PETROGRAPHY OF THE UPPER ORDOVICIAN TRENTON AND BLACK RIVER GROUP CARBONATE RESERVOIRS, APPALACHIAN BASIN

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March 29, 2005 Presentation

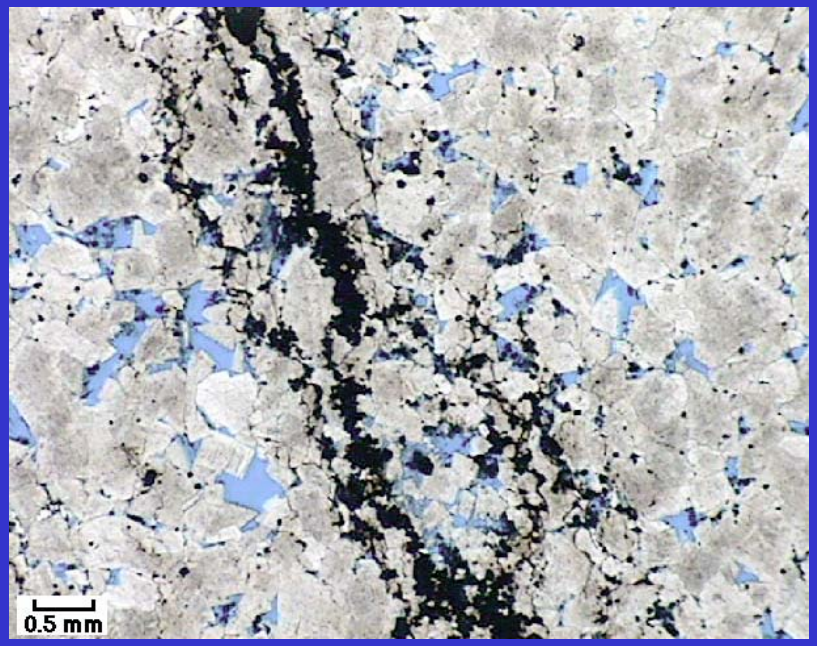
- Brief update of previous presentation (September 2004)
- Regional petrography of Trenton and Black River carbonates:
  - Composition
  - Classification
  - Depositional environments
  - Limestone diagenesis
- Dolomite textures in Trenton and Black River carbonate reservoir rocks:
  - Dolostone textural classification
  - Pore classification in dolostones
  - Dolograinstone and dolopackstone reservoirs
  - Dolowackestone and dolomudstone reservoirs
  - Remaining work

PETROGRAPHY - PURPOSE

- Enhance field studies and core descriptions:
  - Identification of constituent grains
  - Detailed classification of reservoir rocks
  - Interpretation of depositional environments
- Diagenesis
  - Timing of significant diagenetic events (i.e., cementation or secondary porosity development relative to the emplacement of hydrocarbons)

PETROGRAPHY - PURPOSE

- Frame of reference for geochemical studies
  - Dolomitization processes:
    - Stable isotopes
    - Fluid inclusions
    - $^{87}Sr/ ^{86}Sr$
    - Trace elements
  - Source rock studies

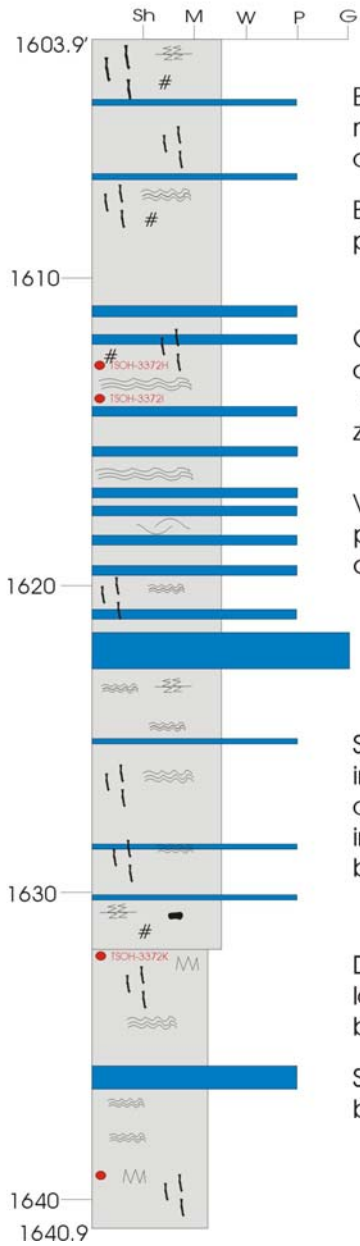


CORE AND OUTCROP SAMPLING PROGRESS as of MARCH, 2005

- PENNSYLVANIA:
  - Union Furnace outcrop and cores, Blair Co.
  - McKnight #1 well, Mercer Co.
  - Montgomery #4 well, Mercer Co.
- WEST VIRGINIA:
  - Sandhill well, Wood Co.
- KENTUCKY:
  - Cominco American well, Montgomery Co.
  - J. B. Allen #3 well, Clark Co.
- OHIO:
  - Strayer #1well, Allen Co.
  - Prudential #1 well, Marion Co.
  - #3267 well, Auglaize Co.
  - Henderson well (#3479), Hancock Co.
  - #2459 well, Wood Co.
  - #2858 well, Delaware Co.
  - #2854 well, Delaware Co.
    #2971 well, Wood Co.
  - #3256 well, Williams Co.
  - #645 well, Logan Co.
  - #862 well, Lucas Co.

Prudential 1A, #3372, Marion County, OH
Black River Formation
1603.9' to 1640.9'

Sample Core Description



Burrowed MS/WS w/ some thin PS lenses throughout and coarser material associated with some of the burrows; fracture filled with calcite and pyrite

Burrowed MS/WS with dark discontinuous laminations, highly burrowed, pyrite associated with the argillaceous zones

GS/PS with some MS/WS zone, but the coarser zones dominate, dark argillaceous laminae are present throughout, small amount of pyrite is present and this zone is more intensely burrowed than the underlying zone

Very similar to above material, but a little coarser grained, burrows are present, but burrowing is less intense than above, the laminae are wavy and convoluted, but end to be continuous here and above

Skeletal grainstone

Similar to underlying rocks, but slightly coarser, containing an increase in skeletal material, but bioturbation has homogenized some of the coarser and finer zones making it some what difficult to pick out the individual packstone beds; wavy laminations have increased, discrete burrows are also present, fractures throughout, vugs in last 2'

Dark gray MS/WS, color mottled appearance, wavy discontinous laminations, with some associated compaction features extensively burrowed/bioturbated

Skeletal/Intraclastic Packstone, coarser than above and below, but contains wavy argillaceous laminae

Petrographic Analyses-Progress

- 605 thin sections analyzed to date
- 280 thin sections still in preparation (early May 2005 arrival)
- 136 core samples examined by SEM and energy dispersive spectroscopy

Components

- Carbonate grains
  - Skeletal
    - Mollusks
    - Brachiopods
    - Bryozoans
    - Echinoderms
    - Arthropods
    - Cephalopods
    - Coral
  - Non-skeletal grains
    - Ooids
    - Peloids
    - Intrclasts
- Non-carbonate grains
  - Silicates
    - Quartz
    - Chert
    - Feldspar
  - Sulfides
    - Pyrite
    - Galena
    - Marcasite
    - Other
  - Sulfates
    - Gypsum
    - Anhydrite

Depositional Environments

Supratidal

mudstone, wackestones

Intertidal

packstones, grainstones

Subtidal

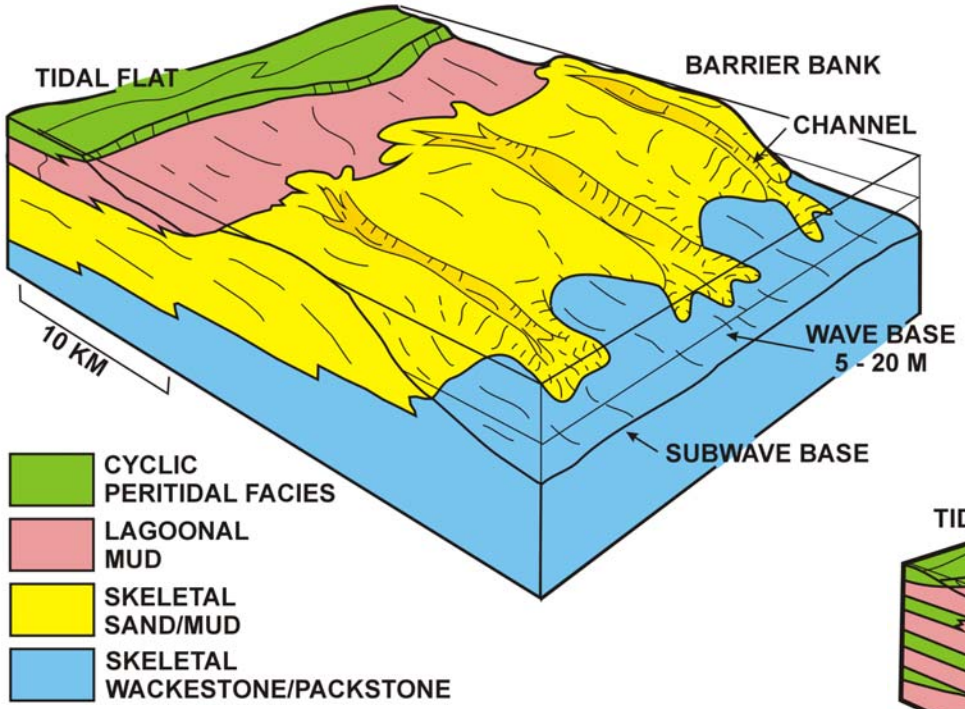
Middle Ramp

wackestones, packstones

Outer Ramp

shale, mudstones, wackestones

Overall Depositional Setting

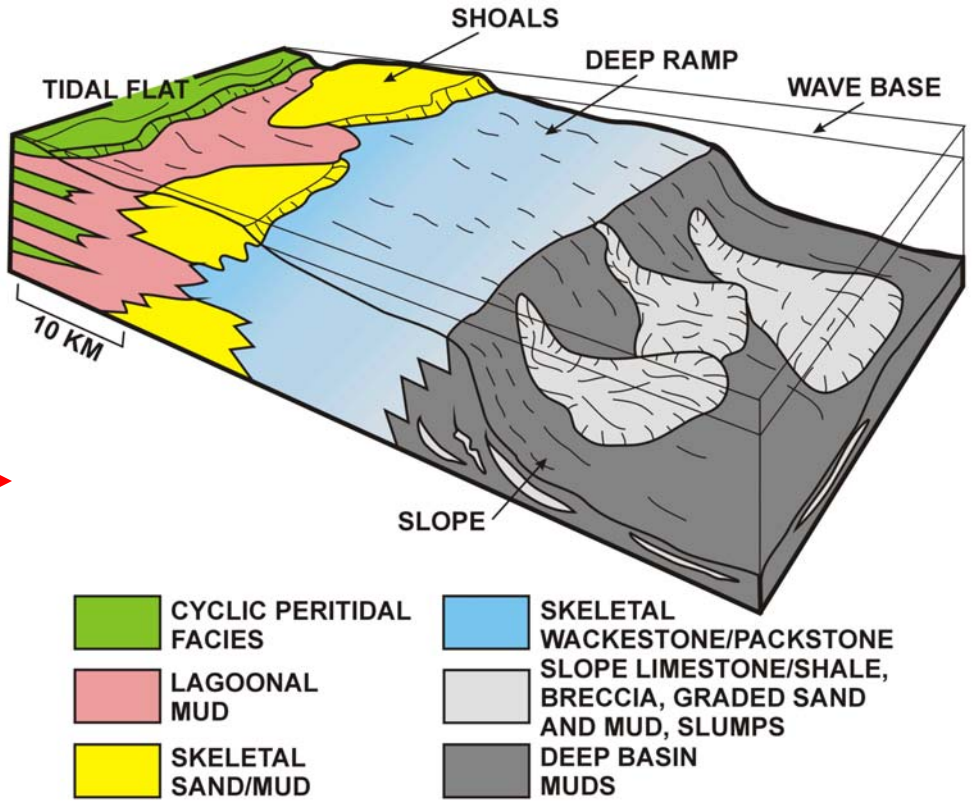


Homoclinal Ramp

Black River

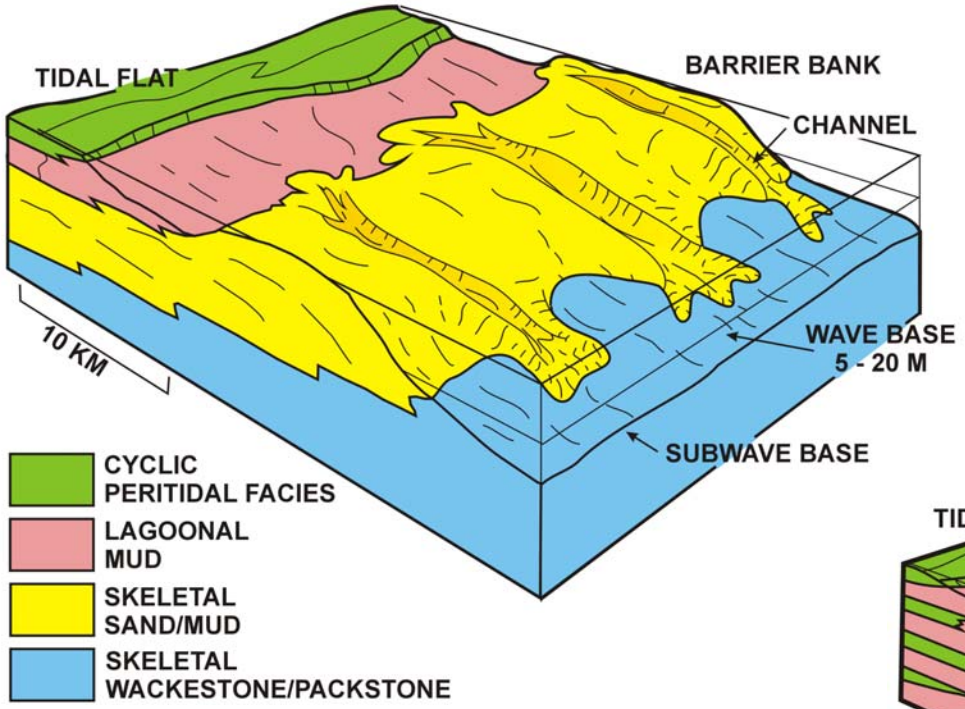
Distally steepened ramp

Trenton



From Read, 1985

Overall Depositional Setting

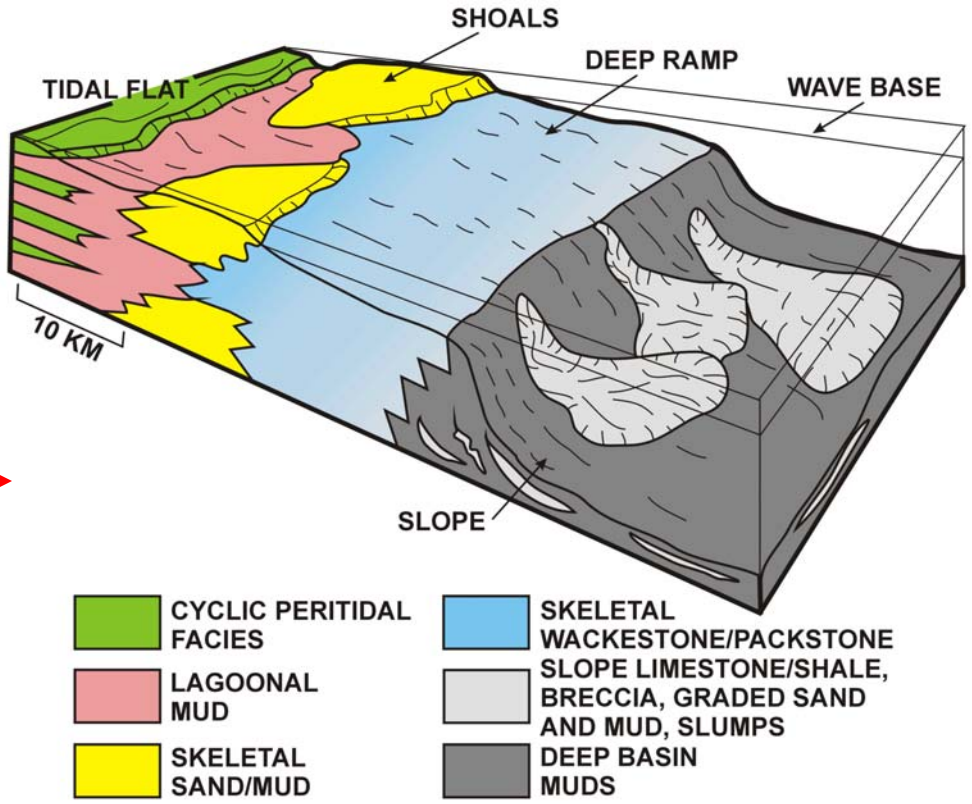


Homoclinal Ramp

Black River

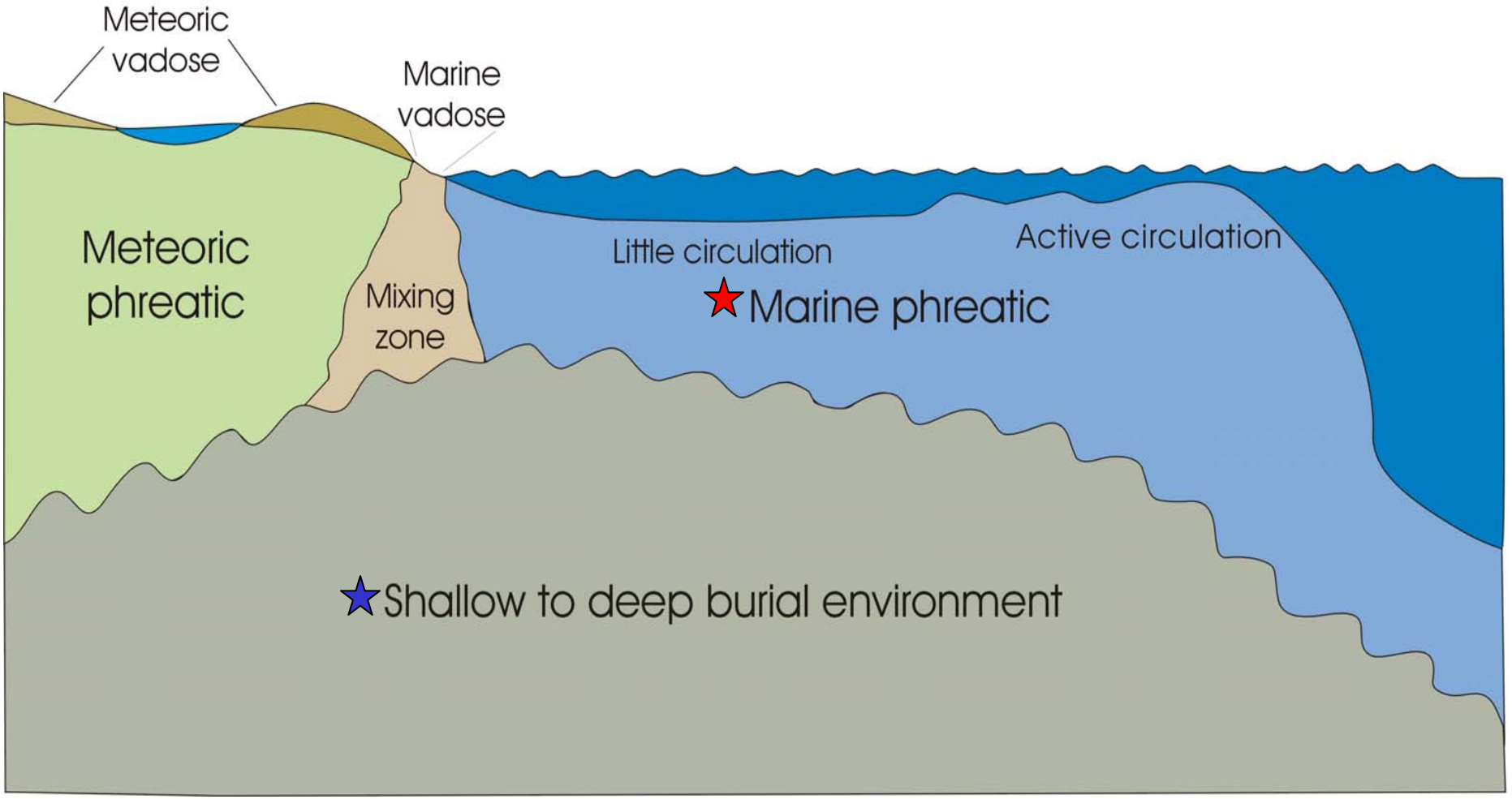
Distally steepened ramp

Trenton



From Read, 1985

Carbonate Diagenetic Environments



Modified from Tucker, 1981

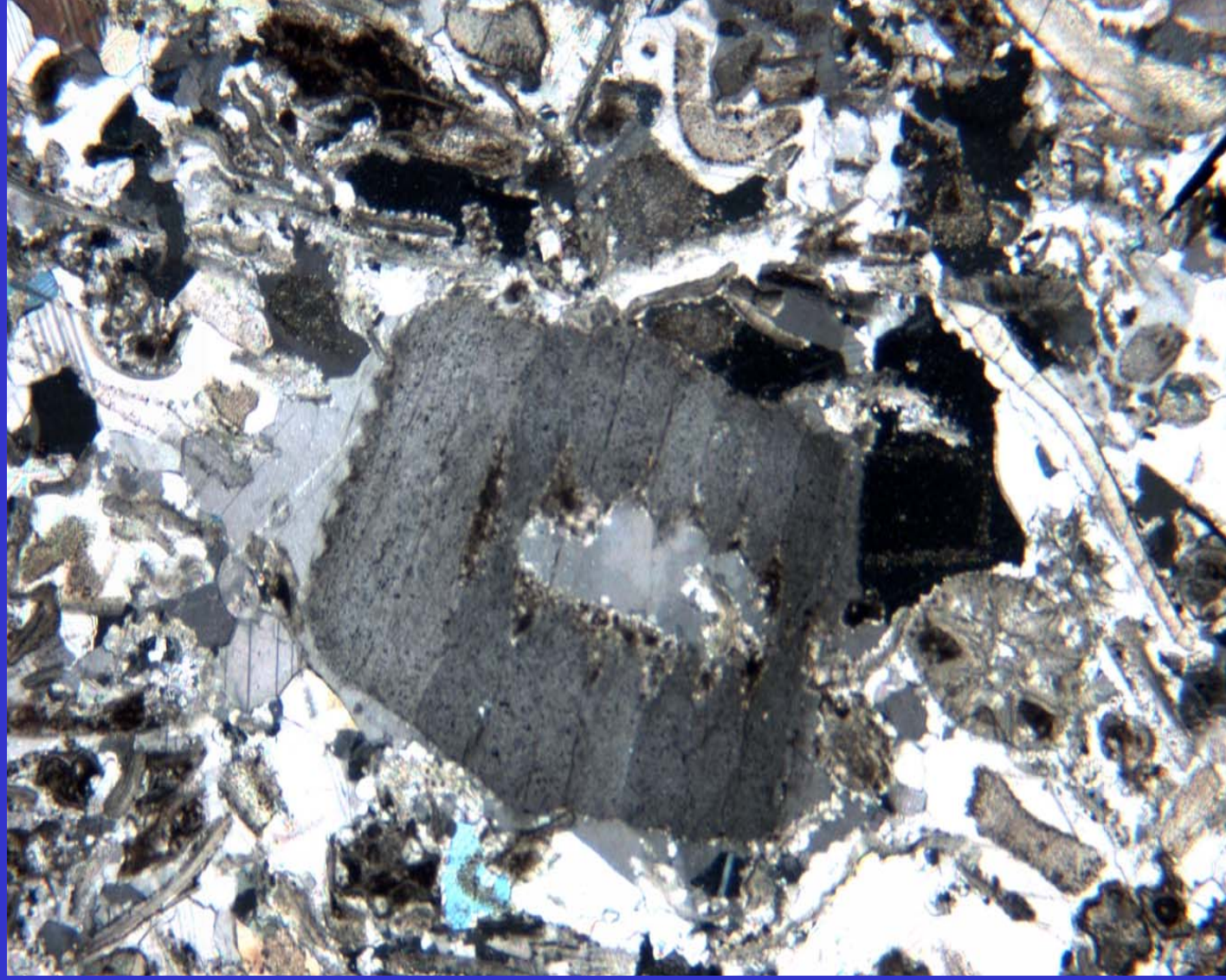
Micritization

↓

Isopachus Rims / Syntaxial overgrowths

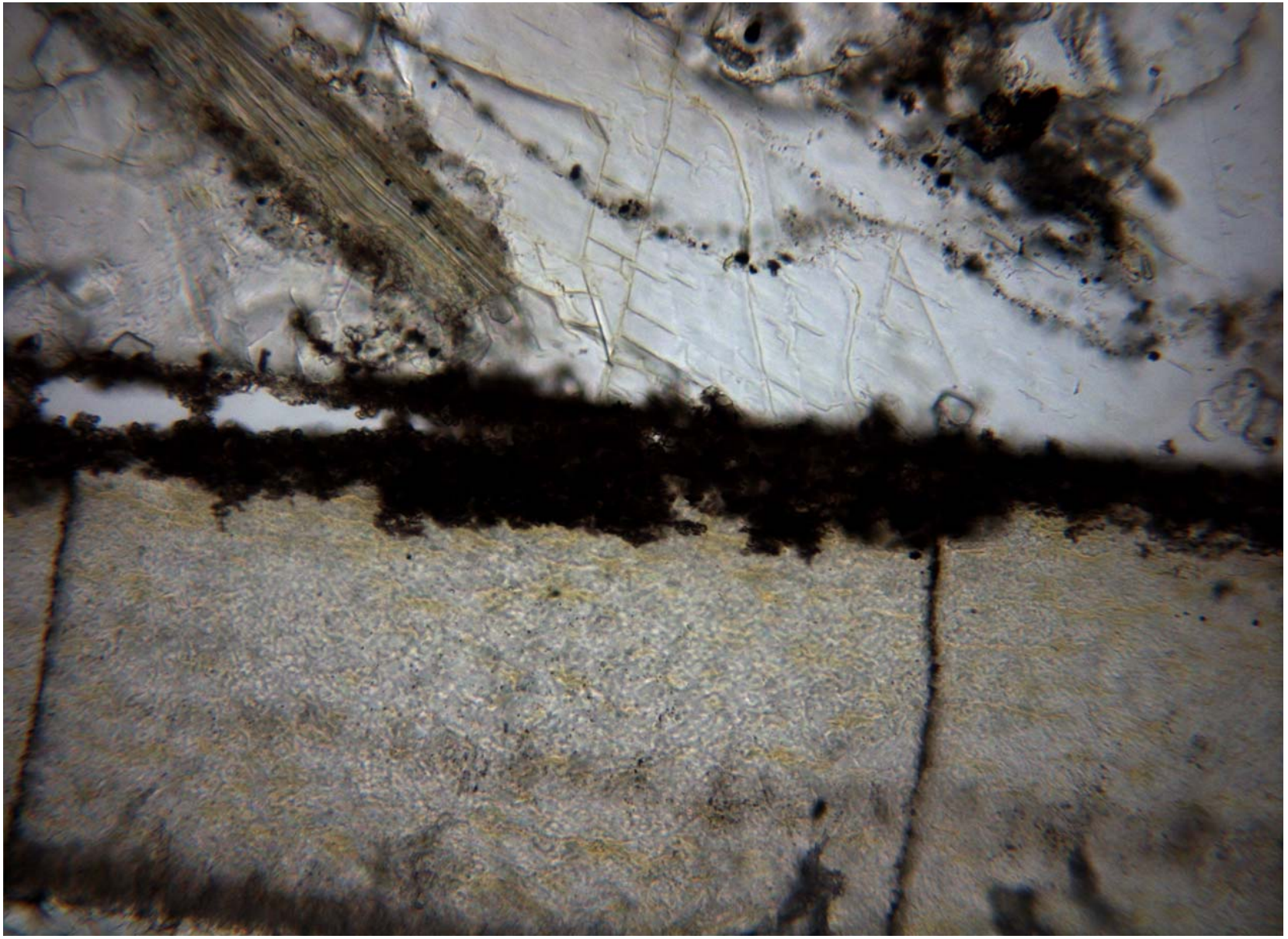
↓

Equant, pore-filling cement

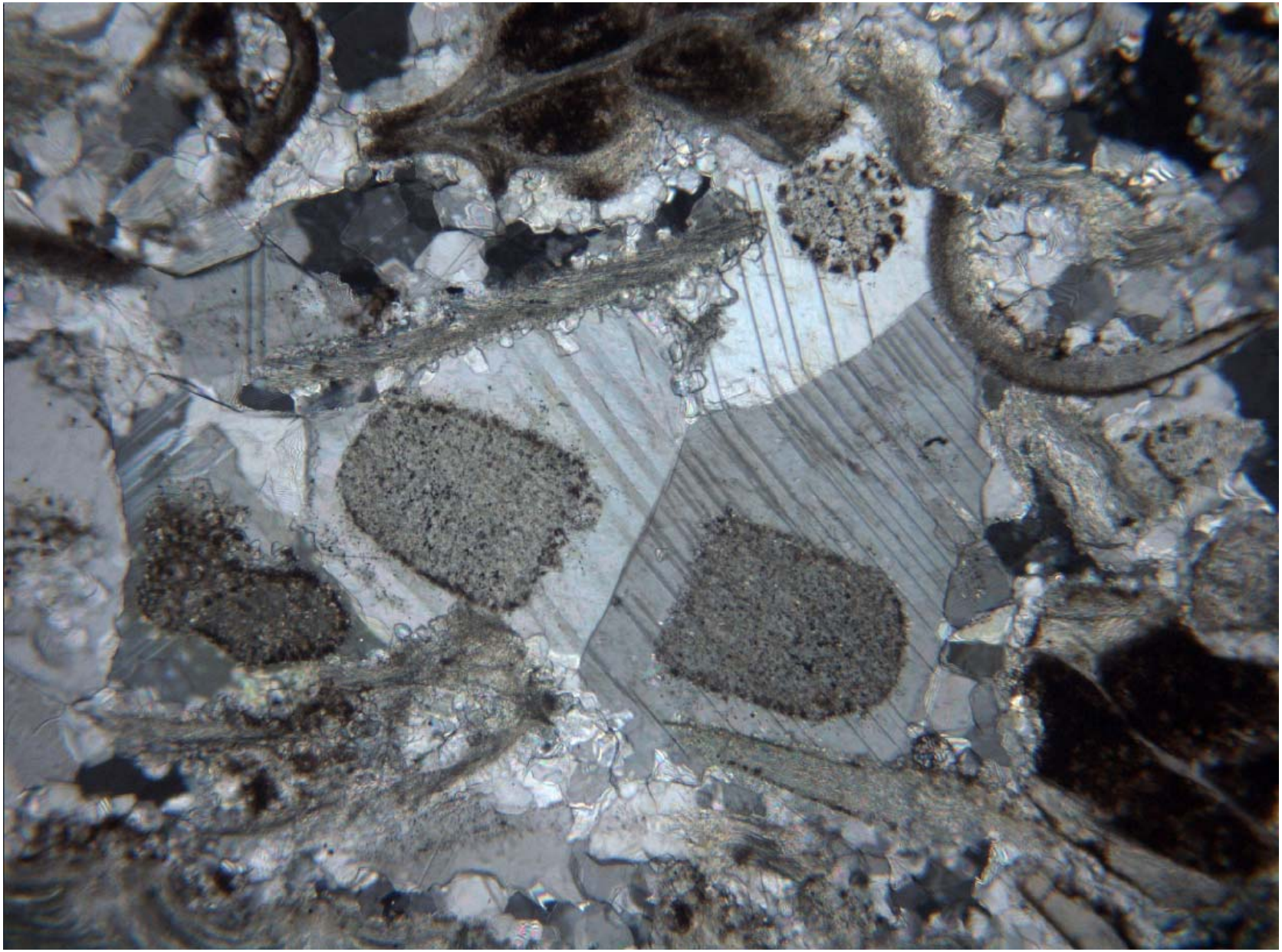


Sequence of diagenetic events

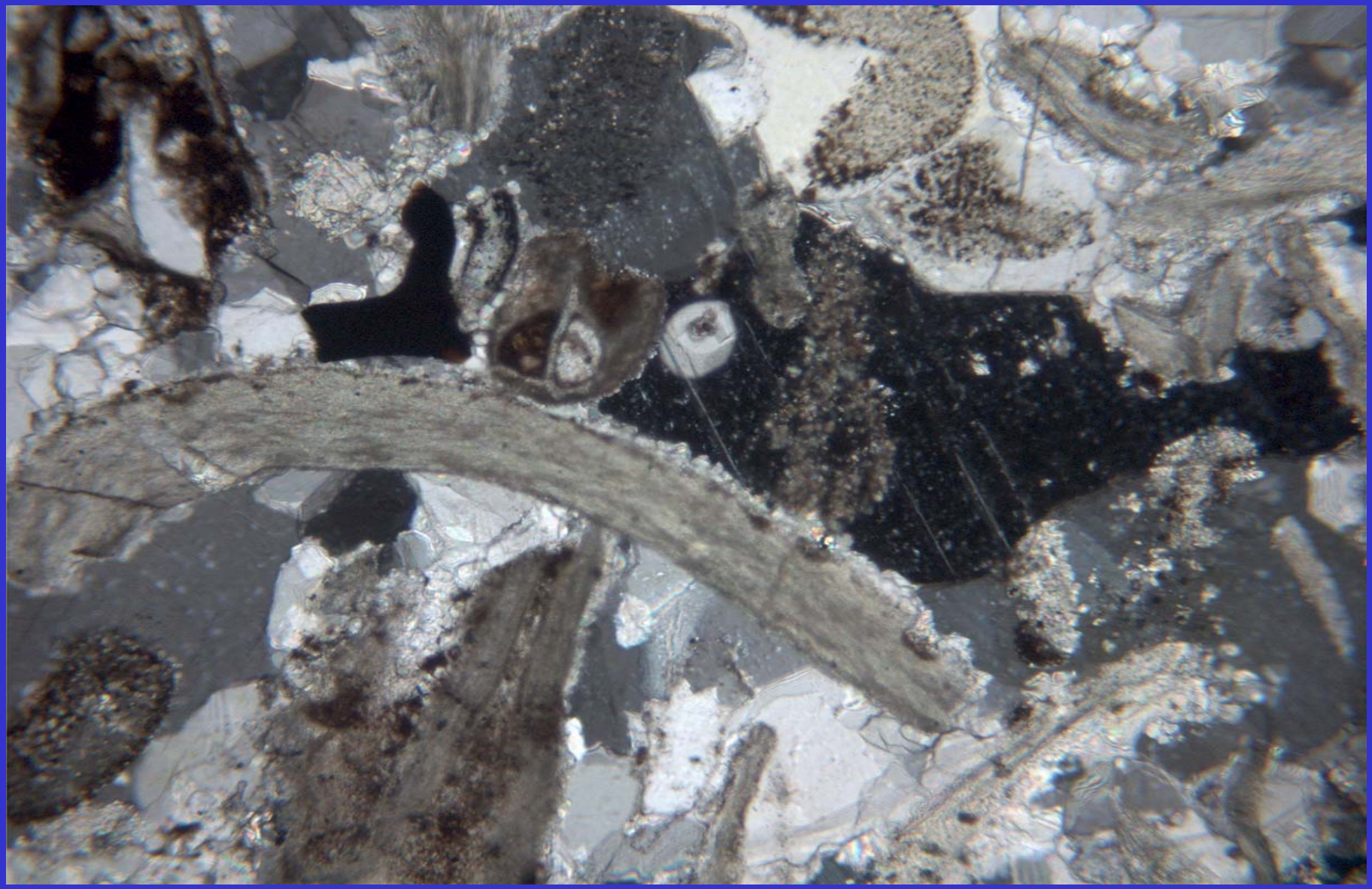
Micritization



Syntaxial overgrowths

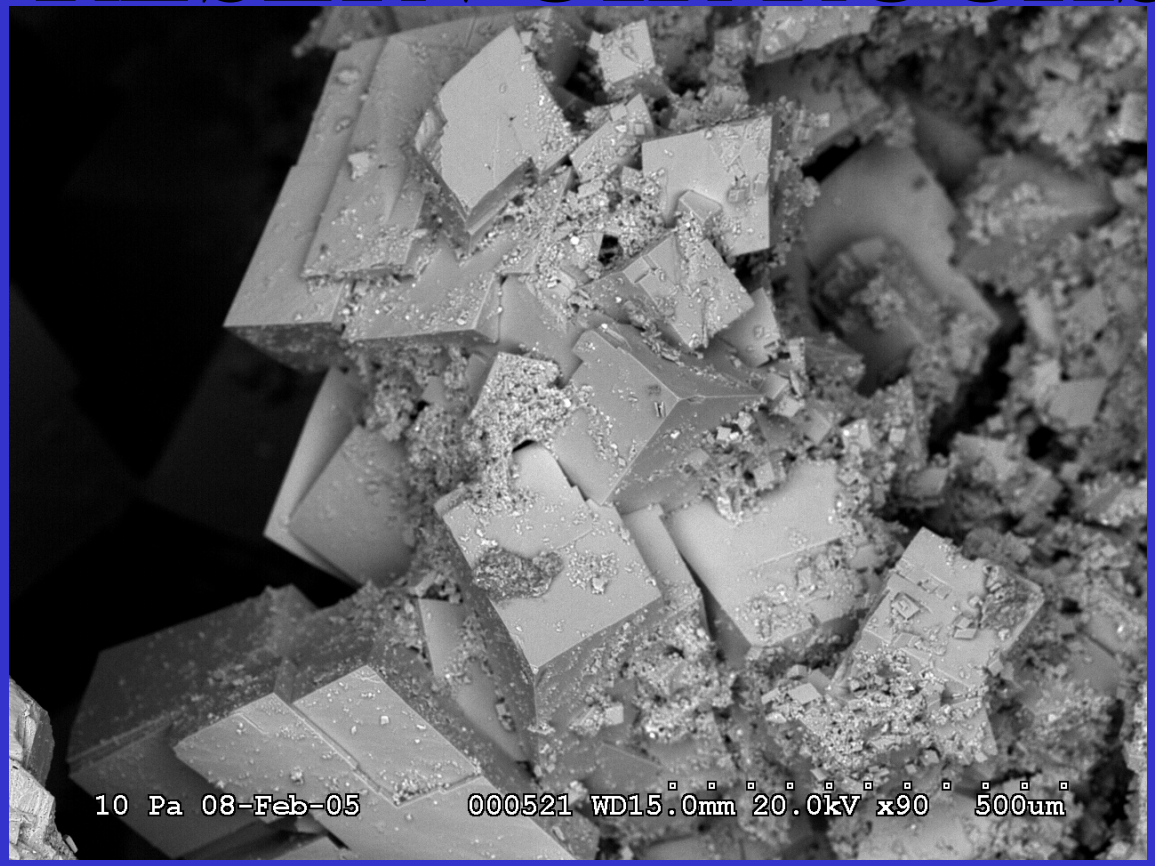


Isopachous fringe cement



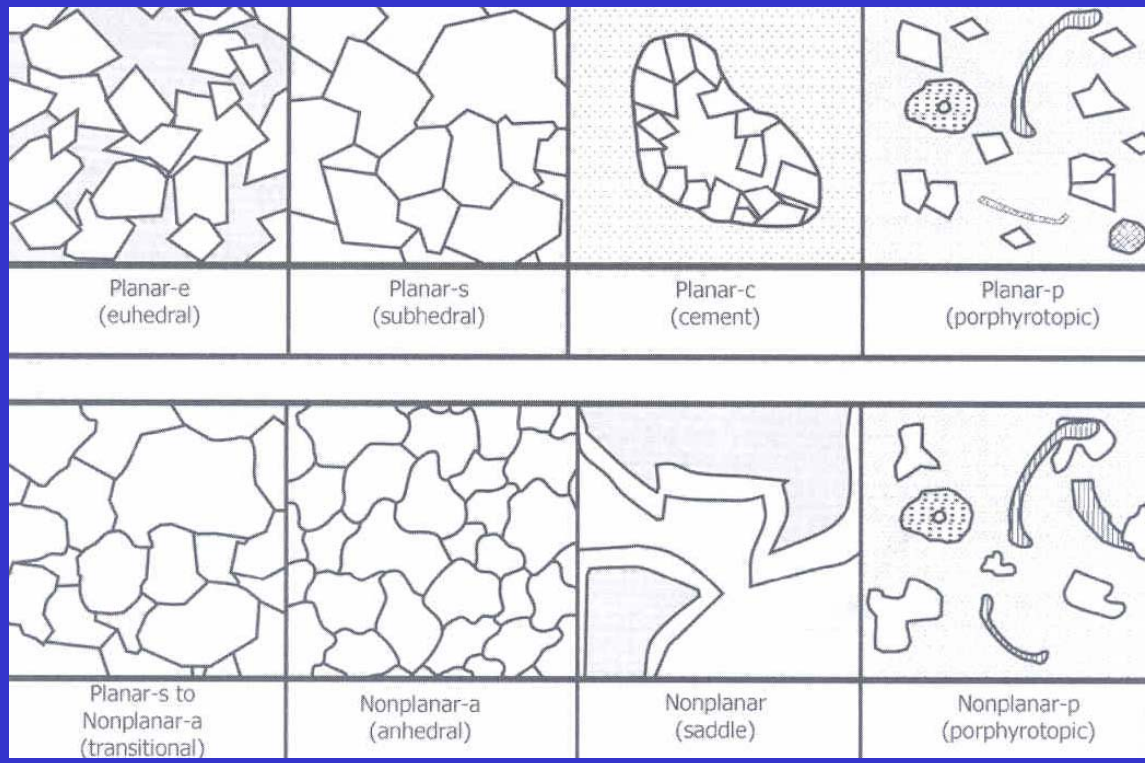
Equant, blocky cement

DOLOMITE TEXTURES IN TRENTON AND BLACK RIVER CARBONATE RESERVOIR ROCKS



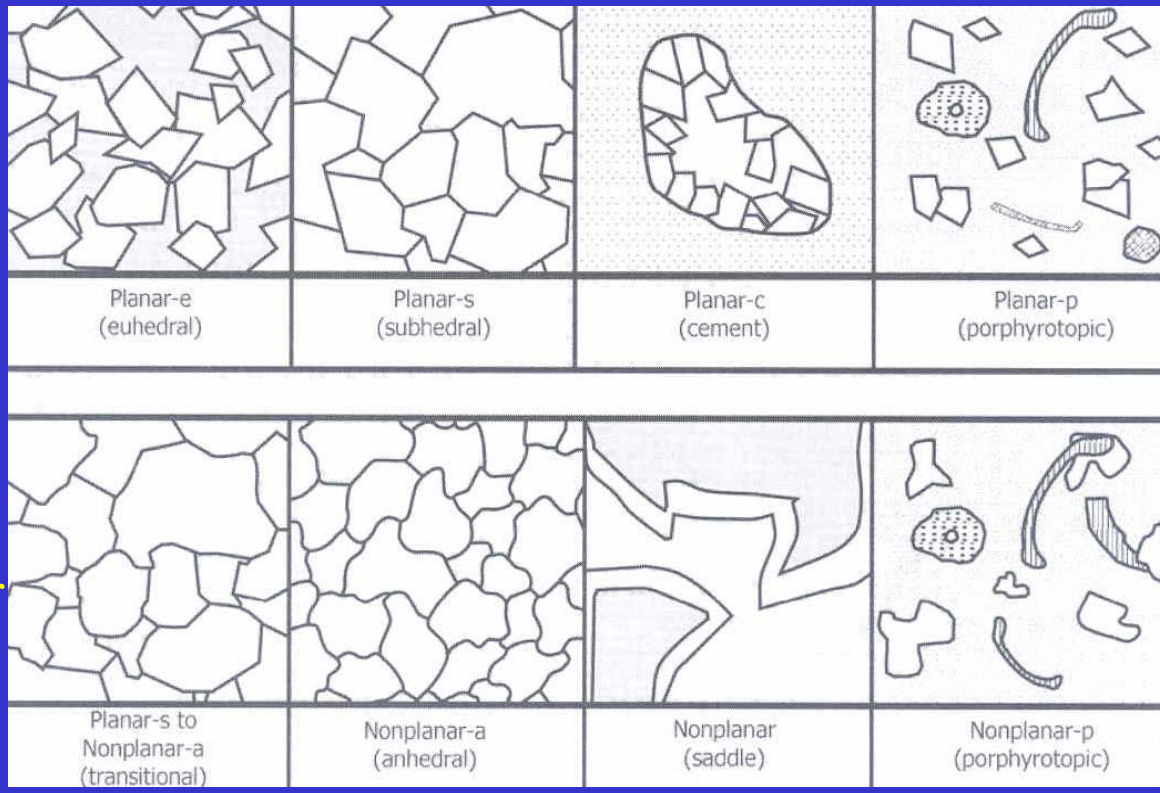
Dolostone Textural Classification

- Sibley and Gregg (1984; 1987; modified by Wright, 2001)
- Simple and mostly descriptive
- Carries some genetic implications, and restricted to microscope scale



Dolostone Textural Classification

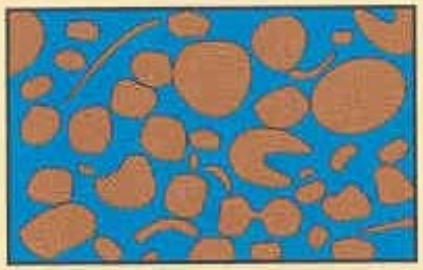
- Crystal size distributions:
  - Unimodal
  - Polymodal
- Crystal Shapes:
  - Planar-e
  - Planar-s
  - Nonplanar-a
  - Planar-c
  - Planar-p and nonplanar-p
  - Saddle dolomite: nonplanar or nonplanar-c
  - Transitional
- Recognizable allochems, matrix, and void-filling



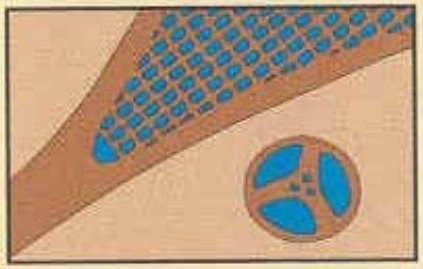
Dolostone Textural Classification

- Particles and cement:
  - Unreplaced
  - Partially replaced:
    - Mimetic
    - Non-mimetic
  - Completely replaced
    - Mimetic
    - Non-mimetic

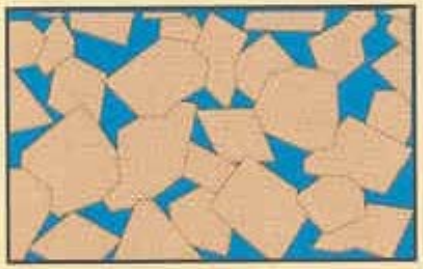
Fabric Selective Porosity Types



Inter-particle

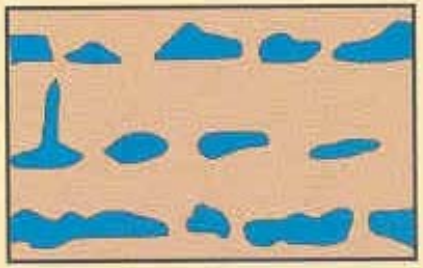


Intra-particle

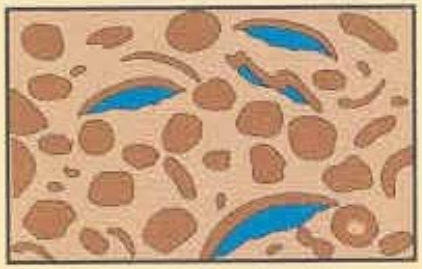


Inter-crystal

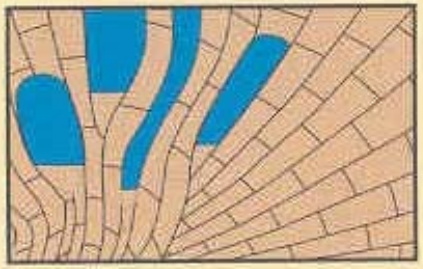
Moldic



Fenestral

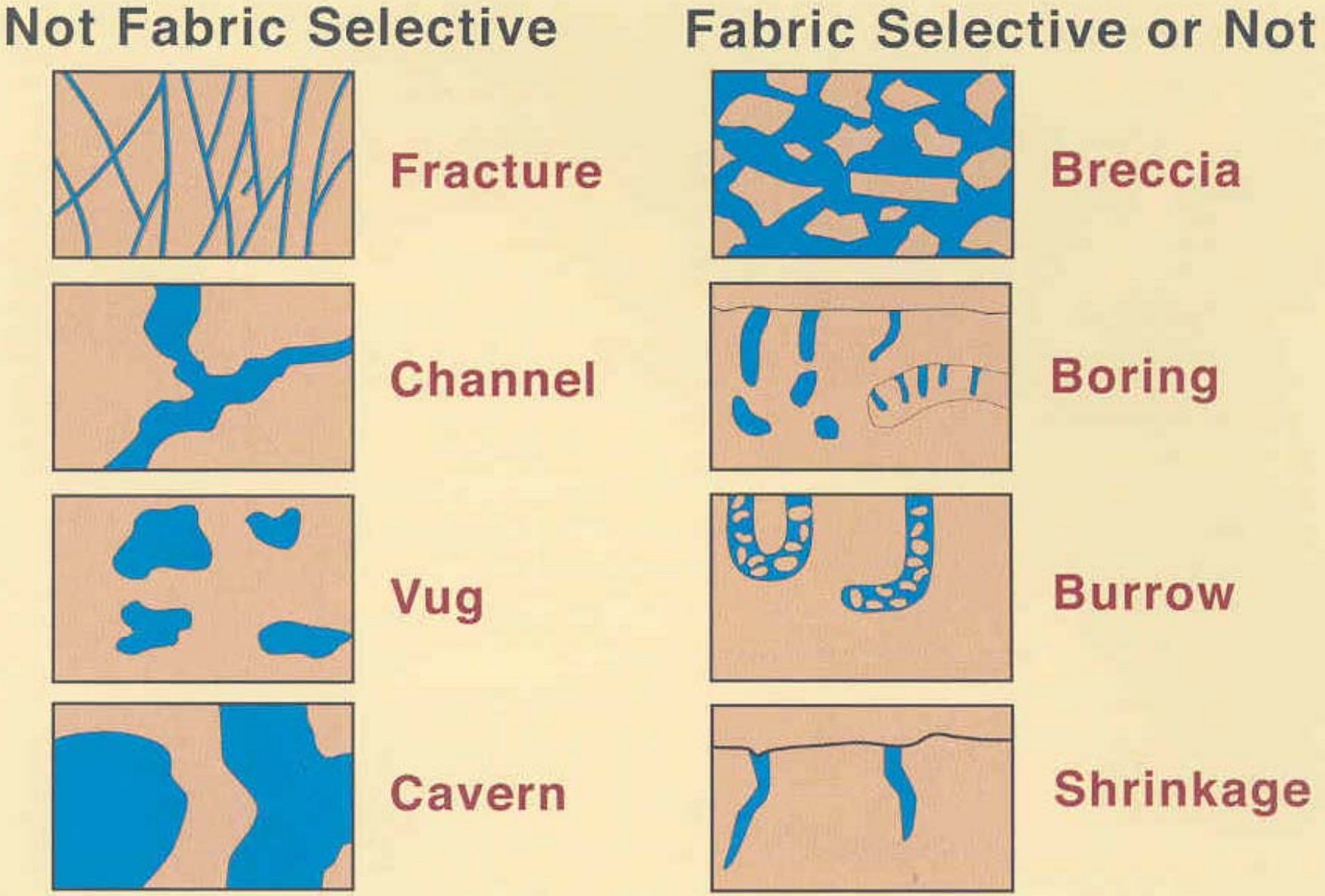


Shelter

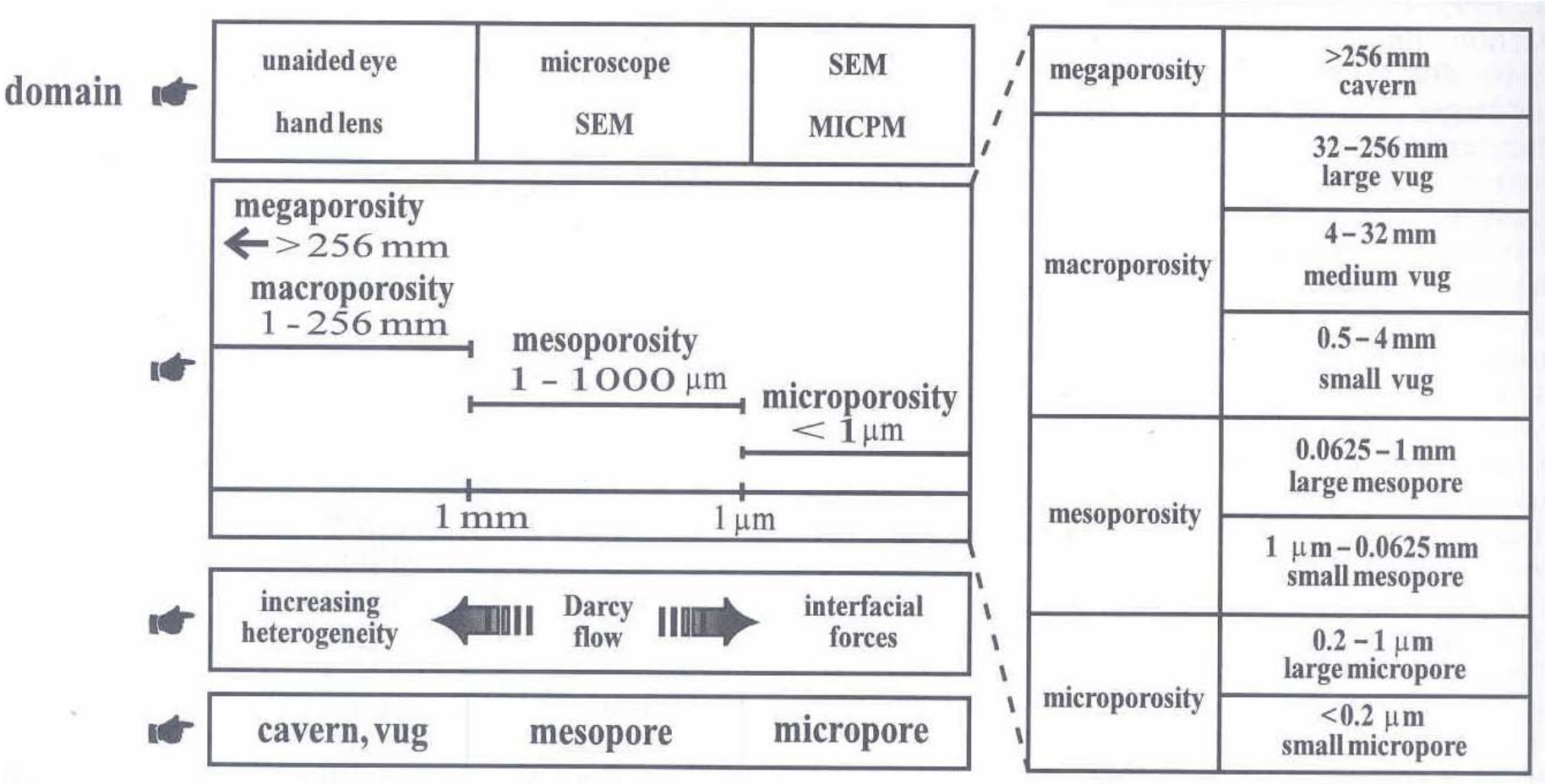


Growth framework

Choquette and Pray, 1970



Choquette and Pray, 1970



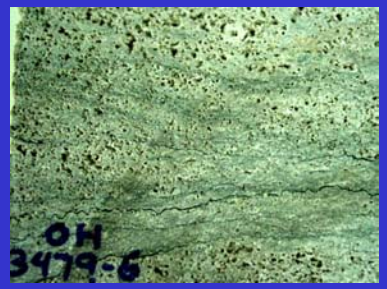
Lou and Machel (1995), AAPG Bulletin v.79, p.1698 – 1720)

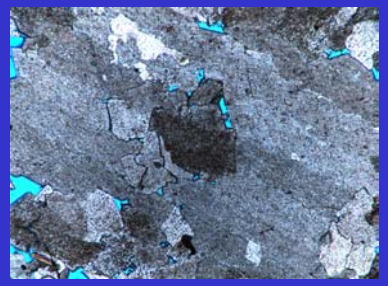
DOLOGRAINSTONES AND DOLOPACKSTONES

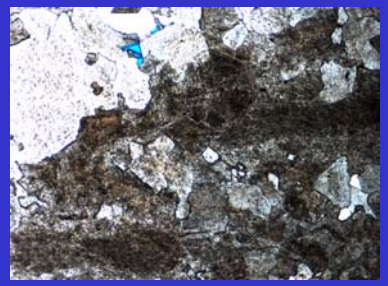
- Productive reservoir rocks in northwestern Ohio
- Depositional texture may or may not be recognizable to unaided eye
- Planar-s to nonplanar-a and saddle dolomites

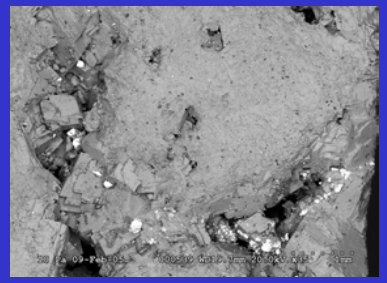
Porosity

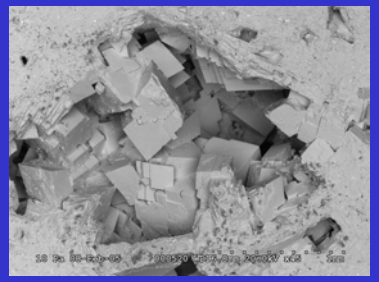
- Macroporosity:
  - Not fabric-selective:
    - Small to medium vugs
    - Fractures
- Mesoporosity
  - Fabric-selective:
    - Moldic
    - Intercrystalline
- Microporosity

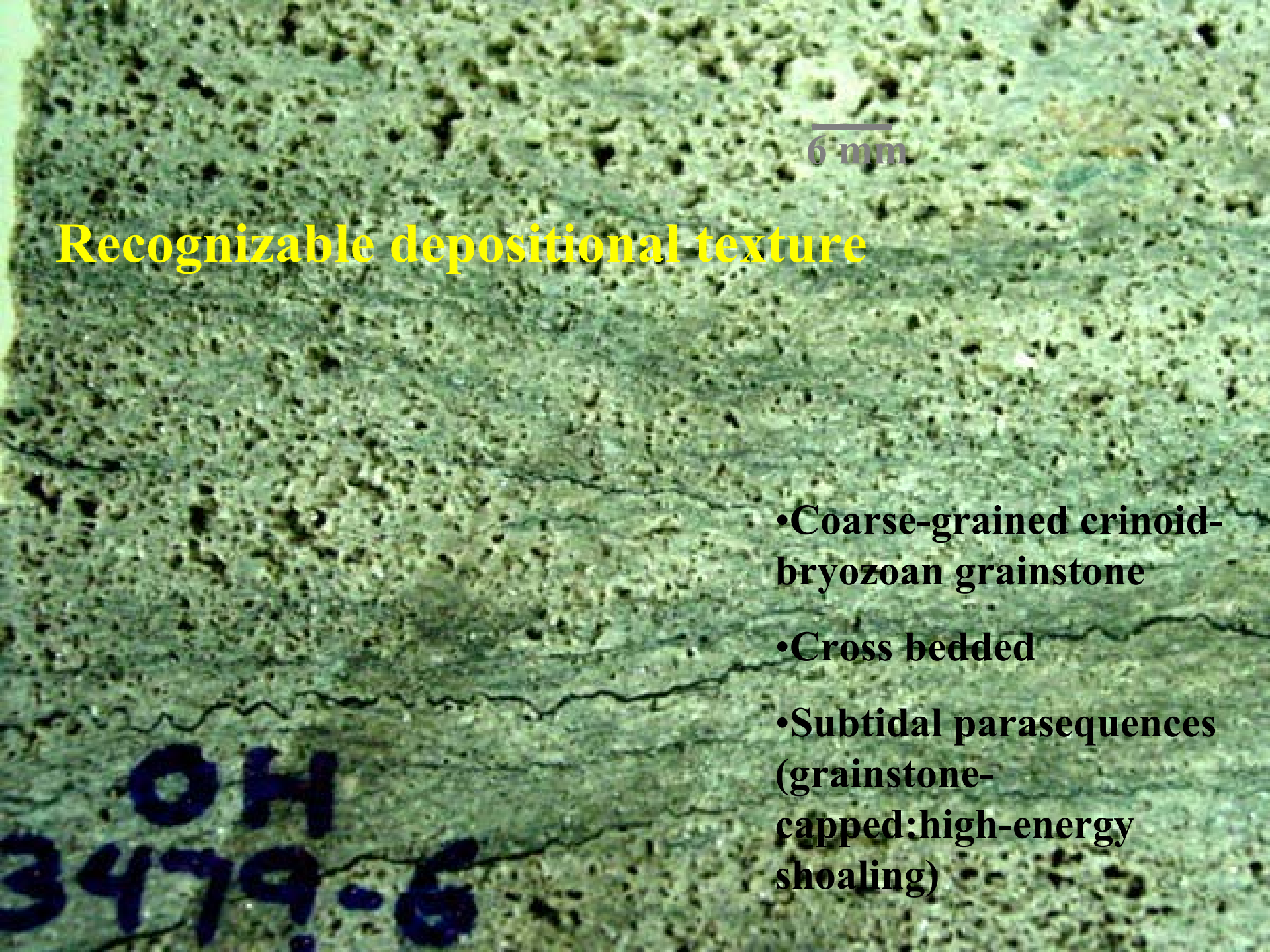


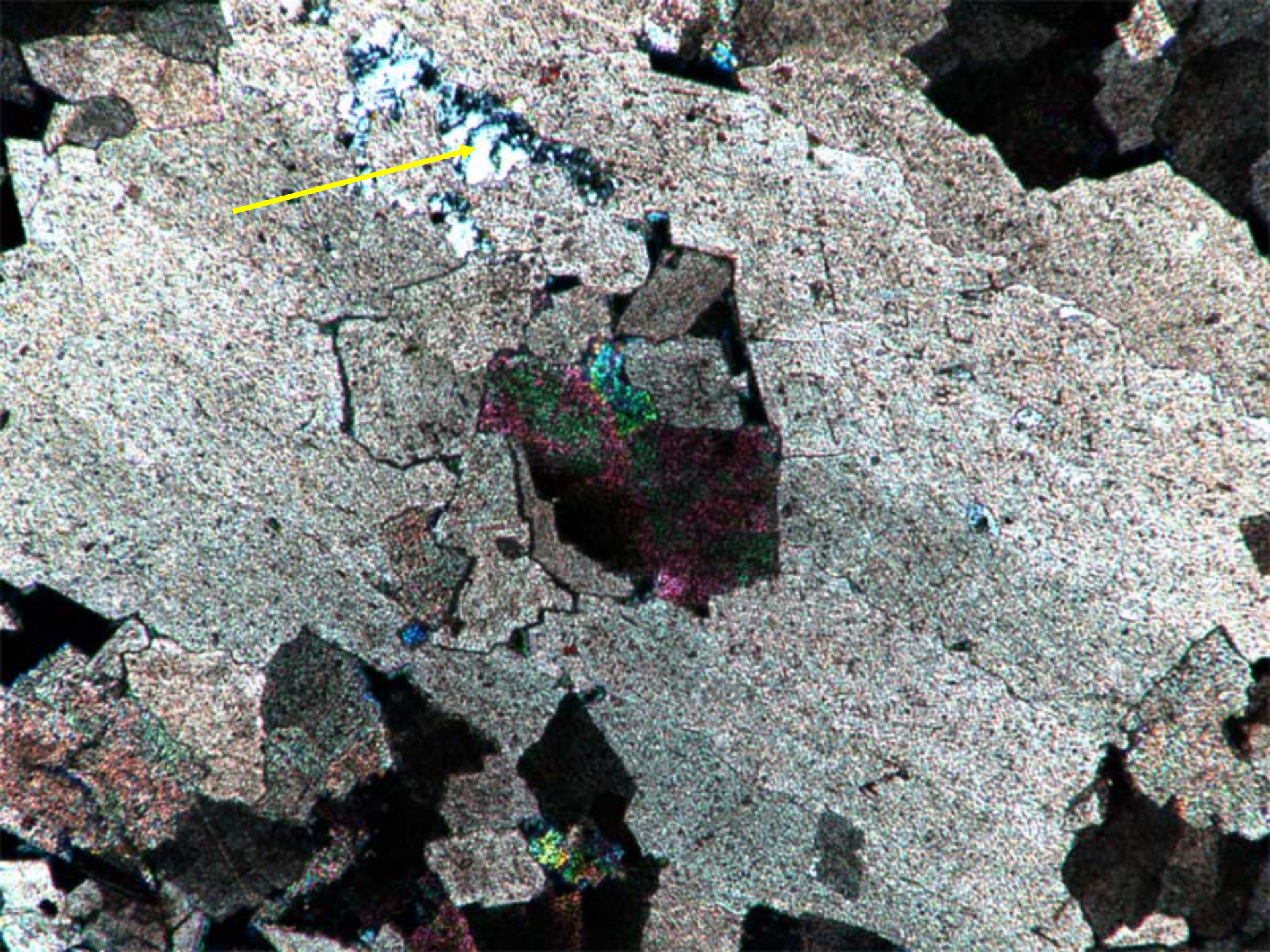


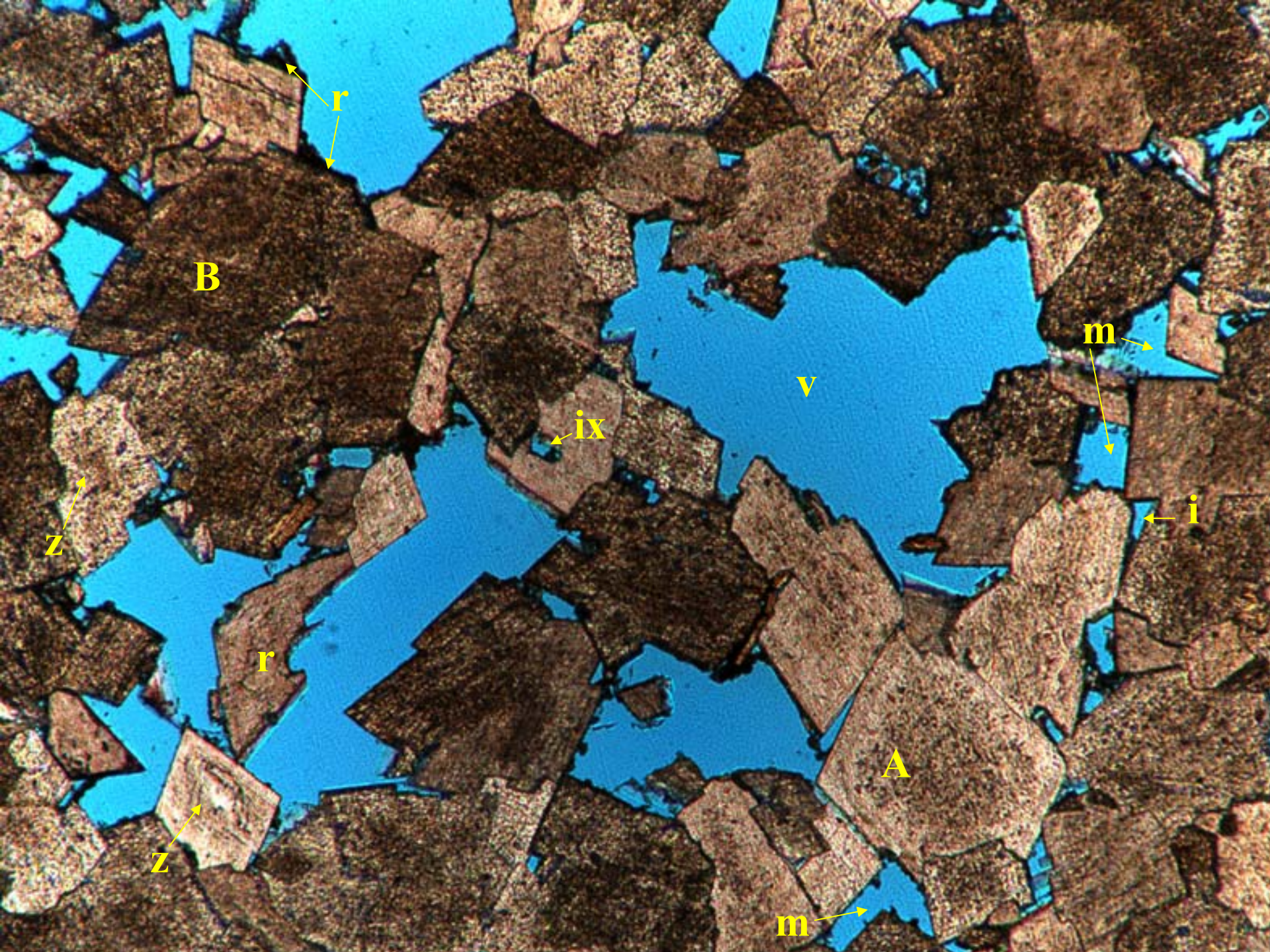







6 mm
Recognizable depositional texture
•Coarse-grained crinoid-bryozoan grainstone
•Cross bedded
•Subtidal parasequences (grainstone-capped:high-energy shoaling)
OH
3479-6




r
B
m
v
ix
i
z
r
A
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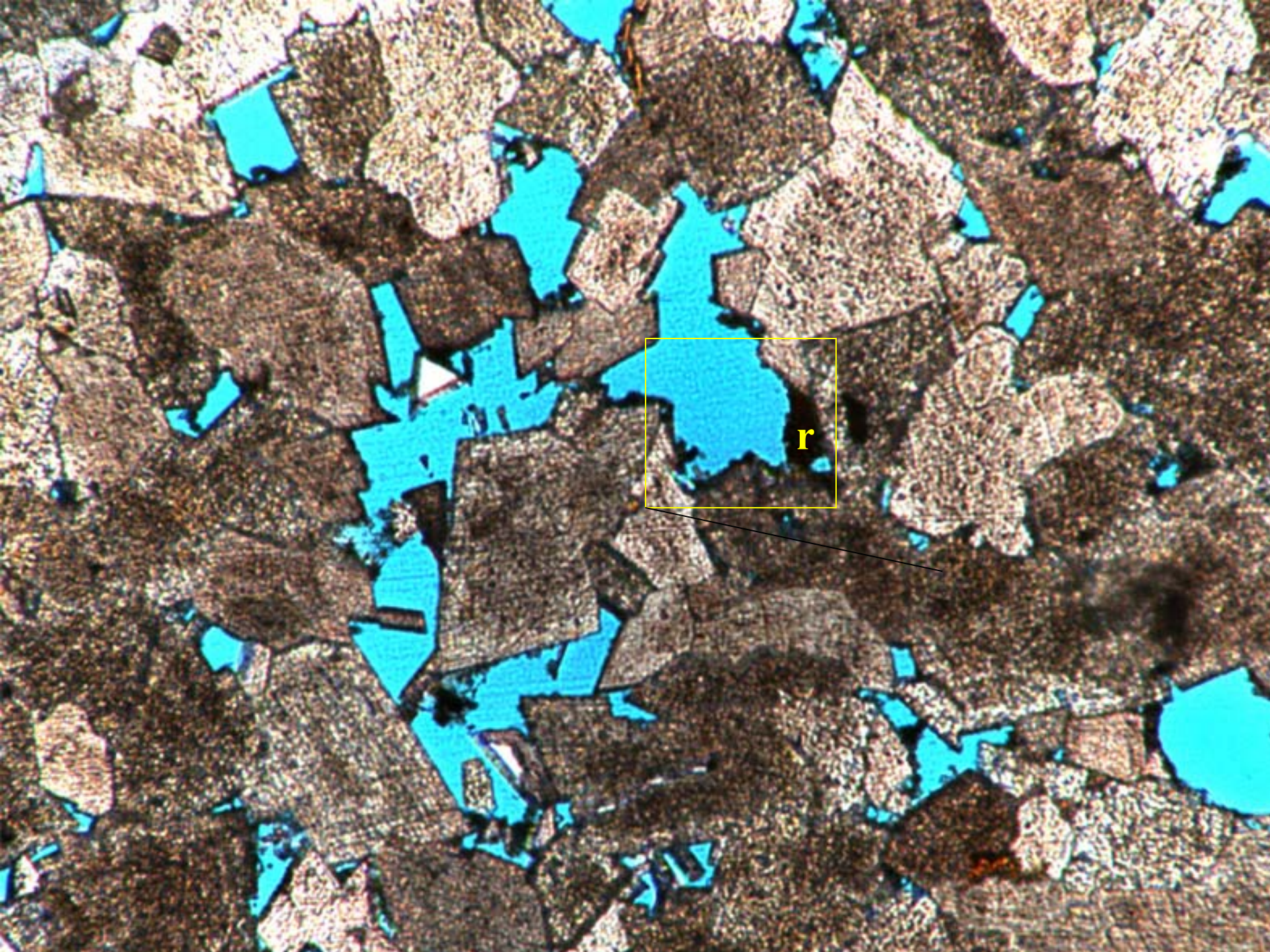
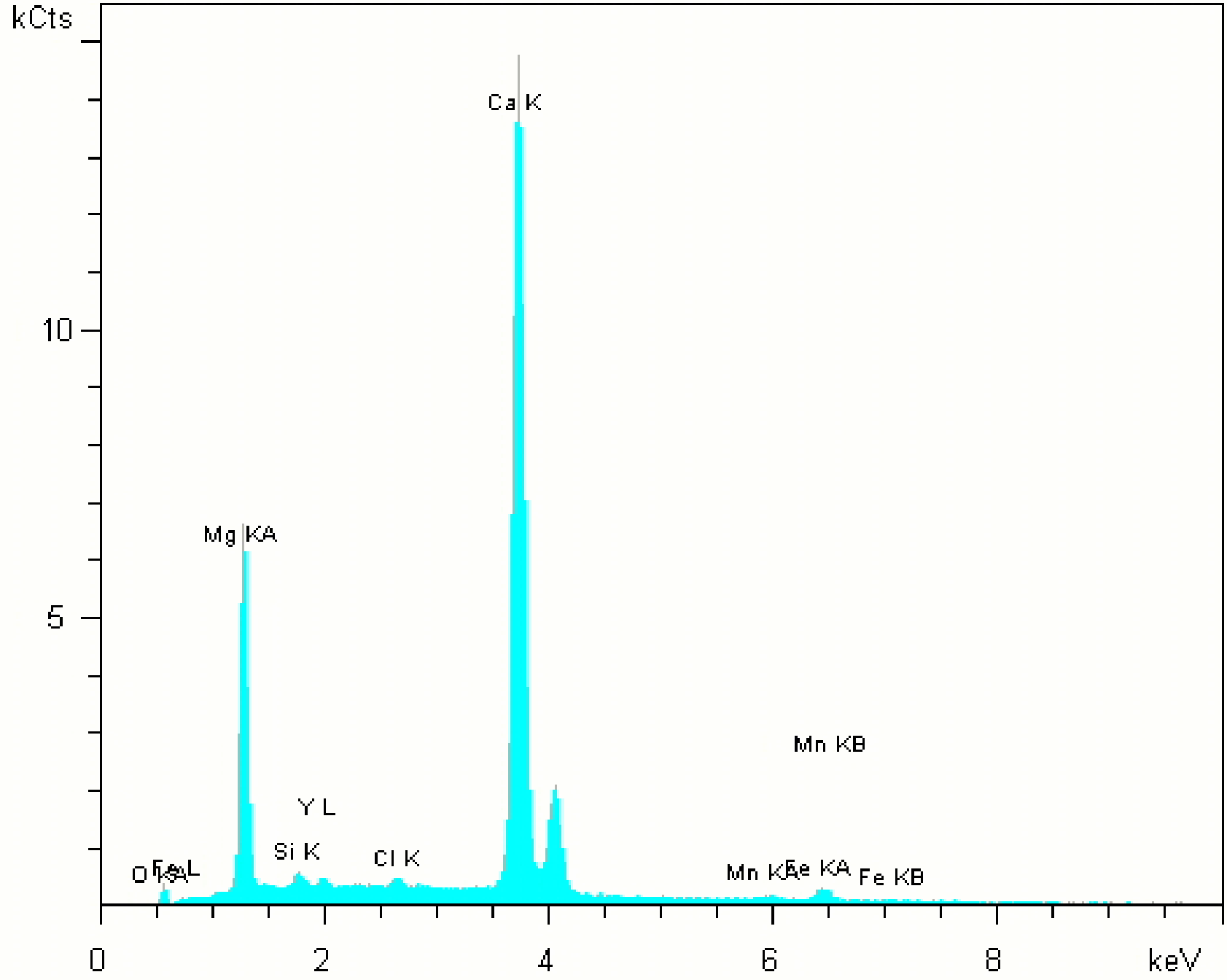
ix
B
v
Nonplanar-c dolomite
r
10 Pa 08-Feb-05 000520 WD16.8mm 20.0kV x45 1mm


r


r


pyrite
10 Pa 08-Feb-05
000521 WD15.1mm 20.0kV x90
500um


kCts
10
5
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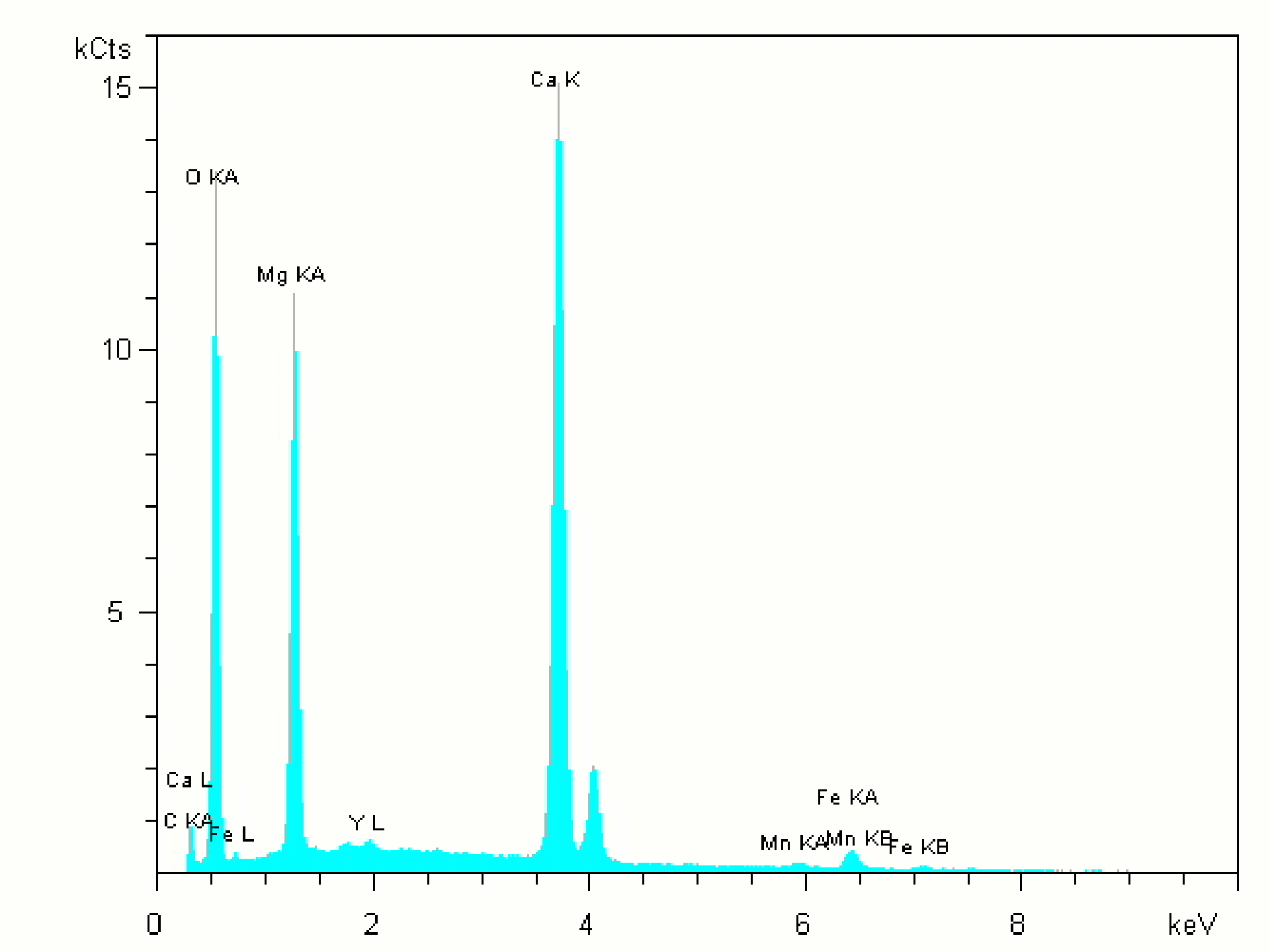
keV
Ca K
Mg KA
Y L
Si K
Cl K
Mn KB
Mn KA
Fe KA
Fe KB


10 Pa 08-Feb-05
000522 WD15.0mm 20.0kV x90 500um


kCts
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C KA
Fe L
Y L
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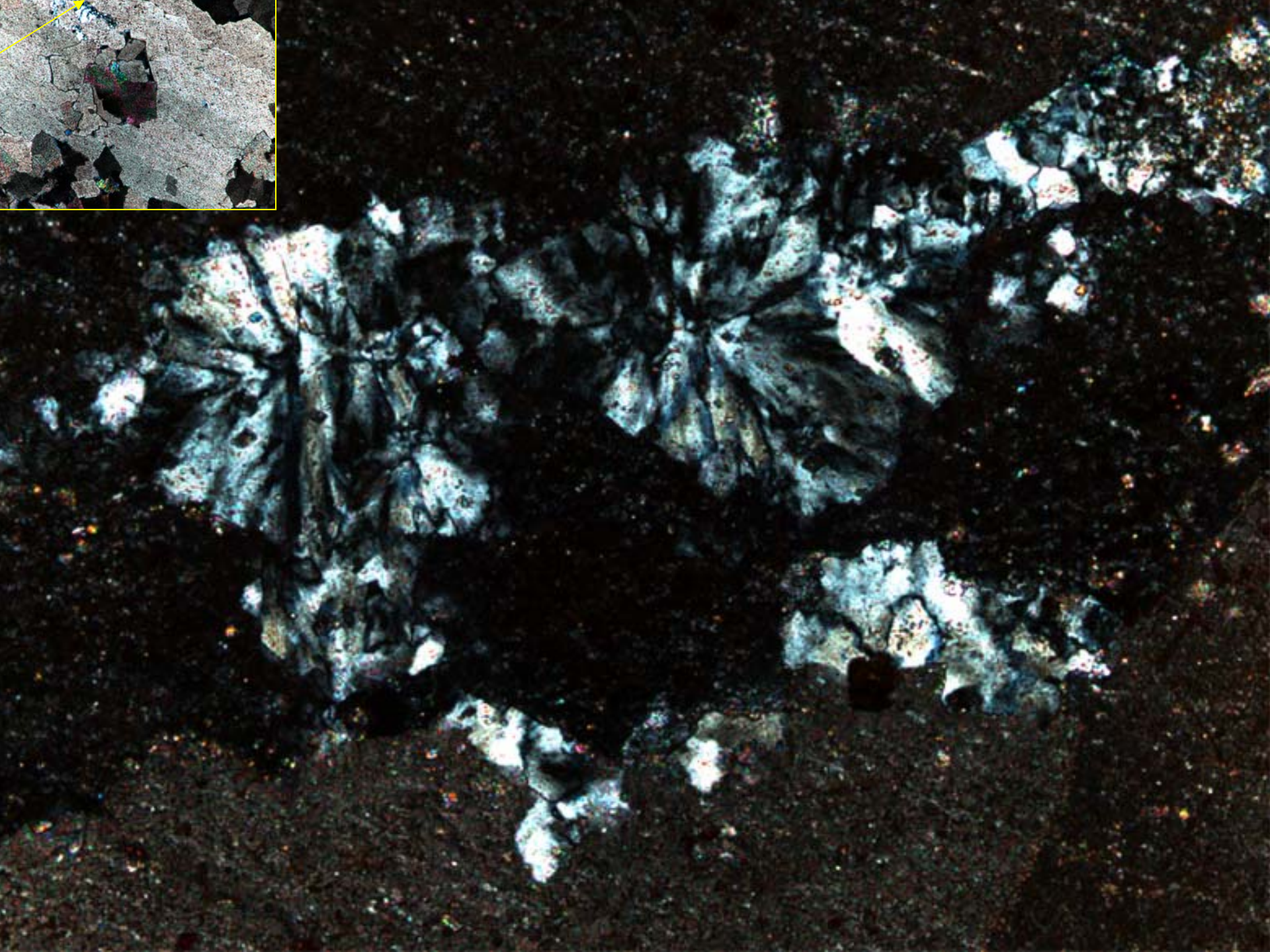
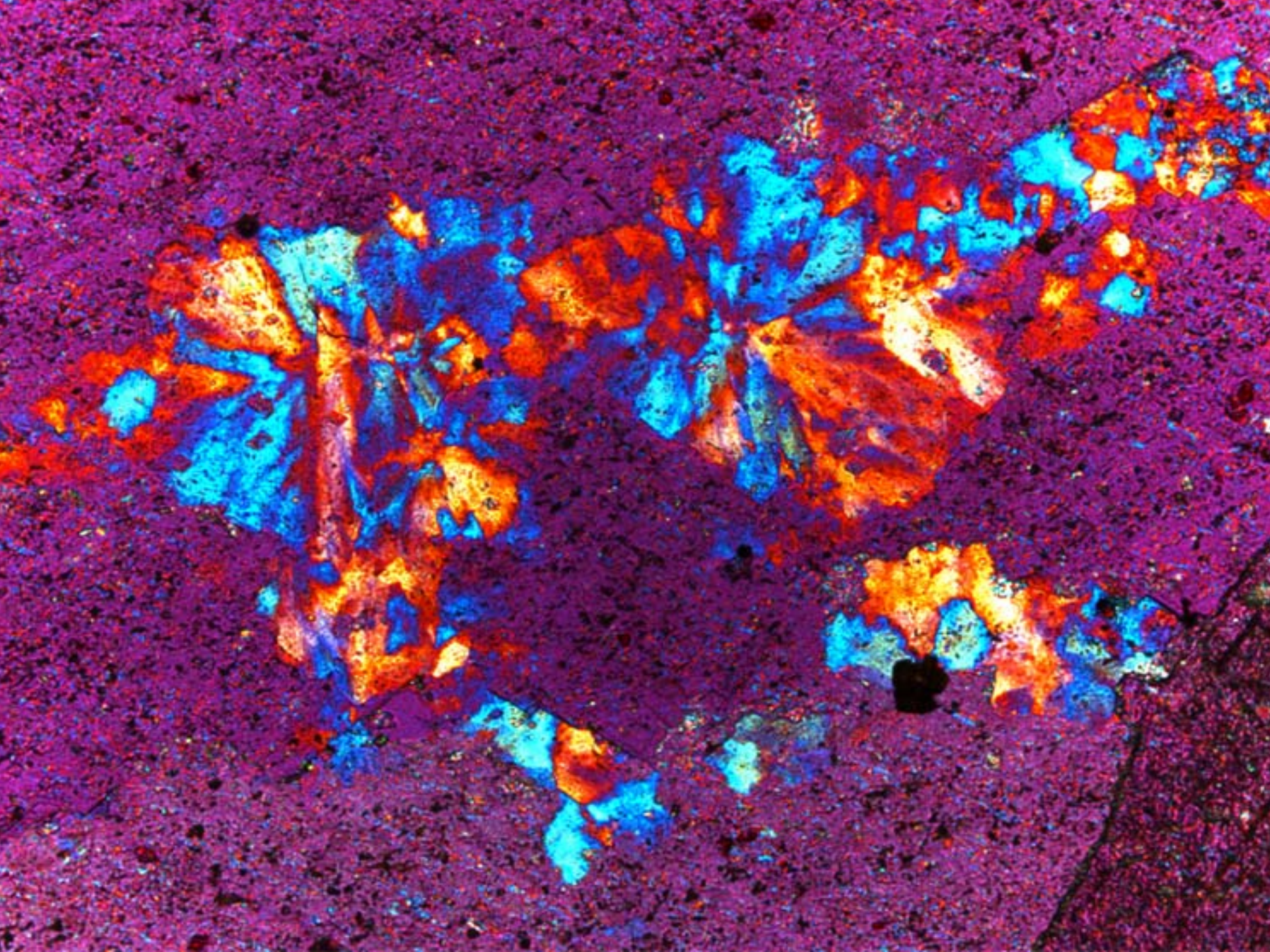
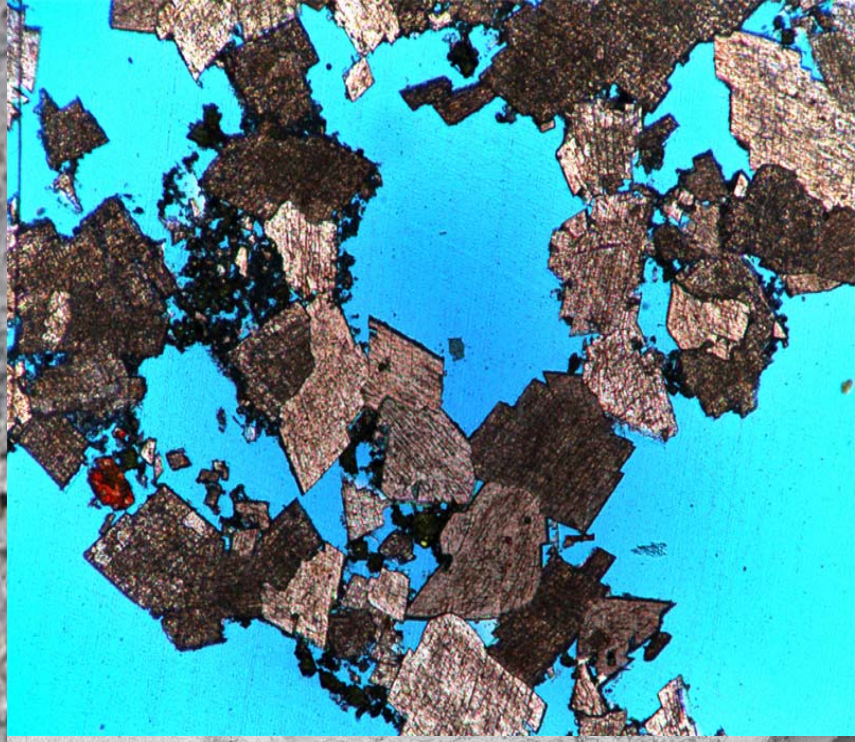
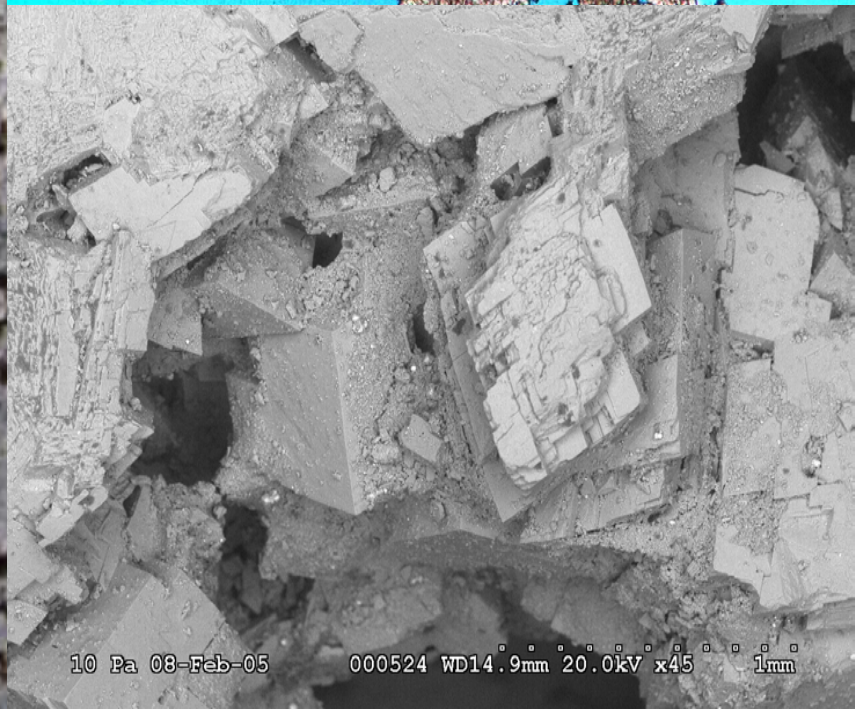
Mn KA
Mn KB
Fe KB

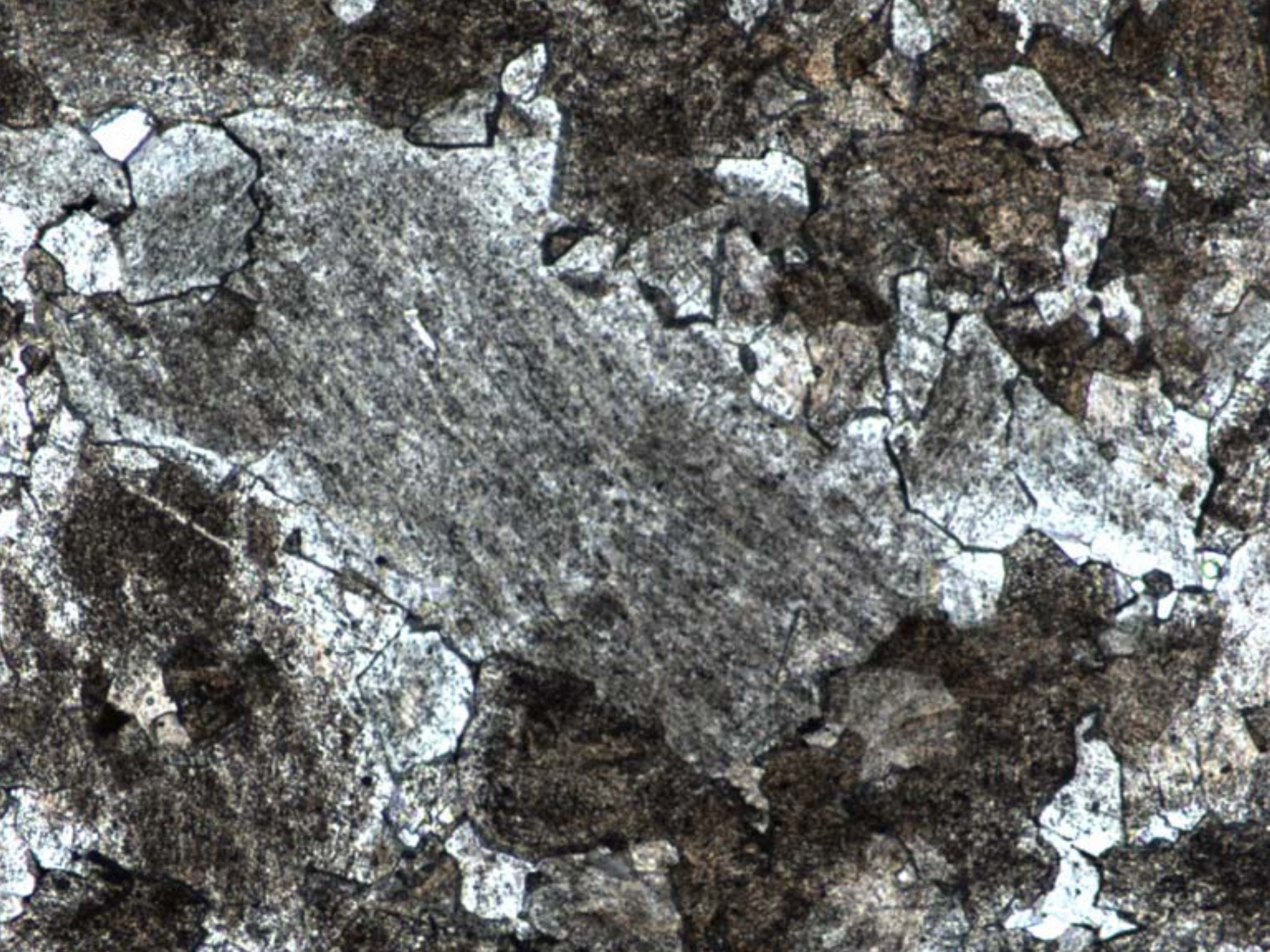


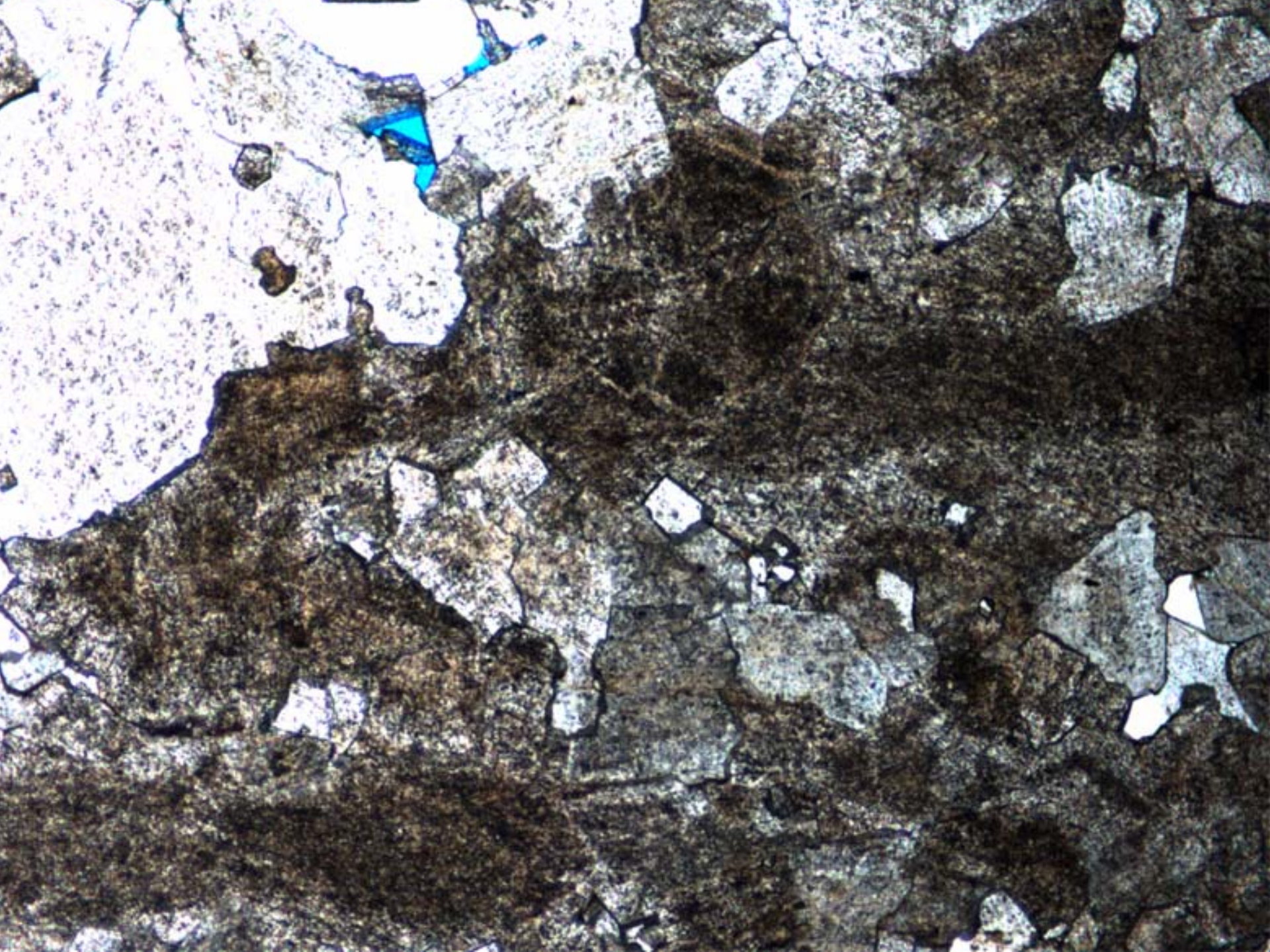


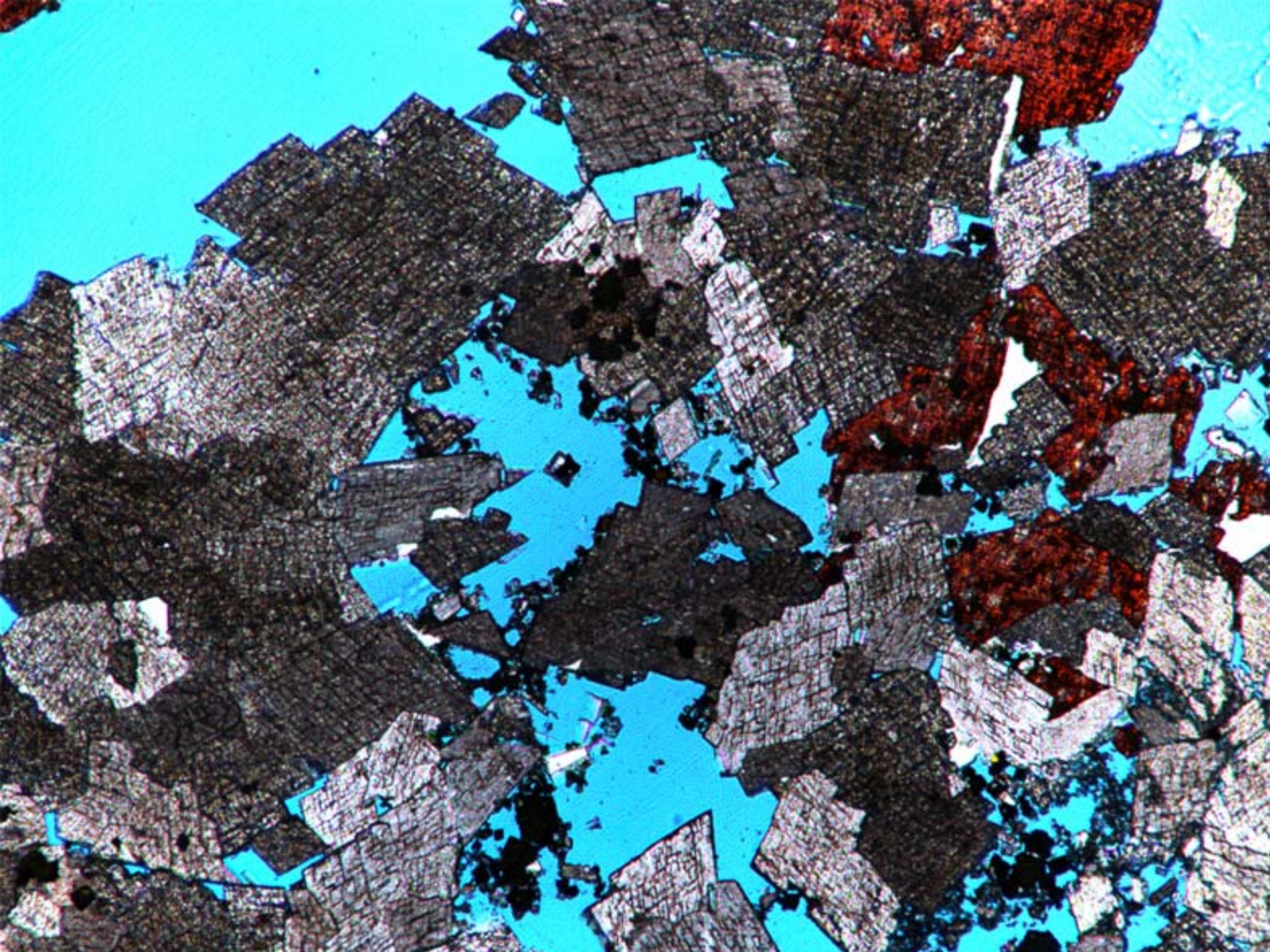
Depositional texture unrecognizable

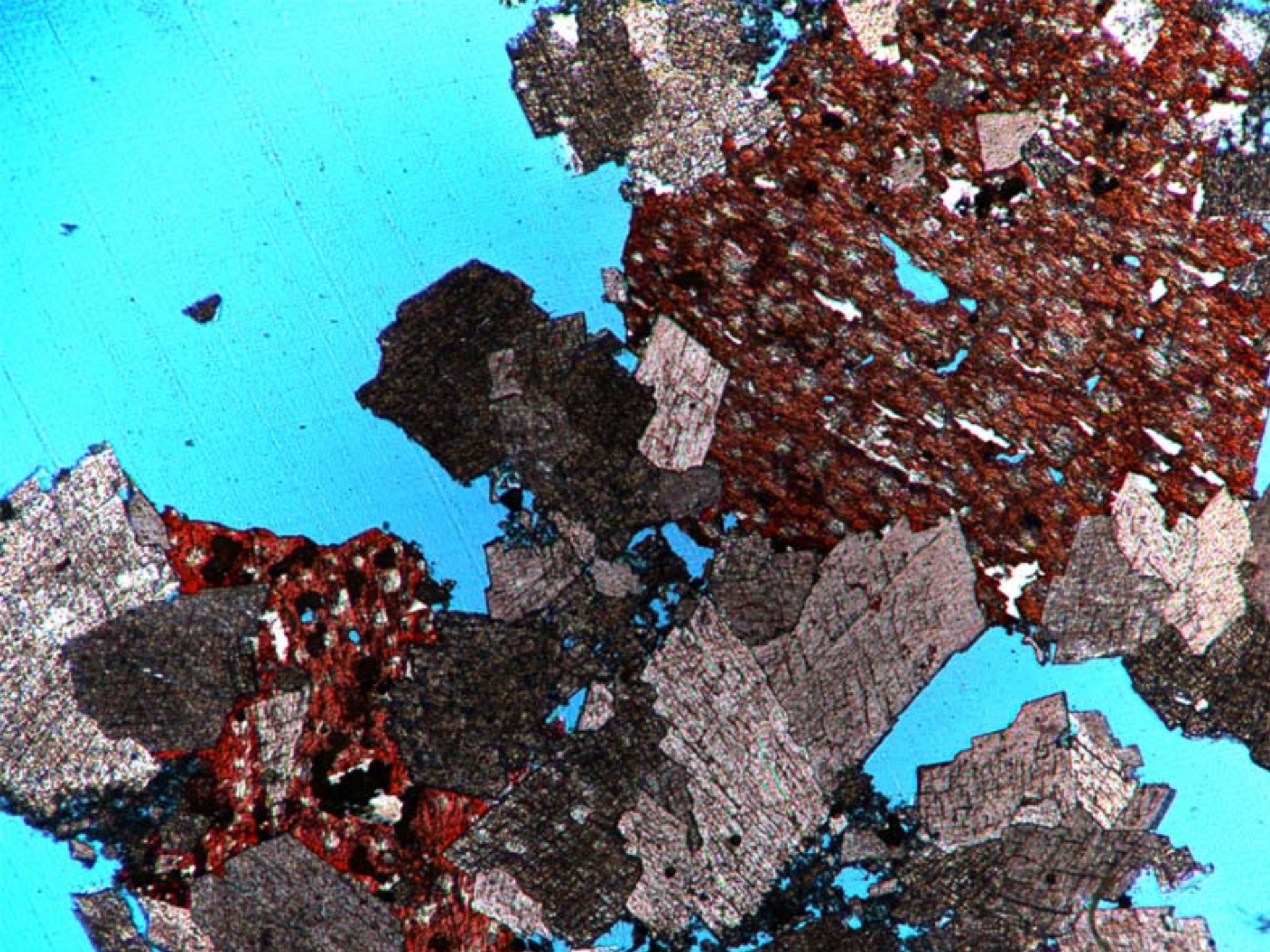


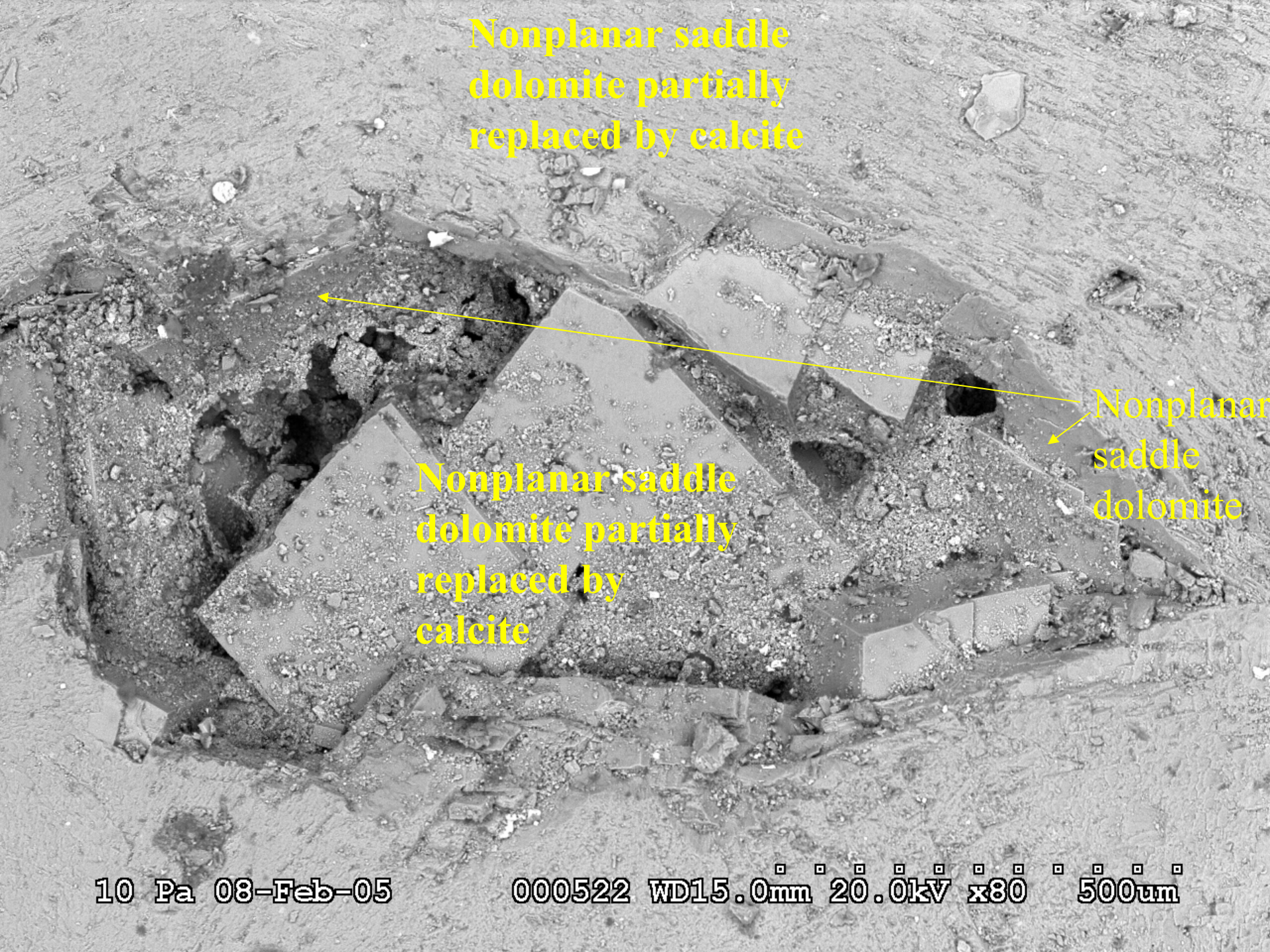


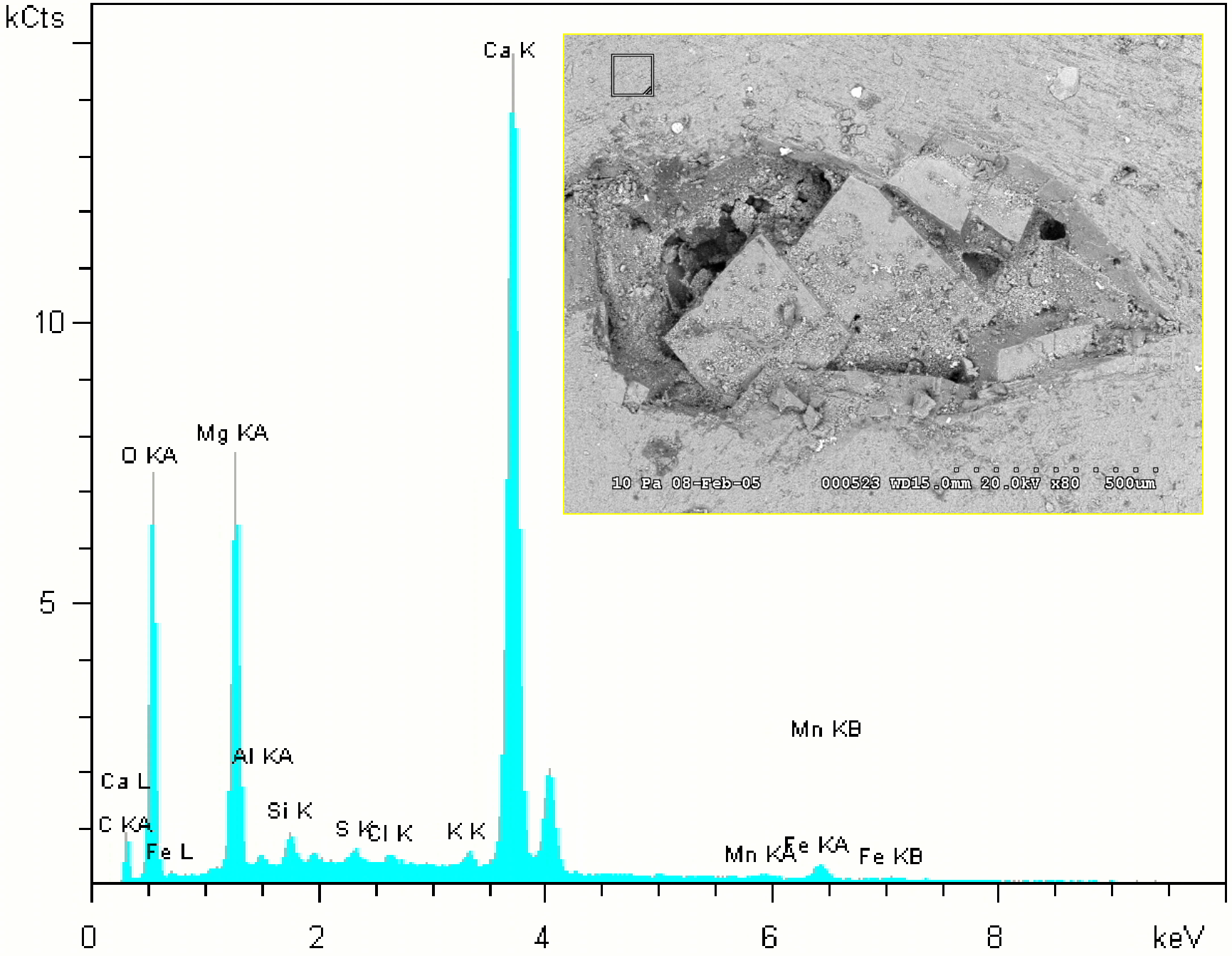









Nonplanar saddle dolomite partially replaced by calcite
Nonplanar saddle dolomite
Nonplanar saddle dolomite partially replaced by calcite
10 Pa 08-Feb-05
000522 WD15.0mm 20.0kV x80 500um


kCts
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5
Ca K
O KA
Mg KA
Al KA
Ca L
C KA
Fe L
Si K
S K
Cl K
K K
Mn KB
Mn KA
Fe KA
Fe KB
0
2
4
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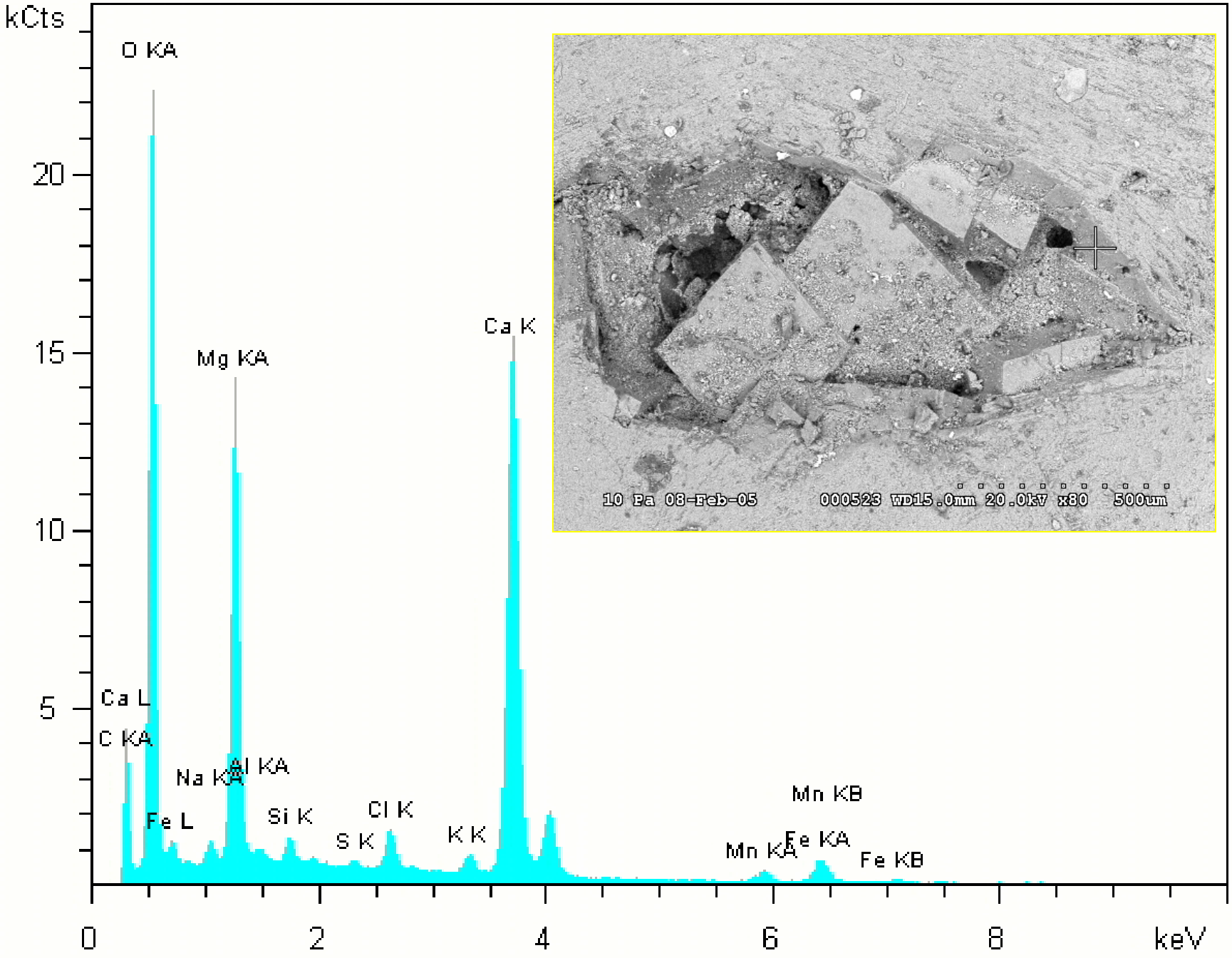
8
keV
10 Pa 08-Feb-05
000523 WD15.0mm 20.0kV x80 500um


kCts
O KA
Mg KA
Ca K
Ca L
C KA
Na KA
Al KA
Fe L
Si K
S K
Cl K
K K
Mn KB
Mn KA
Fe KA
Fe KB
20
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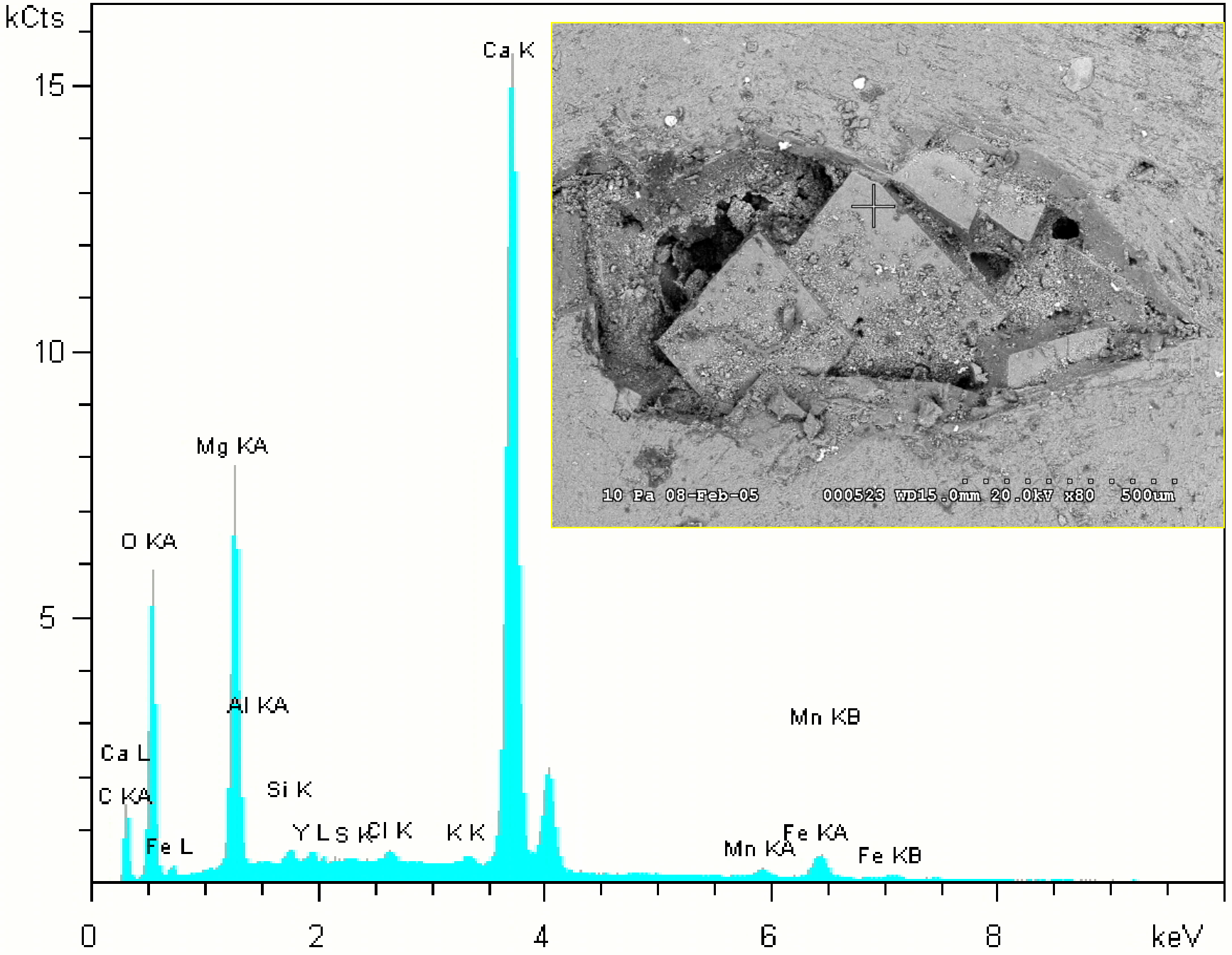
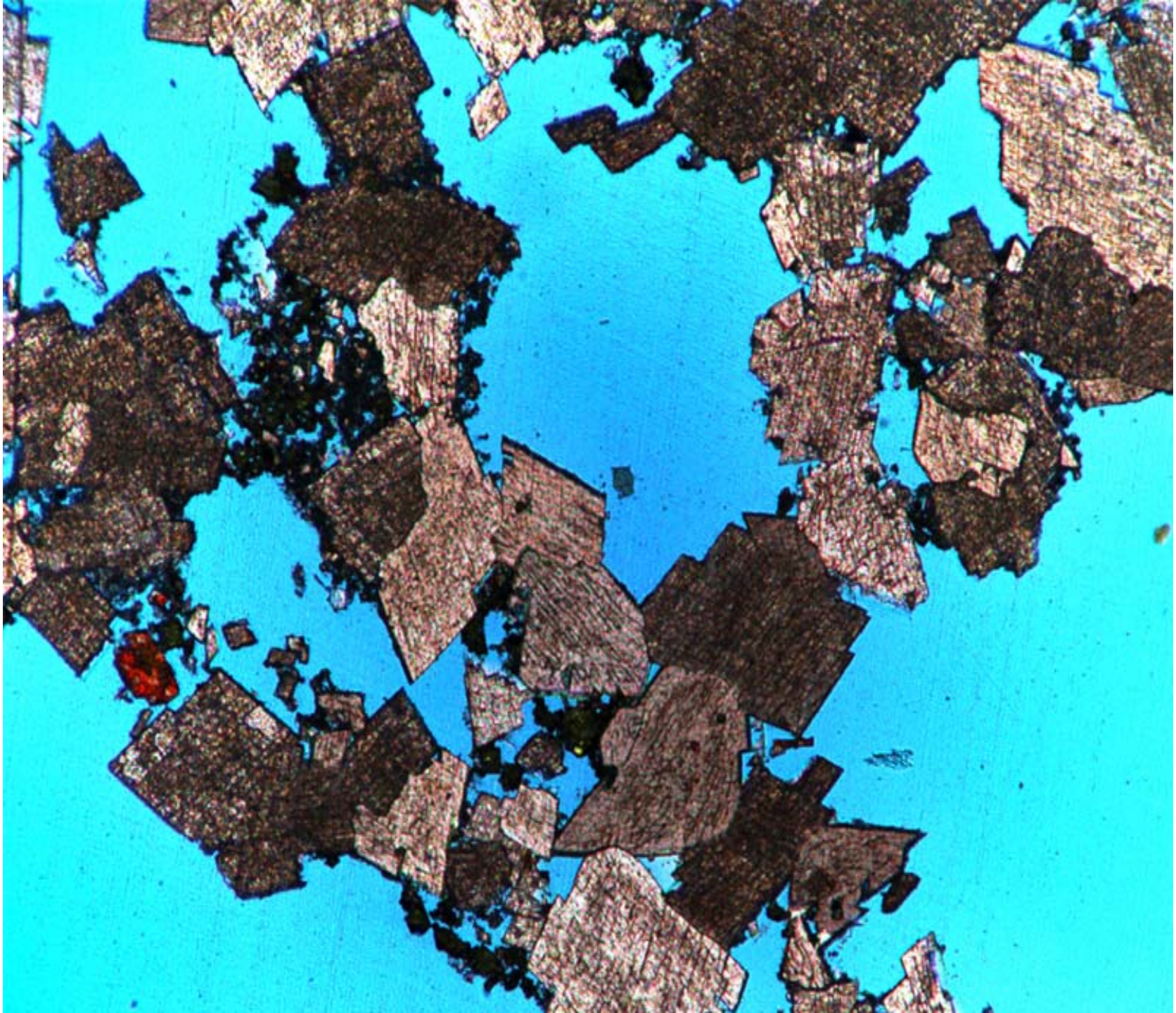
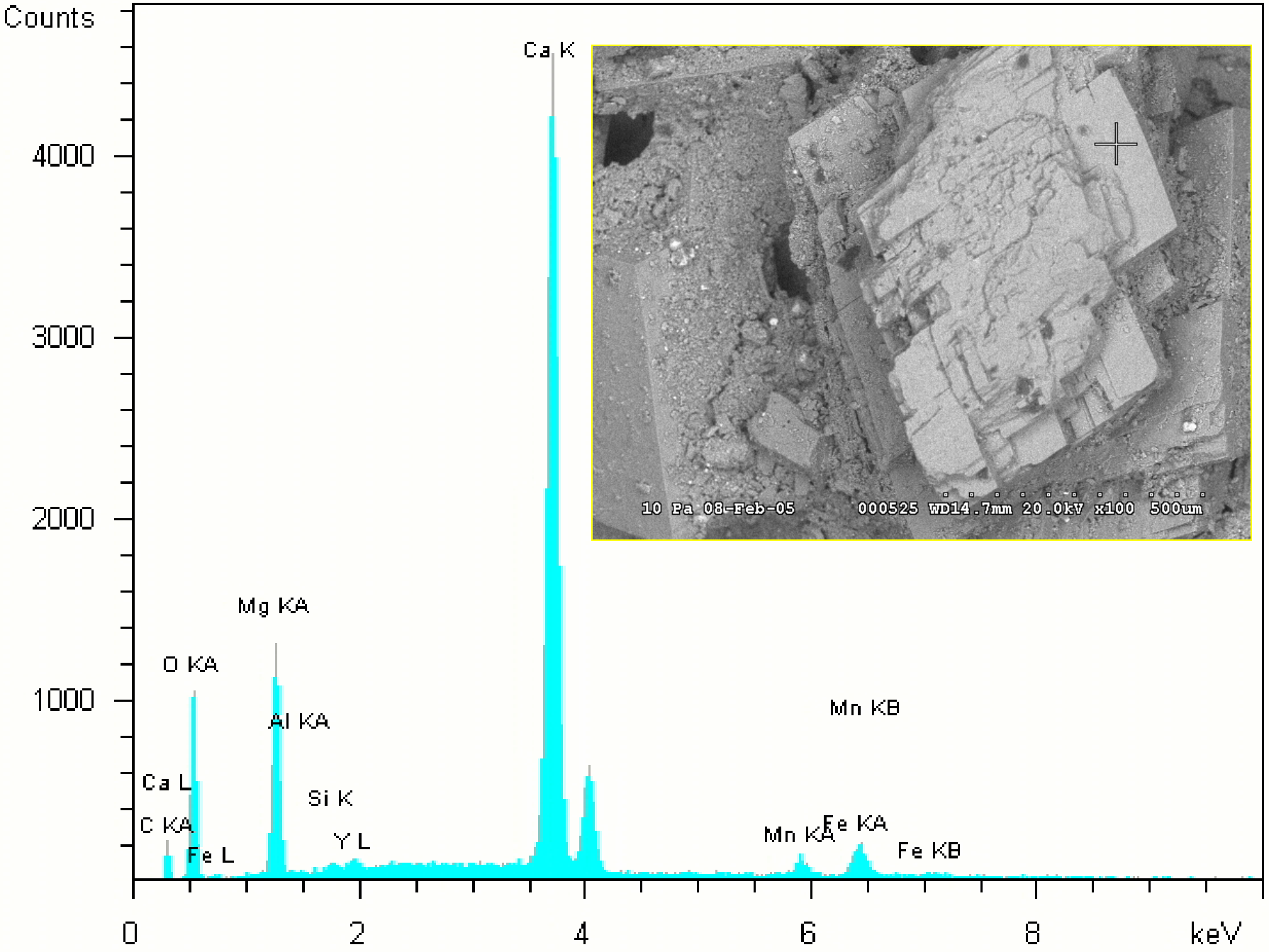
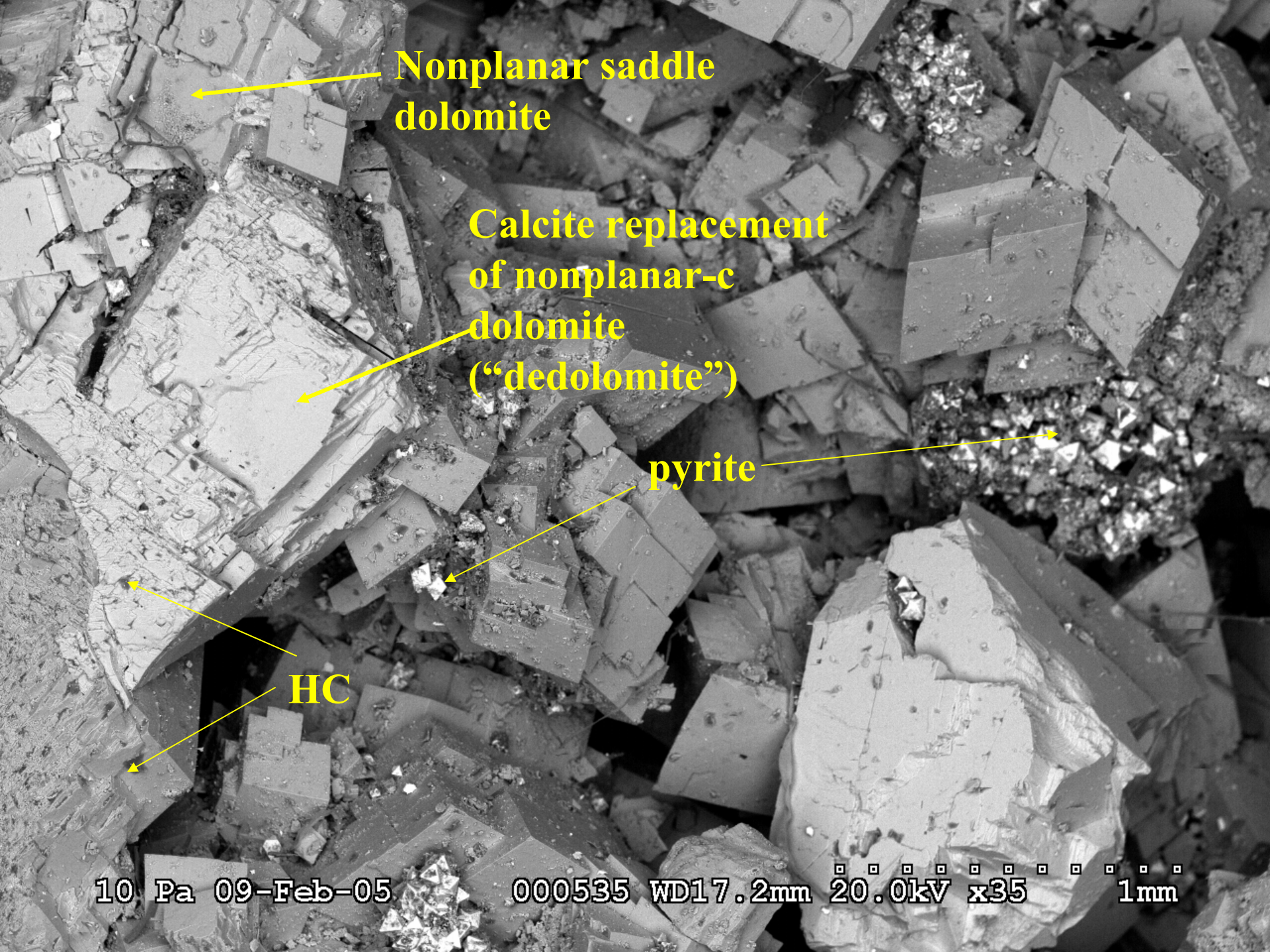
10
5
0
2
4
6
8
keV
10 Pa 08-Feb-05 000523 WD15.0mm 20.0kV x80 500um

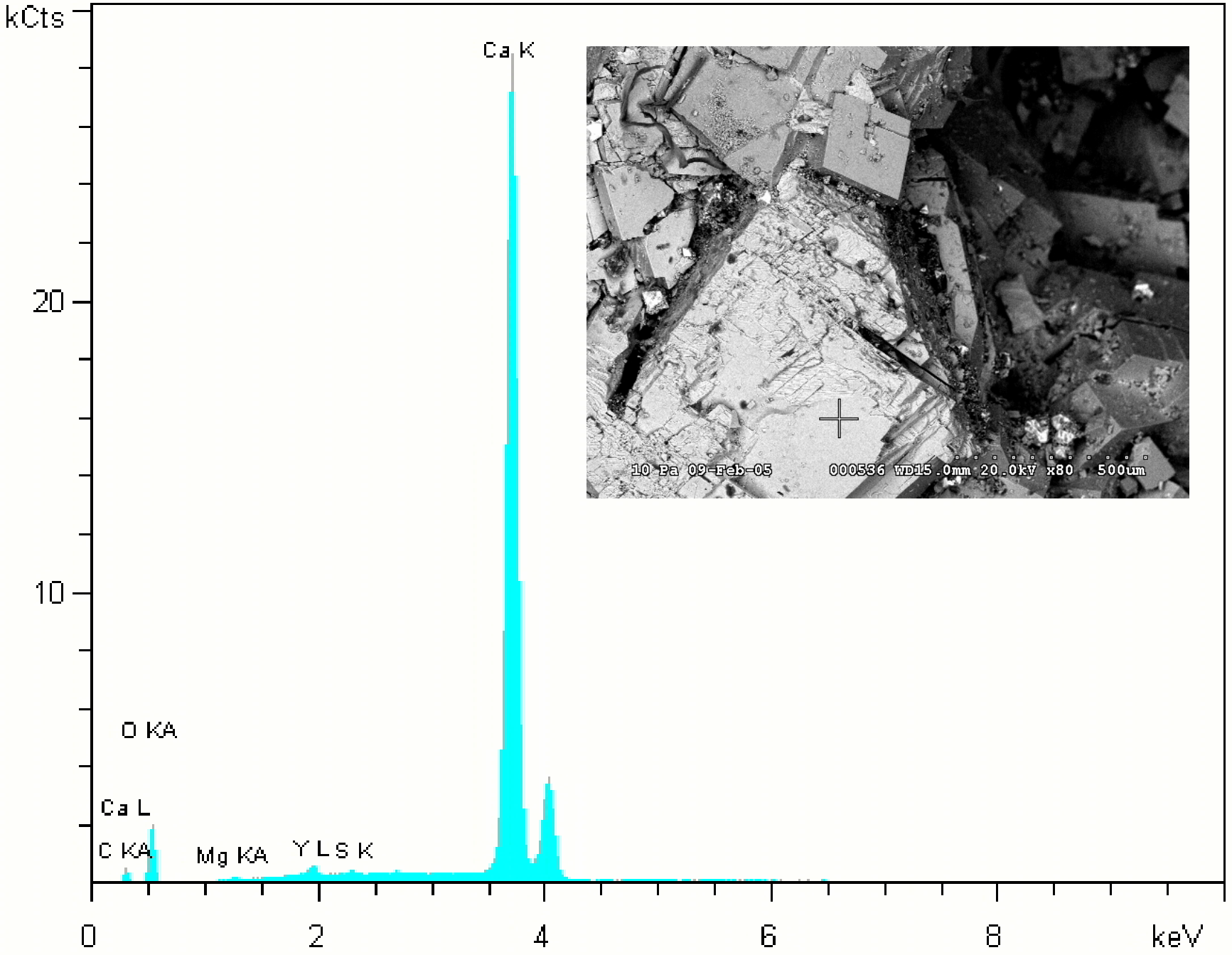

kCts
15
10
5
0
2
4
6
8
keV
Ca K
Mg KA
O KA
Al KA
Ca L
C KA
Fe L
Si K
Y L s K
Cl K
K K
Mn KB
Mn KA
Fe KA
Fe KB
10 Pa 08-Feb-05 000523 WD15.0mm 20.0kV x80 500um

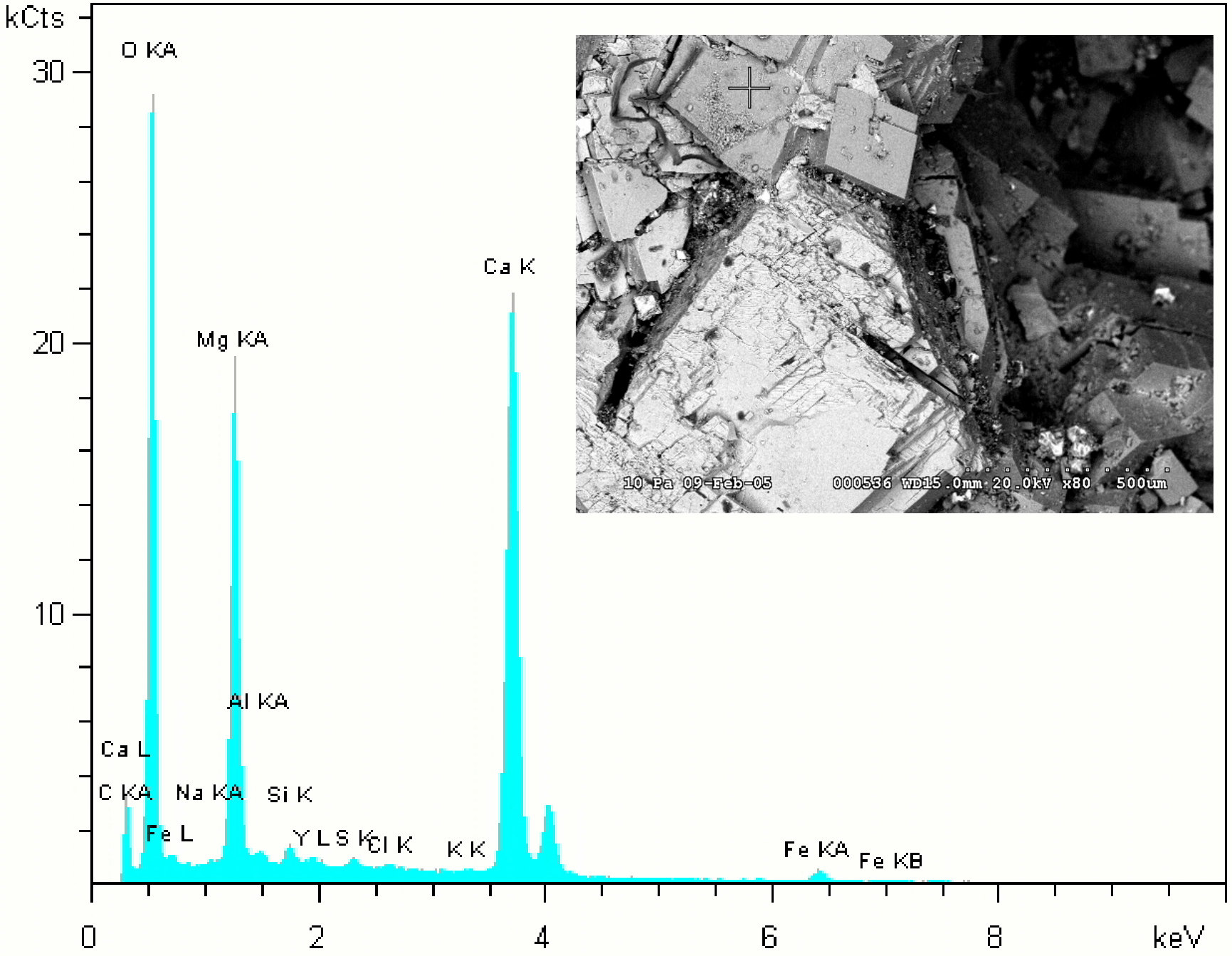


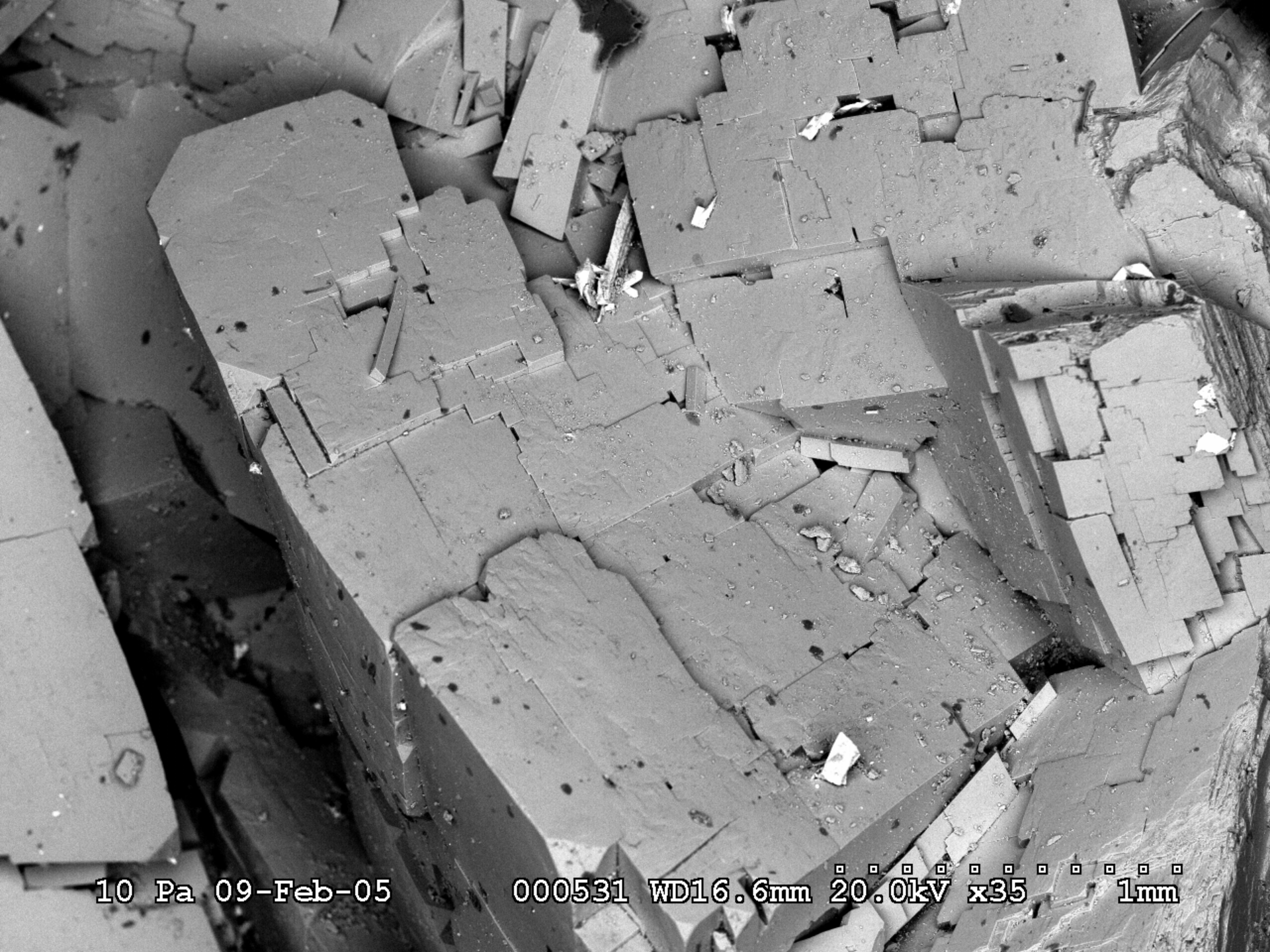

10 Pa 08-Feb-05 000524 WD14.9mm 20.0kV x45 1mm

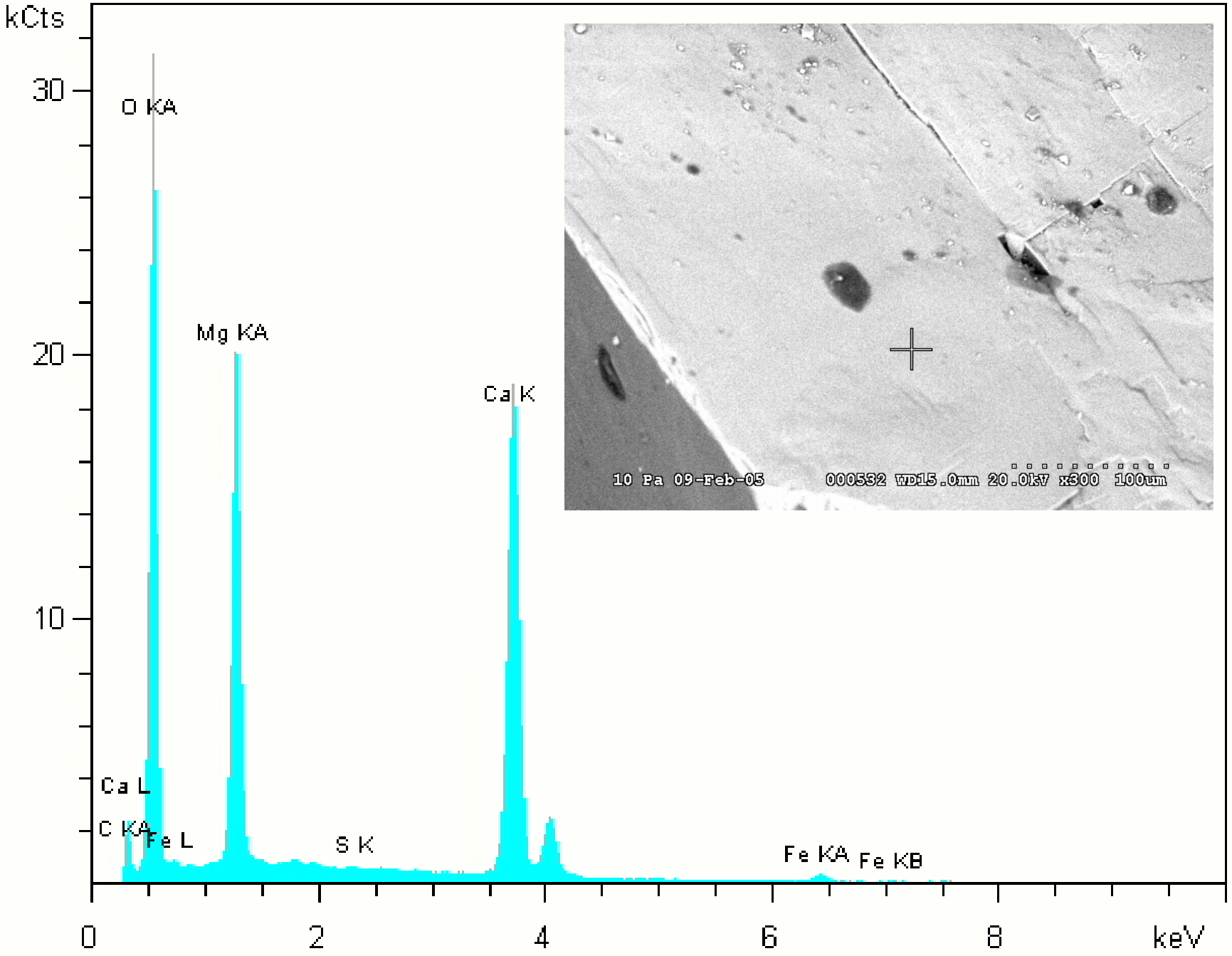

Counts
4000
3000
2000
1000
Ca K
Mg KA
O KA
Al KA
Ca L
Si K
C KA
Fe L
Y L
Mn KB
Mn KA
Fe KA
Fe KB
0
2
4
6
8
keV
10 Pa 08-Feb-05
000525 WD14.7mm 20.0kV x100 500um

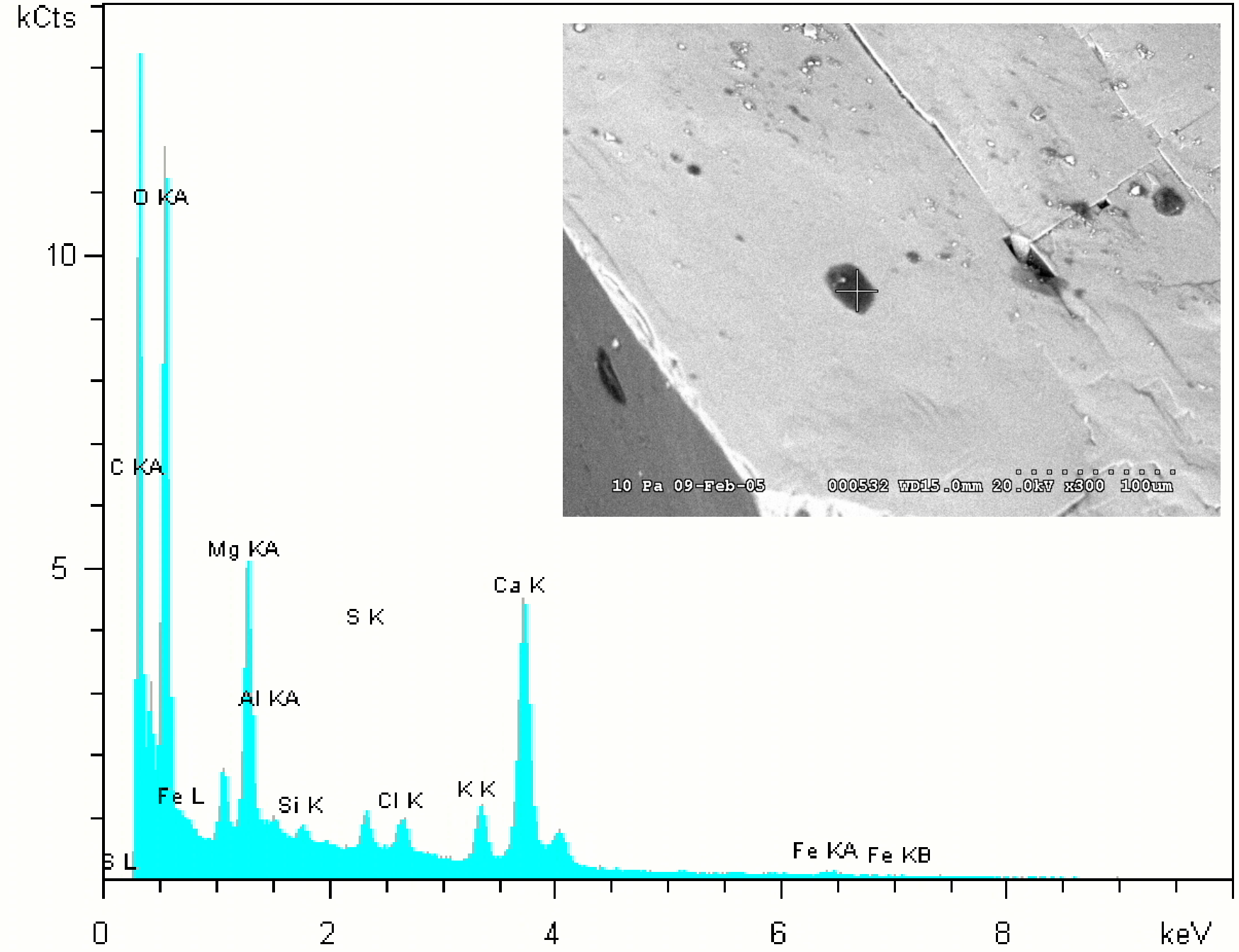

Nonplanar saddle dolomite
Calcite replacement of nonplanar-c dolomite ("dedolomite")
pyrite
HC
10 Pa 09-Feb-05 000535 WD17.2mm 20.0kV x35 1mm

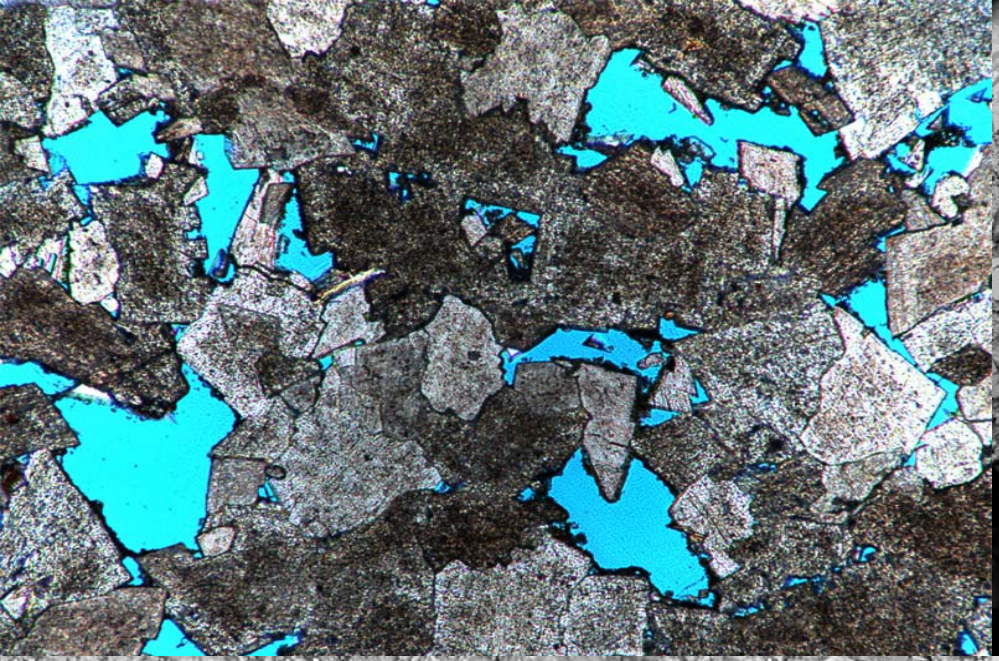

kCts
20
10
Ca K
O KA
Ca L
C KA
Mg KA
Y L S K
0
2
4
6
8
keV
10 Pa 09-Feb-05
000536 WD15.0mm 20.0kV x80 500um

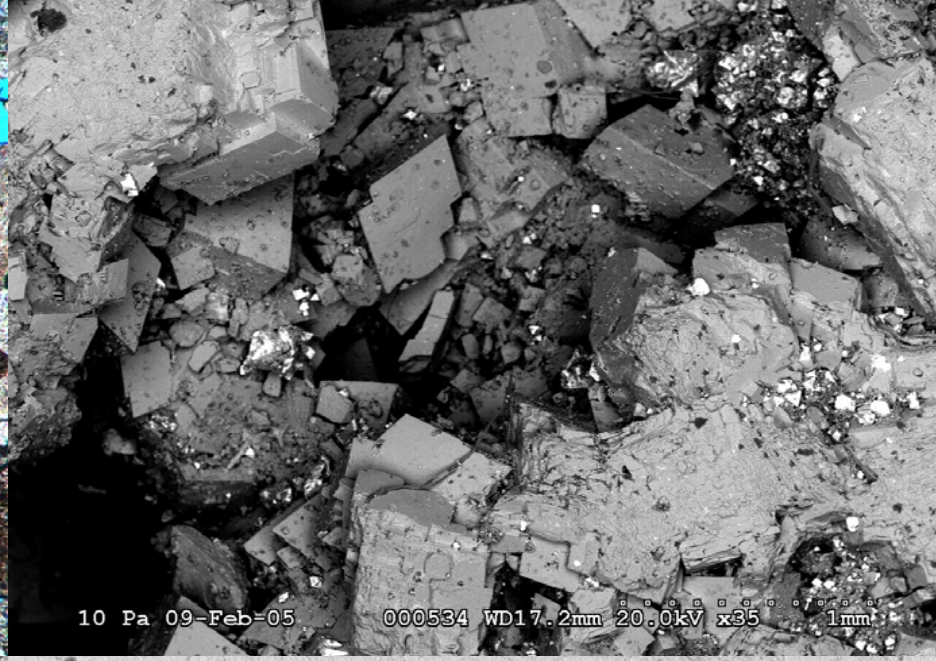

kCts
30
20
10
O KA
Mg KA
Ca K
Al KA
Ca L
C KA
Na KA
Si K
Fe L
Y L S K
Cl K
K K
Fe KA
Fe KB
0
2
4
6
8
keV
10 Pa 09-Feb-05
000536 WD15.0mm 20.0kV x80 500um


10 Pa 09-Feb-05 000531 WD16.6mm 20.0kV x35 1mm

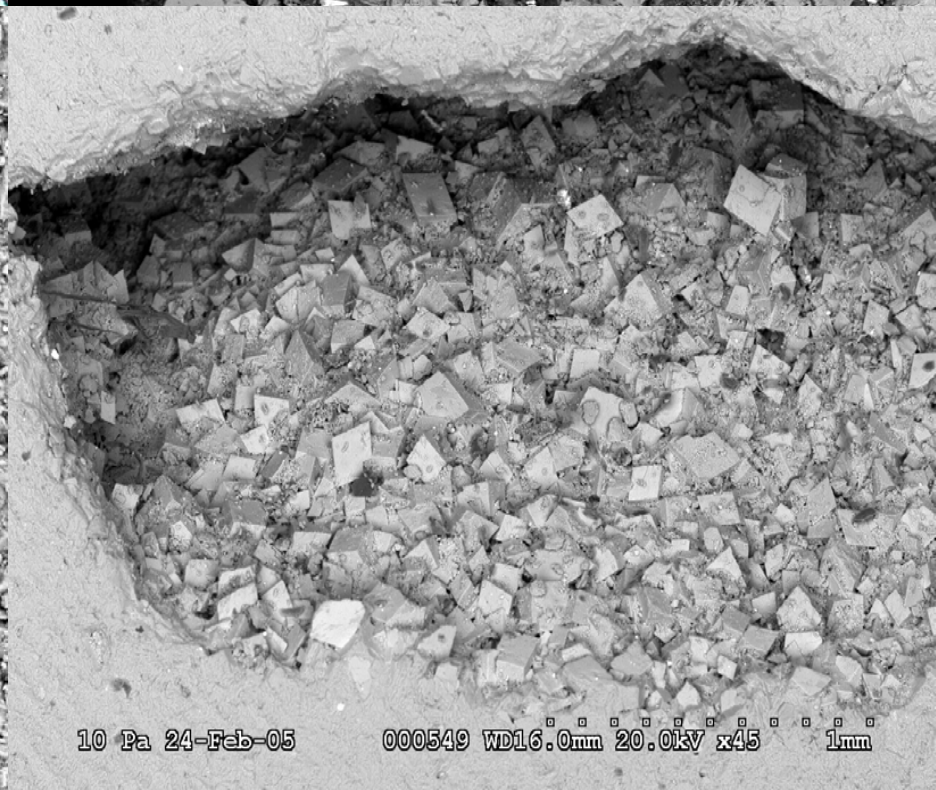

kCts
30
20
10
O KA
Mg KA
Ca K
Ca L
C KA
Fe L
S K
Fe KA
Fe KB
0
2
4
6
8
keV
10 Pa 09-Feb-05 000532 WD15.0mm 20.0kV x300 100um

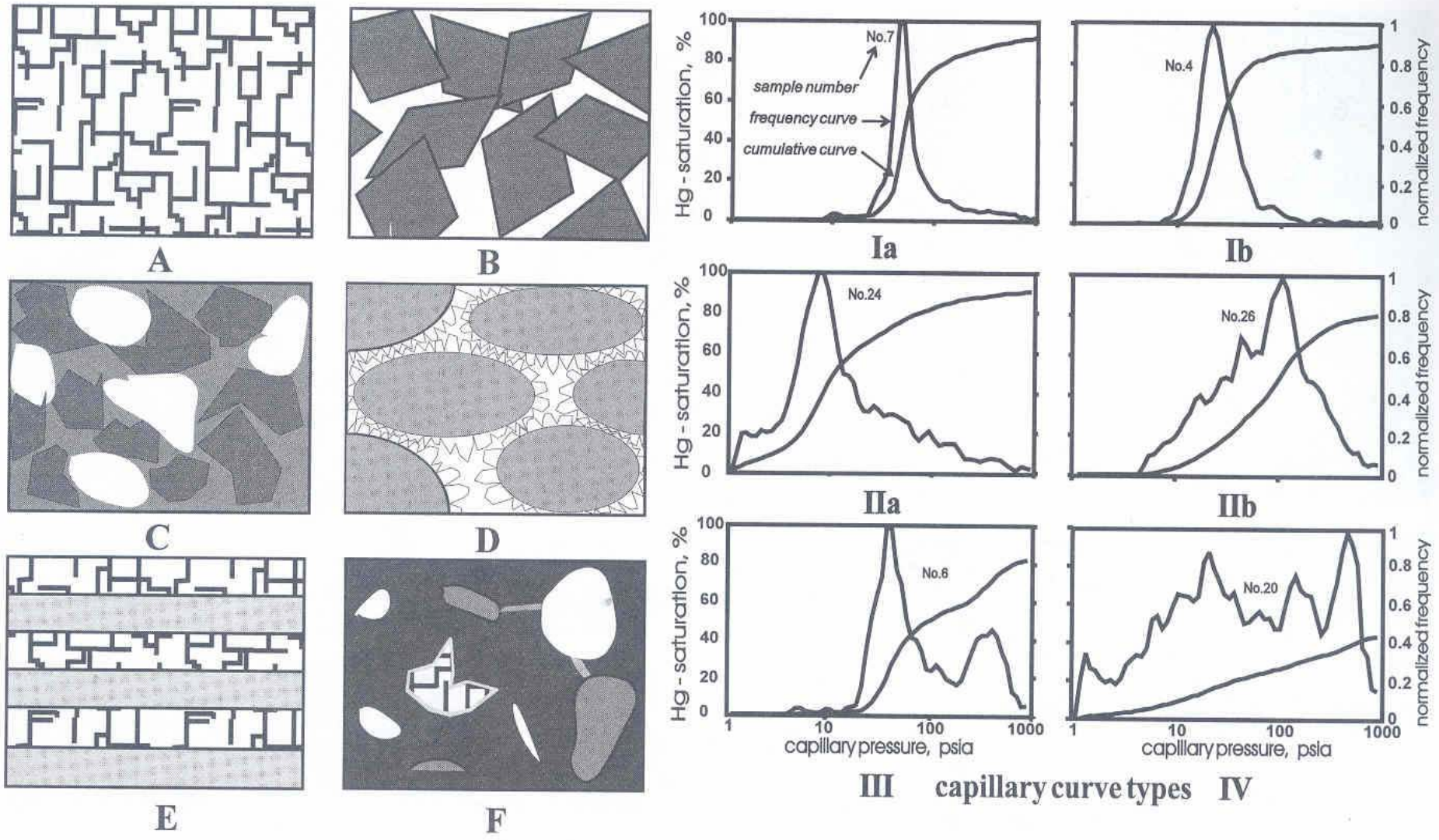

kCts
10
5
O KA
C KA
Mg KA
Al KA
Si K
S K
Cl K
K K
Ca K
Fe L
S L
Fe KA
Fe KB
0
2
4
6
8
keV
10 Pa 09-Feb-05
000532 WD15.0mm 20.0kV x300 100um




10 Pa 09-Feb-05 000534 WD17.2mm 20.0kV x35 1mm


20 Pa 09-Feb-05 000533 WD15.4mm 20.0kV x300 100um


10 Pa 24-Feb-05 000549 WD16.0mm 20.0kV x45 1mm



pervasive solution-enlarged porosity

dolomite rhomb

void space

tight matrix

tight block of mosaic dolomites

micro-porosity

inter-crystalline porosity

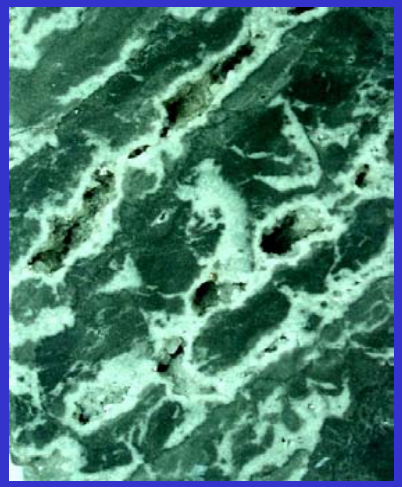
intraclast with cements

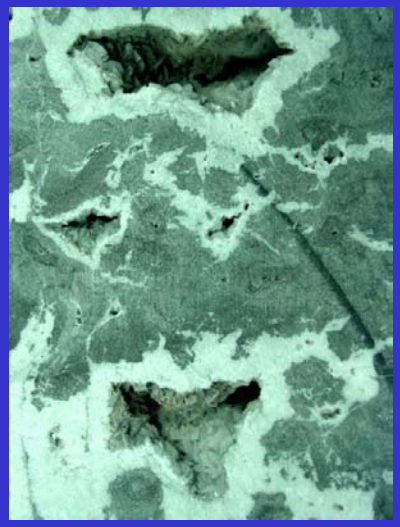
DOLOWACKESTONES AND DOLOMUDSTONES

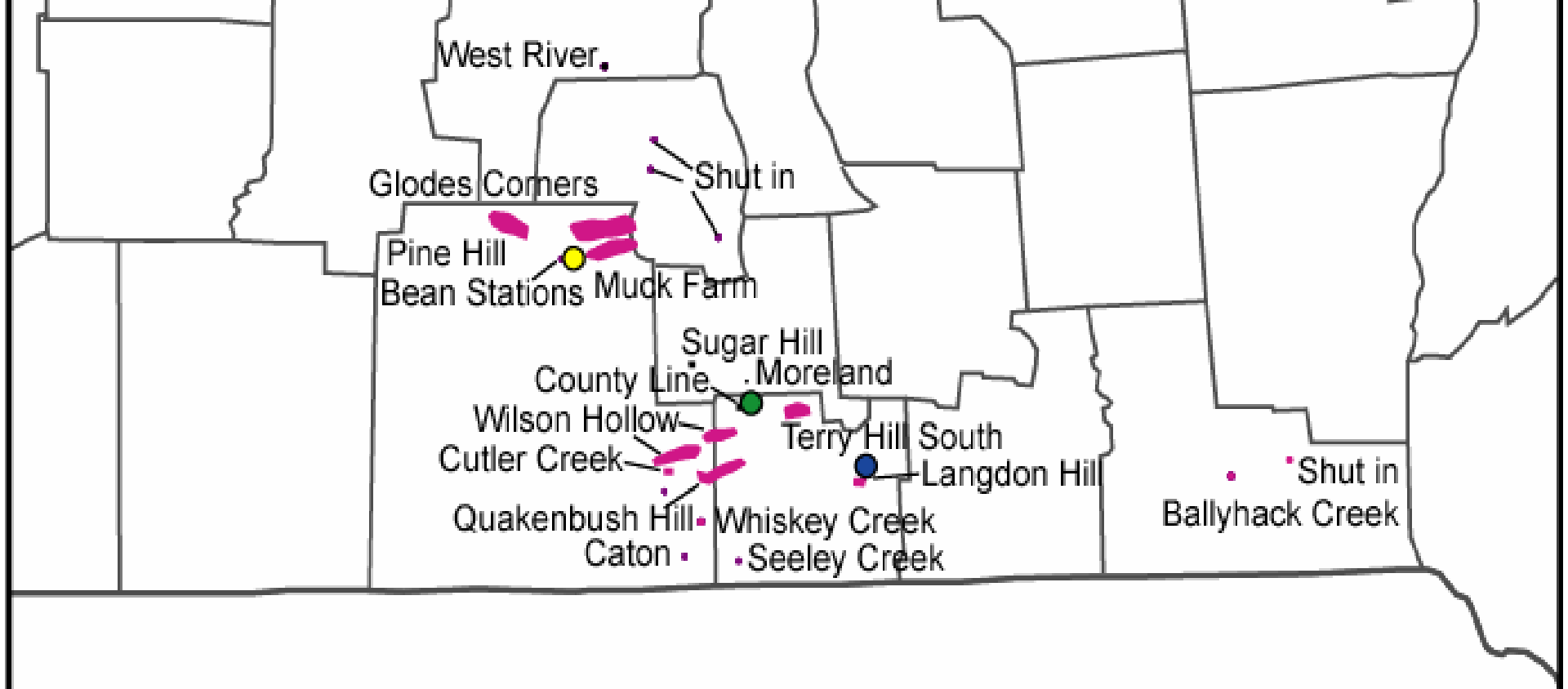
- Most productive reservoir rocks in the basin
- Recognizable depositional texture
- Planar-s to nonplanar-a and saddle dolomites

Porosity

- Macroporosity:
  - Not fabric-selective:
    - Voids associated with zebra and breccia fabrics
    - Small to large vugs
    - Fractures
- Mesoporosity:
  - Fabric-selective:
    - Intercrystalline
    - Moldic
- Microporosity







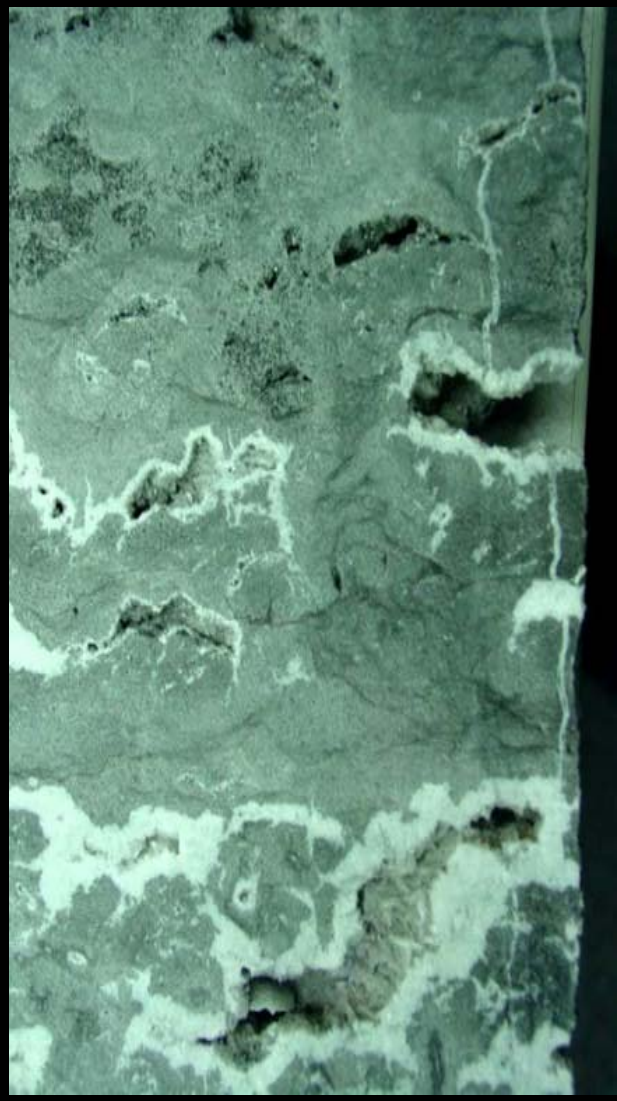
Trenton Black River Hydrothermal Dolomite Fields

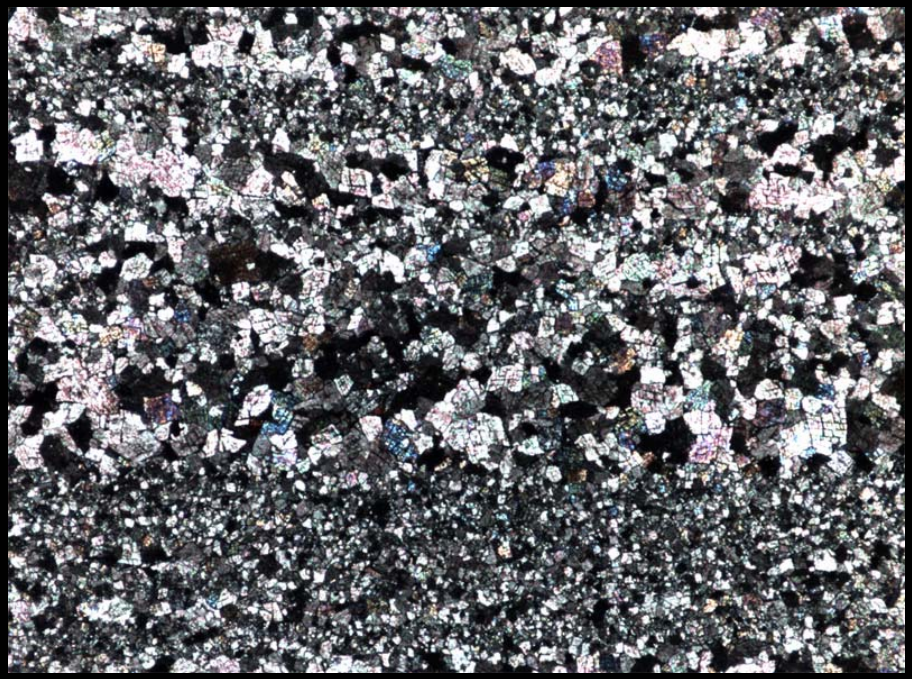
Gray #1 Core

Whiteman #1 Core

Matejka #1 Core





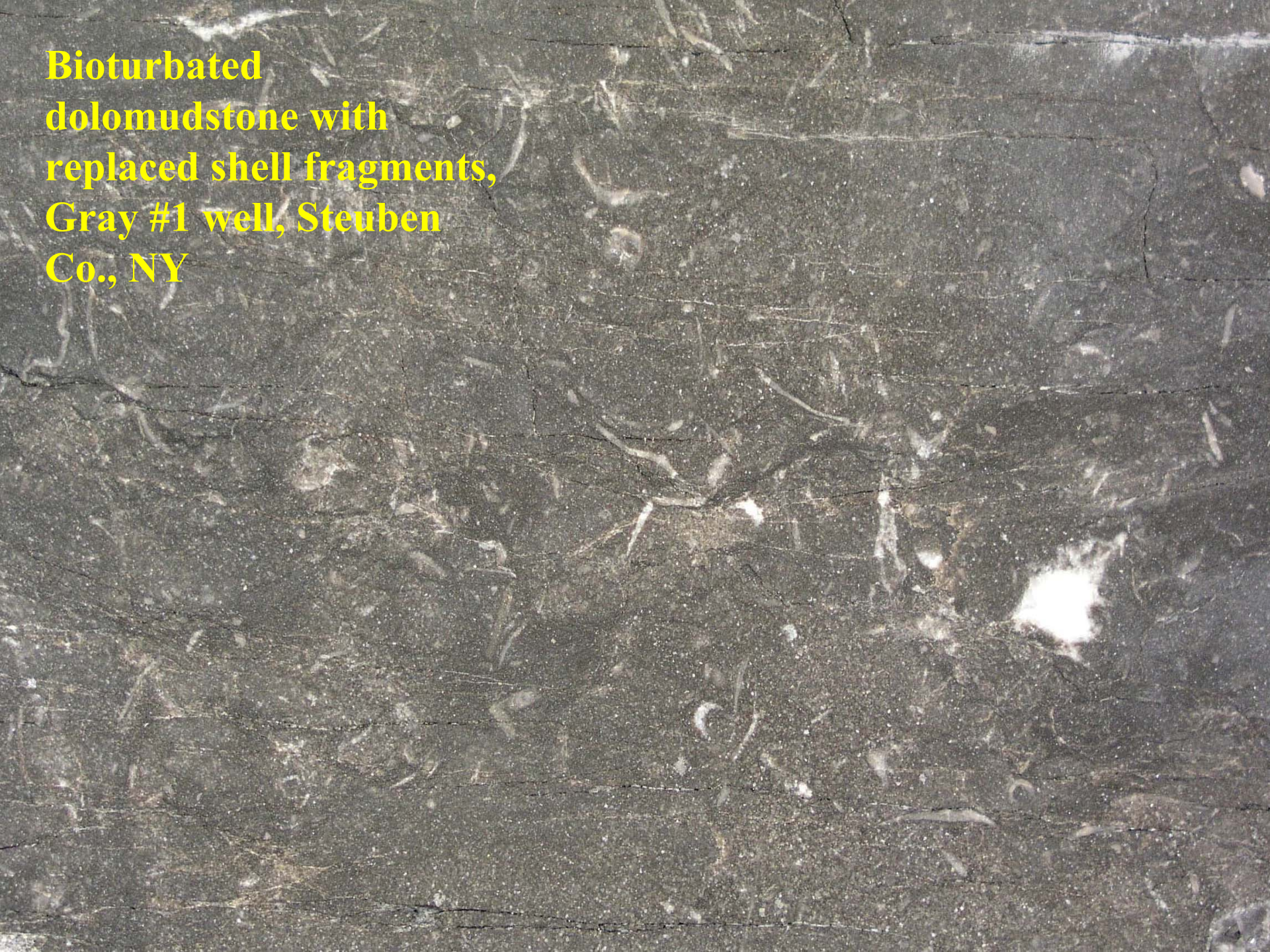



10 Pa 09-Feb-05 000530 WD15.5mm 20.0kV x45 1mm

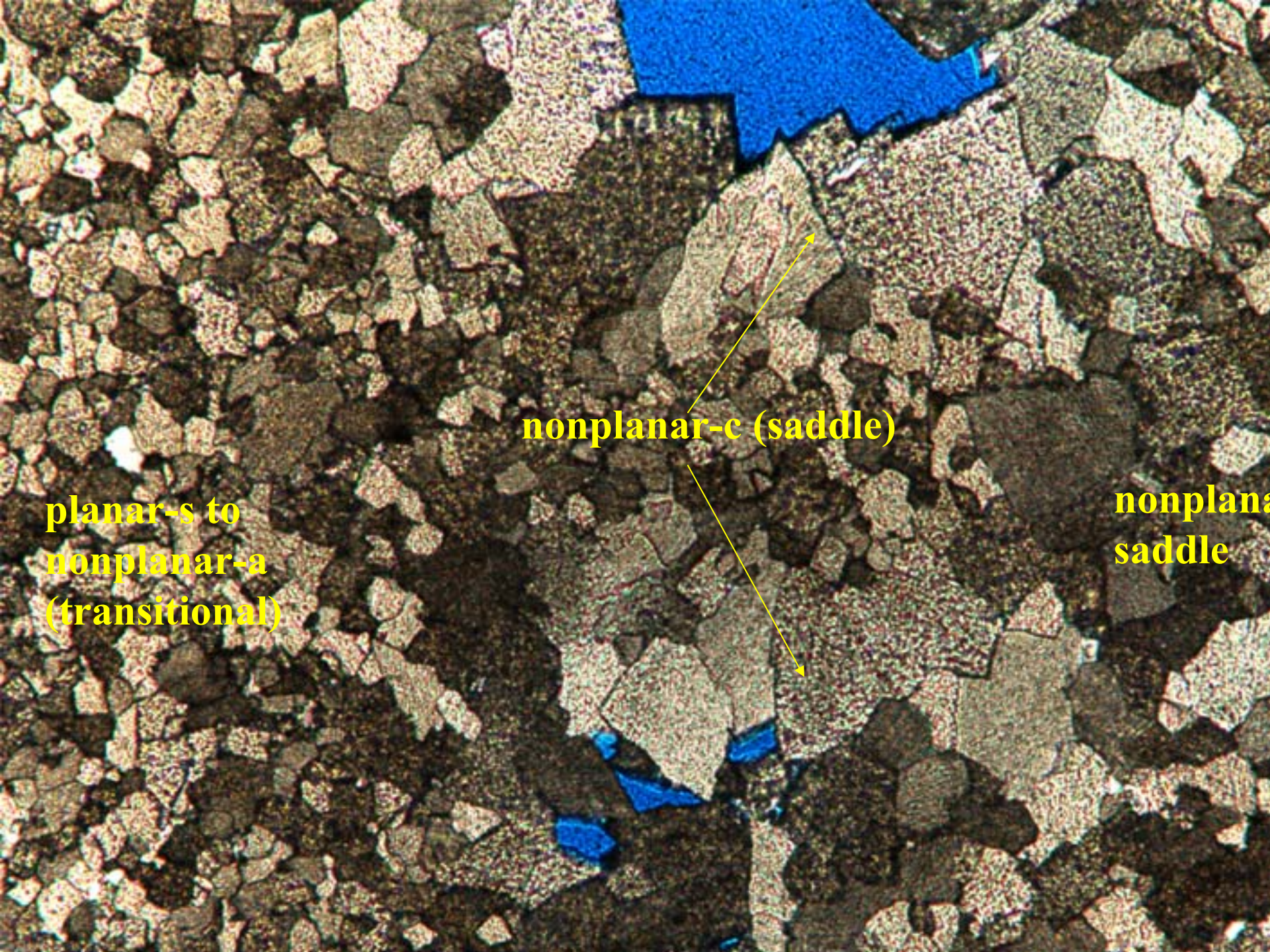
DOLOMITIZED, BIOTURBATED MUDSTONE AND WACKESTONE

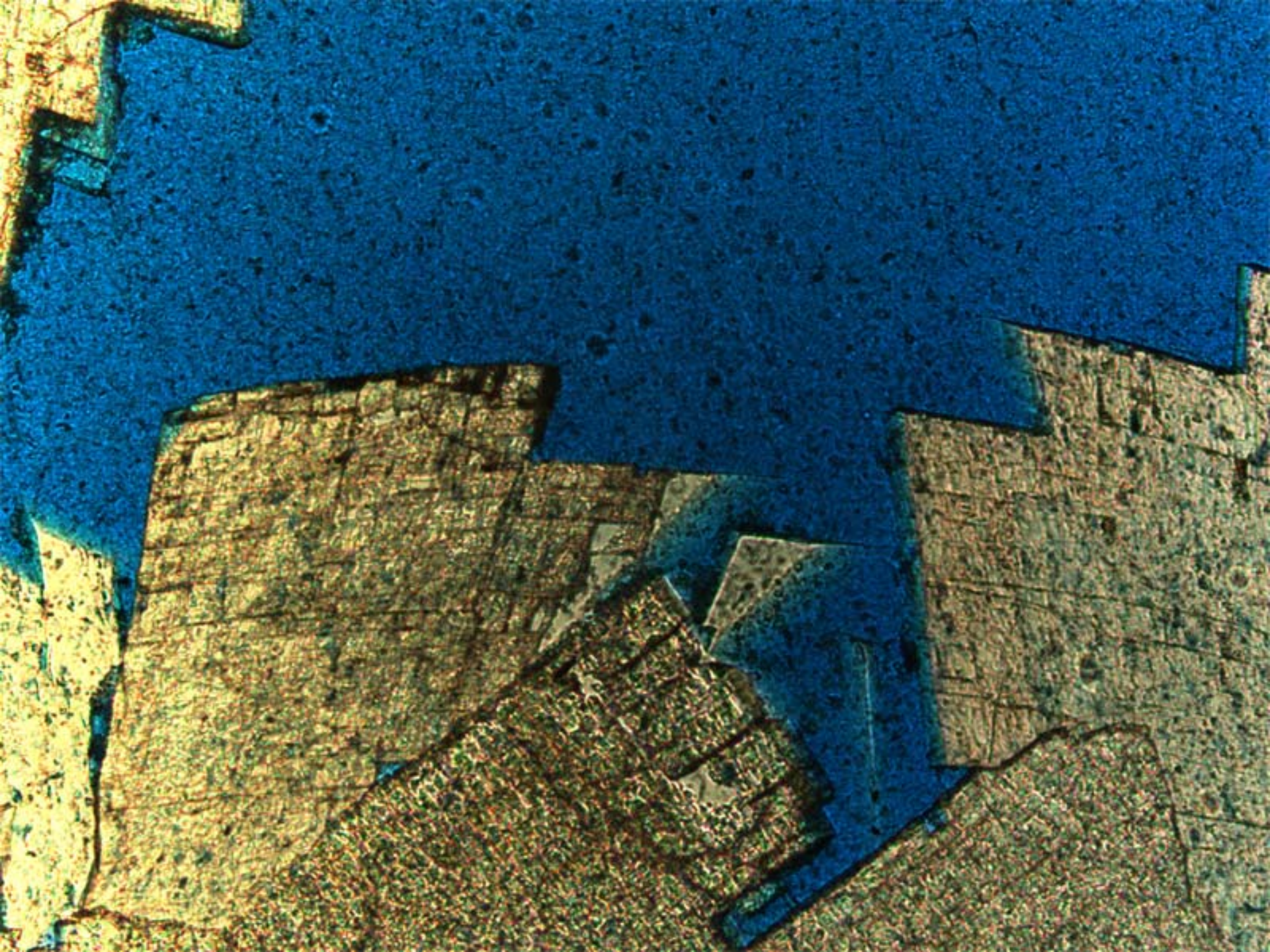
DOLOMITIZED, BIOTURBATED MUDSTONE AND WACKESTONE

OH3372/1840 ft.

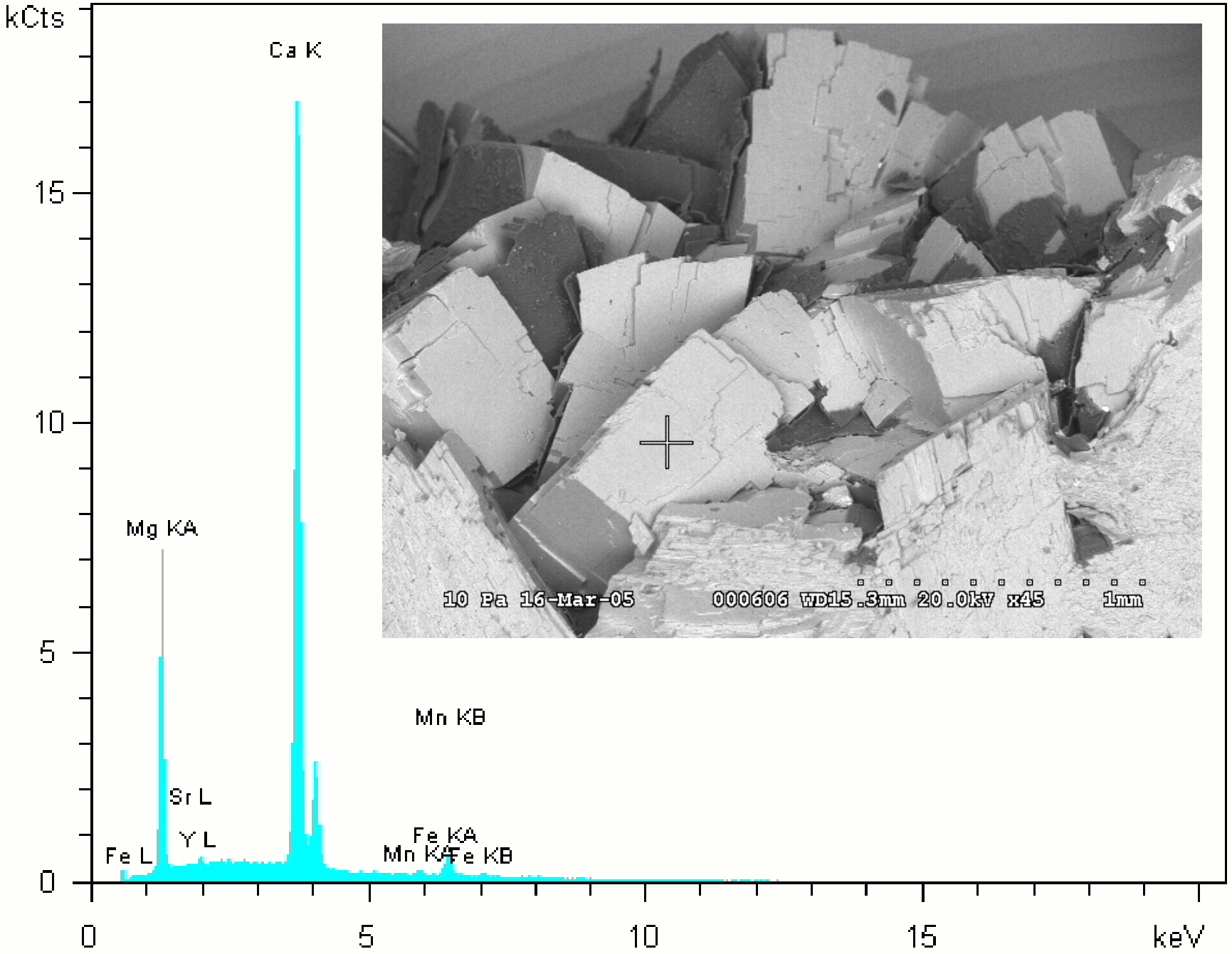

Bioturbated
dolomudstone with
replaced shell fragments,
Gray #1 well, Steuben
Co., NY

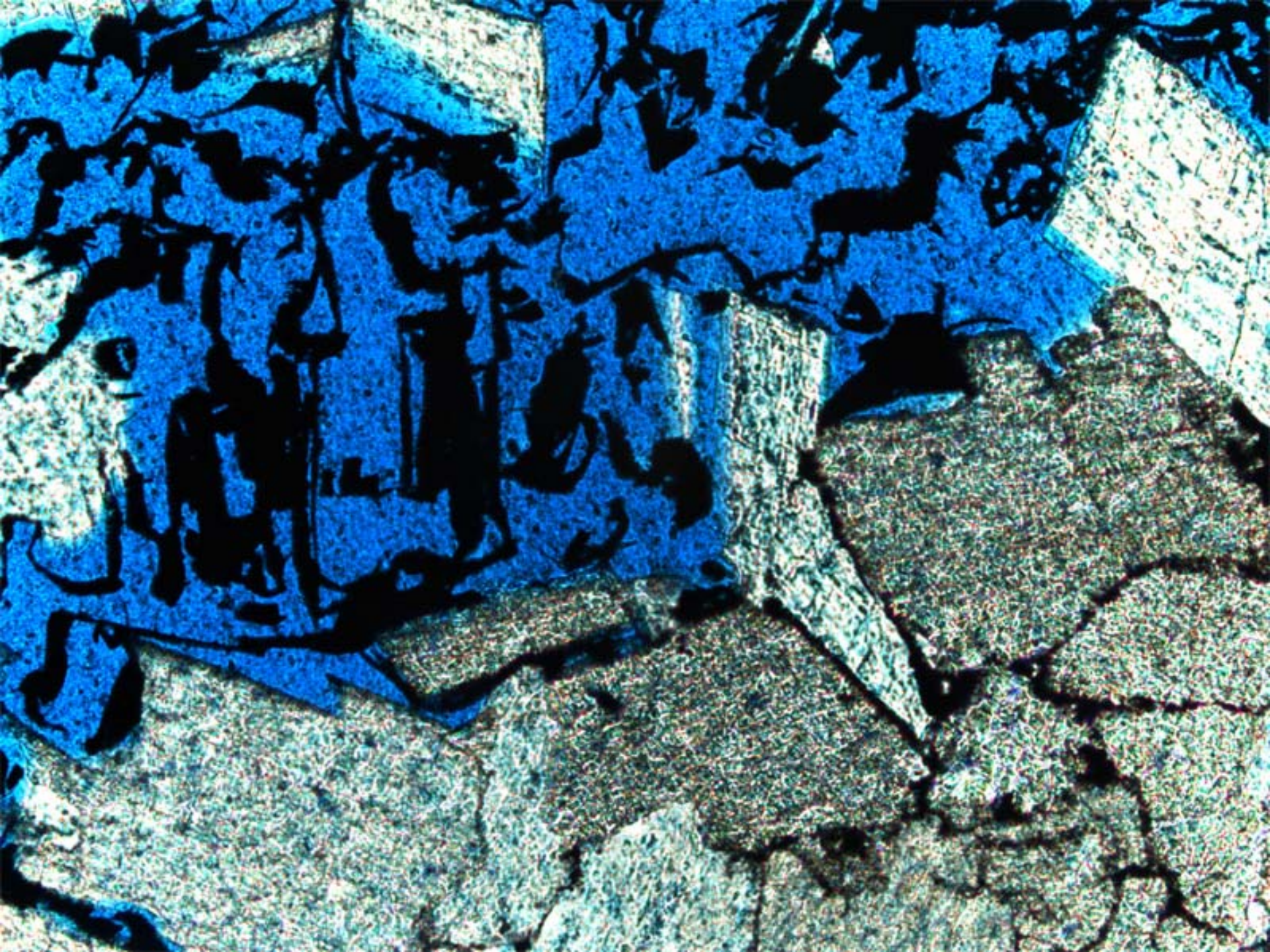

planar-s to nonplanar-a (transitional) dolomite

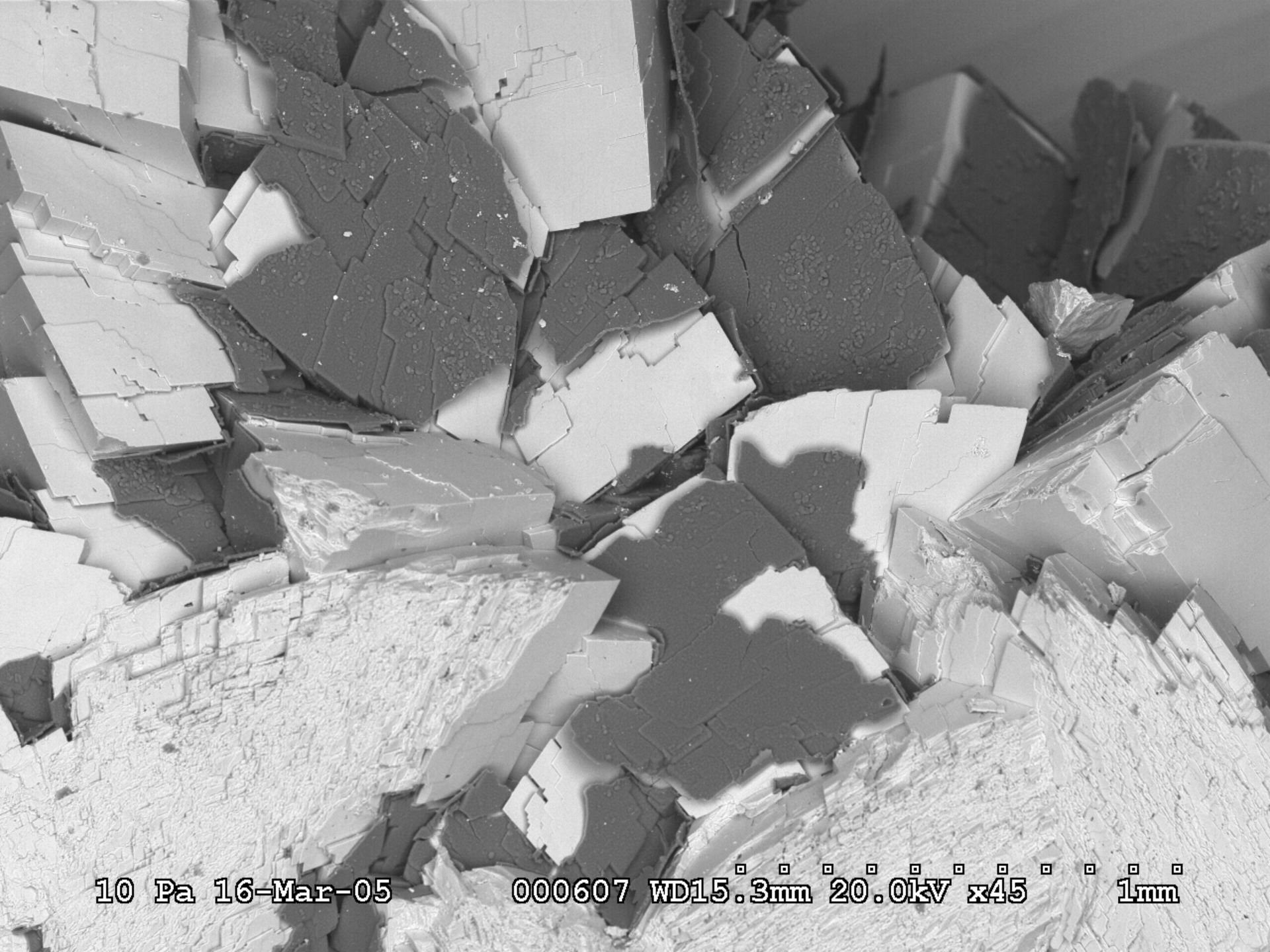

nonplanar-c (saddle)
planar-s to
nonplanar-a
(transitional)
nonplana
saddle

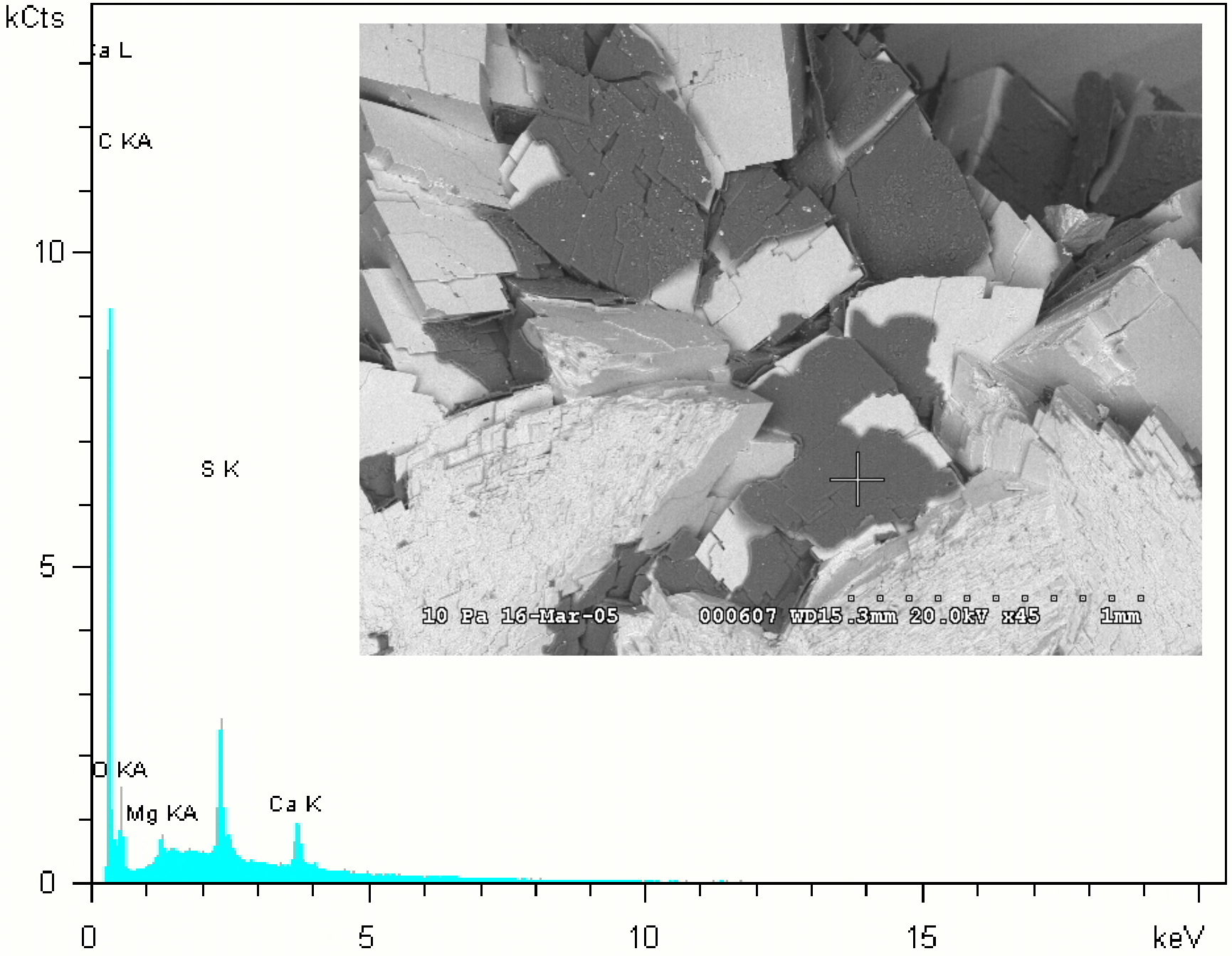


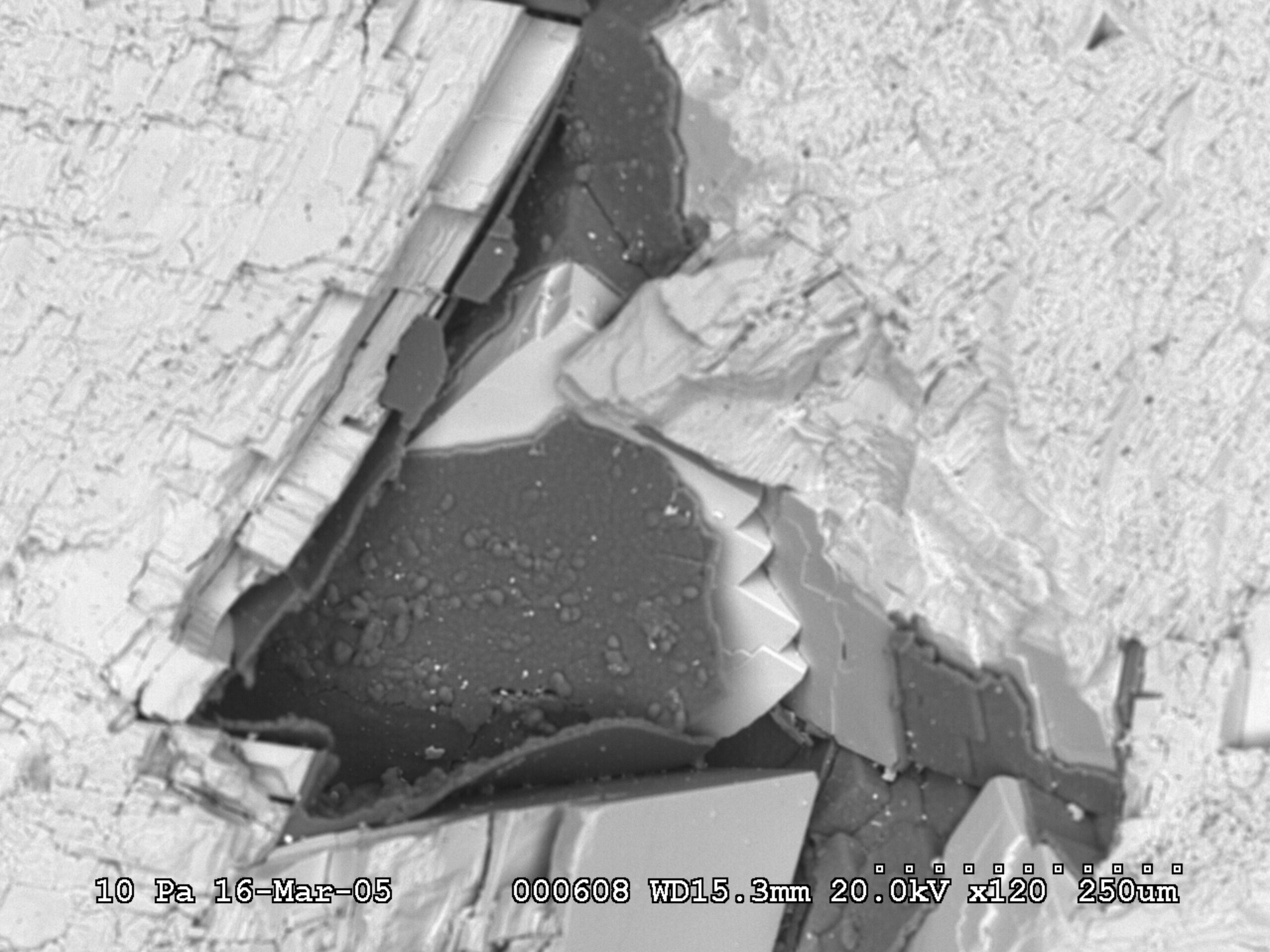

10 Pa 16-Mar-05 000605 WD16.6mm 20.0kV x45 1mm

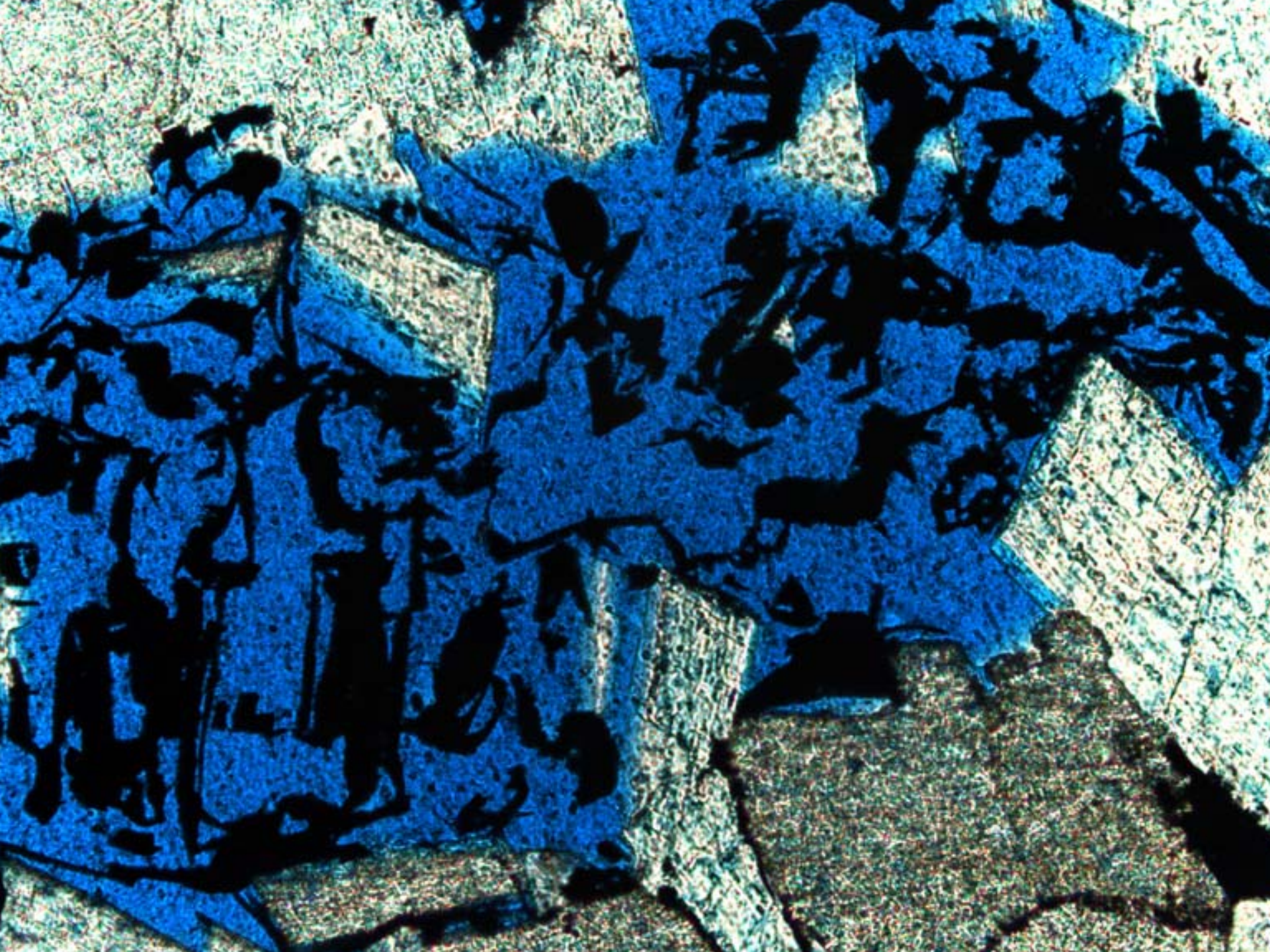

kCts
15
10
5
0
Ca K
Mg KA
Mn KB
Sr L
Y L
Fe L
Fe KA
Mn KA
Fe KB
10 Pa 16-Mar-05
000606 WD15.3mm 20.0kV x45
1mm
0
5
10
15
keV

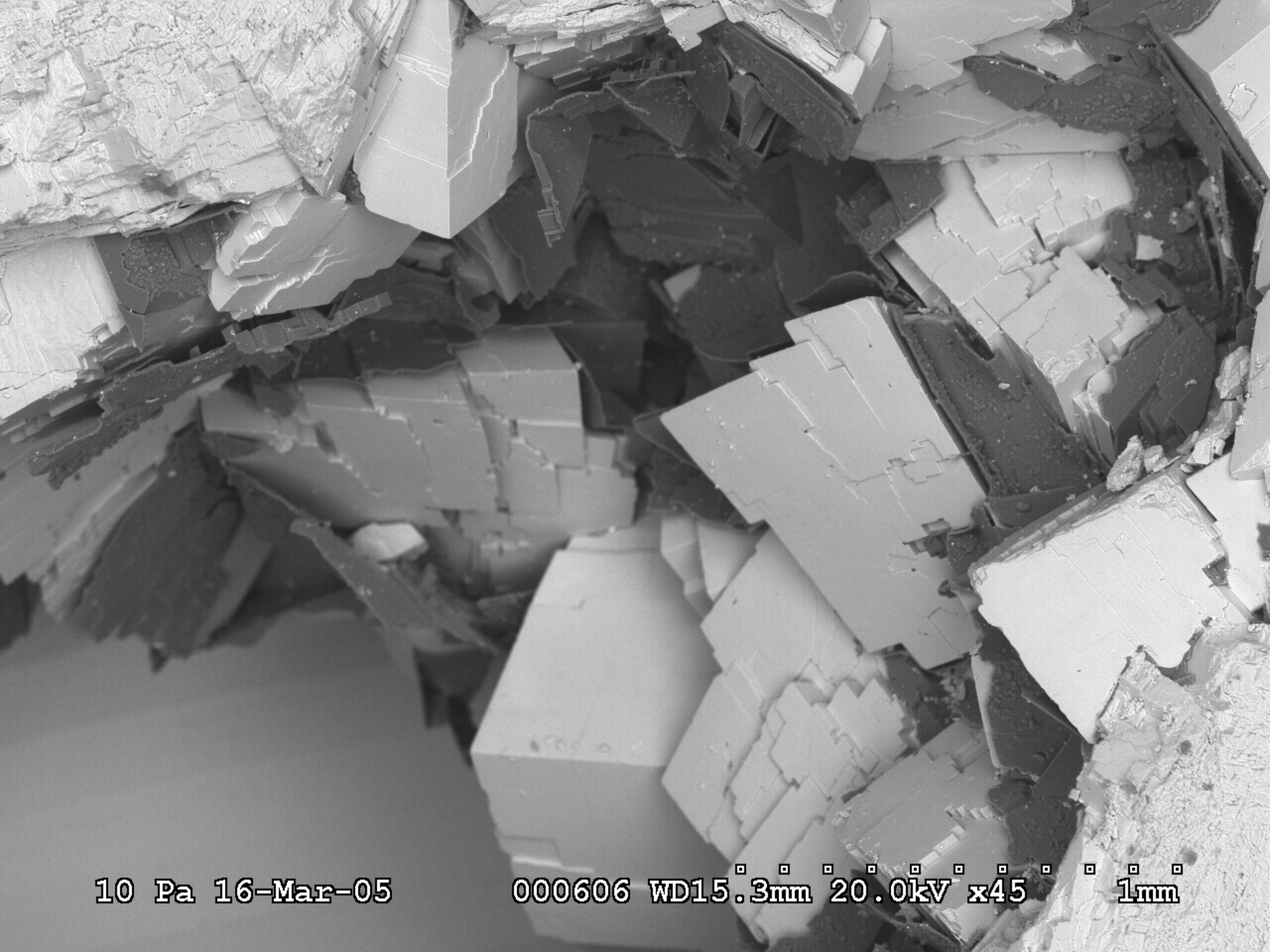


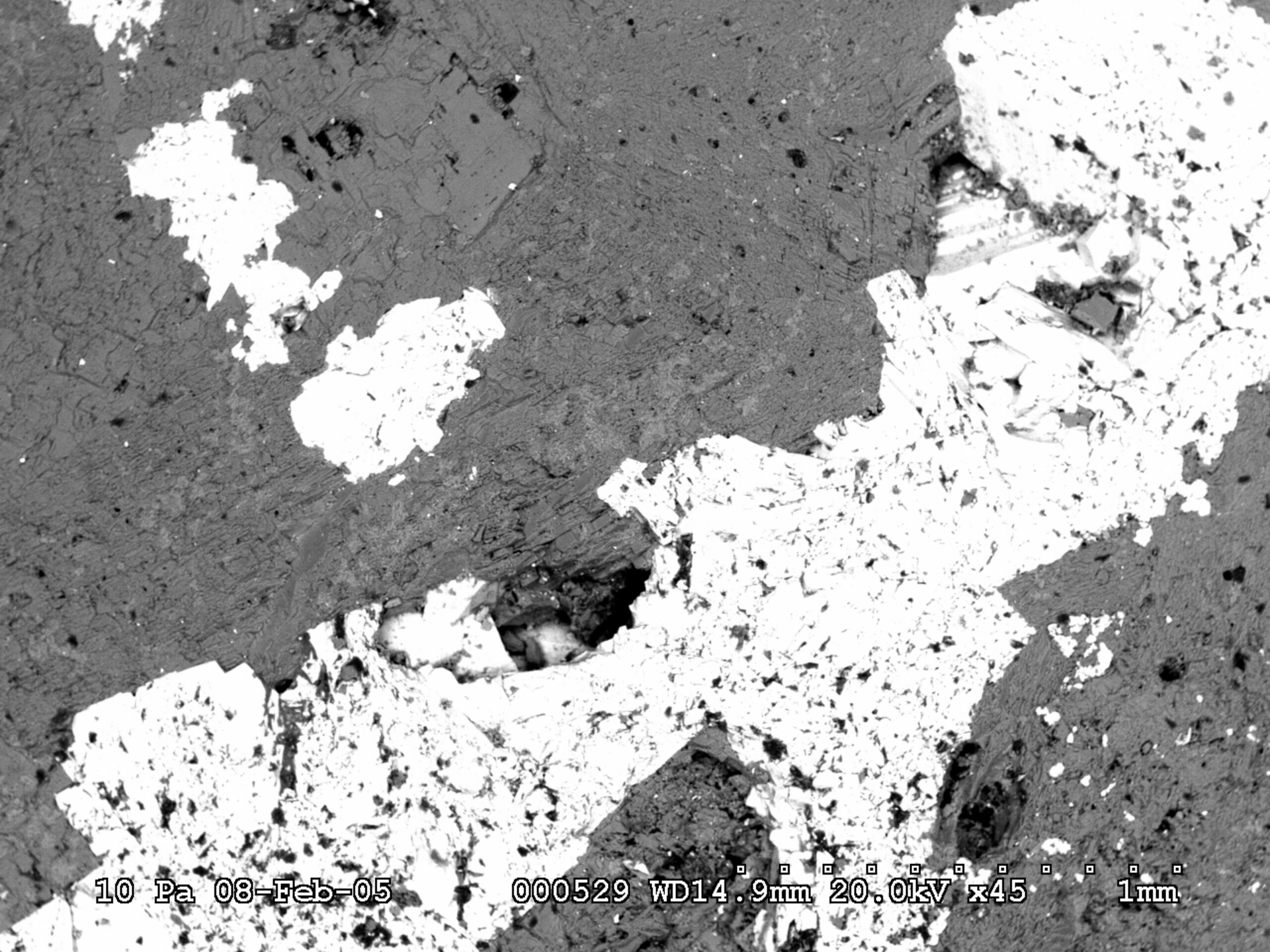

10 Pa 16-Mar-05 000607 WD15.3mm 20.0kV x45 1mm

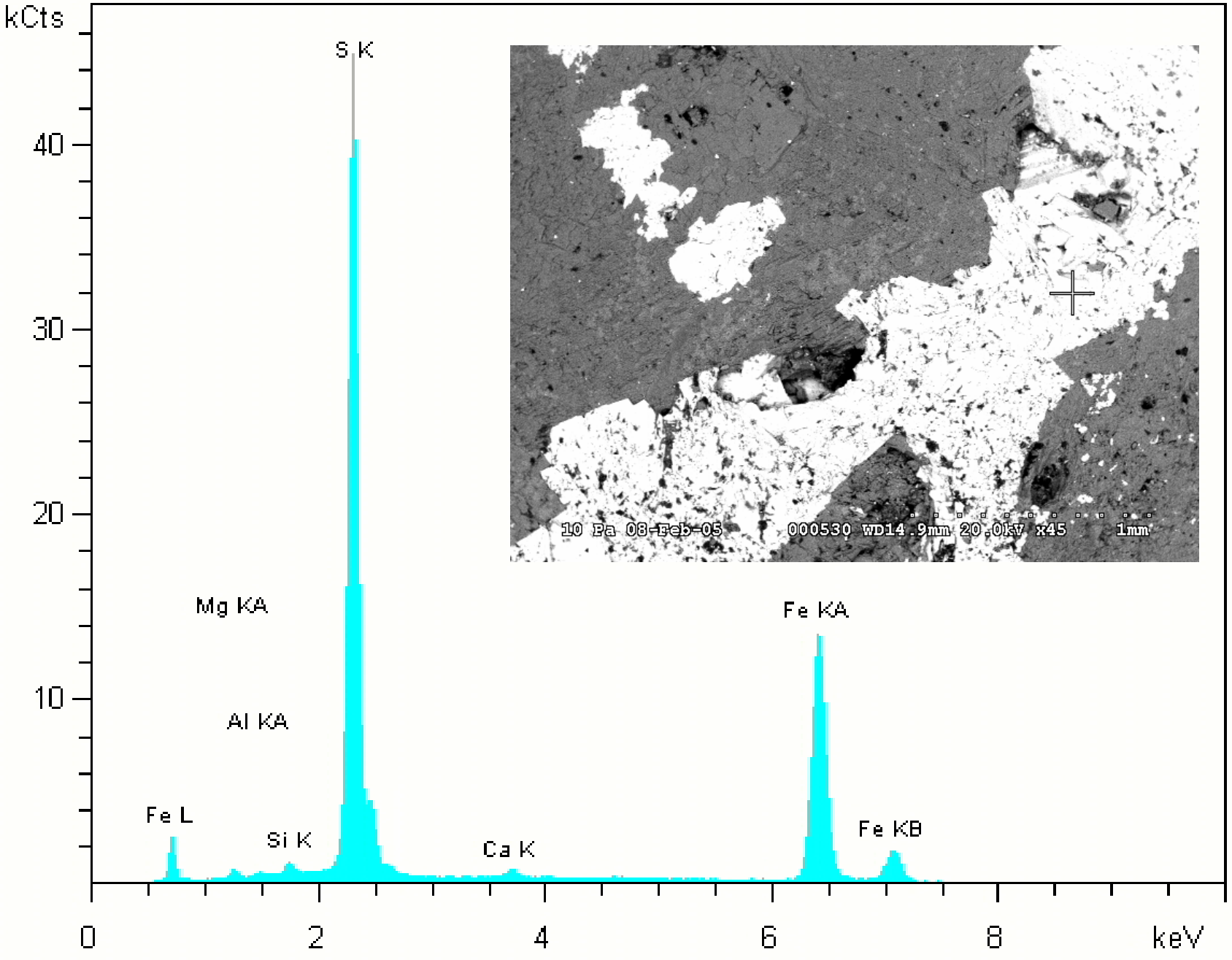

kCts
a L
C KA
10
S K
5
O KA
Mg KA
Ca K
0
0
5
10
15
keV
10 Pa 16-Mar-05
000607 WD15.3mm 20.0kV x45
1mm

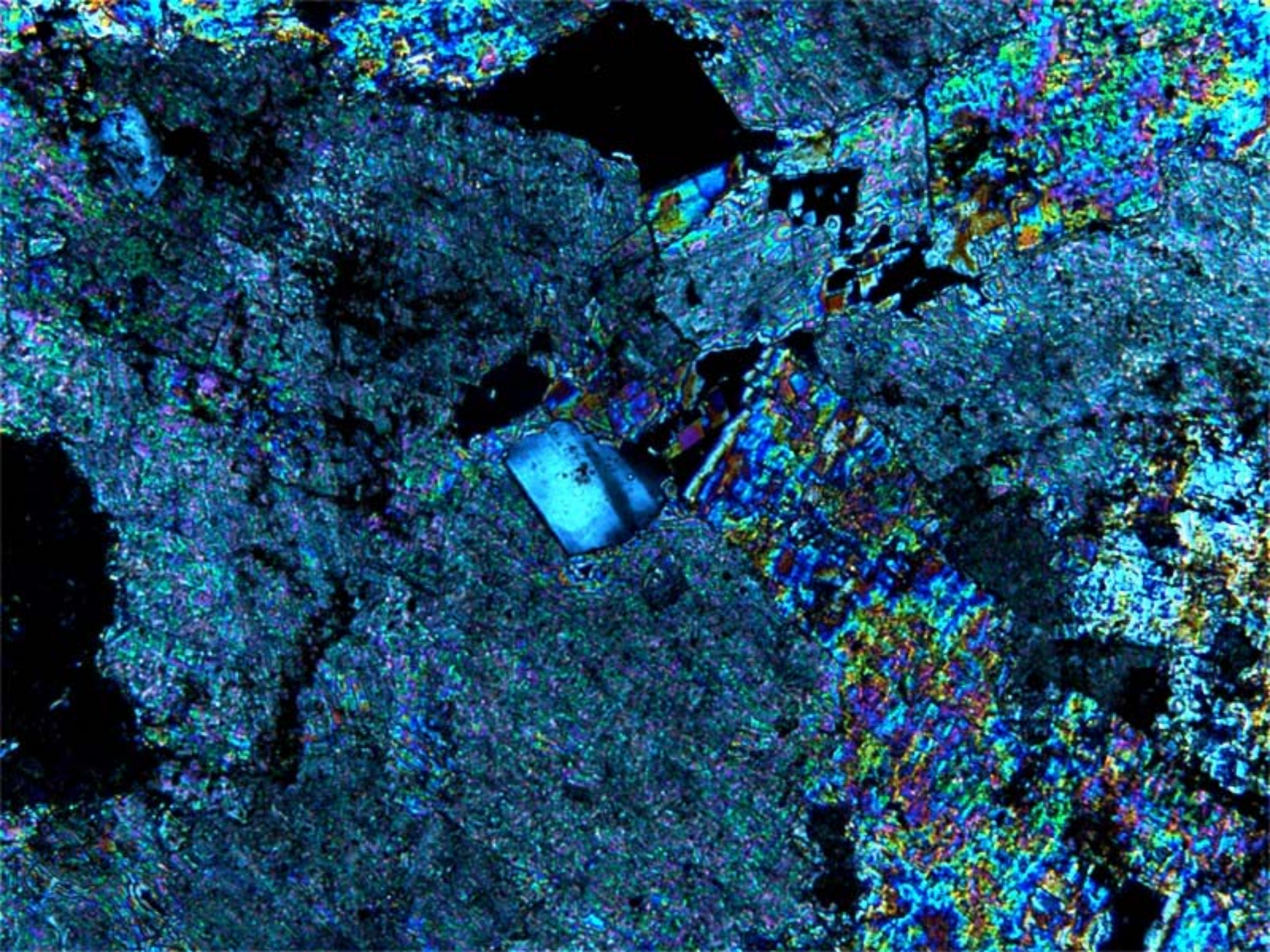

10 Pa 16-Mar-05 000608 WD15.3mm 20.0kV x120 250um

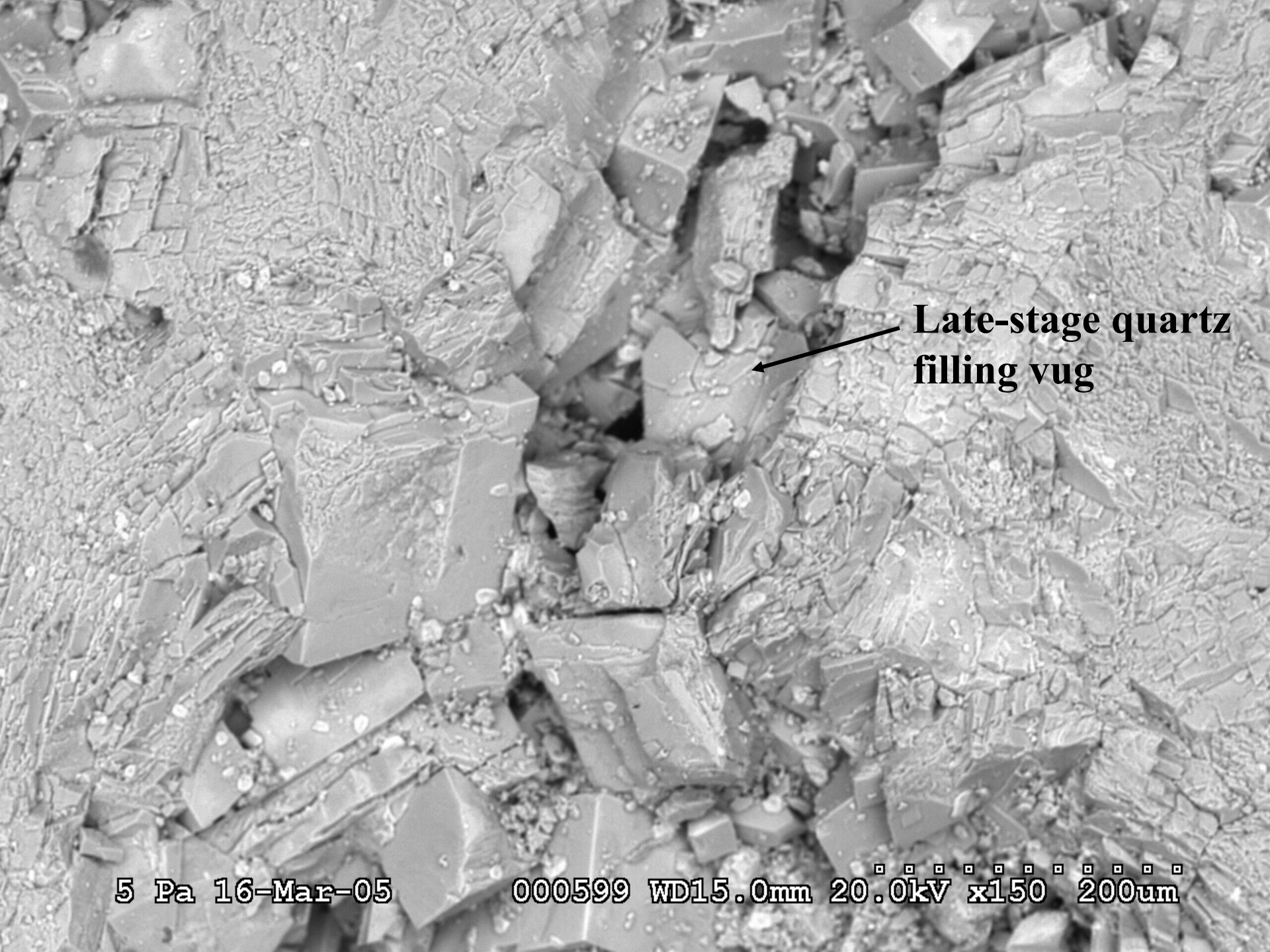


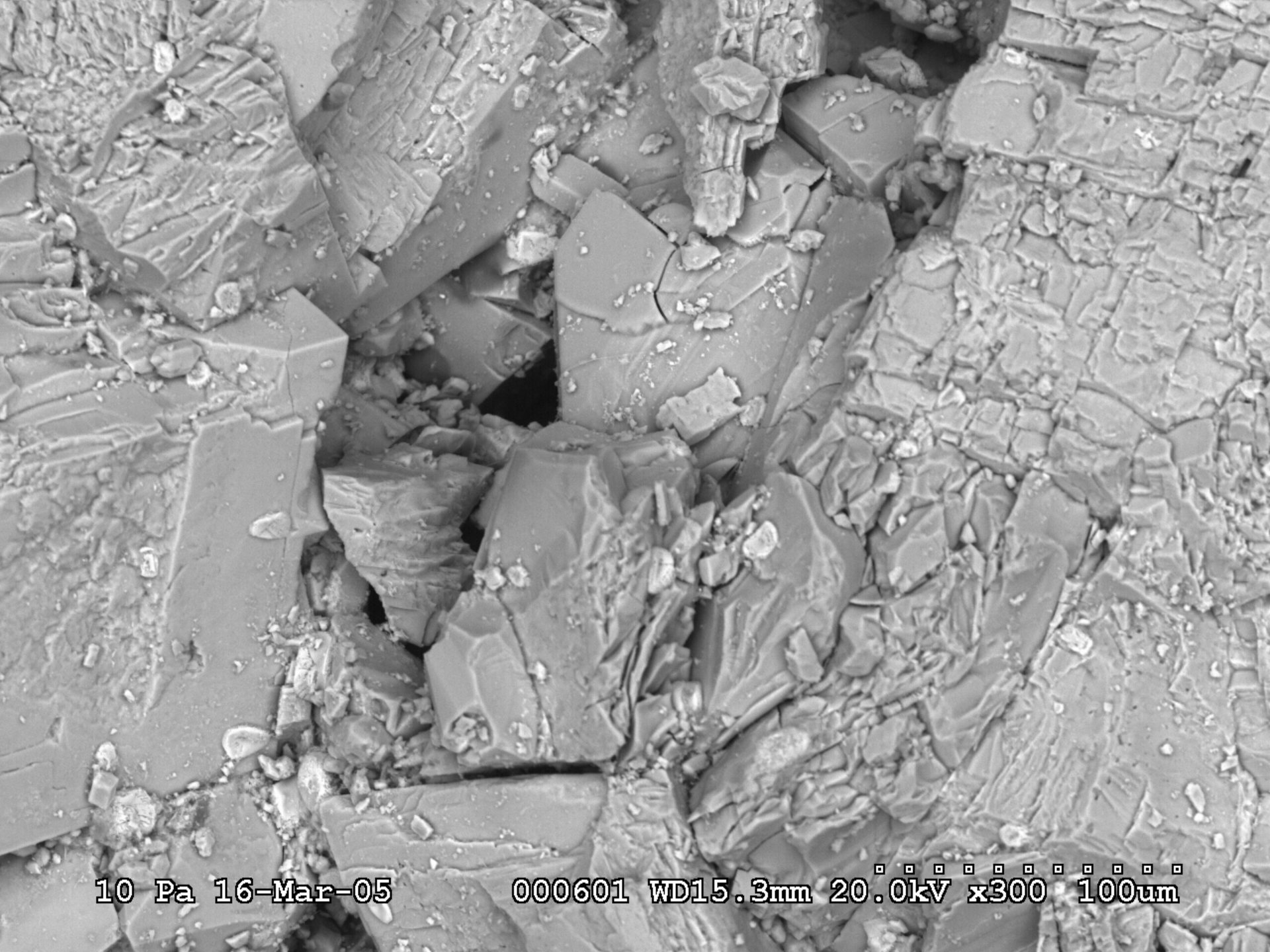

10 Pa 16-Mar-05
000606 WD15.3mm 20.0kV x45
1mm

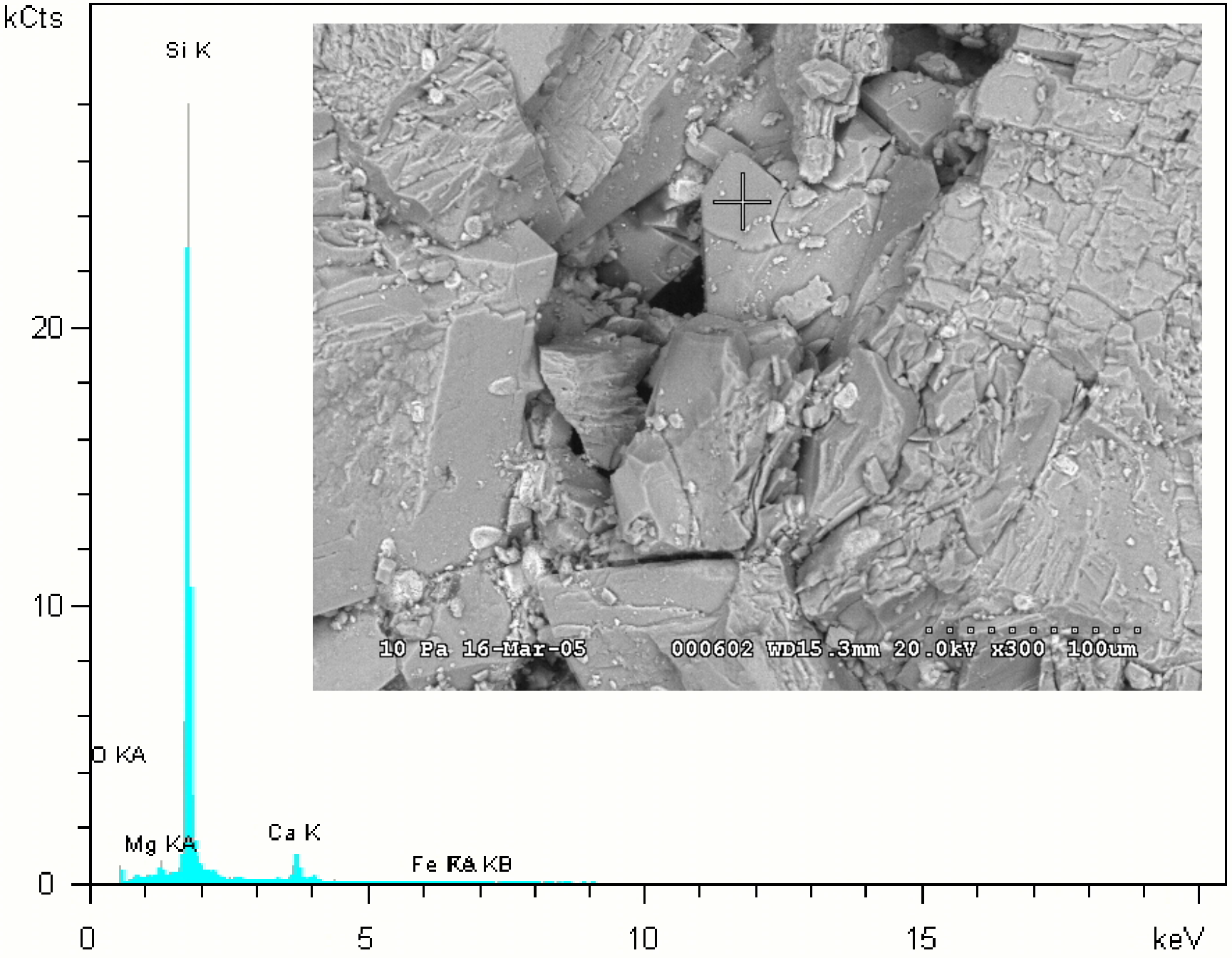

10 Pa 08-Feb-05 000529 WD14.9mm 20.0kV x45 1mm

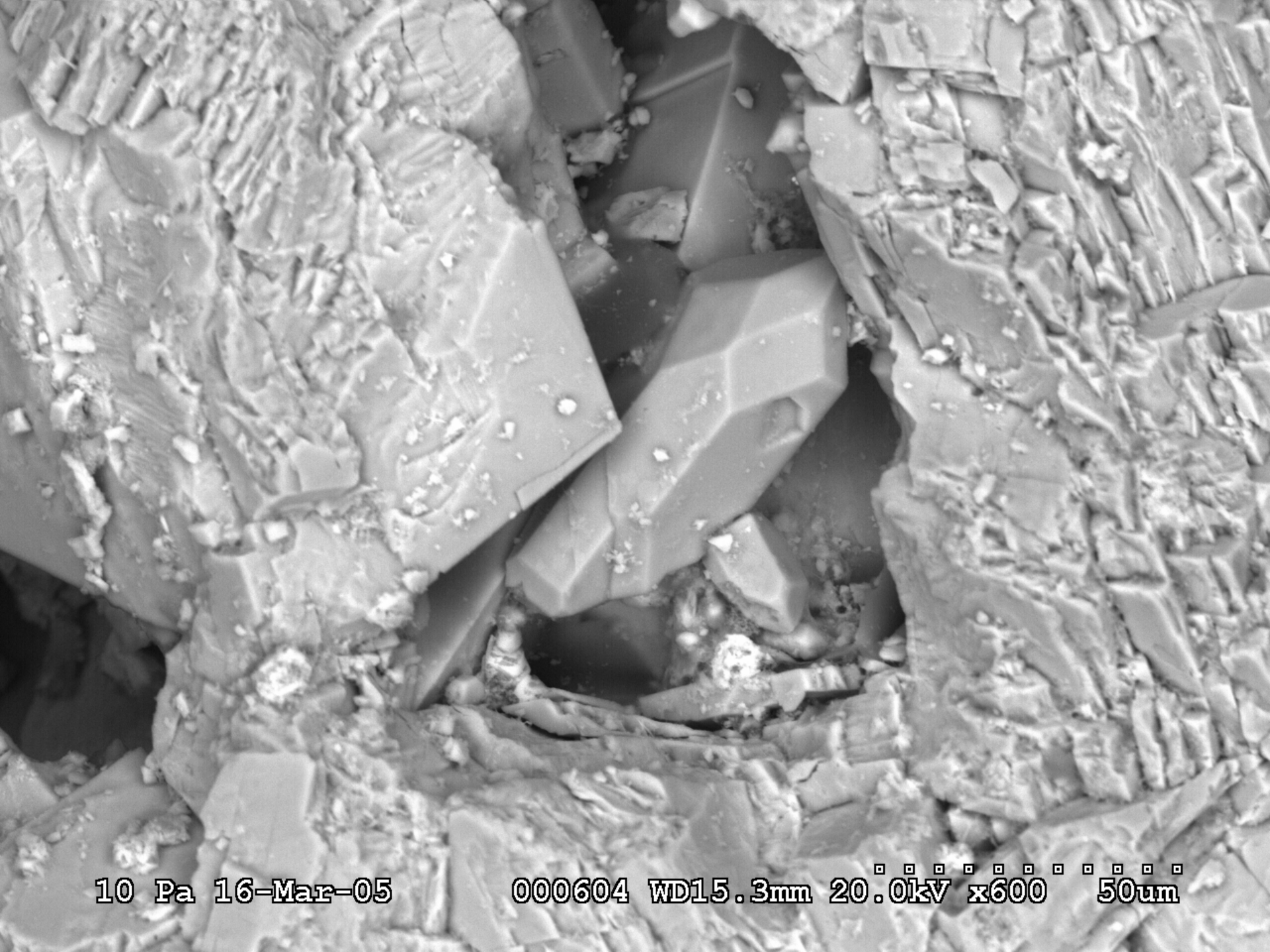

kCts
40
30
20
10
0
2
4
6
8
keV
S K
Mg KA
Al KA
Fe L
Si K
Ca K
Fe KA
Fe KB
10 Pa 08-Feb-05 000530 WD14.9mm 20.0kV x45 1mm



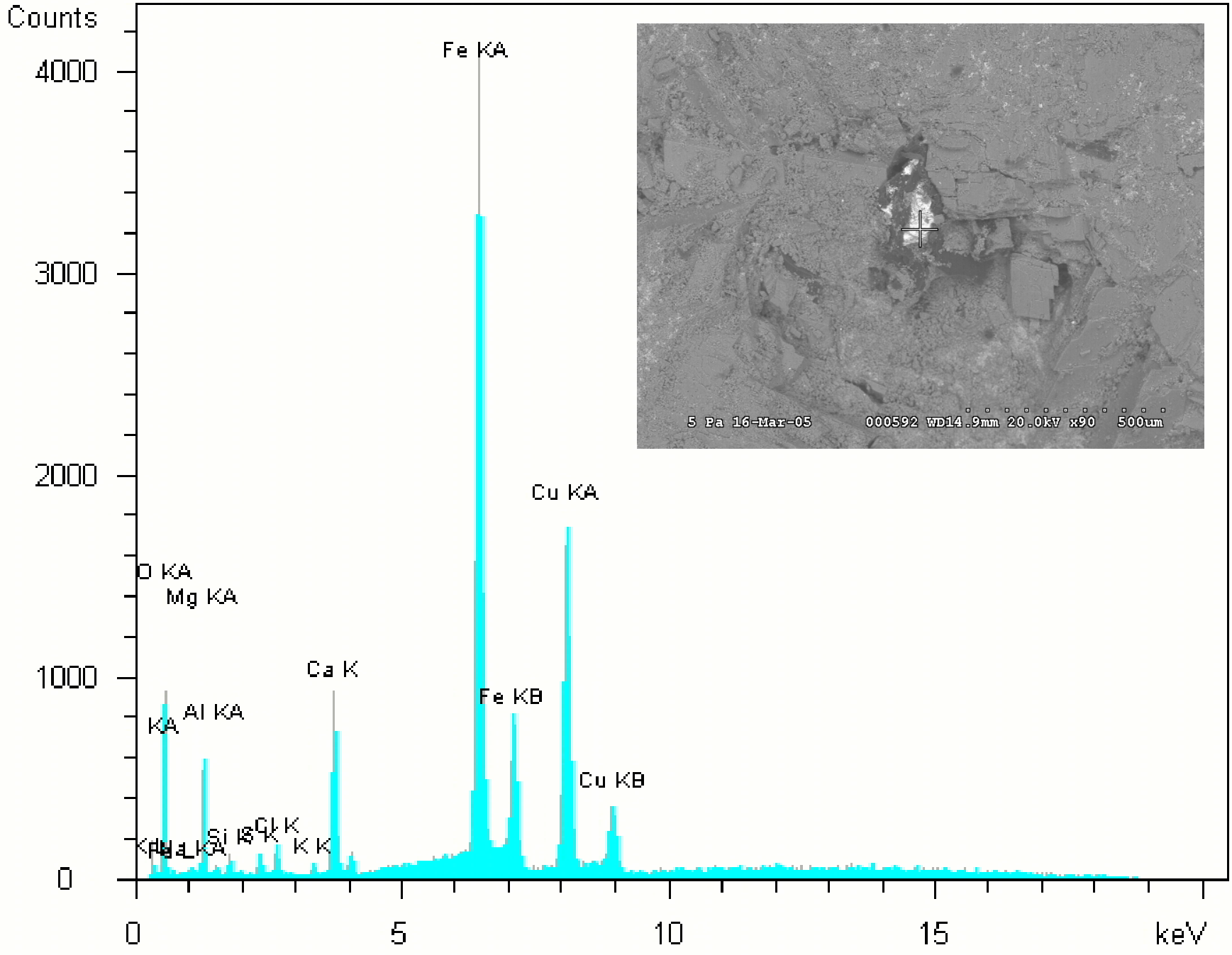

Late-stage quartz
filling vug
5 Pa 16-Mar-05 000599 WD15.0mm 20.0kV x150 200um

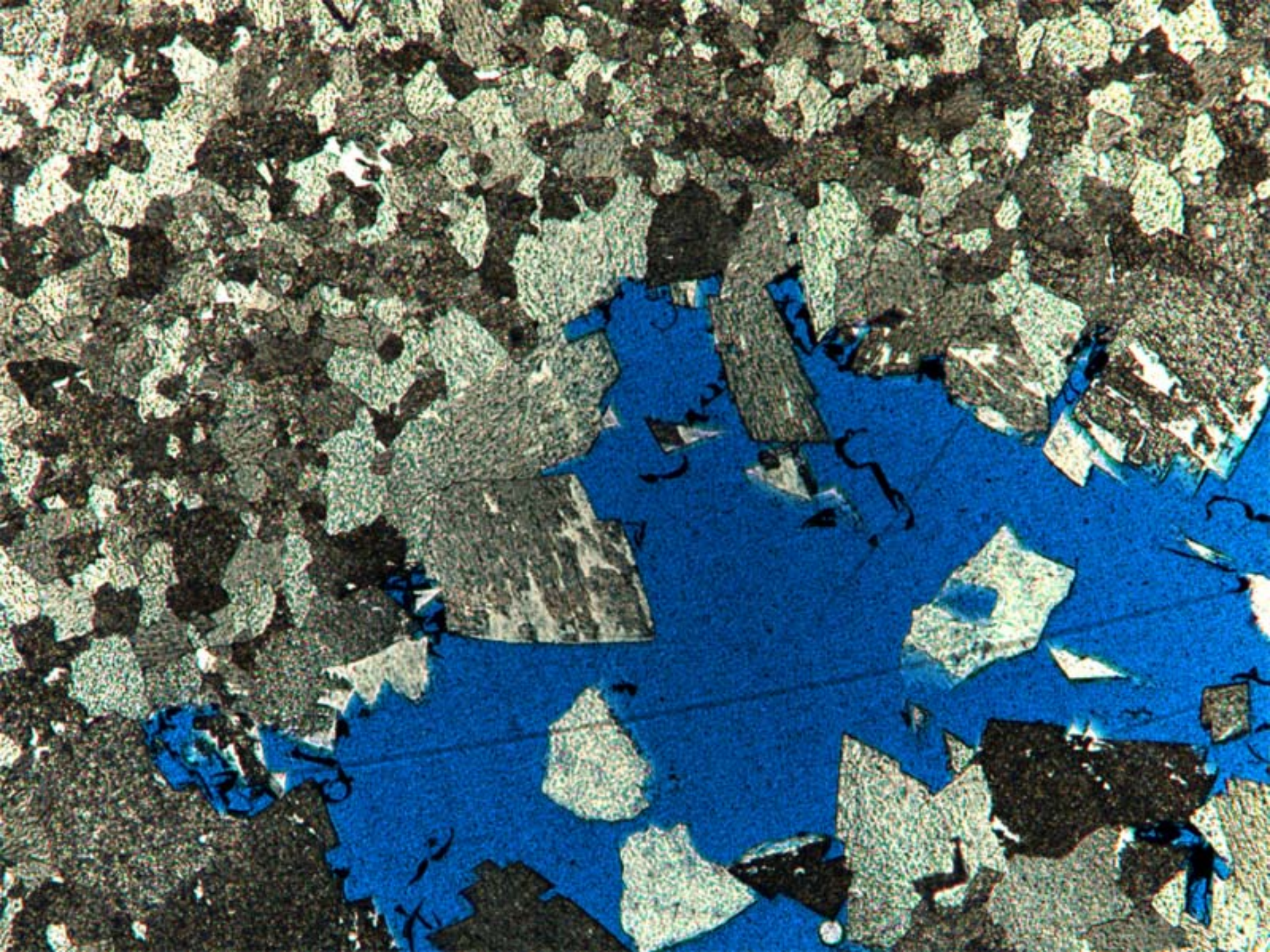

10 Pa 16-Mar-05 000601 WD15.3mm 20.0kV x300 100um

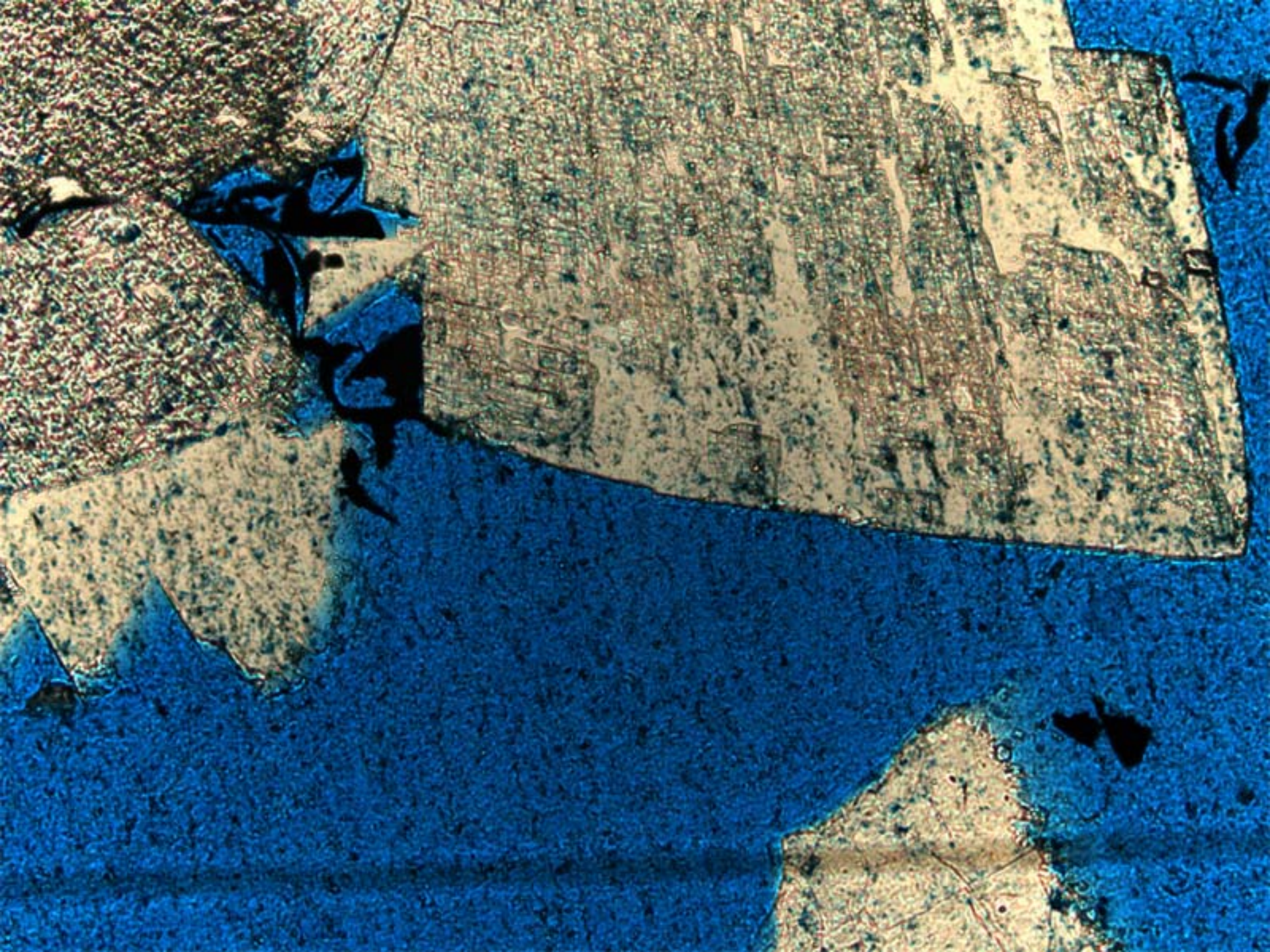

kCts
Si K
20
10
0
O KA
Mg KA
Ca K
Fe KA KB
0
5
10
15
keV
10 Pa 16-Mar-05
000602 WD15.3mm 20.0kV x300 100um

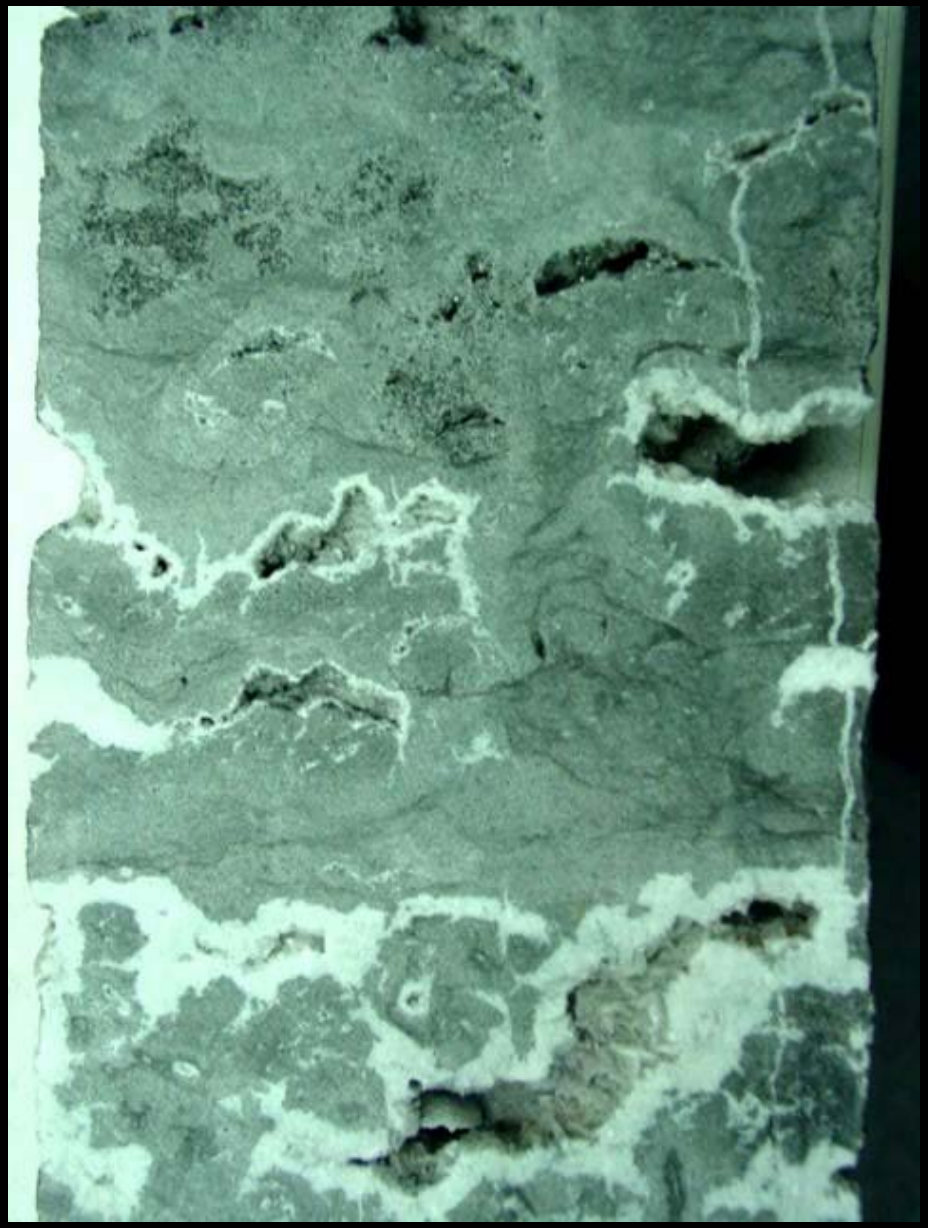

10 Pa 16-Mar-05 000604 WD15.3mm 20.0kV x600 50um

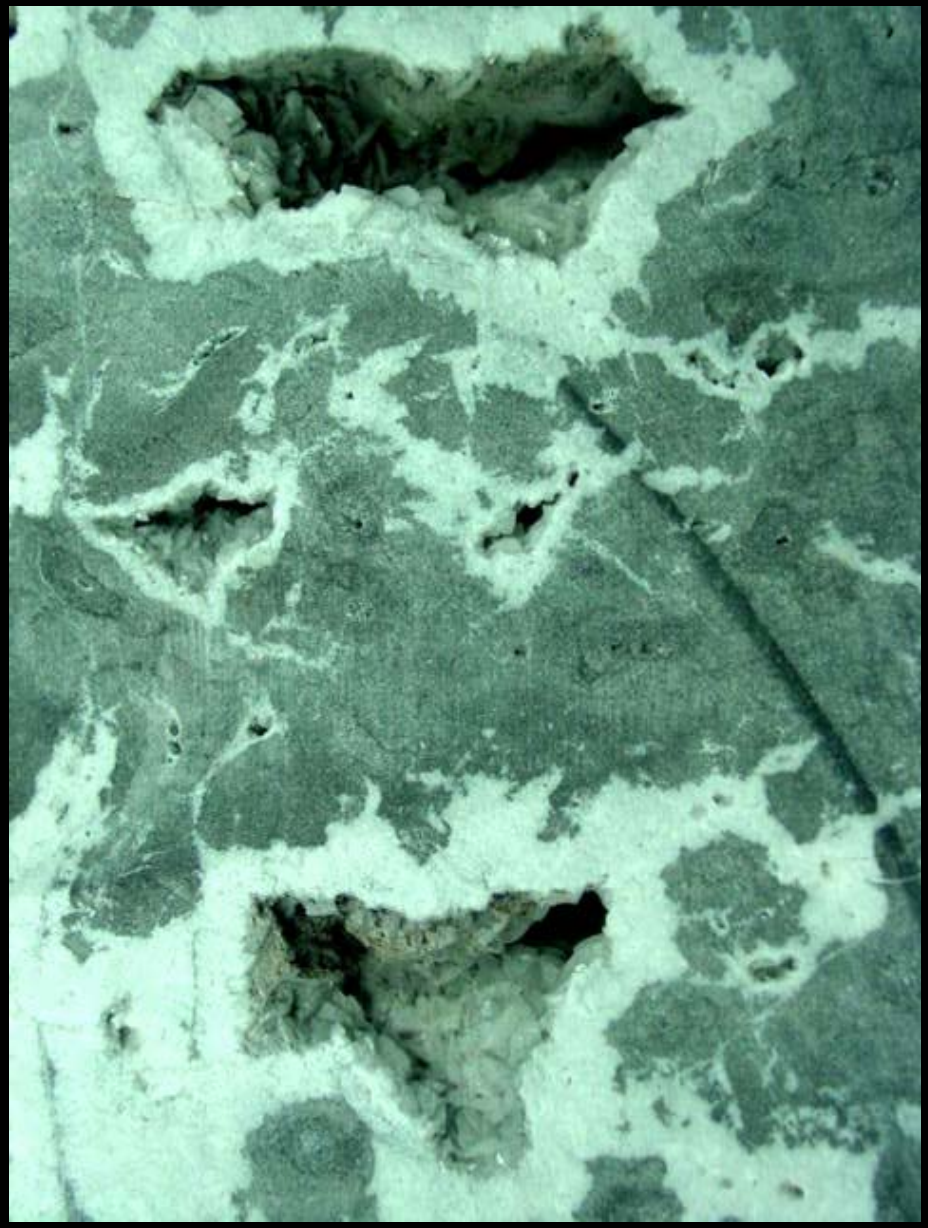

5 Pa 16-Mar-05 000592 WD14.9mm 20.0kV x180 250um

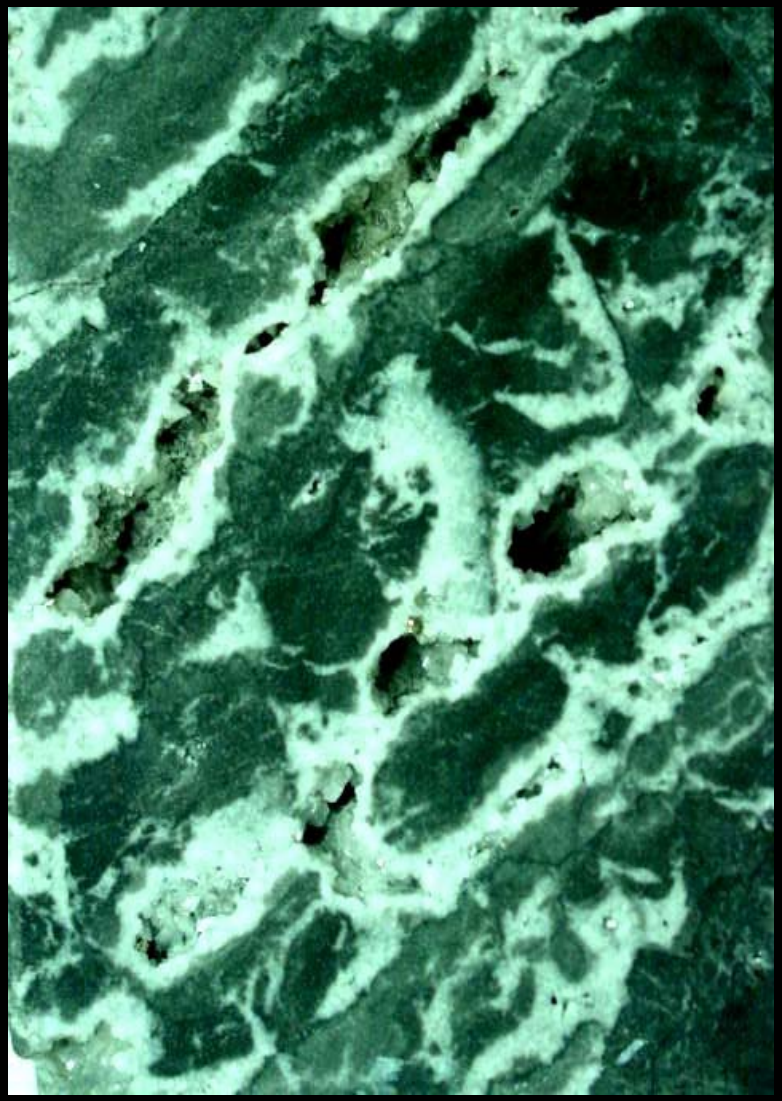

Counts
4000
3000
2000
1000
0
Fe KA
Cu KA
O KA
Mg KA
Ca K
Fe KB
Al KA
KA
Cu KB
Si KA
Ck K
K K
0
5
10
15
keV
5 Pa 16-Mar-05
000592 WD14.9mm 20.0kV x90
500um

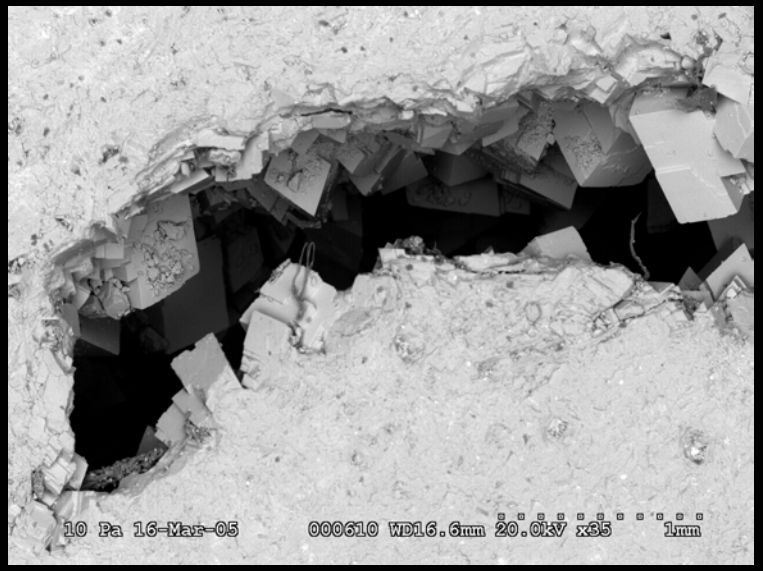






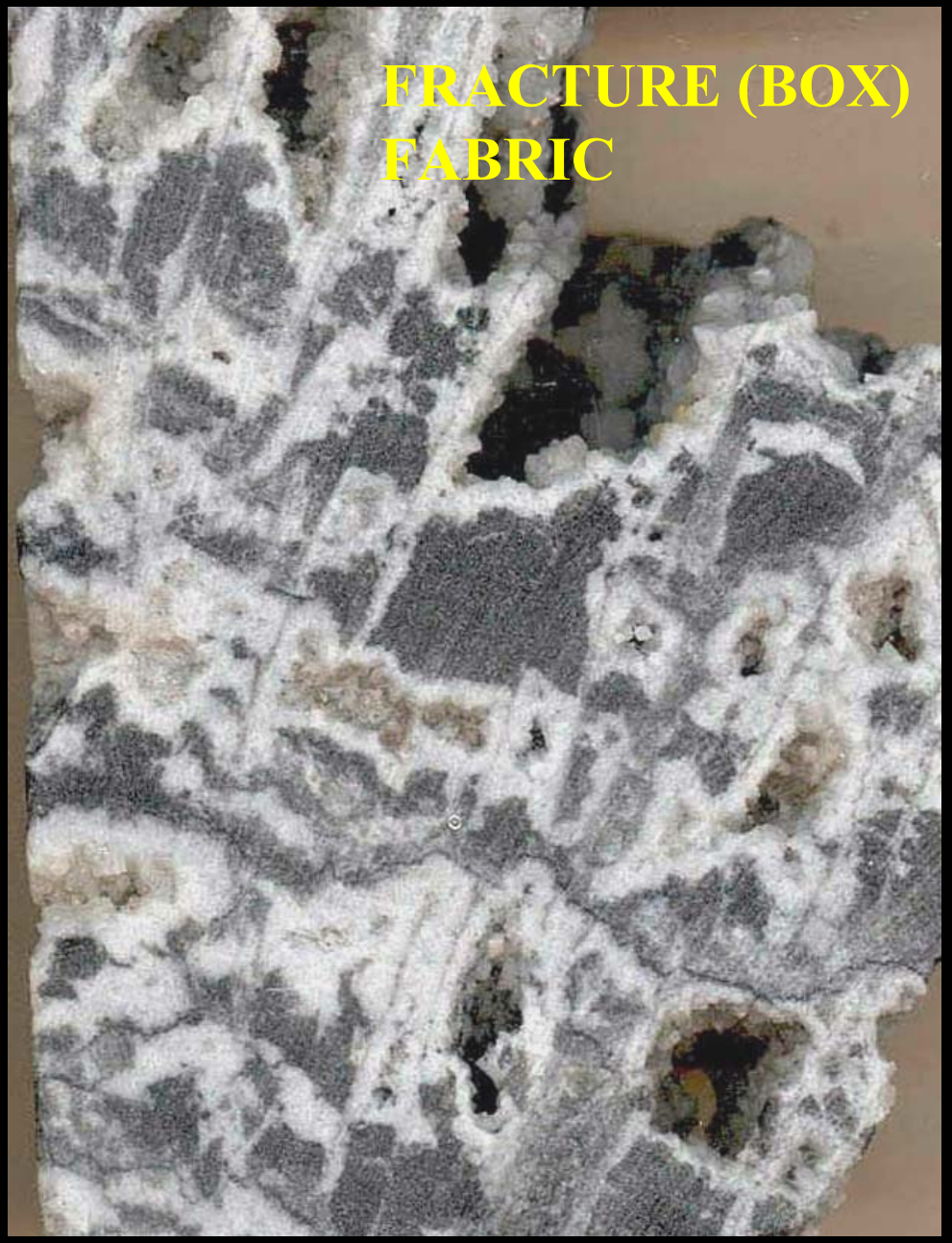




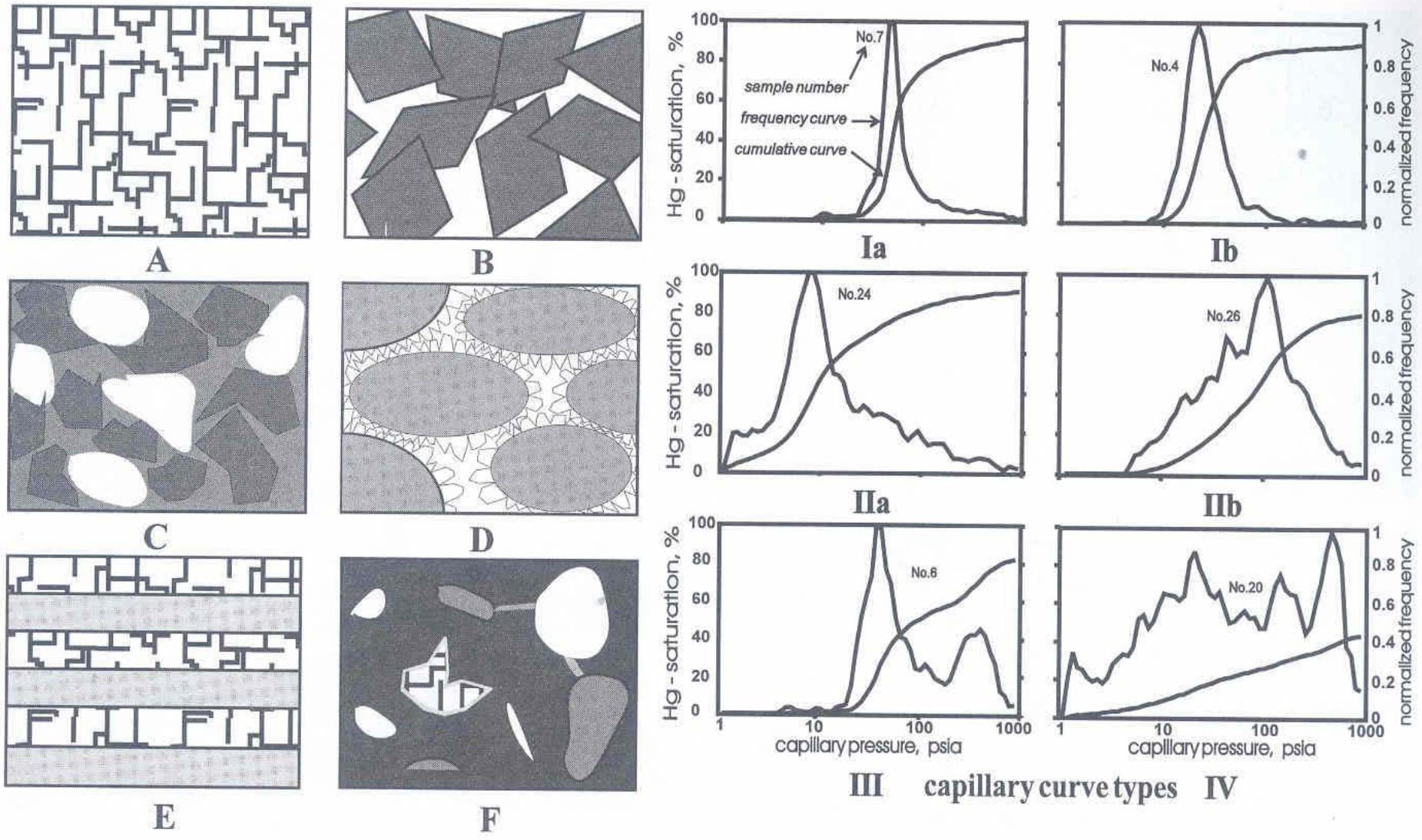


ZEBRA FABRIC


BRECCIA FABRIC


FRACTURE (BOX)
FABRIC


GRAY WELL SAMPLE
10 Pa 16-Mar-05
000603 WD15.3mm 20.0kV x45
1mm



pervasive solution-enlarged porosity

dolomite rhomb

void space

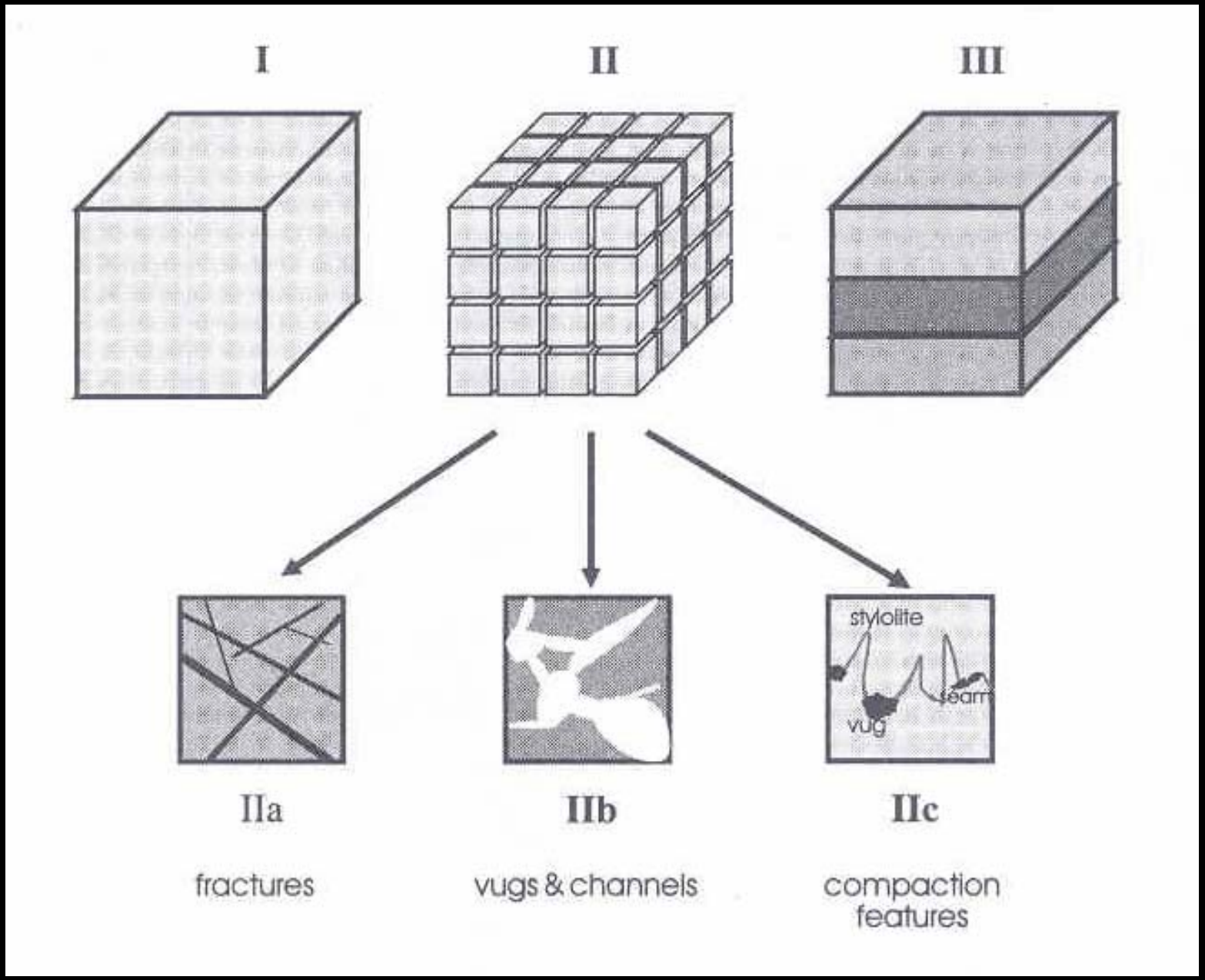
tight matrix

tight block of mosaic dolomites

micro-porosity

inter-crystalline porosity

intraclast with cements


I
II
III
stylolite
seam
vug
IIa
fractures
IIb
vugs & channels
IIc
compaction features