Petrography E.g. Sandstones

- **Sandstone** = grain-supported siliciclastic rock in which particle size varies from 1/16 mm to 2.0 mm
- **Intergranular pores** may be void or filled with *cement* and/or finer siliciclastic particles (~0.03 mm) called *matrix*
- **Mineralogy** is usually determined by using a *petrographic microscope*

Sandstone mineralogy

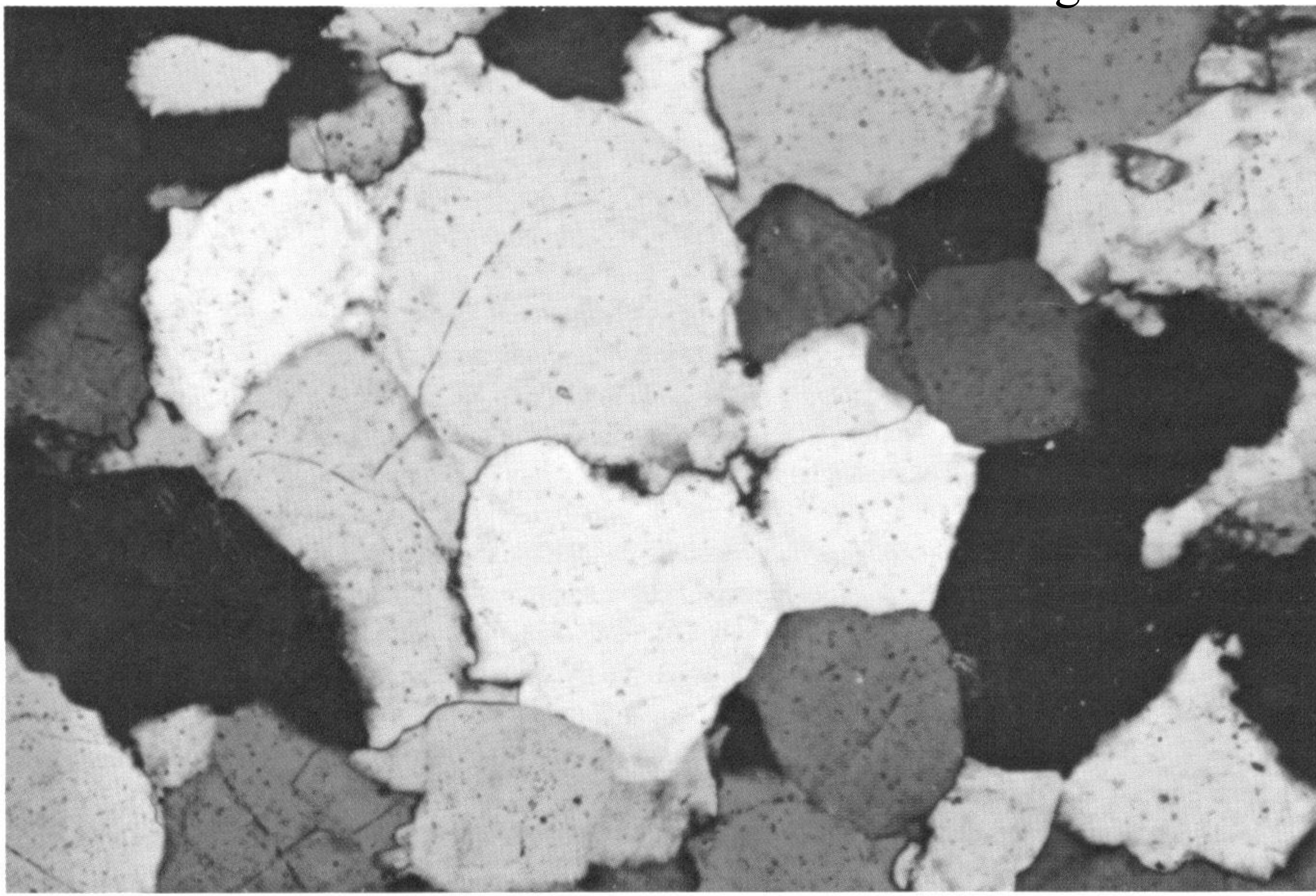
- **Most common minerals** in sandstones are:
  - quartz
  - feldspars
  - clay minerals
- **Accessory minerals** include:
  - micas
  - “heavies”
- **Other major components**:
  - lithic (rock) fragments

Sandstone mineralogy (cont.)

- **<u>Quartz</u>**
  - *Exceedingly durable*; can be derived from igneous, metamorphic or sedimentary source rocks
  - Usually makes up 50-60% of framework grains in sandstone
  - Occurs as single grains (*monocrystalline*) or composite grains (*polycrystalline*); *microcrystalline* grains are known as chert
  - **Characterized petrographically by undulatory ("sweeping") extinction, lack of twinning/cleavage, and low birefringence (gray to straw yellow)**

Quartz grains

Low birefringence, lack of cleavage and twinning



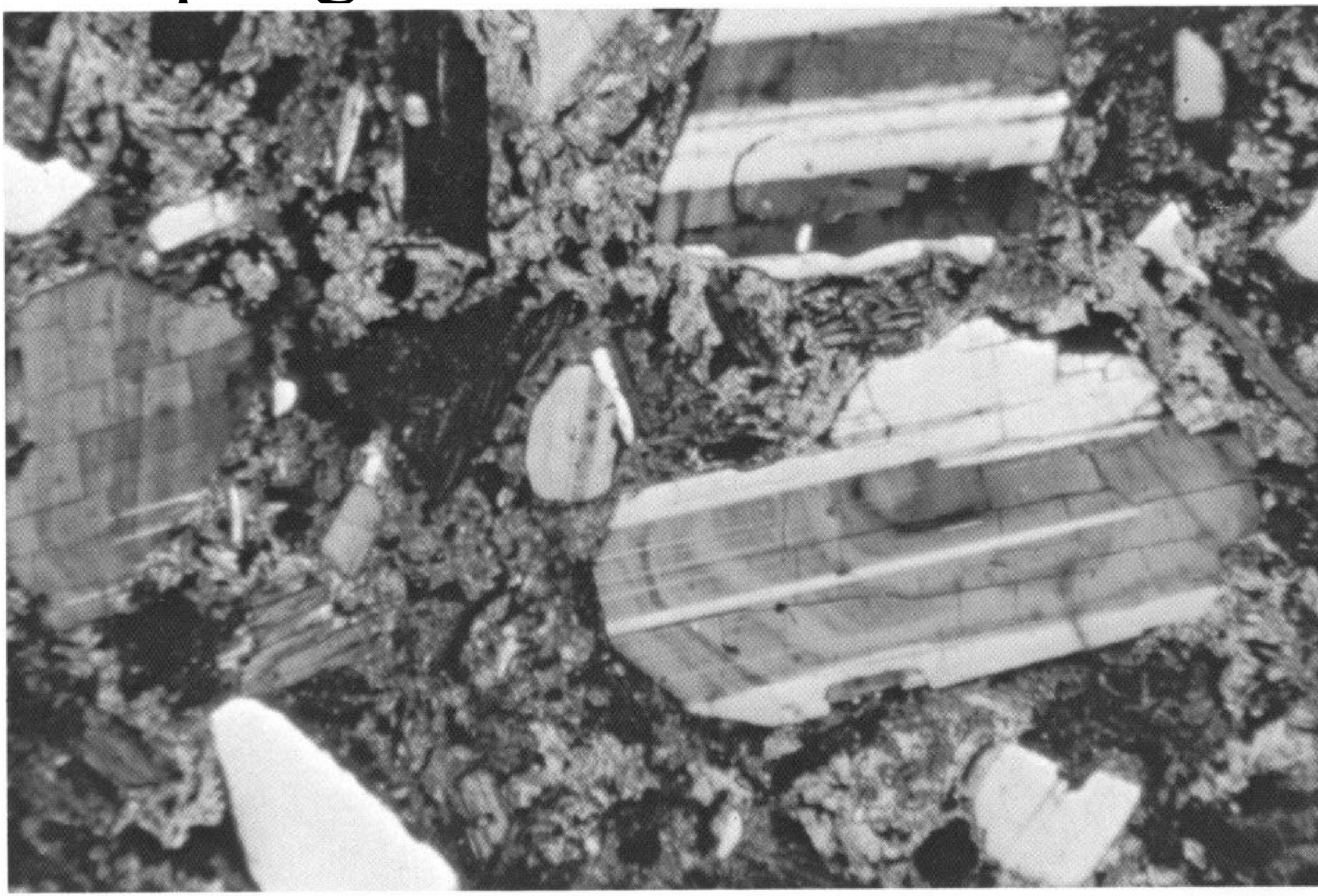
Crossed polarized light

Sandstone mineralogy (cont.)

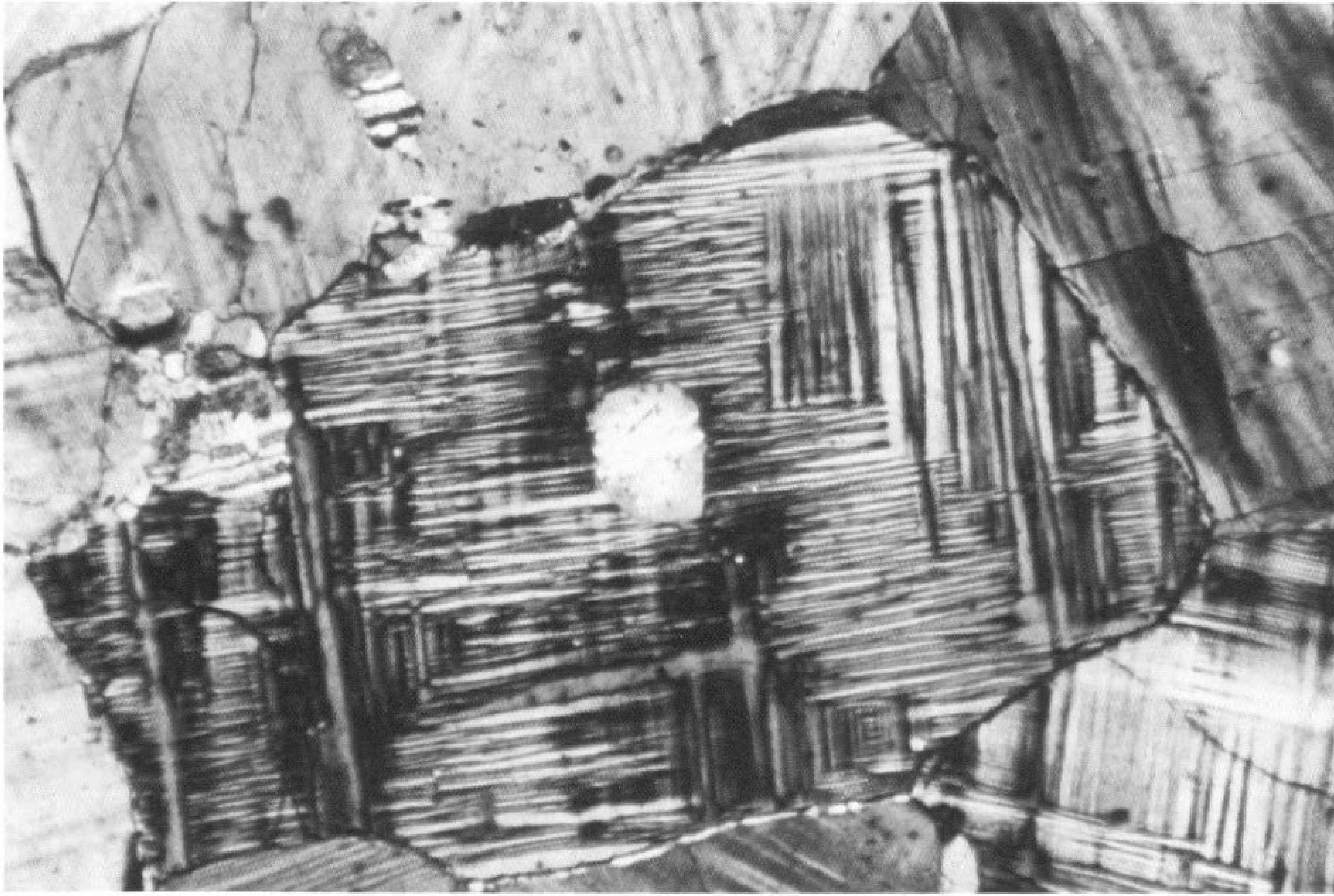
- **<u>Feldspars</u>**
  - *Chemically and mechanically unstable*; usually derived from crystalline source; usually make up 10-20% of framework grains
  - Alkali (K) feldspars
    - Orthoclase, microcline, sanidine, etc.
    - $KAlSi_3O_8$ — $NaAlSi_3O_8$ solid solution series
  - Plagioclase feldspars
    - Albite, oligoclase, anorthite, etc.
    - $NaAlSi_3O_8$ — $CaAl_2Si_2O_8$ solid solution series
  - **Characterized petrographically by good cleavage, twinning, low birefringence, unit to slightly sweeping extinction**

Feldspar grains Plagioclase with albite twinning

XN



Microcline (K-spar) with cross-hatched/grid twinning XN

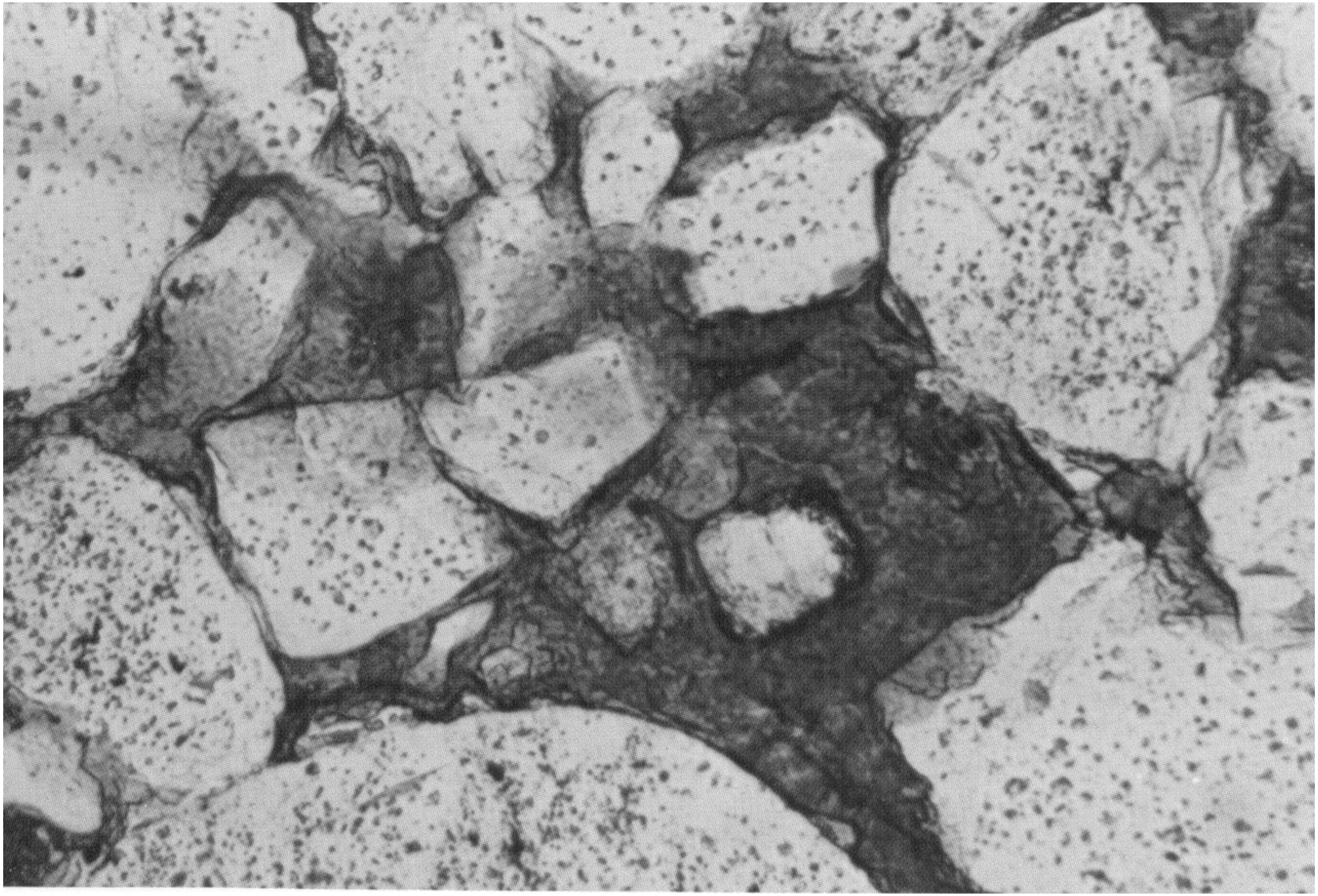


Sandstone mineralogy (cont.)

- **Clay minerals**
  - Usually derived as *secondary* minerals from subaerial weathering (hydrolysis of feldspars)
  - Usually make up ~5% of sandstones, *in the form of matrix*
  - Not identifiable petrographically
    - Must use X-ray diffraction, SEM, or other non-optical methods
  - Phyllosilicates (two-dimensional sheet siliciates)
    - Illite, smectite, kaolinite, chlorite

Clay minerals

Clay minerals completely filling pore spaces among quartz sand grains



Sandstone mineralogy (cont.)

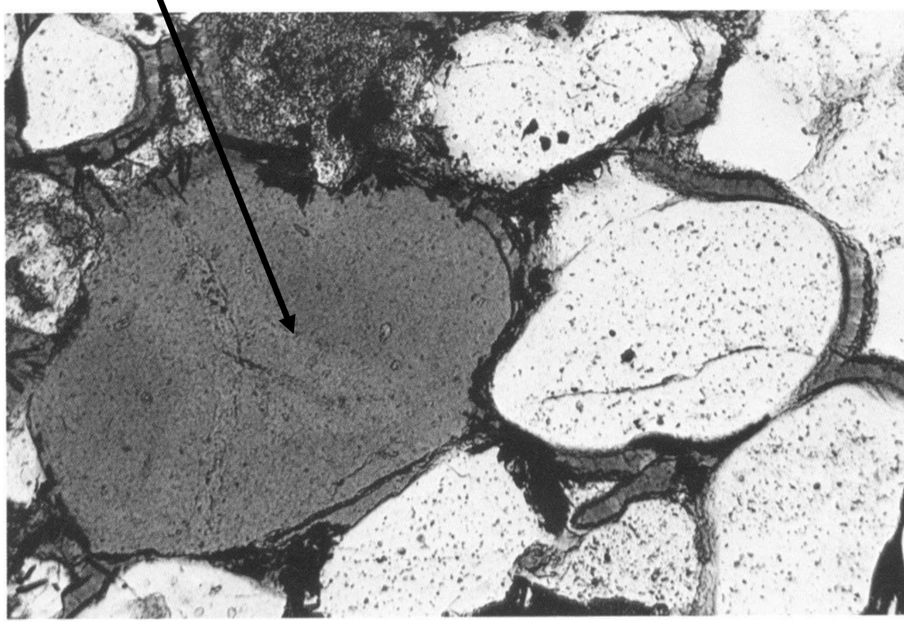
- **Accessory minerals** (1-2% of grains)
  - **Micas**
    - biotite, muscovite
    - distinguishable by flaky or platy habit, higher birefringence
    - usually derived from igneous or metamorphic source
  - **Heavy minerals**
    - Specific gravity > 2.9
    - zircon, rutile, magnetite, pyroxene, amphibole
    - *Variable stability*; with more stable types capable of withstanding repeated sedimentation cycles, less stable types usually come directly from a crystalline source

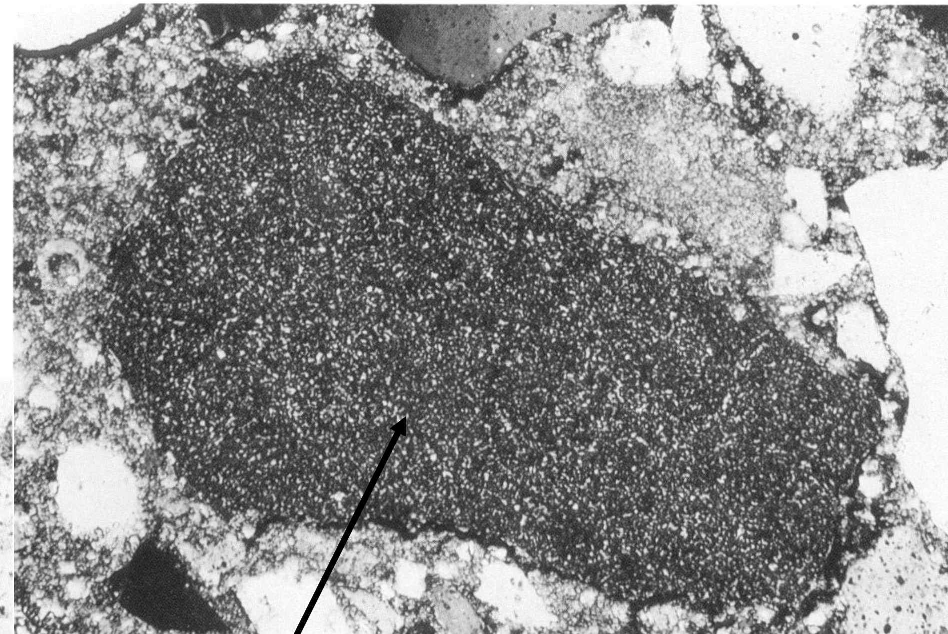
Sandstone mineralogy (cont.)

- **Rock (lithic) fragments**
  - Usually make up 15-20% of framework grains
  - Can be mineral grain composites from crystalline or sedimentary source rocks, *but sand size lithic fragments usually come from **fine grained** parents*
  - Usually from *volcanic* source or *fine grained metamorphics* such as slate, phyllite, schist
  - Very useful in provenance studies (more useful than *individual* grains of quartz or feldspar)

Rock (lithic) fragments

Claystone (shale) lithic fragment in quartz sandstone





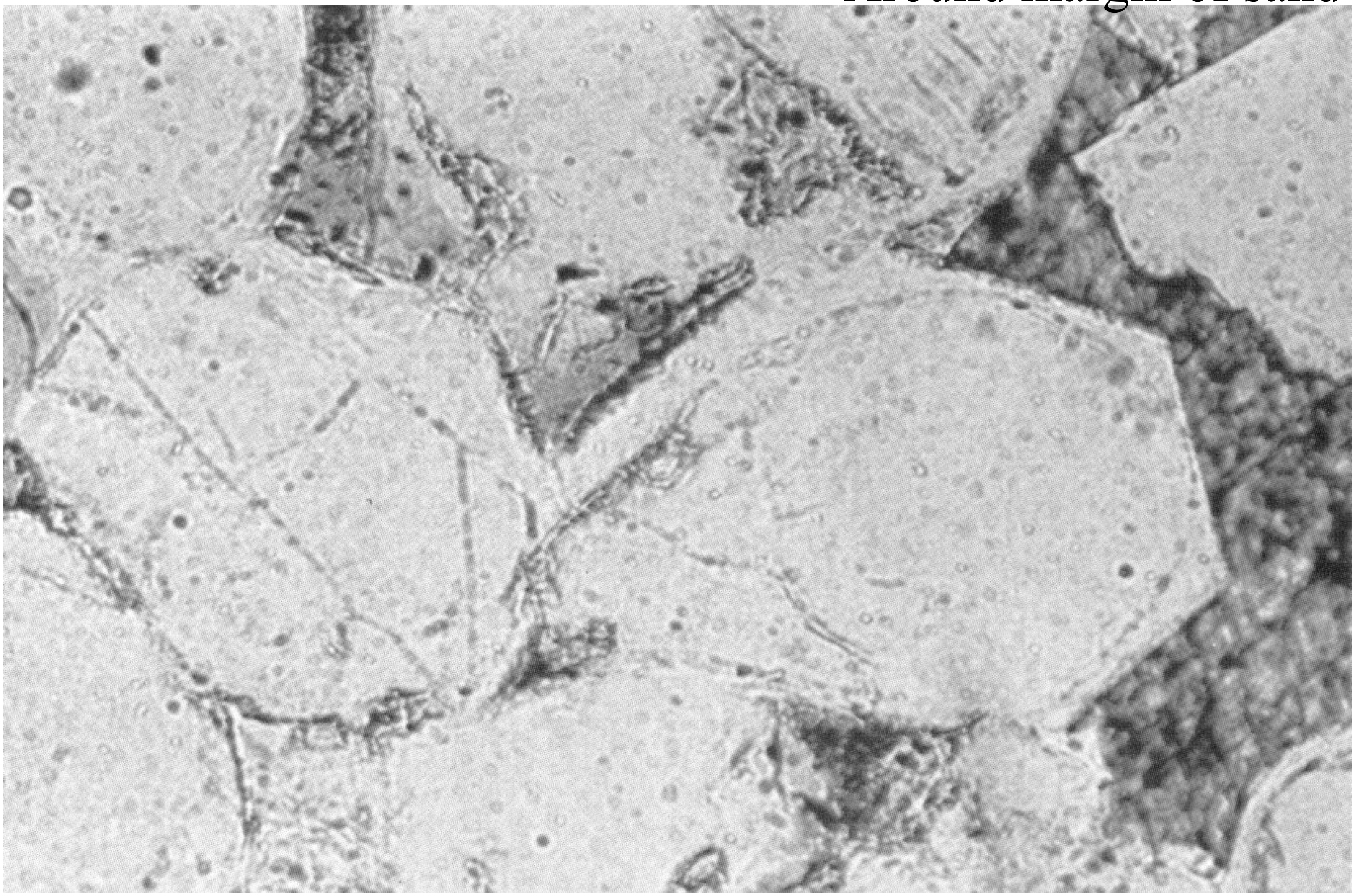
Microcrystalline quartz (chert) fragment in poorly sorted sandstone

Sandstone cements

- **Mineral cements**
  - **Silicate cements**
    - Quartz
      - Usually precipitates as overgrowths on quartz grains, in *optical continuity* with the quartz grain crystal: **syntaxial overgrowths**
      - Less commonly, precipitated as microcrystalline quartz (= chert)
    - Opal
      - Usually recrystallizes to microcrystalline quartz (= chert)
  - **Non-silicate cements**
    - Calcite/dolomite
    - Hematite
    - Sulphates (anhydrite, gypsum, barite)

Sandstone cements

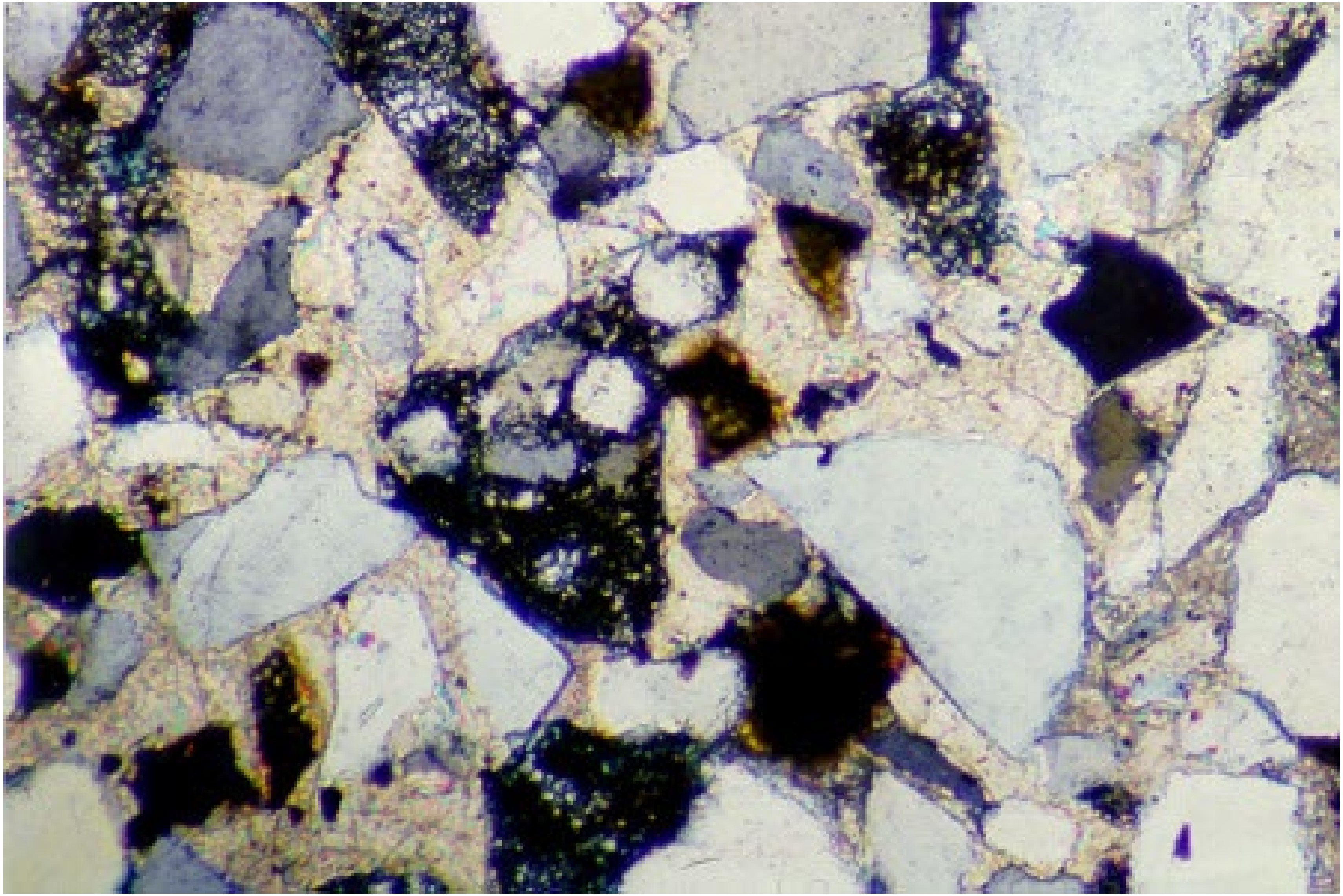
<u>Quartz overgrowth</u>:
note euhedral form and *dustline*
Around margin of sand grain



Because it is a *<u>syntaxial overgrowth</u>*, this cement displays the same optical extinction as the grain it surrounds

Calcite cemented

High birefringence colors

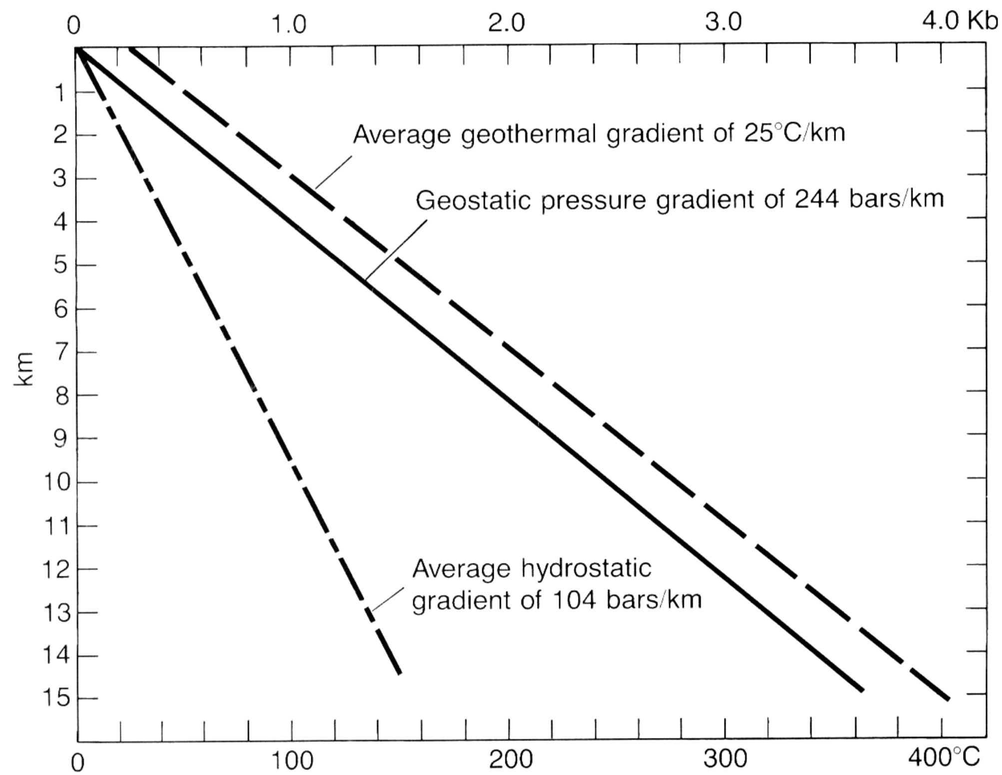


Diagenesis of siliciclastics

- **Diagenesis** = the sum of physical and chemical changes that take place after deposition of sediment, at temperatures < 300°C (anything hotter is considered metamorphism)
  - Compaction
  - Cementation
  - Dissolution
  - Mineral replacement
- Most diagenetic changes take place as a consequence of **burial-related phenomena**

Diagenesis (cont.)

- Burial-related phenomena:
  - Increase in **hydrostatic** (fluid) pressure
  - Increase in **geostatic** (rock) pressure
  - Increase in **temperature**
  - Change in **pore-water chemistry**
    - Usually, but not always, increase in **salinity**

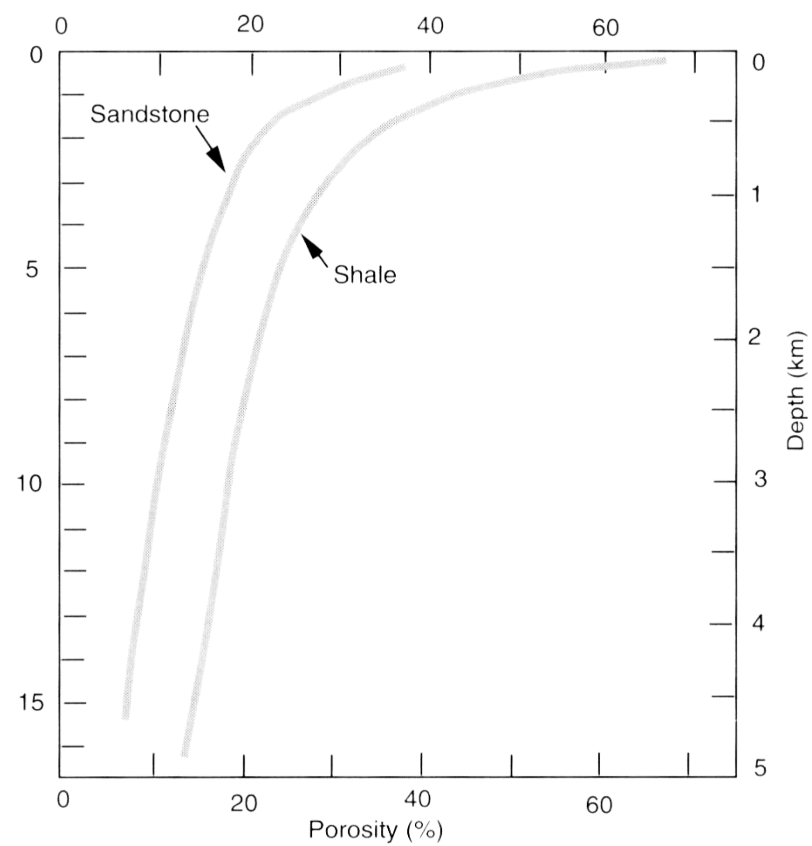


Stages of diagenesis

- **Shallow burial** ("eodiagenesis")
  - **Organic reworking** (bioturbation)
  - **Cementation and replacement**
    - Formation of pyrite in reducing environments
    - Formation of iron oxides in oxidizing environments
    - Precipitation of quartz and feldspar overgrowths
    - Precipitation of carbonate cements
  - **Minor compaction**

Stages of diagenesis (cont.)

- **<u>Deep burial</u>** ("mesodiagenesis")
  - **<u>Compaction</u>**
    - *Porosity reduction* and thinning of beds
    - Pressure solution



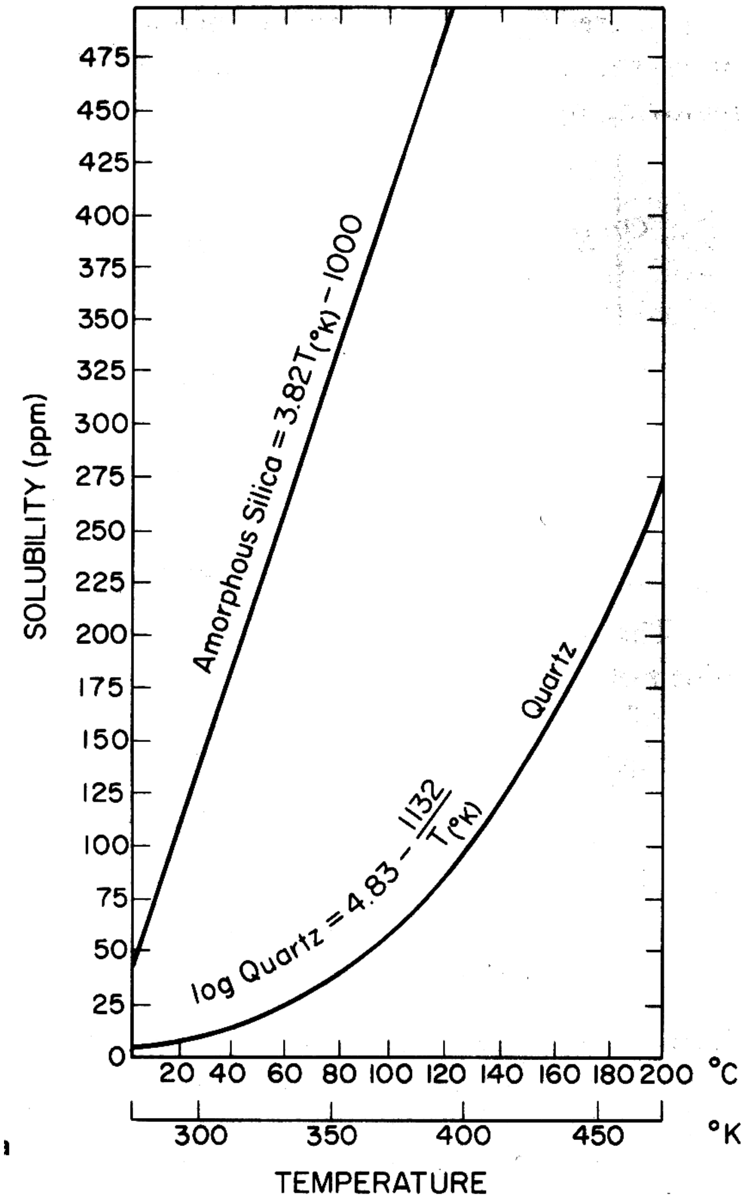
Stages of diagenesis (cont.)

- **<u>Deep burial</u>** (cont.)—***Chemical changes***
  - Increase in temperature greatly increases the **<u>rate</u>** at which chemical changes occur
    - Increase temp = increase solubility of silicates
    - Increase temp = decrease solubility of carbonates
  - Increase in CO_2 → decrease in pH → increase in solubility of carbonates

Stages of diagenesis (cont.)

- **Deep burial** (cont.)—***Cementation***
  - *Carbonate cementation*:
    - Favored by **increase in temperature**, increase in pH, and increase in concentration of calcium carbonate in pore waters
  - *Silicate cementation*:
    - Favored by **decrease in temperature** and increase in concentration of silica in pore waters
    - Note importance of **upward-migrating fluids**

Silica solubility vs. Temperature



Stages of diagenesis (cont.)

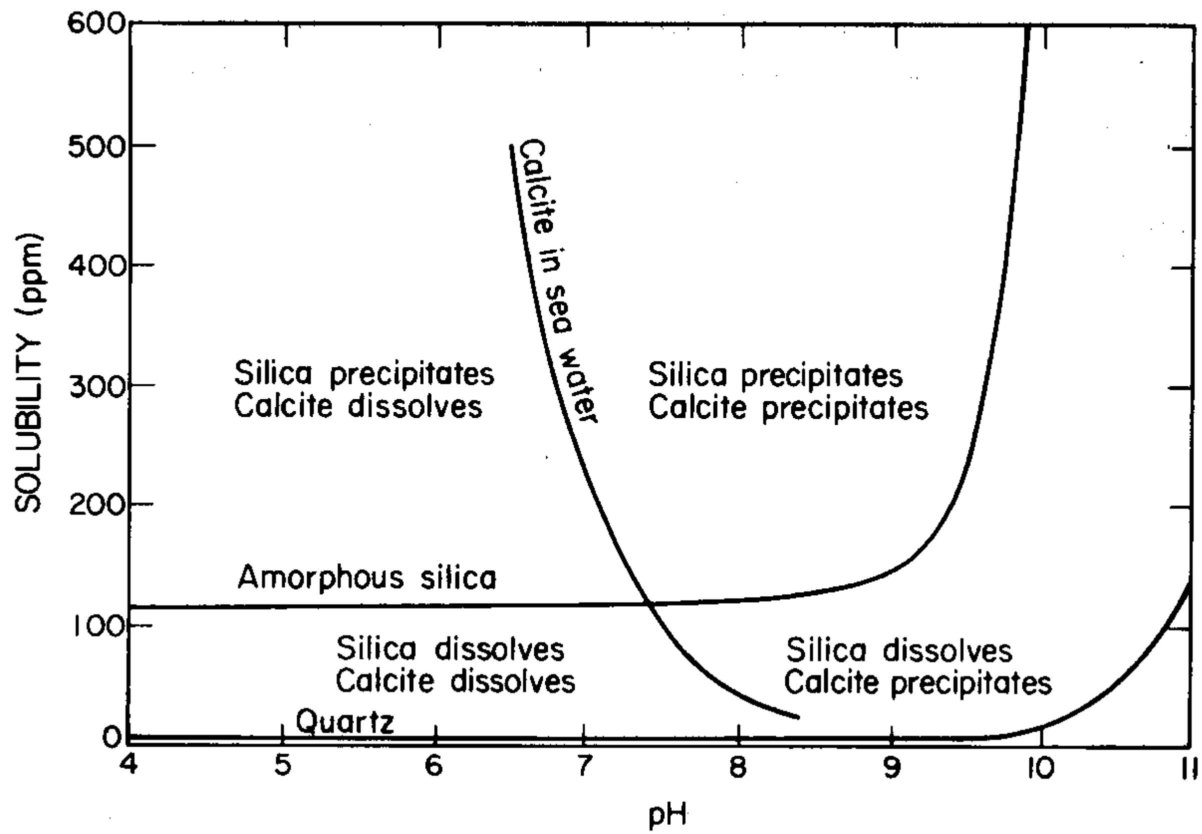
- **Deep burial** (cont.)
  - **Dissolution** is essentially the reverse of cementation
    - **Carbonate dissolution** occurs at lower temps and lower pH
    - **Silicate dissolution** occurs at higher temps and in the presence of organic acids
  - Dissolution can create **secondary porosity**, especially at depths > 3 km

Stages of diagenesis (cont.)

- **Deep burial** (cont.)
  - **Mineral replacement** = the essentially simultaneous replacement of one mineral by another without significant change in volume
    - Carbonates → chert
    - Feldspars/quartz → carbonates
    - Feldspars → clays
    - Volcanics → clays
  - **Clay mineral alteration**
    - Smectite → illite + water
    - Smectite → chlorite
    - Kaolinite → illite

Carbonate/Silica solubility vs. pH

<u>Note</u>:
- <u>Calcite</u> is highly soluble at pH < 7
- <u>Quartz</u> is insoluble at pH < 10
- Solubility of <u>amorphous silica</u> increases dramatically at pH > 9



Stages of diagenesis (cont.)

- **Telodiagenesis** = diagenesis that occurs during uplift (basically a reversal of burial)
  - *Lower temperature and pressure*
  - *Pore waters become less saline, more oxygenated*
  - **Cementation/dissolution/oxidation**–depending on minerals present and what happened during burial diagenesis
- Telodiagenesis *grades into surface weathering processes*