?

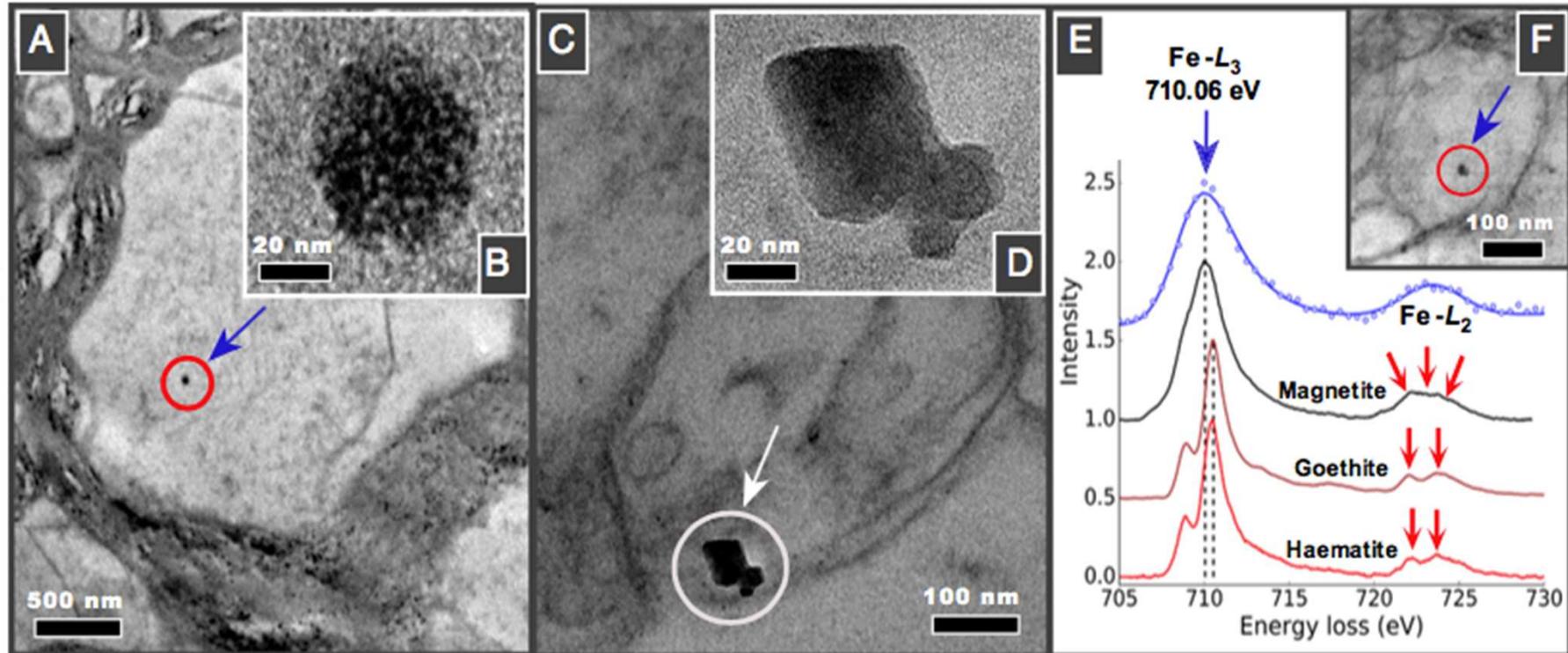
How many?

How small?



Magnetite pollution nanoparticles in the human brain

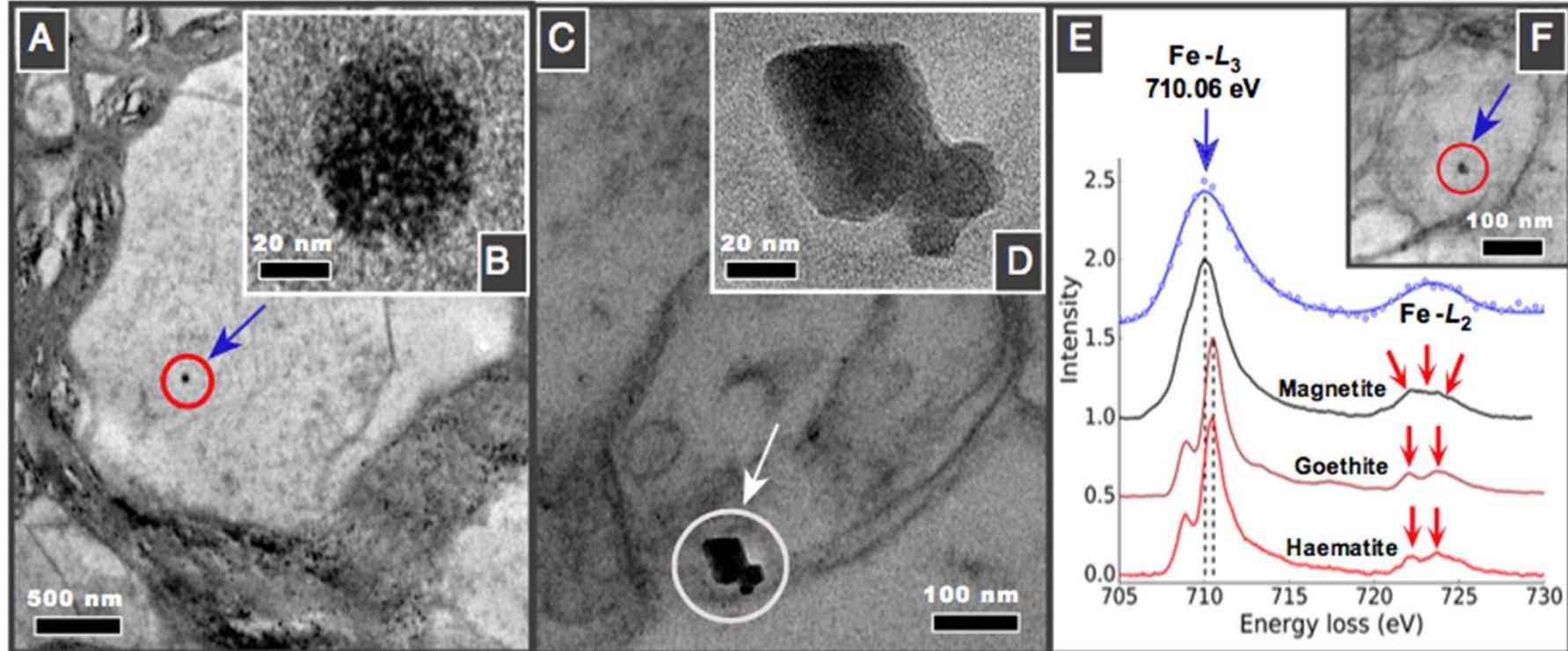
Barbara A. Maher^{a,1}, Imad A. M. Ahmed^b, Vassil Karloukovski^a, Donald A. MacLaren^c, Penelope G. Foulds^d, David Allsop^d, David M. A. Mann^e, Ricardo Torres-Jardón^f, and Lilian Calderon-Garciduenas^{g,h}



Maher et al. (2016)

Magnetite pollution nanoparticles in the human brain

Barbara A. Maher^{a,1}, Imad A. M. Ahmed^b, Vassil Karloukovski^a, Donald A. MacLaren^c, Penelope G. Foulds^d, David Allsop^d, David M. A. Mann^e, Ricardo Torres-Jardón^f, and Lilian Calderon-Garciduenas^{g,h}

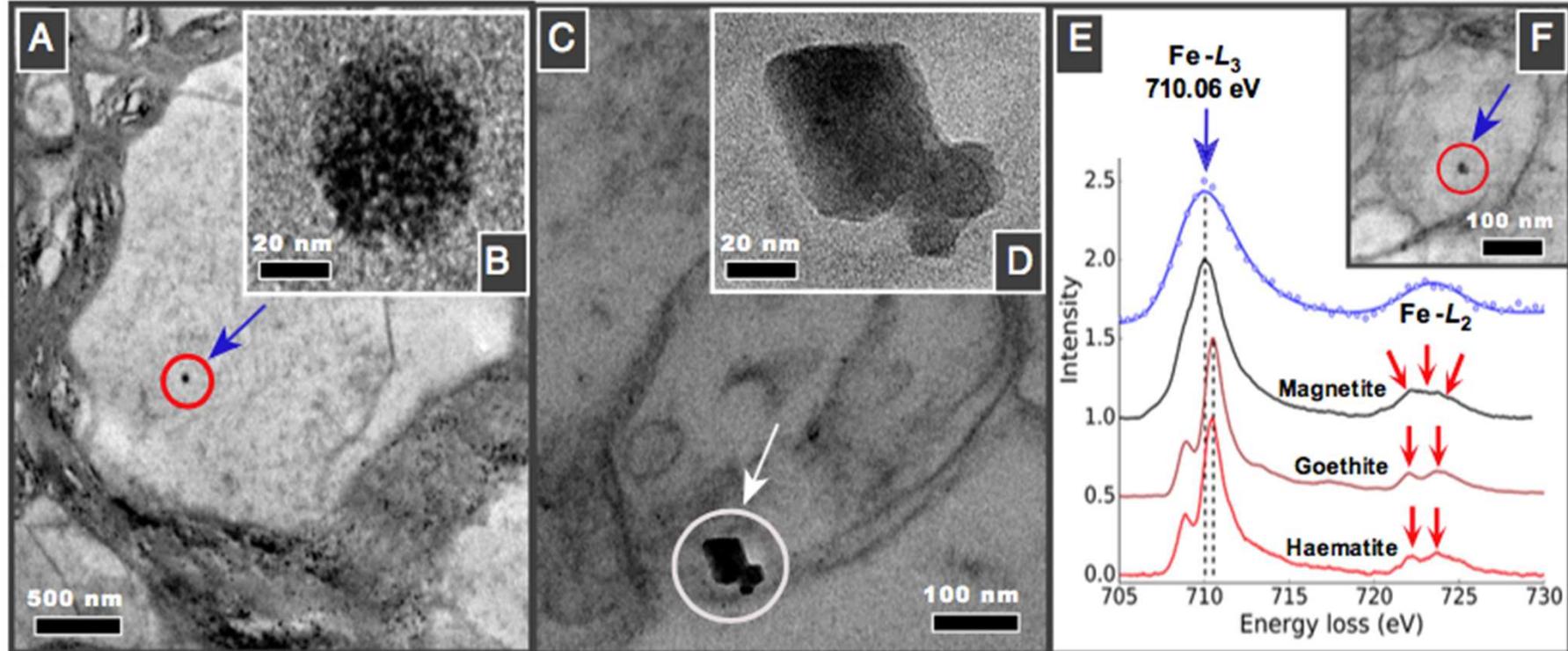


Endogena

Maher et al. (2016)

Magnetite pollution nanoparticles in the human brain

Barbara A. Maher^{a,1}, Imad A. M. Ahmed^b, Vassil Karloukovski^a, Donald A. MacLaren^c, Penelope G. Foulds^d, David Allsop^d, David M. A. Mann^e, Ricardo Torres-Jardón^f, and Lilian Calderon-Garciduenas^{g,h}



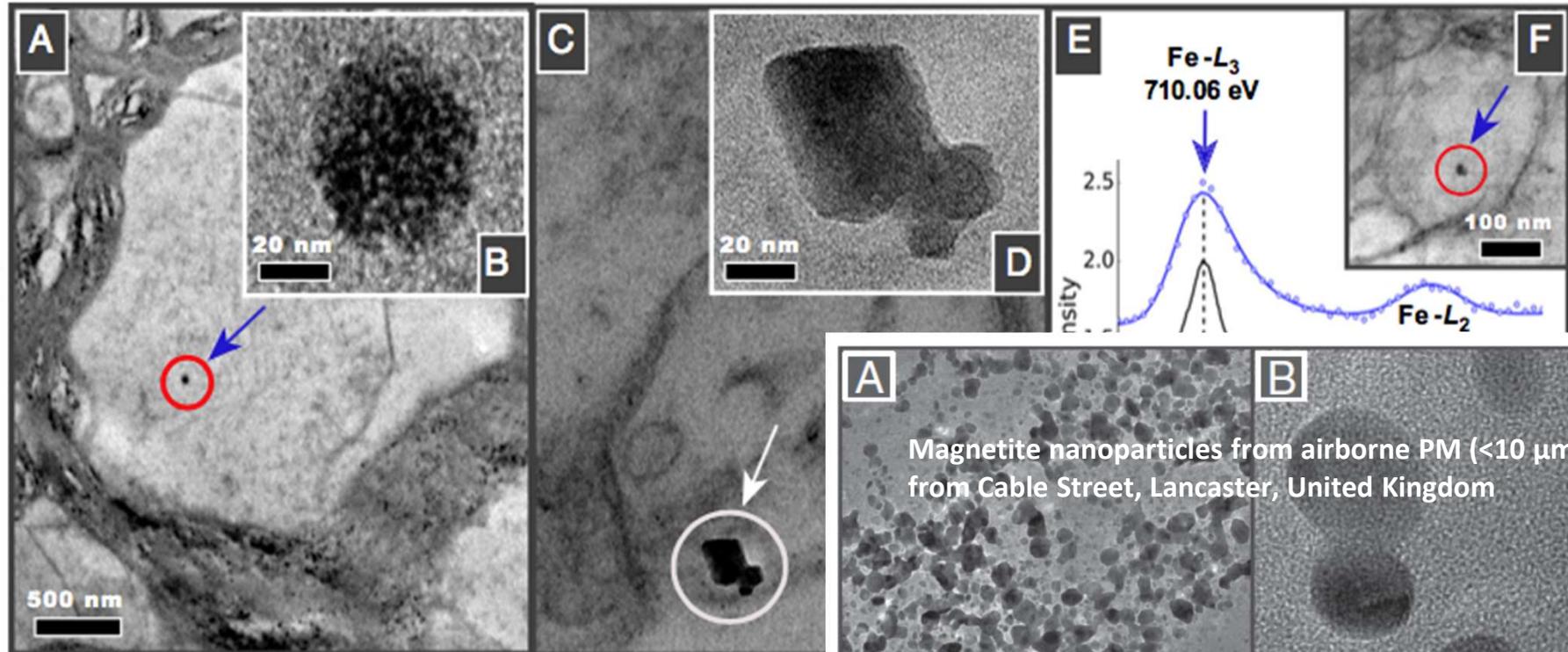
Exógena?

Endogena

Maher et al. (2016)

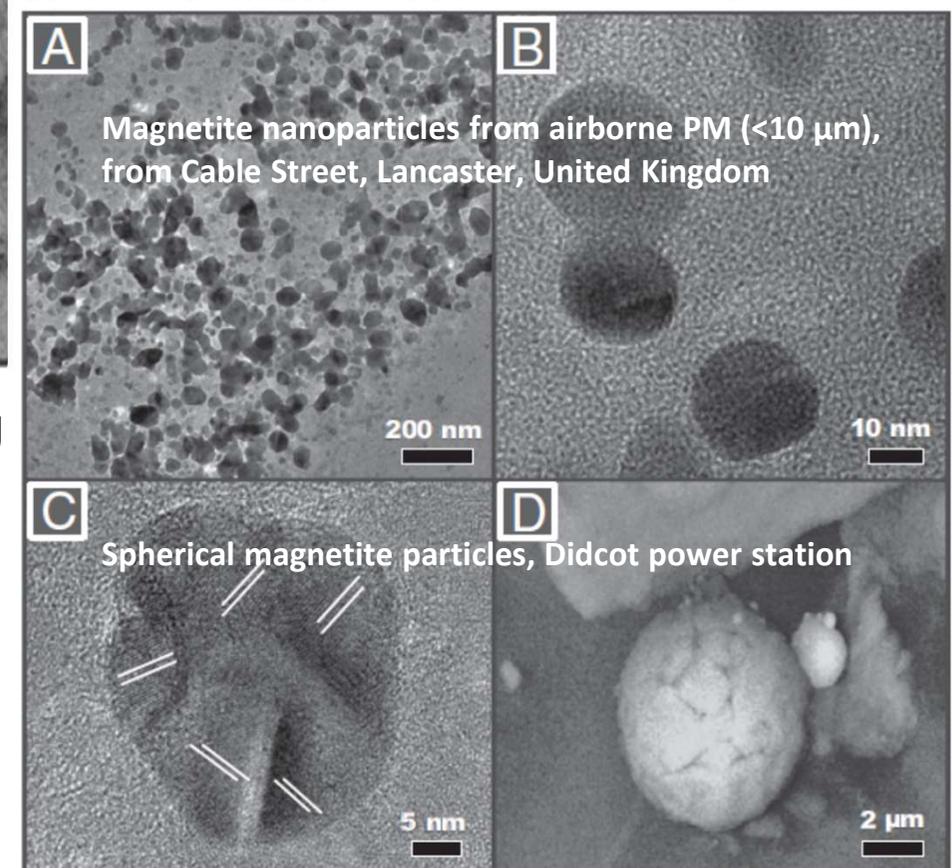
Magnetite pollution nanoparticles in the human brain

Barbara A. Maher^{a,1}, Imad A. M. Ahmed^b, Vassil Karloukovski^a, Donald A. MacLaren^c, Penelope G. Foulds^d, David Allsop^d, David M. A. Mann^e, Ricardo Torres-Jardón^f, and Lilian Calderon-Garciduenas^{g,h}



Exógena?

Endog



GLOSSARY

Accumulation mode – A particle-size range between 100 nm and 1 μm (upper value also listed as 2 μm or 2.5 μm in the literature)

Aerosol – A dispersion of small (diameter of less than $\sim 30 \mu\text{m}$) solid or liquid particles suspended in a gas

Aitken mode – Particle-size range between 10 nm and 100 nm

Albedo – A measure of how strongly an object (e.g. ice) reflects radiation. It is quantified as the proportion of incident solar radiation (of all wavelengths) that is reflected.

BC – Black carbon. This collective term is used in the atmospheric sciences to describe a range of carbonaceous particles that strongly absorb shortwave solar radiation. BC is formed during combustion of fossil fuels, biofuels, and biomass and consists of various materials, including char particles, soot, and a mixture of partially burned and pyrolyzed plant materials. Most commonly, BC is determined by measuring light attenuation (e.g. by using an aethalometer)

Bulk (ensemble) methods – Methods used for bulk characterization of PM. These methods include: inductively coupled plasma mass spectrometry and optical emission spectrometry (ICP-MS and ICP-OES), aerosol mass spectrometry (AMS), X-ray fluorescence (XRF), particle-induced X-ray emission (PIXE) spectroscopy, ion chromatography (IC), thermo-optical methods for determining OC and EC contents, X-ray diffraction (XRD), and aethalometry (a method that determines the light attenuation by aerosol particles)

Cascade impactor – A device for simultaneous sampling of multiple size fractions through a series of stacked substrates, each of which collects a different particle-size range

CCN – Cloud condensation nuclei

Coarse particles – Particles with diameters of $>2.5 \mu\text{m}$. The limit of 2.5 μm was defined on a regulatory rather than scientific basis (see text). It does not coincide with the volume-distribution minimum that separates particles formed by different processes (SEE FIG. 5).

Cryosphere – A collective term describing the areas of the Earth's surface where water is present as ice. The cryosphere thus comprises ice sheets, glaciers, sea ice, lake ice, river ice, snow cover, and frozen ground (including permafrost).

Deliquescence – A process by which a solid absorbs moisture from the air until it dissolves in the absorbed water and forms a solution

Dry deposition – A term describing the overall physical process through which gases and particles are transferred directly to the surface of the Earth

GLOSSARY

EC – Elemental carbon. This is a poorly defined term, used in the atmospheric sciences to describe mostly elemental carbon in aerosol particles. EC refers to the most refractory part of carbonaceous aerosol particles, the part that oxidizes above a certain threshold value (established in combustion experiments). It is determined by thermal or thermo-optical methods.

Fine particles – Particles with diameters of $<2.5 \mu\text{m}$ ($\text{PM}_{2.5}$). The limit of $2.5 \mu\text{m}$ was defined on a regulatory rather than scientific basis (see text). It does not coincide with the volume-distribution minimum that separates particles formed by different processes (SEE FIG. 5).

Fine volcanic ash – Volcanic ash particles with diameters of $<63 \mu\text{m}$

HULIS – Humic-like substances. These chemical compounds are similar to the humic and fulvic acids in soils, but form primarily during biomass burning and also during secondary chemical reactions in the atmosphere (i.e. particle ageing).

Hydrometeor – An atmospheric particle formed by condensation of water vapor or freezing of water

Hygroscopicity – A term describing the tendency of a substance to absorb moisture from the air (but not necessarily to the point of dissolution)

Impactor – A device for separating PM according to size so that the size mode of interest accumulates on a sampling substrate

IN – Ice-forming nuclei

Mixing state – A term describing whether aerosol particles occur as single or multiple phases. Single-phase particles are known as *externally mixed*, whereas multiple-phase particles are called *internally mixed*.

Nucleation mode – A particle-size range with diameters of $<10 \text{ nm}$

OC – Organic carbon. The term describes the mass of carbon contained in all organic compounds present in an aerosol particle. OC is typically determined by thermo-optical methods, along with EC.

OM – Organic matter. This is a collective term describing thousands of individual organic compounds, which vary widely in regard to physical and chemical properties.

GLOSSARY

PAH – Polycyclic aromatic hydrocarbon. PAHs are aromatic compounds (e.g. anthracene, benzo[a]pyrene, naphthalene), some of which are carcinogenic and mutagenic. They are produced during combustion of fossil fuels and biomass burning.

PAN – Peroxyacetyl nitrates. These substances form photochemically from nitrogen dioxide (NO_2) and hydrocarbons emitted into the atmosphere by combustion processes. They are respiratory and eye irritants.

PBAP – Primary biogenic aerosol particles (e.g. plant debris, animal fragments, pollen, spores, algae, fungi, bacteria, and viruses)

PCB – Polychlorinated biphenyl. PCBs are toxic organic compounds with 1–10 chlorine atoms attached to biphenyl, an aromatic hydrocarbon.

PM (**PM₁₀**, **PM_{2.5}**, **PM_{0.1}**) – Particulate matter (with diameters of $<10\ \mu\text{m}$, $<2.5\ \mu\text{m}$, and $<0.1\ \mu\text{m}$, respectively)

POA – Primary organic aerosol particles. These are particles emitted directly into the atmosphere

RF – Radiative forcing. A term describing how a compound or process influences the balance of incoming and outgoing energy at the tropopause. A positive RF leads to global mean surface warming, whereas a negative RF produces global mean surface cooling.

Single-particle methods – Methods used to characterize individual aerosol particles. These methods include: scanning electron microscopy (SEM) combined with energy-dispersive X-ray (EDX) spectroscopy, electron probe microanalysis (EPMA), transmission electron microscopy (TEM) combined with selected-area electron diffraction (SAED), particle-induced X-ray emission (μ -PIXE) spectroscopy, confocal laser-scanning microscopy (CLSM), optical microscopy combined with automated image analysis, synchrotron-based X-ray microscopy (e.g. NEXAFS, μ -XRF), aerosol time-of-flight mass spectrometry (ATOFMS).

SOA – Secondary organic aerosol particles. Particles formed in the atmosphere from volatile organic compounds (VOCs).

Soot – A primary combustion-derived particle type with a characteristic and well-defined structure consisting of graphene-like layers, which are wrapped into spherules with diameters of 20–50 nm. These spherules aggregate into clusters that typically have a chain-like fractal appearance (FIG. 4A). Soot strongly absorbs solar radiation and reemits it as heat, thus exerting a strong positive RF.

Ultrafine particles – Particles with diameters of $<0.1\ \mu\text{m}$ (**PM_{0.1}**)

VOC – Volatile organic compound. These organic substances have relatively high vapor pressures and are of both natural (e.g. terpene) and anthropogenic (e.g. formaldehyde, acetone) origin.

Wet deposition – A term describing the overall physical process through which rain removes materials from the atmosphere. Wet deposition can be further subdivided into “rain-out” (in-cloud scavenging) and “wash-out” (below-cloud scavenging).



Discussão em grupos 6

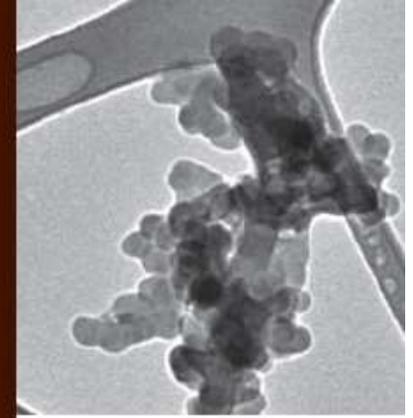
Particulado Volátil e Aerotransportado

AGG 0201 Geoquímica de Ambientes Superficiais

Profa. Andréa Teixeira Ustra

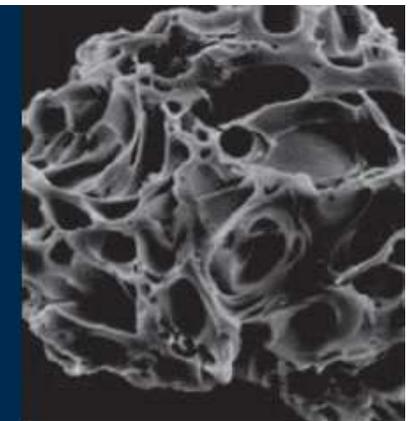
Atmospheric Brown Clouds: From Local Air Pollution to Climate Change

Guenter Engling¹ and András Gelencsér²



Atmospheric and Environmental Impacts of Volcanic Particulates

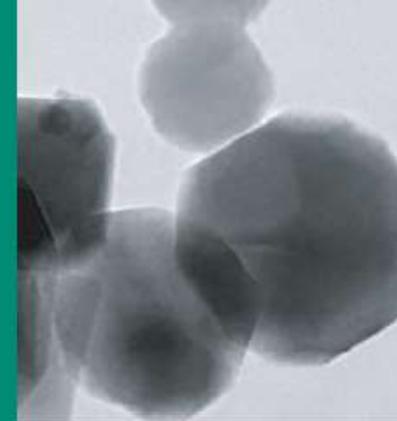
Adam J. Durant¹, Costanza Bonadonna², and Claire J. Horwell³



A single ash particle
erupted during the 18
May 1980 eruption of
Mount St. Helens, USA.
The dark voids are
vesicles formed as gases

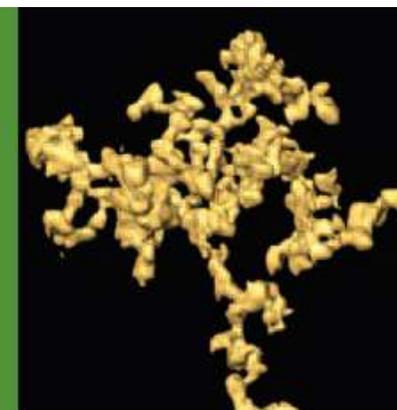
Airborne Particles in the Urban Environment

Bernard Grobéty¹, Reto Gieré², Volker Dietze³, and Peter Stille⁴



Nanoparticles in the Atmosphere

Peter R. Buseck and Kouji Adachi*



Part of a soot particle aggregate collected from a diesel tailpipe exhaust. Each soot spherule in this aggregate is a few