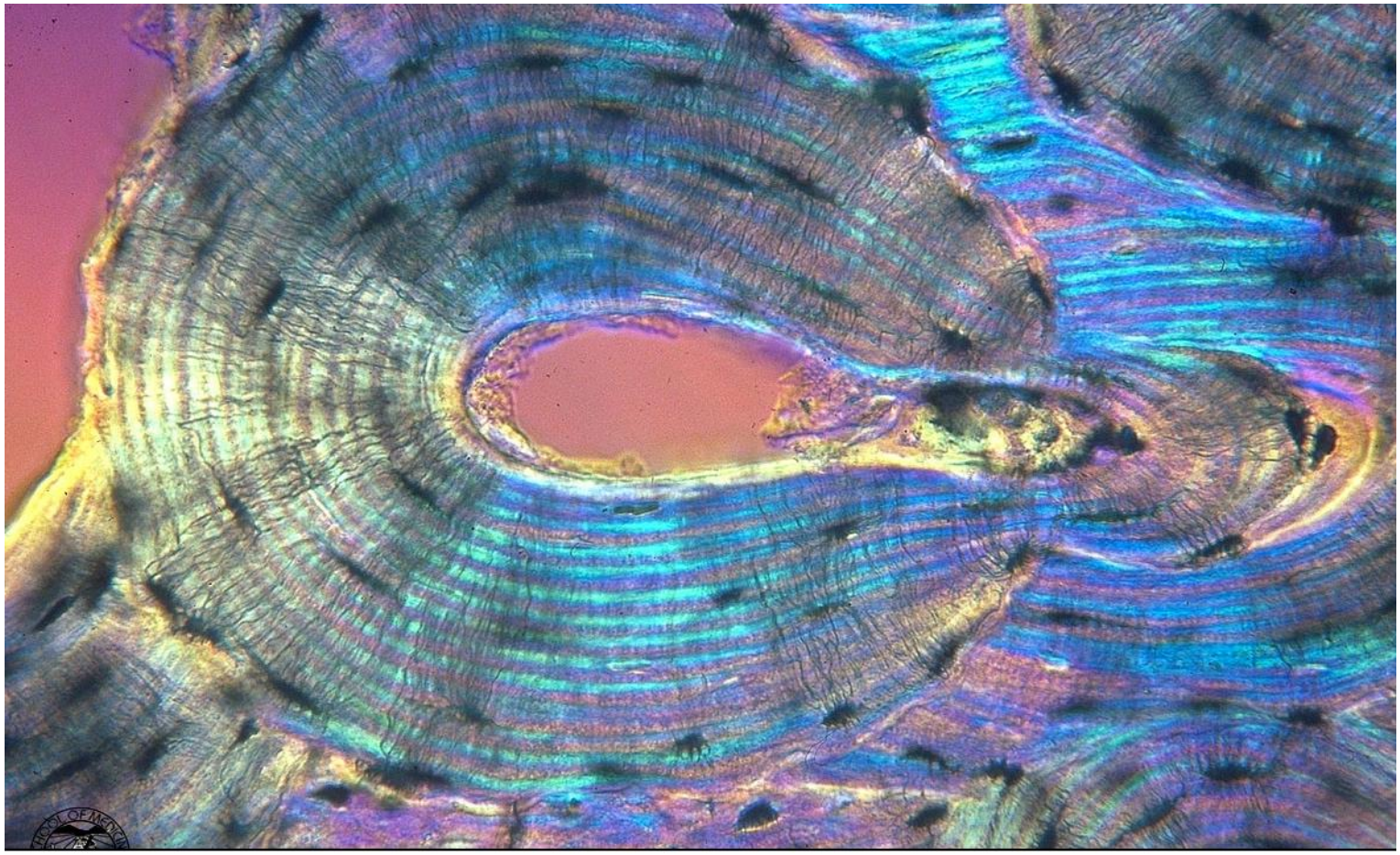
Bone



Functions of Bone

- **Primary structural framework** for **support** and **protection** of the organs of the body, ex. skull around brain

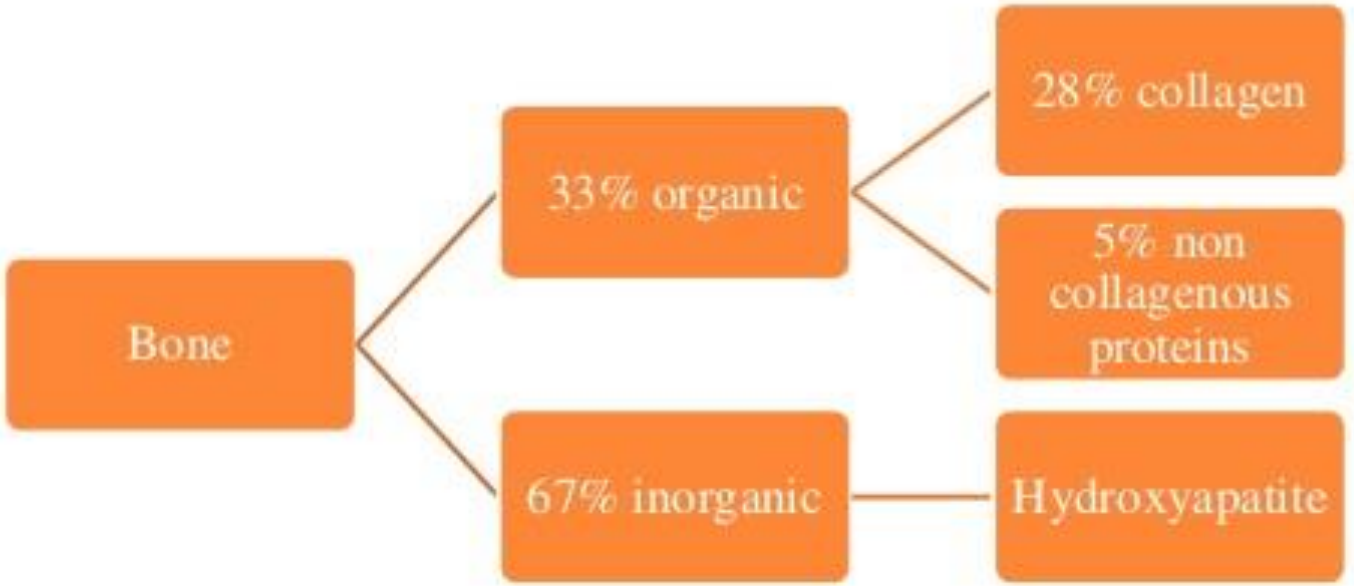
- Serve as **levers** for the muscles attached to them, thereby multiplying the force of the muscles to attain movement.

- Acts as a **reservoir** for calcium and phosphorous. Released or stored in a controlled fashion to maintain constant concentrations in body fluid.

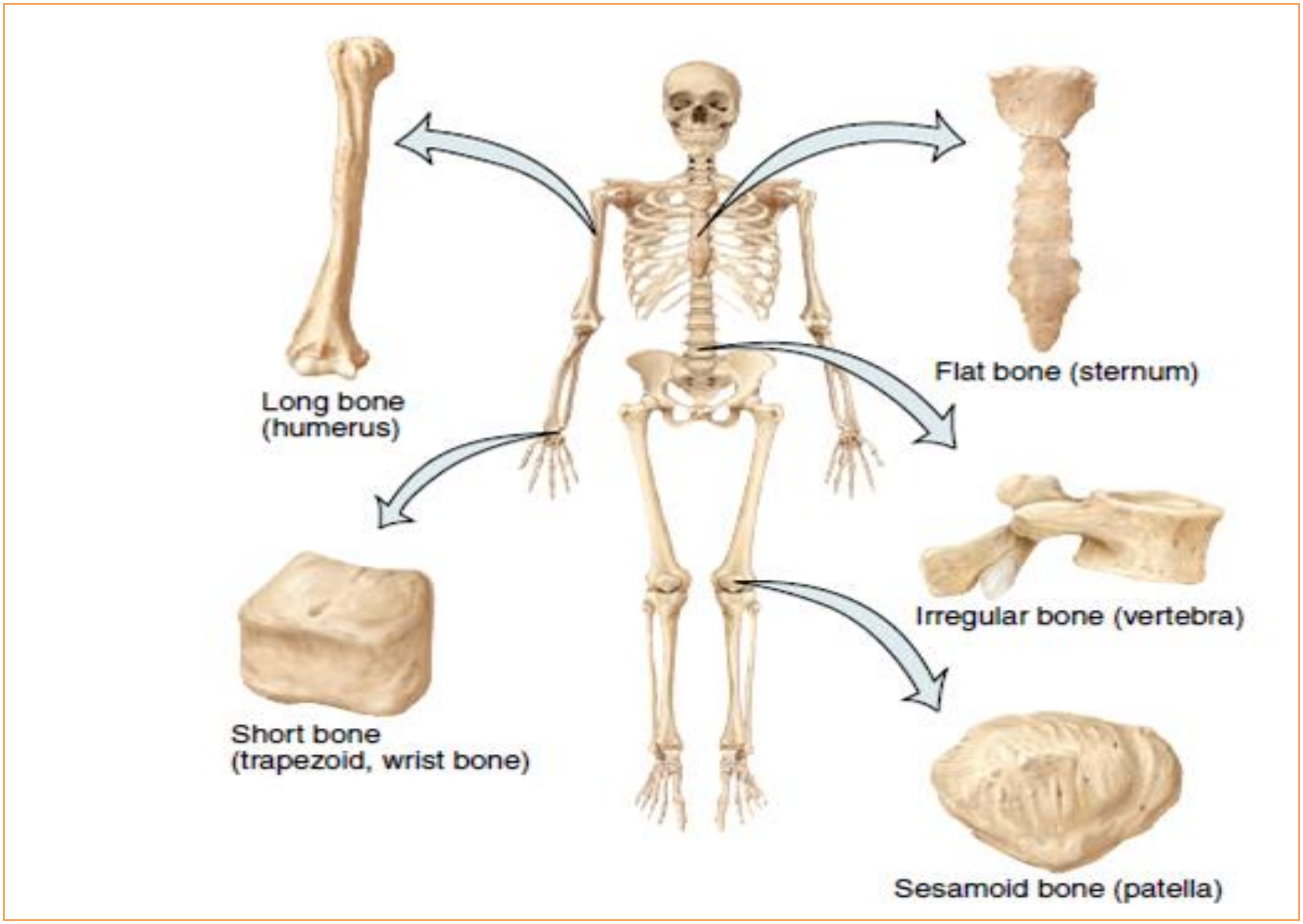
- Contain a central cavity, the **marrow cavity,** which houses the **bone marrow,** a hemopoietic organ. Bone marrow gives rise to blood cells and platelets (Hematopoiesis).

- Fat stored in marrow cavities.

COMPOSITION OF BONE:



Shape of bones

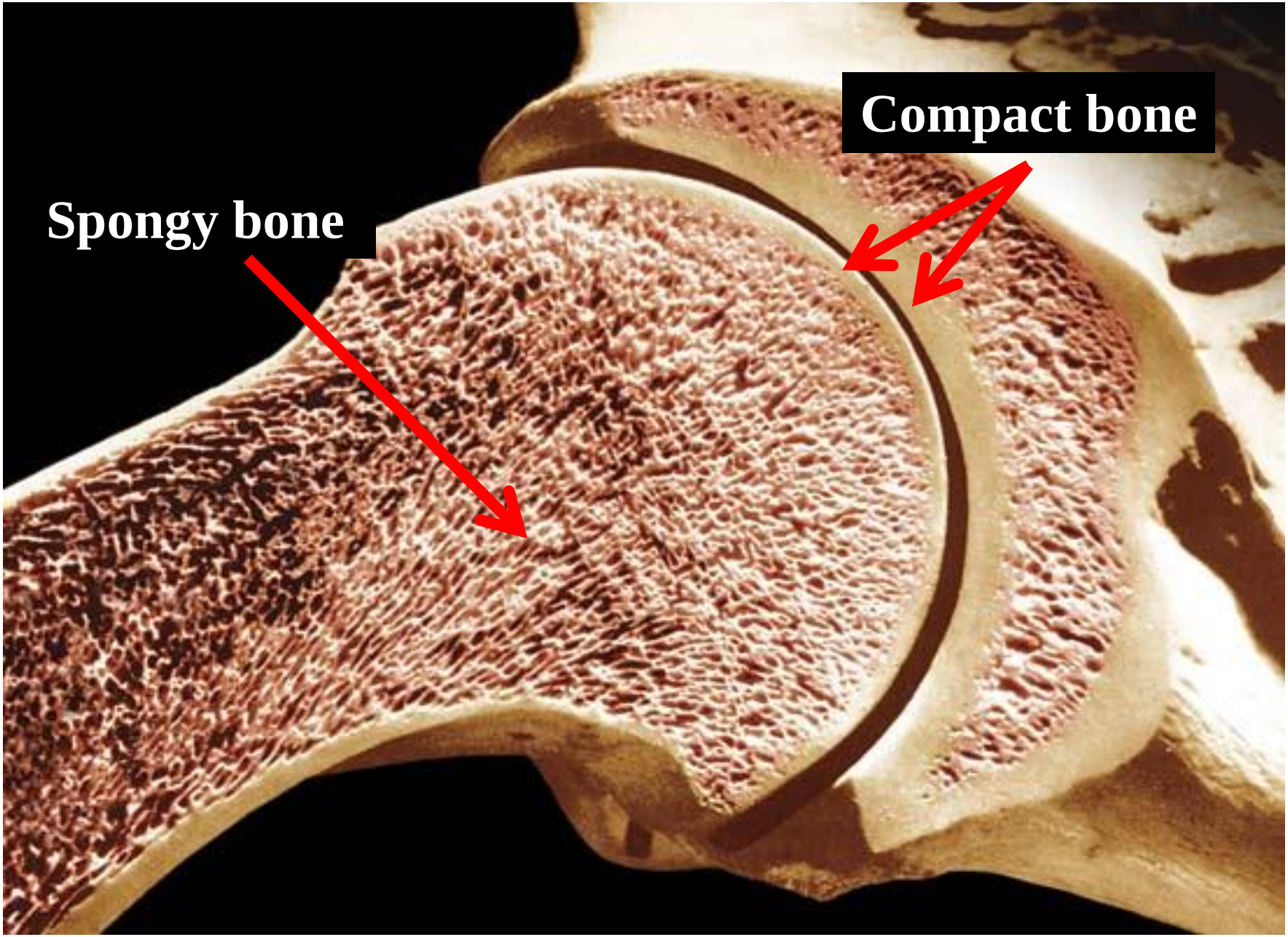


Types of bone

- **Gross observation** of a bone in cross section shows:

  Compact (cortical) bone: a dense area near the surface , which represent 80% of the total bone mass.

  Cancellous (trabecular or spongy) bone: deeper areas with numerous interconnecting cavities, consisting about 20 %of total bone mass.


Compact bone
Spongy bone

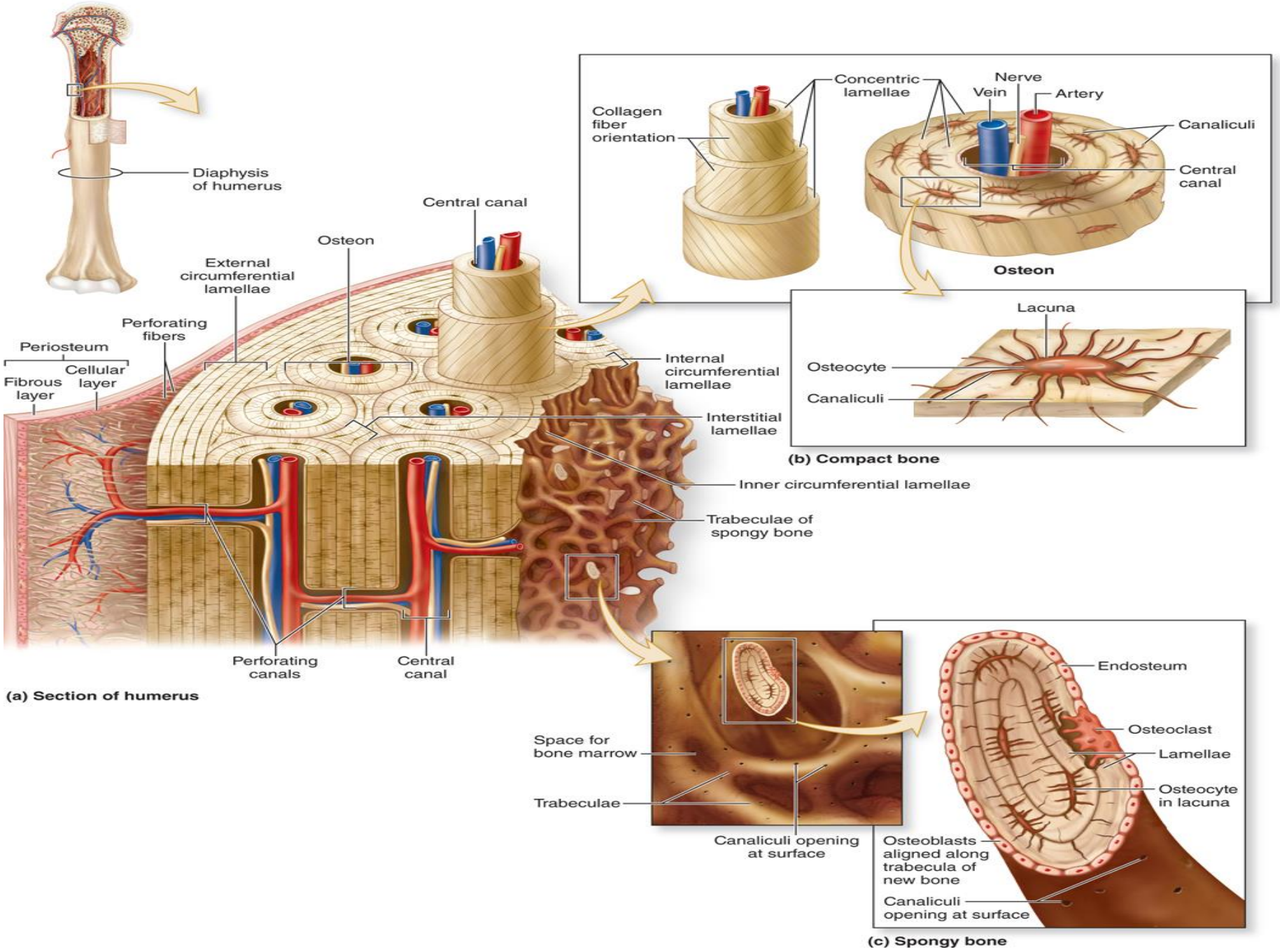
Compact (cortical) bone

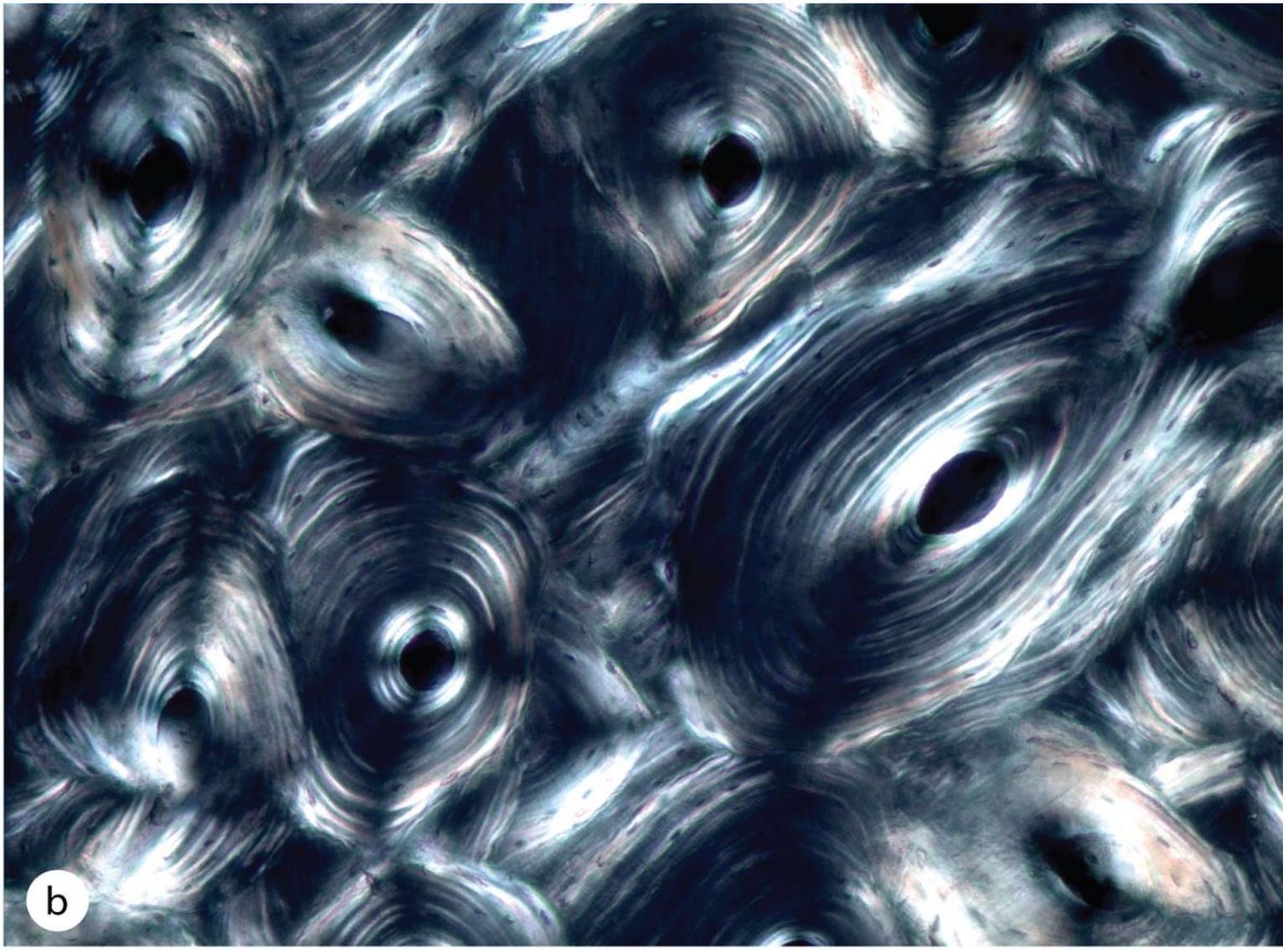
- An **osteon (or Haversian system**): is the complex of concentric lamella surrounding a small canal containing blood vessels, nerves, loose CT and lined by endosteum.

- Between successive lamellae are lacunae (each with one osteocyte).

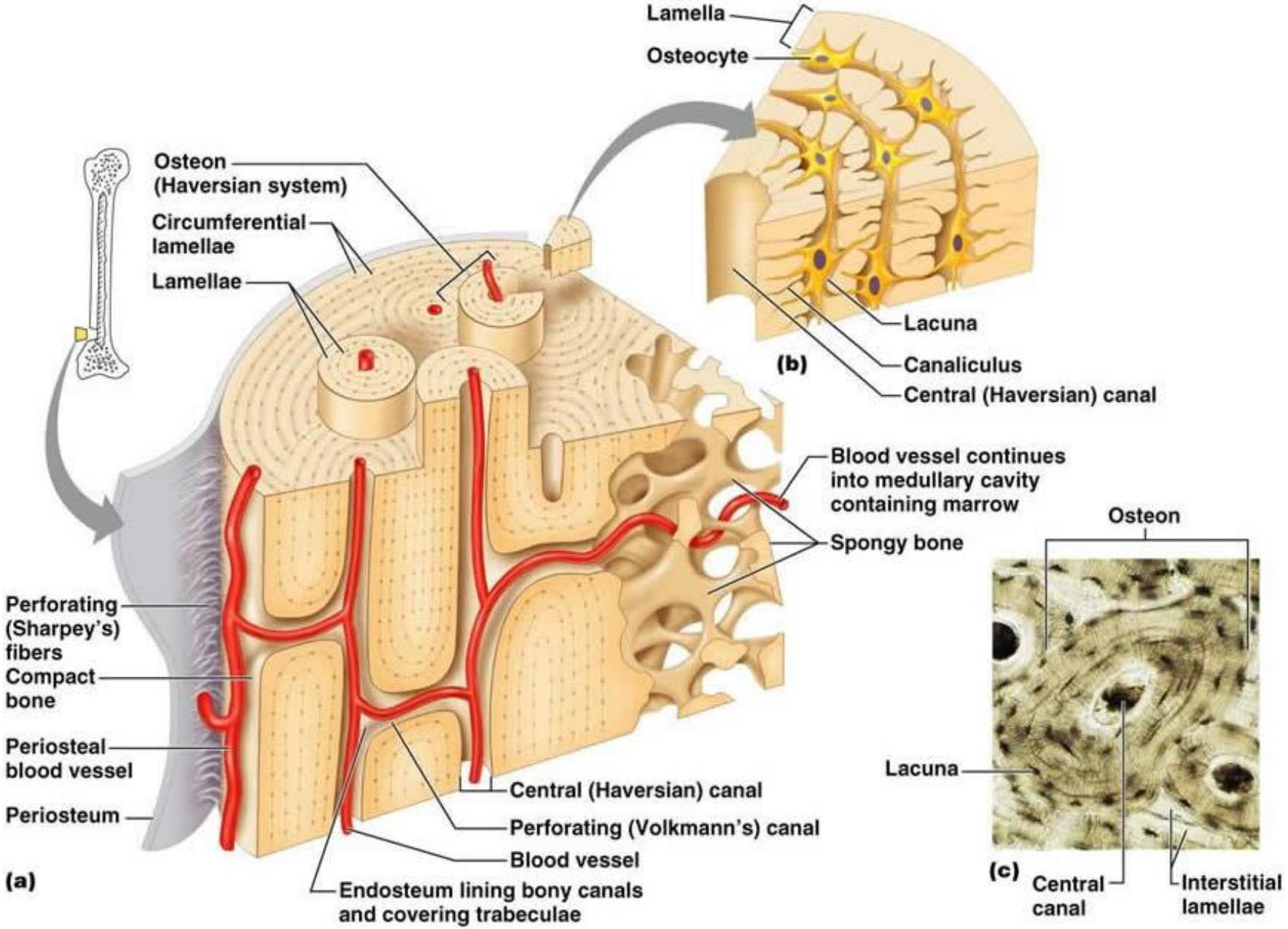
- The outer boundary of each osteon is called the **cement line.**

- The central canal communicate with the marrow cavity and the periosteum and with one another through transverse **Perforating canals (or** Volkmann's canal).


Diaphysis of humerus
Central canal
Osteon
External circumferential lamellae
Perforating fibers
Periosteum
Fibrous layer
Cellular layer
Internal circumferential lamellae
Interstitial lamellae
Inner circumferential lamellae
Trabeculae of spongy bone
Perforating canals
Central canal
(a) Section of humerus
Concentric lamellae
Collagen fiber orientation
Nerve
Vein
Artery
Canaliculi
Central canal
Osteon
Lacuna
Osteocyte
Canaliculi
(b) Compact bone
Space for bone marrow
Trabeculae
Canaliculi opening at surface
Endosteum
Osteoclast
Lamellae
Osteocyte in lacuna
Osteoblasts aligned along trabecula of new bone
Canaliculi opening at surface
(c) Spongy bone



Alternating bright and dark bands indicate that collagen fibers in successive lamellae have different orientations.

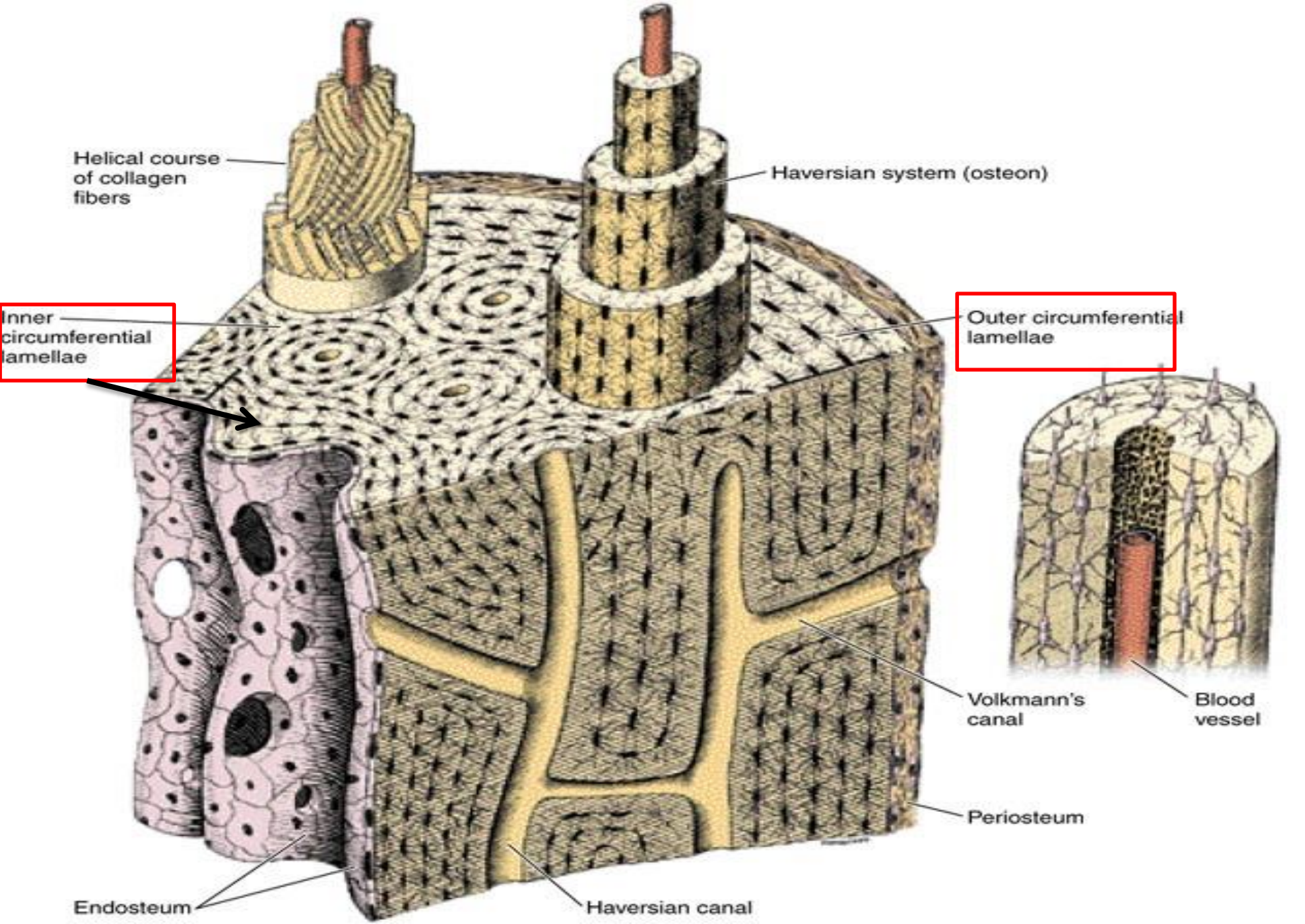

Lamella
Osteocyte
Osteon
(Haversian system)
Circumferential
lamellae
Lamellae
Lacuna
(b)
Canaliculus
Central (Haversian) canal
Blood vessel continues
into medullary cavity
containing marrow
Spongy bone
Perforating
(Sharpey's)
fibers
Compact
bone
Periosteal
blood vessel
Periosteum
Central (Haversian) canal
Perforating (Volkmann's) canal
Blood vessel
Endosteum lining bony canals
and covering trabeculae
(a)
Osteon
Lacuna
(c)
Central
canal
Interstitial
lamellae

Types of lamella:

- **Concentric:**
- **Interstitial**:

- Scattered among the intact osteon.
- Are numerous irregularly shaped groups of parallel lamellae.
- Are lamellae remaining from osteons partially destroyed by osteoclasts during growth and remodeling of bone.

- **Outer circumferential:** located immediately beneath the periosteum.
- **Inner circumferential:** located around the marrow cavity.


Helical course of collagen fibers
Haversian system (osteon)
Inner circumferential lamellae
Outer circumferential lamellae
Volkmann's canal
Blood vessel
Periosteum
Endosteum
Haversian canal

BONE MATRIX

- Inorganic and organic constituents:

Inorganic Component:

- About 67 % of dry weight.
- Composed mostly of calcium and phosphorus, Crystals of calcium hydroxyapatite $[Ca_{10}(PO_4)_6(OH)_2]$.
- Bicarbonate, citrate, magnesium, potassium and sodium ions are also found.

- Surface ions are hydrated ⇨hydration shell.
  - Facilitates fluid exchange

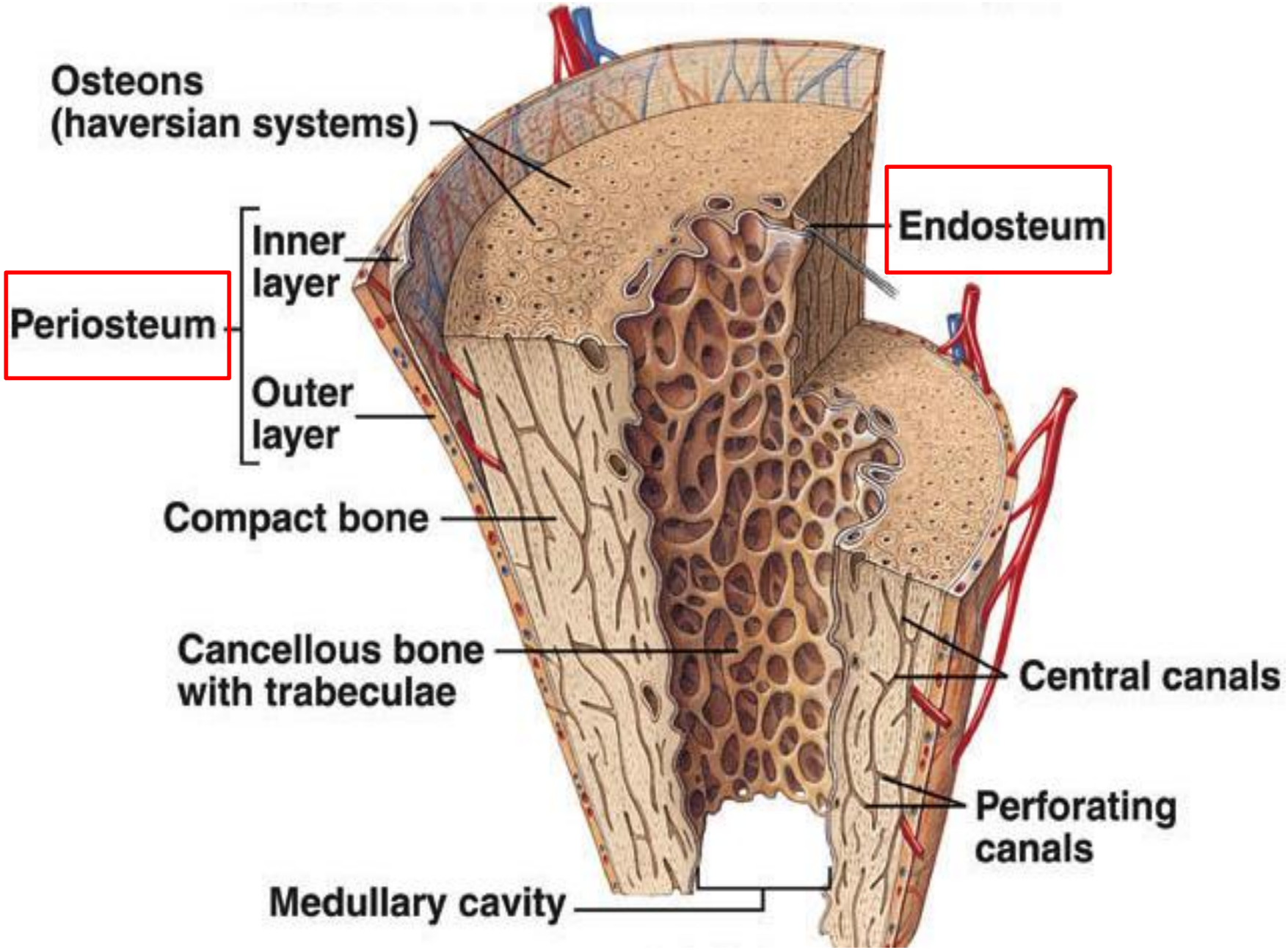
Organic Component:

- About 33% of dry weight.
- Embedded in the calcified matrix.
- Predominantly type I collagen.
- Proteoglycan aggregates.
- Bone specific multiadhesive glycoproteins such as **osteonectin.**
- Calcium –binding glycoproteins , **osteocalcin**.

PERIOSTEUM & ENDOSTEUM

- Surfaces of bone are covered by tissue layers with bone forming cells.

- External surfaces: **Periosteum.**
- Internal surfaces: **Endosteum.**
- **Functions:**
  - Nutrition of bone.
  - Continuous supplying of osteoblasts from progenitor cells for bone growth or repair.


Osteons
(haversian systems)
Endosteum
Periosteum
Inner
layer
Outer
layer
Compact bone
Cancellous bone
with trabeculae
Central canals
Perforating
canals
Medullary cavity

PERIOSTEUM

- Is organized much like the perichondrium.
- **Outer layer:**
  - Is dense connective tissue, with small blood vessels, collagen bundles and fibroblasts.
  - Some bundles penetrate through bone matrix binding the periosteium to bone, called **Perforating (Sharpey's) fibers**.
- **Inner layer:**
  - Is a cellular contains bone lining cells, osteoblast and **osteoprogenitor cells.**

ENDOSTEUM

- Lines the internal cavity of the bone.
- Covers small trabeculae of bone matrix that project into marrow cavities.
- Thinner than the periosteum.
- Composed of a single layer of flat osteoprogenitor cells and osteoblasts.

TECHNIQUE OF PREPARATION

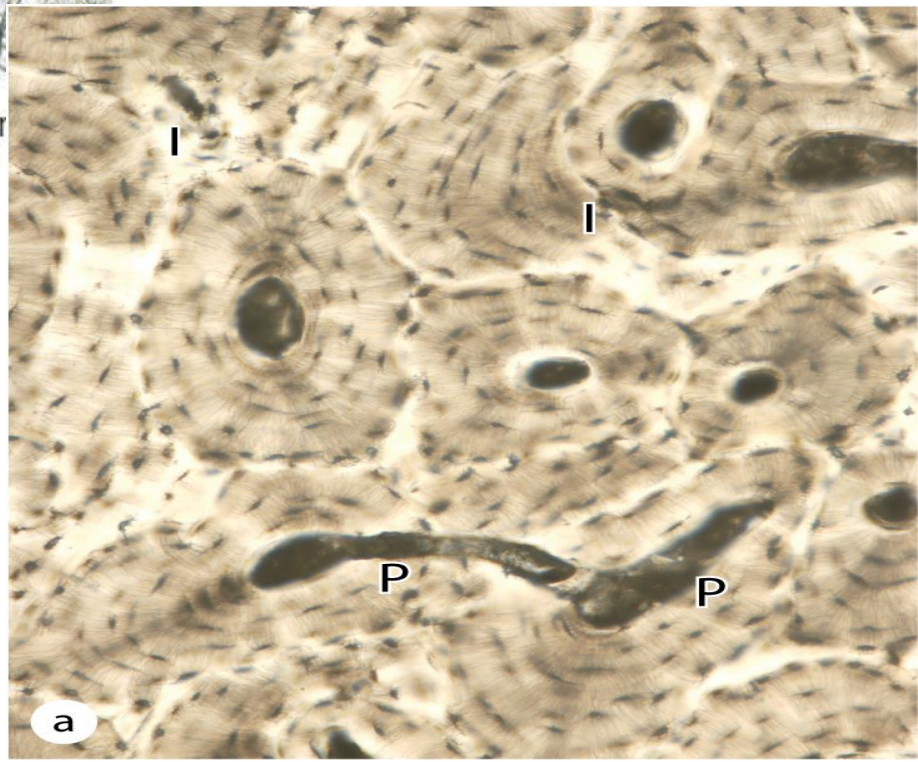
- **Ground bone:**
- **Decalcified bone :**

  Because of its hardness, bone cannot be sectioned routinely. Bone matrix is softened by immersion in a decalcifying solution before paraffin embedding.

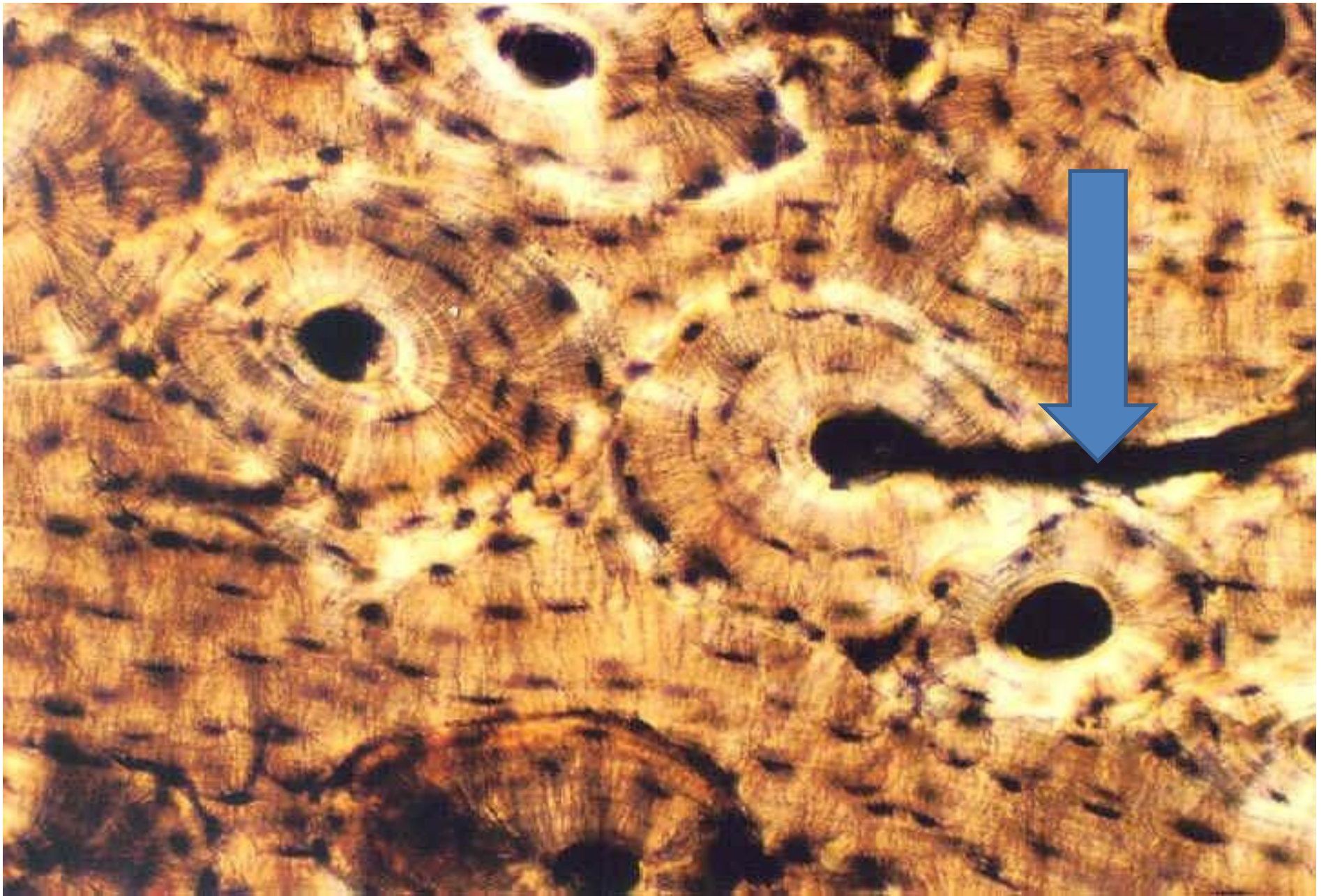
Ground bone

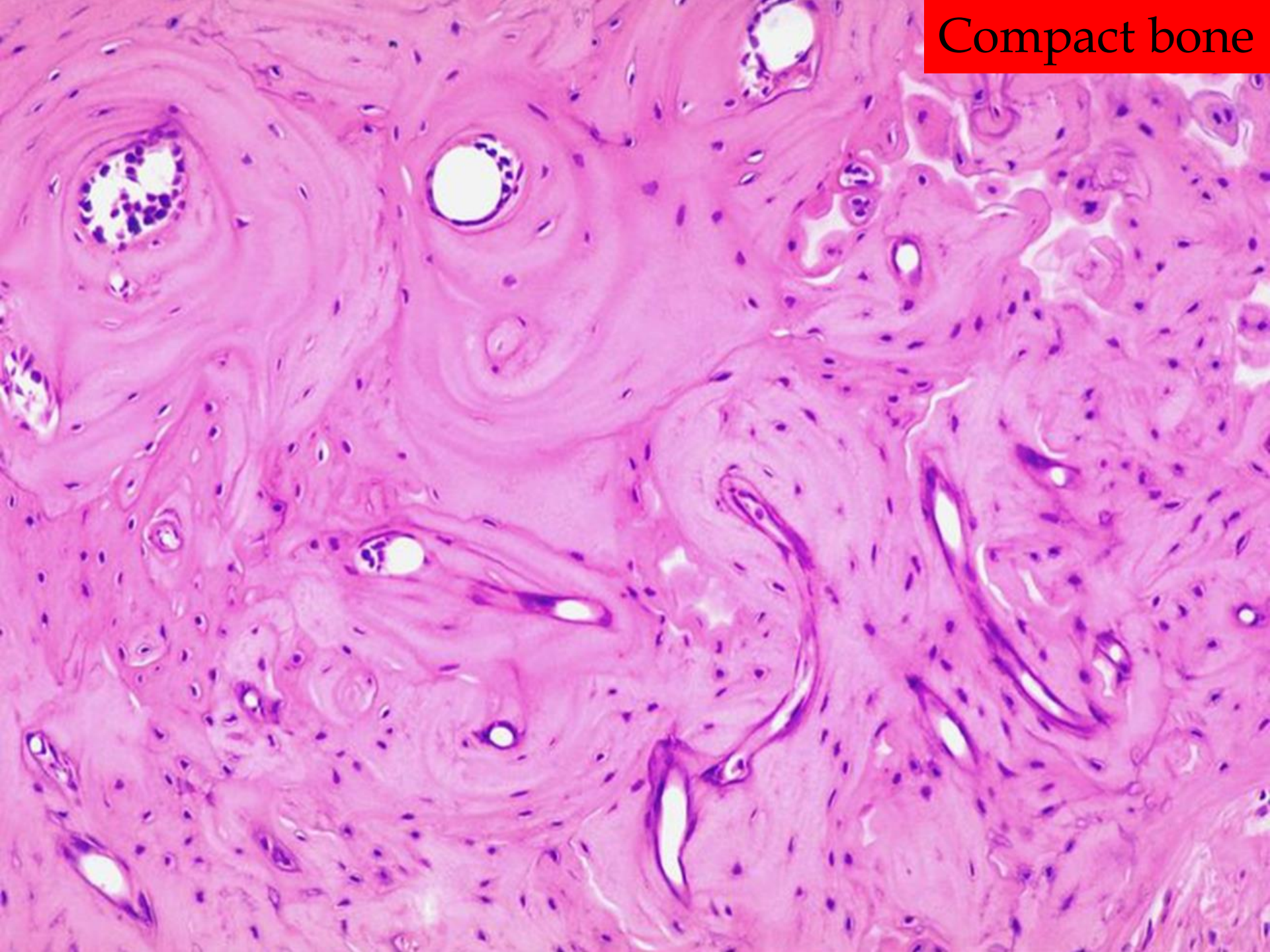
Decalcified bone

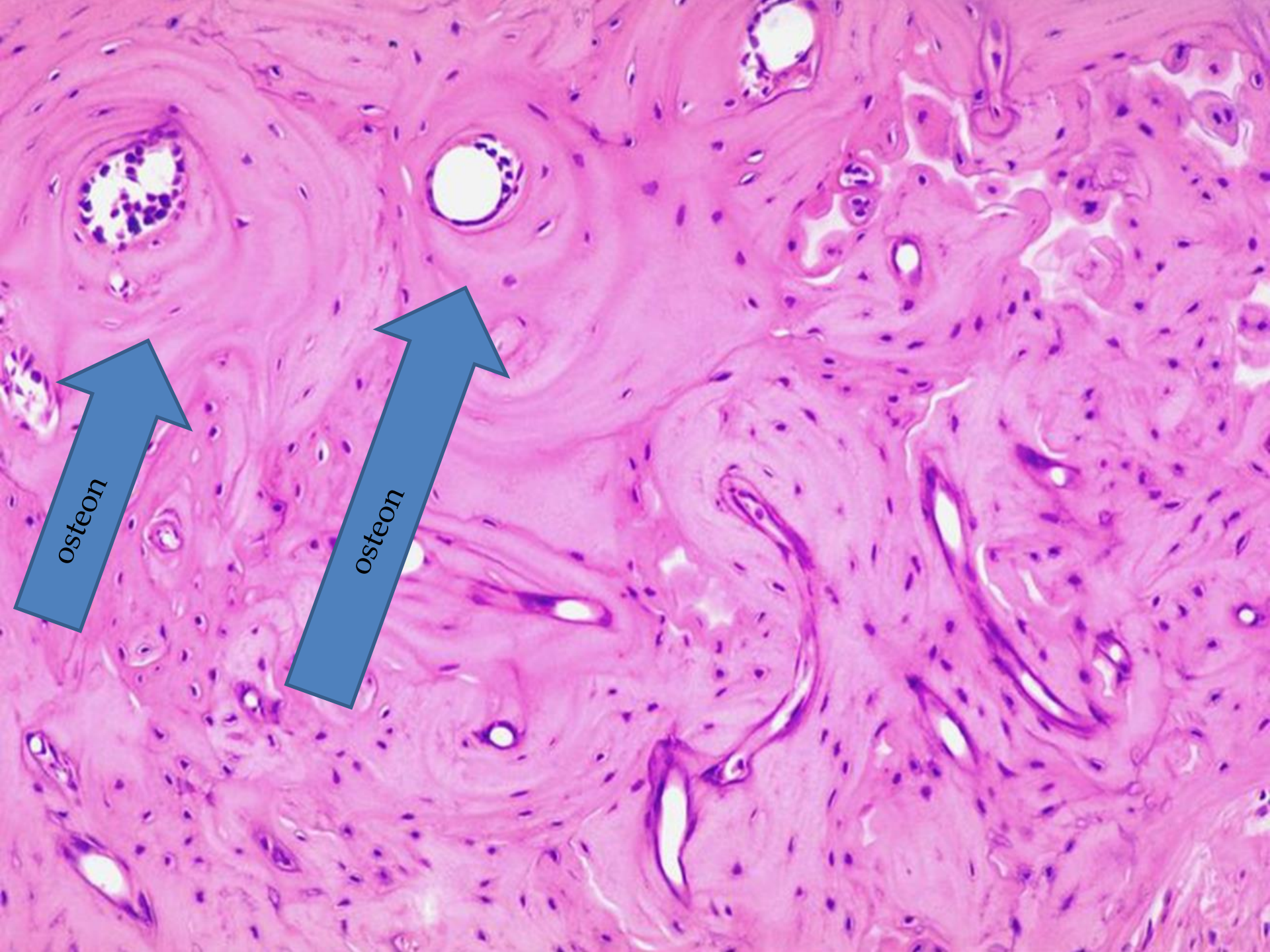
FIGURE 4.19 ■ Dry, compact bone: an osteon, transverse section. High r



VOLKMANN'S CANAL

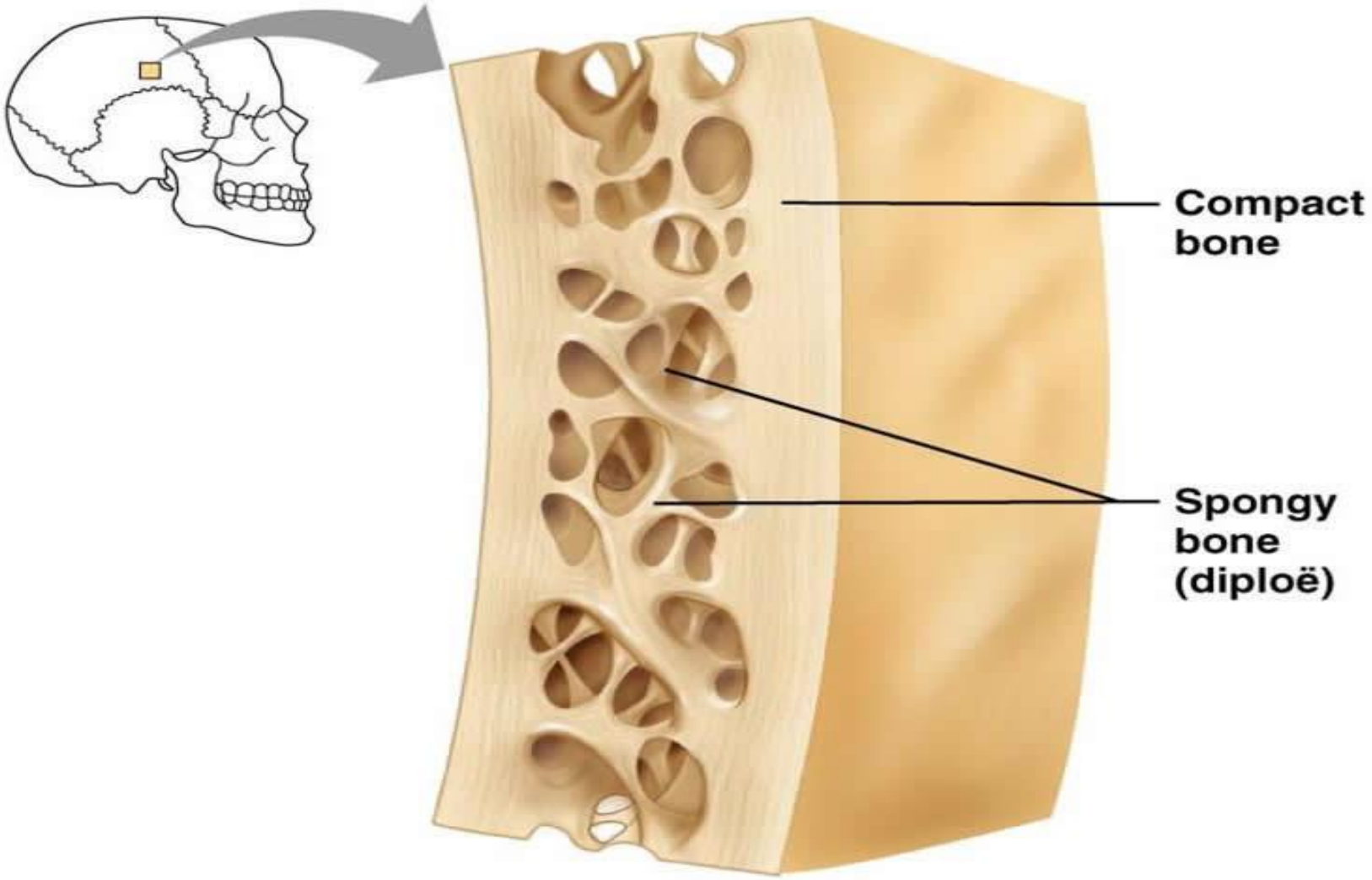


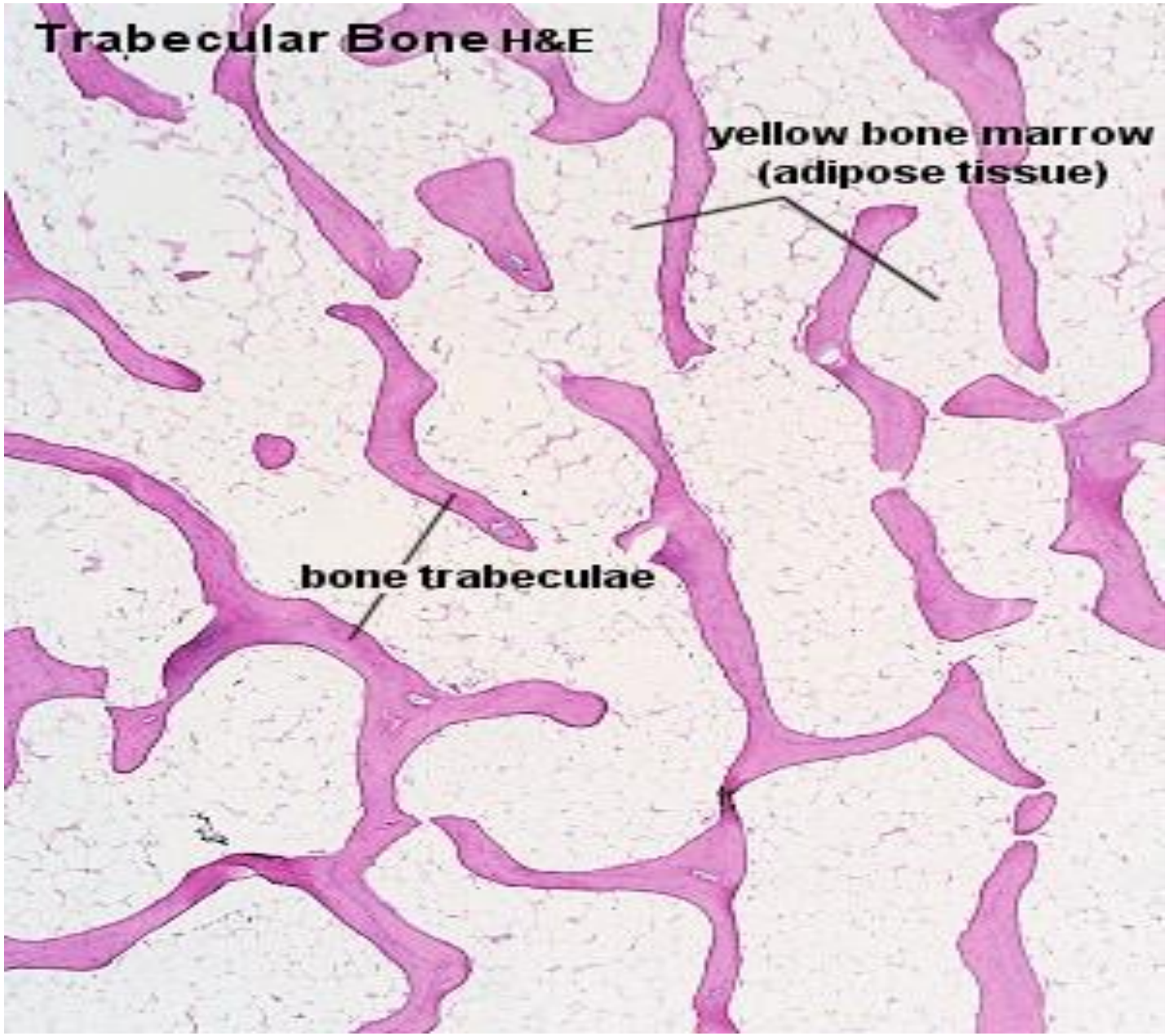

Compact bone

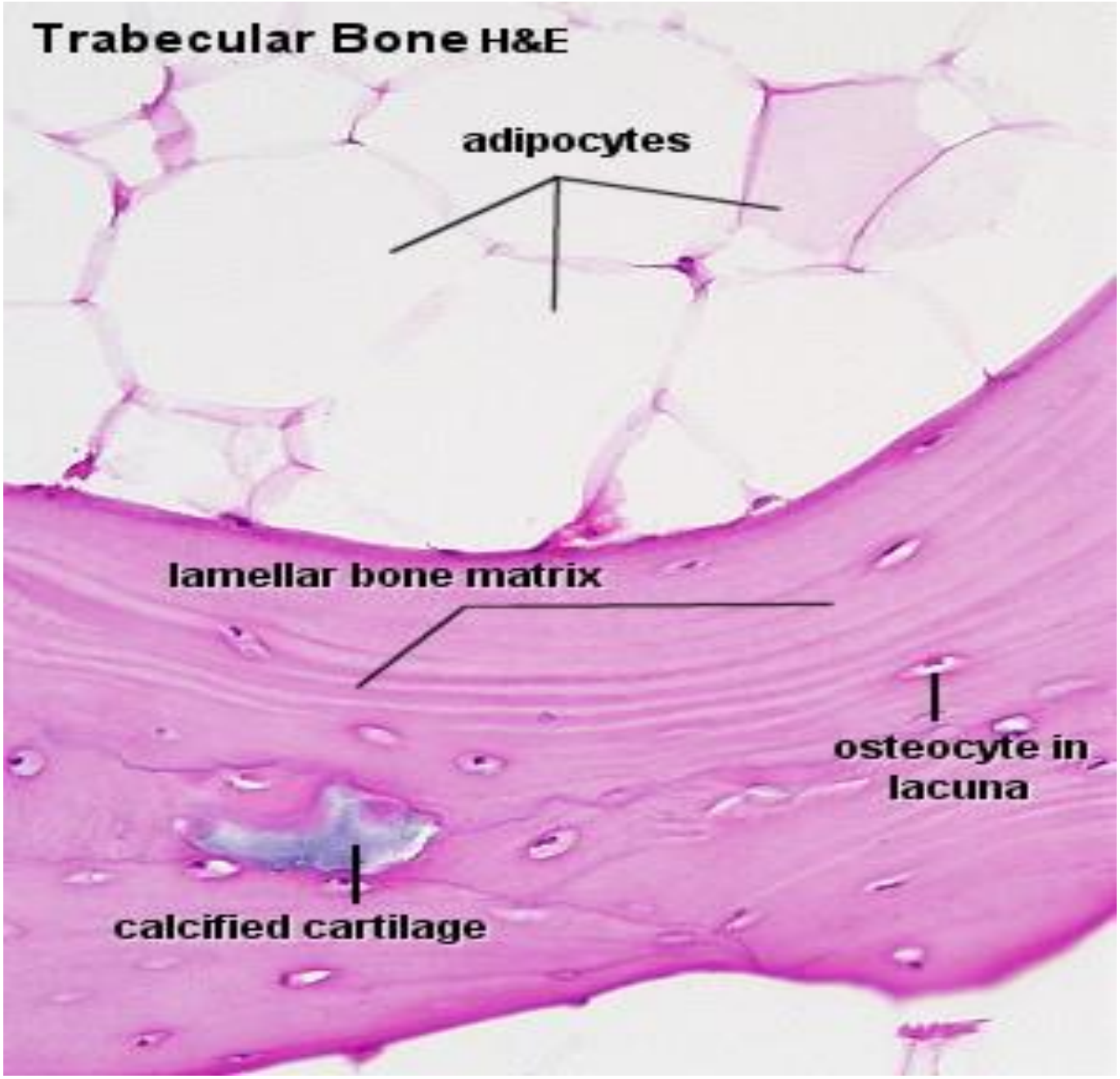

osteon
osteon

Cancellous
(trabecular or spongy) bone

Flat bone

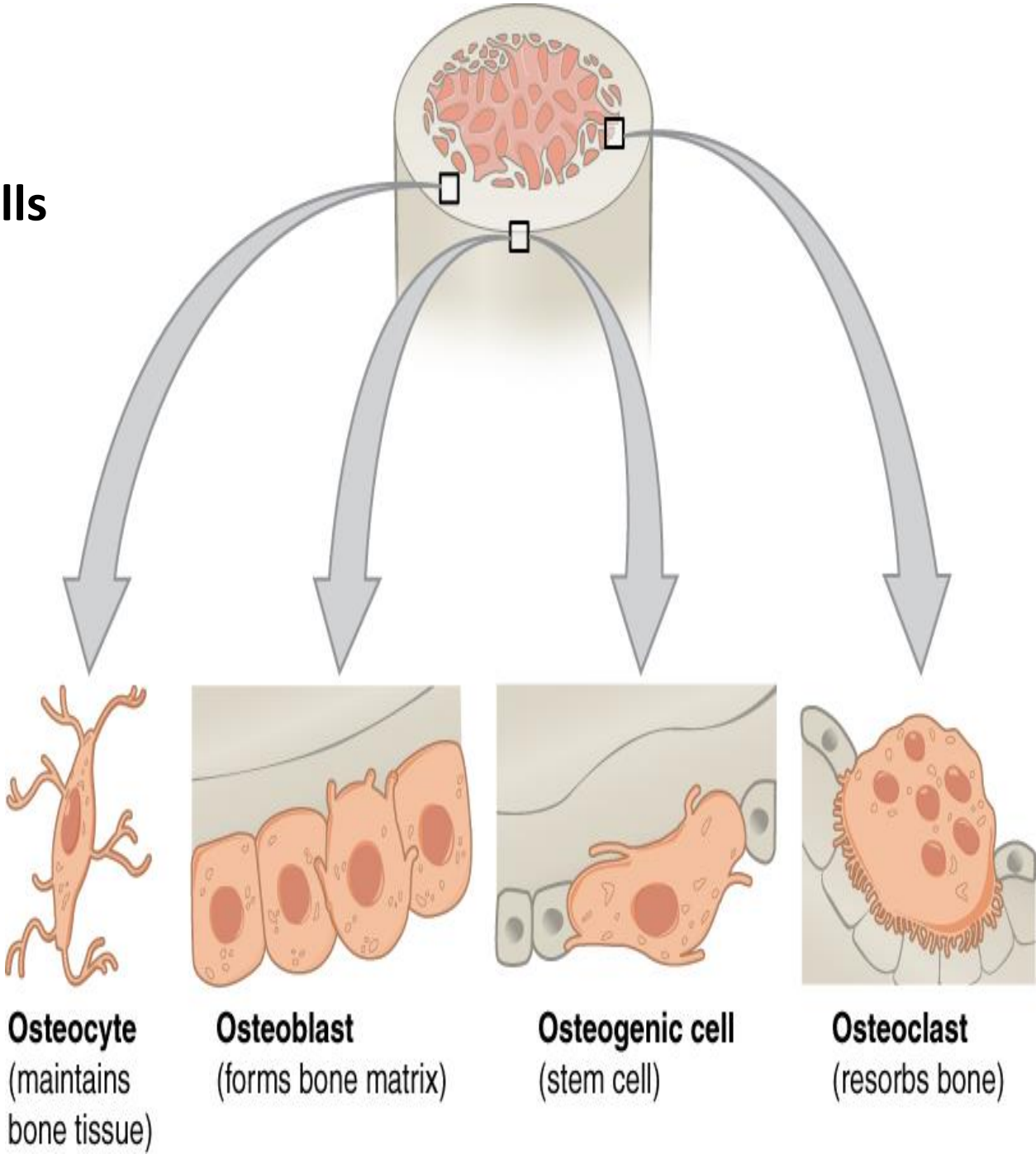



Trabecular Bone H&E
yellow bone marrow
(adipose tissue)
bone trabeculae


Trabecular Bone H&E
adipocytes
lamellar bone matrix
osteocyte in lacuna
calcified cartilage

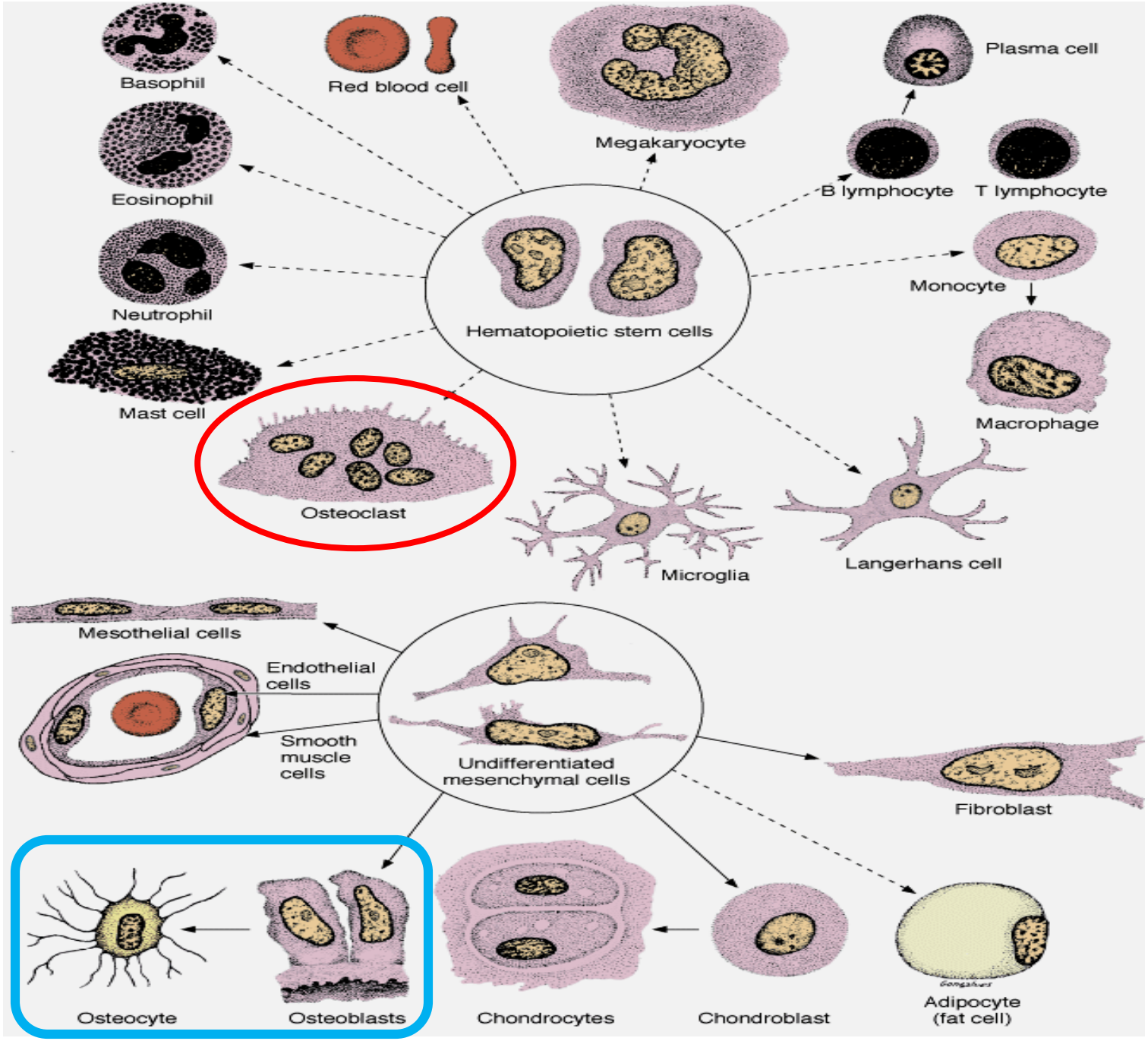
Cells of Bone

- **Osteoprogenitor cells**
- **Osteoblasts**
- **Osteocytes**
- **Osteoclasts**



Osteoprogenitor Cells

- Derived from **embryonic mesenchymal cells**
- Located in the inner cellular layer of the periosteum and in the endosteum.
- Have the potential to differentiate into osteoblasts.


Basophil
Red blood cell
Megakaryocyte
Plasma cell
Eosinophil
B lymphocyte
T lymphocyte
Neutrophil
Hematopoietic stem cells
Monocyte
Mast cell
Macrophage
Osteoclast
Microglia
Langerhans cell
Mesothelial cells
Endothelial cells
Smooth muscle cells
Undifferentiated mesenchymal cells
Fibroblast
Osteocyte
Osteoblasts
Chondrocytes
Chondroblast
Adipocyte (fat cell)

OSTEOBLASTS

- Responsible for synthesis of the organic components of the matrix.
- Deposition of inorganic components also depends on osteoblasts.
- When **active**, appear cuboidal-columnar, typical protein synthesizing cells.
- **Inactive** osteoblasts are flat cells that cover the bone surface. These cells resemble **bone lining cells** in both the endosteum and periosteum.
- Secrete alkaline phosphatase (ALP) and osteocalcin, their circulating levels are used clinically as markers of osteoblast activity.

- **The osteoblast is also responsible for the calcification of bone matrix**.

  The calcification process appears to be initiated by the osteoblast through the secretion into the matrix the noncollagen proteins (small, vitamin k-dependent poly peptide) **osteocalcin.**

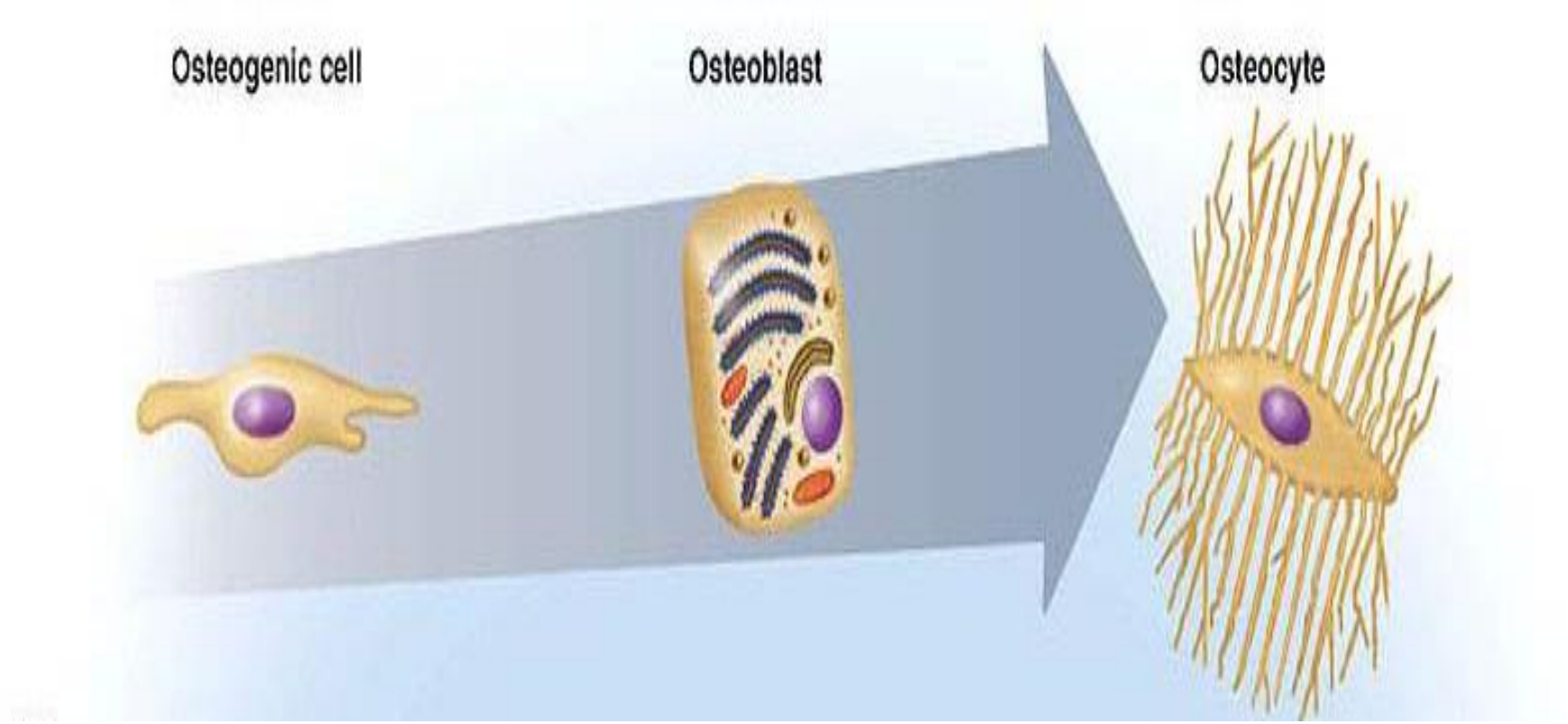
  Small, membrane-limited matrix vesicles are rich in ALP and are actively secreted by osteoblast only during the period in which the cell produces the bone matrix.

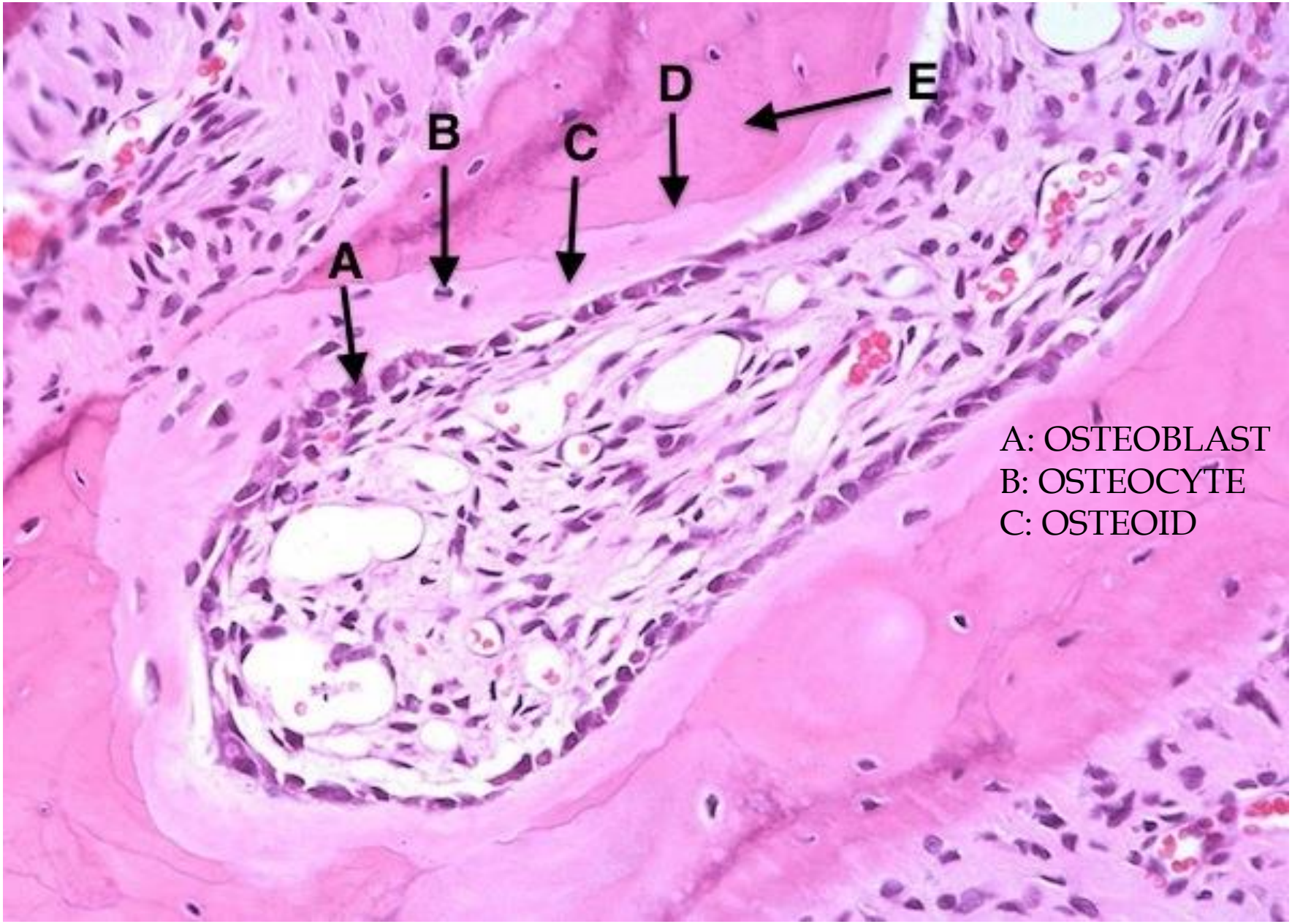
- The newly deposited matrix is not immediately calcified. It stains lightly or not at all compared with the mature mineralized matrix, which stains heavily with eosin.

- Because of this staining property of the newly formed matrix, osteoblasts appear to be separated from the bone by a light band.

- This band represents the **osteoid**, the nonmineralized matrix, between the osteoblast layer and the preexisting bone surface

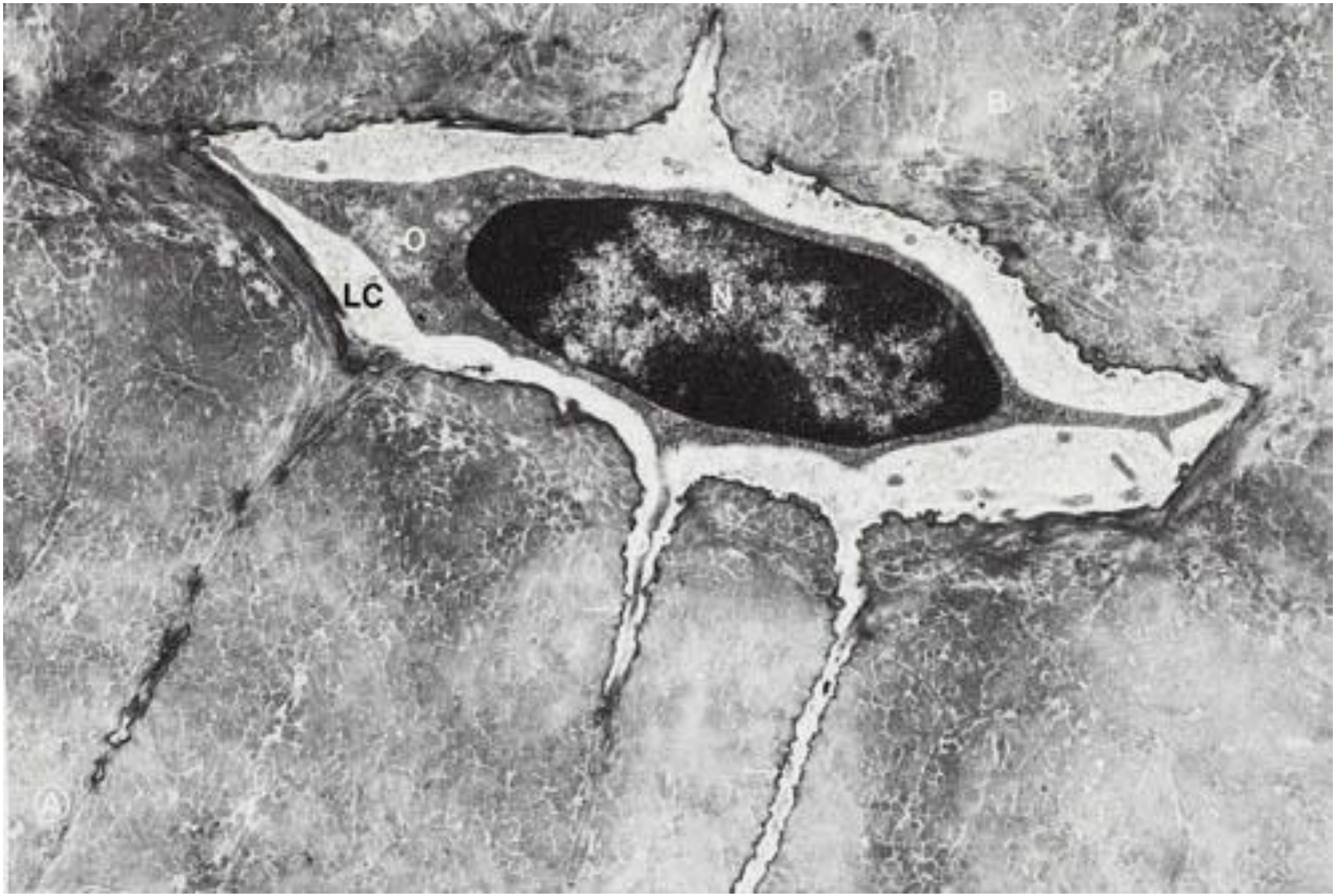
- Osteoblast ⇨ Osteocyte




A
B
C
D
E
A: OSTEOBLAST
B: OSTEOCYTE
C: OSTEOID

OSTEOCYTES

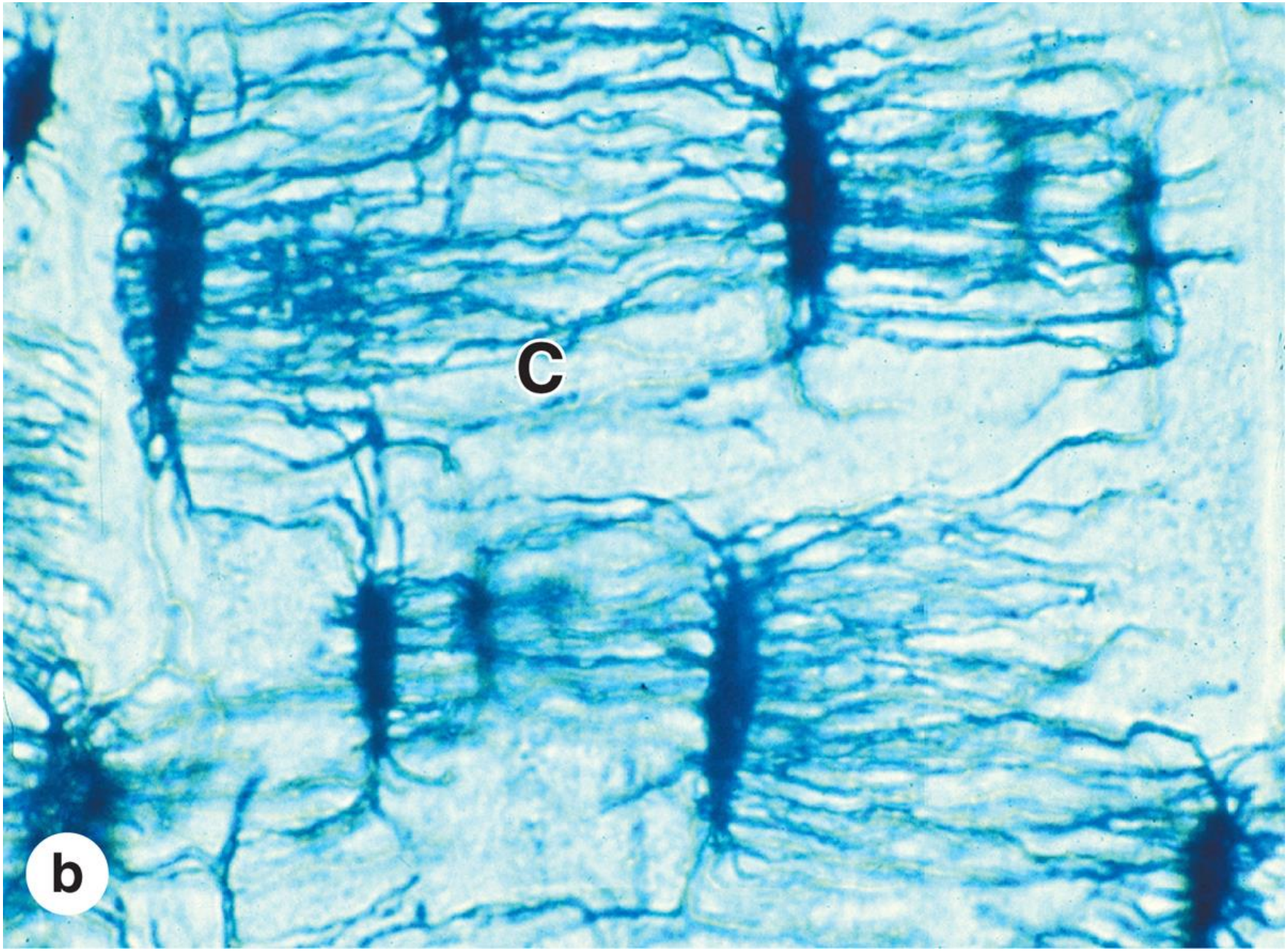
- Mature bone cells derived from osteoblasts that became trapped in their lacunae.
- Situated inside lacuna, one cell in each lacuna.
- Smaller than osteoblasts, almond shaped, with fewer RER, smaller Golgi complexes and more condensed nuclear chromatin.


LC
O
N

OSTEOCYTES

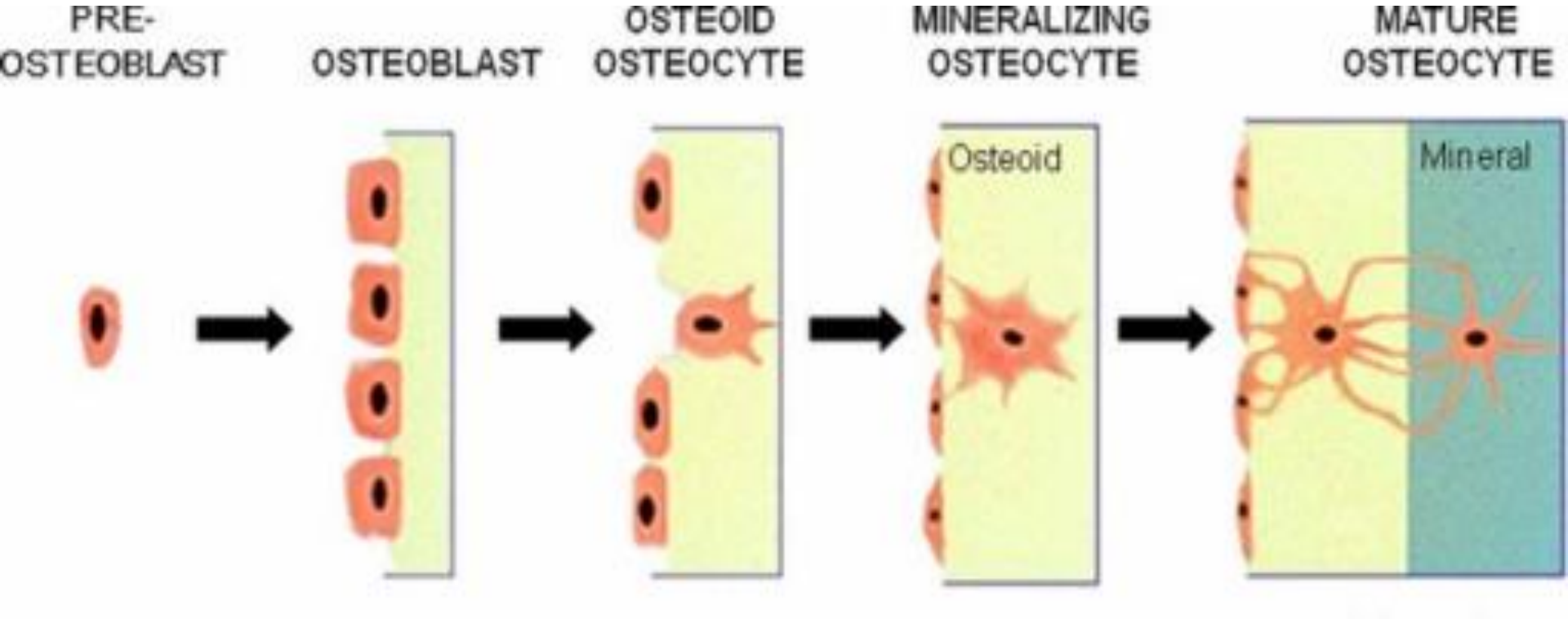
- Radiating out in all directions from the lacuna are narrow, tunnel-like spaces **(canaliculi)** that contain cytoplasmic processes of the osteocyte.

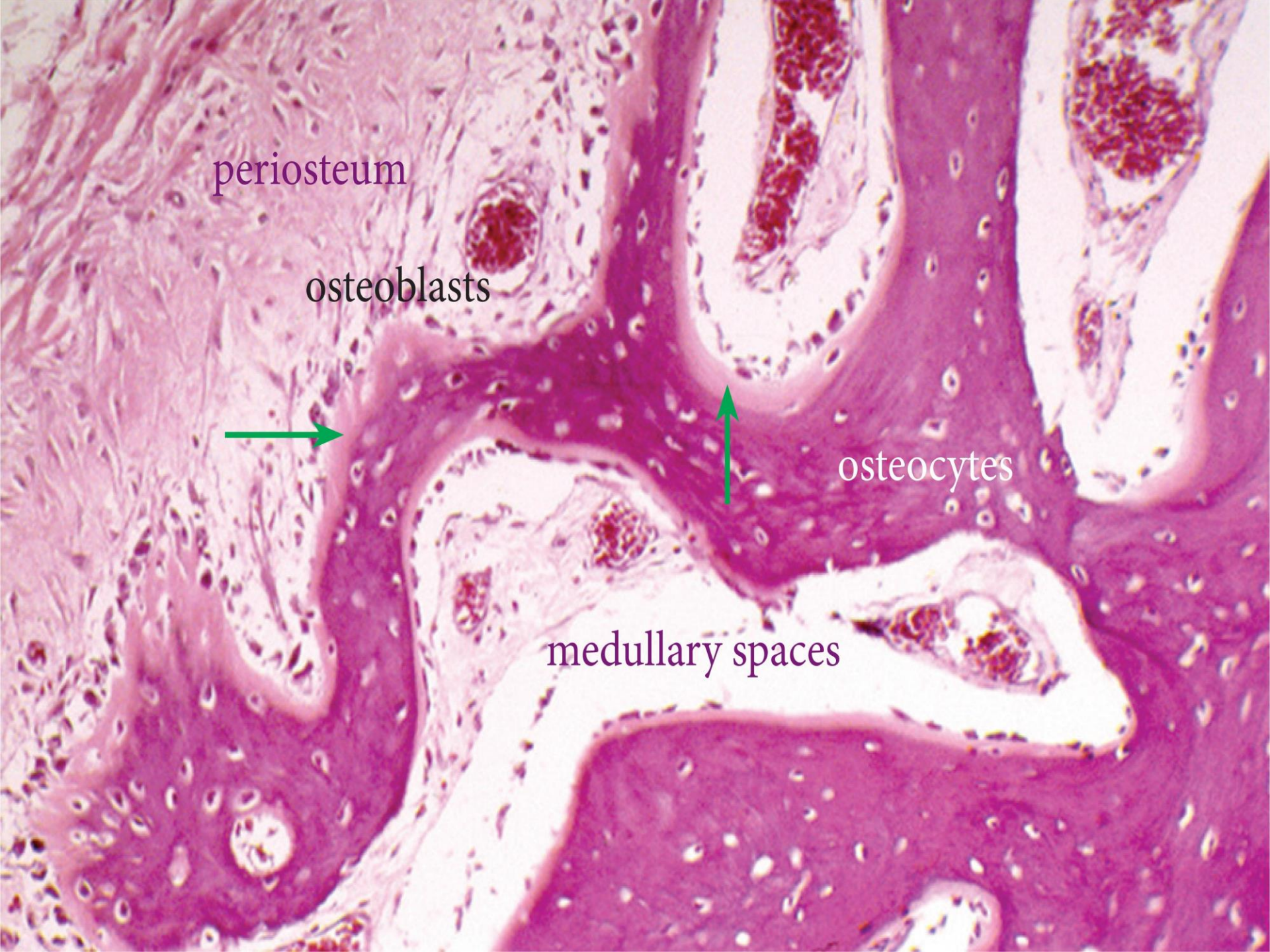
- Processes make contact with similar processes of neighboring osteocytes, forming **gap junctions** through which ions and small molecules can move between the cells.

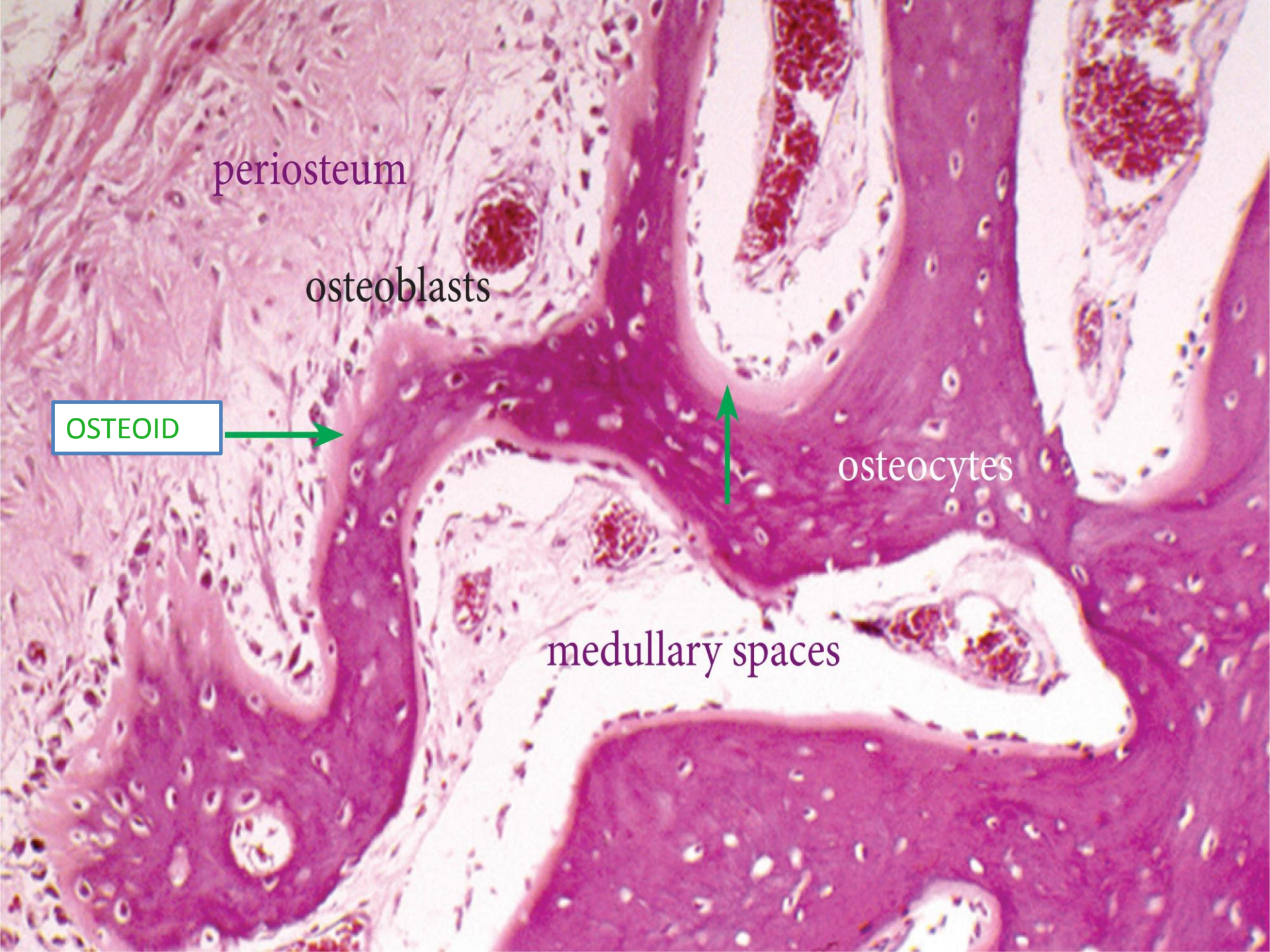

C
b

- Canaliculi also contain extracellular fluid carrying nutrients and metabolites that nourish the osteocytes.

- **Osteocytes actively involved in maintenance of matrix.**

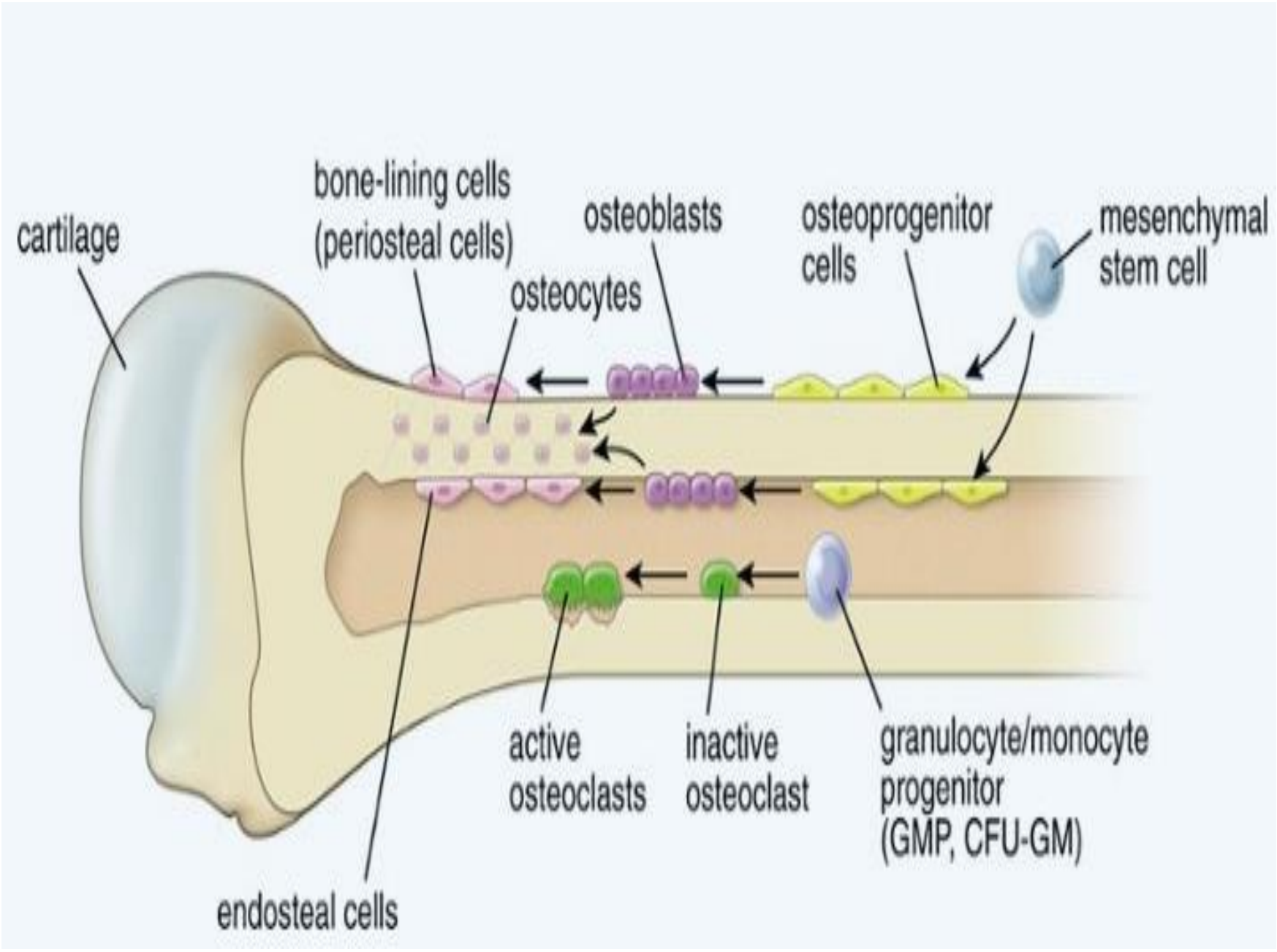

PRE-
OSTEOBLAST
OSTEOBLAST
OSTEOID
OSTEOCYTE
MINERALIZING
OSTEOCYTE
MATURE
OSTEOCYTE
Osteoid
Mineral

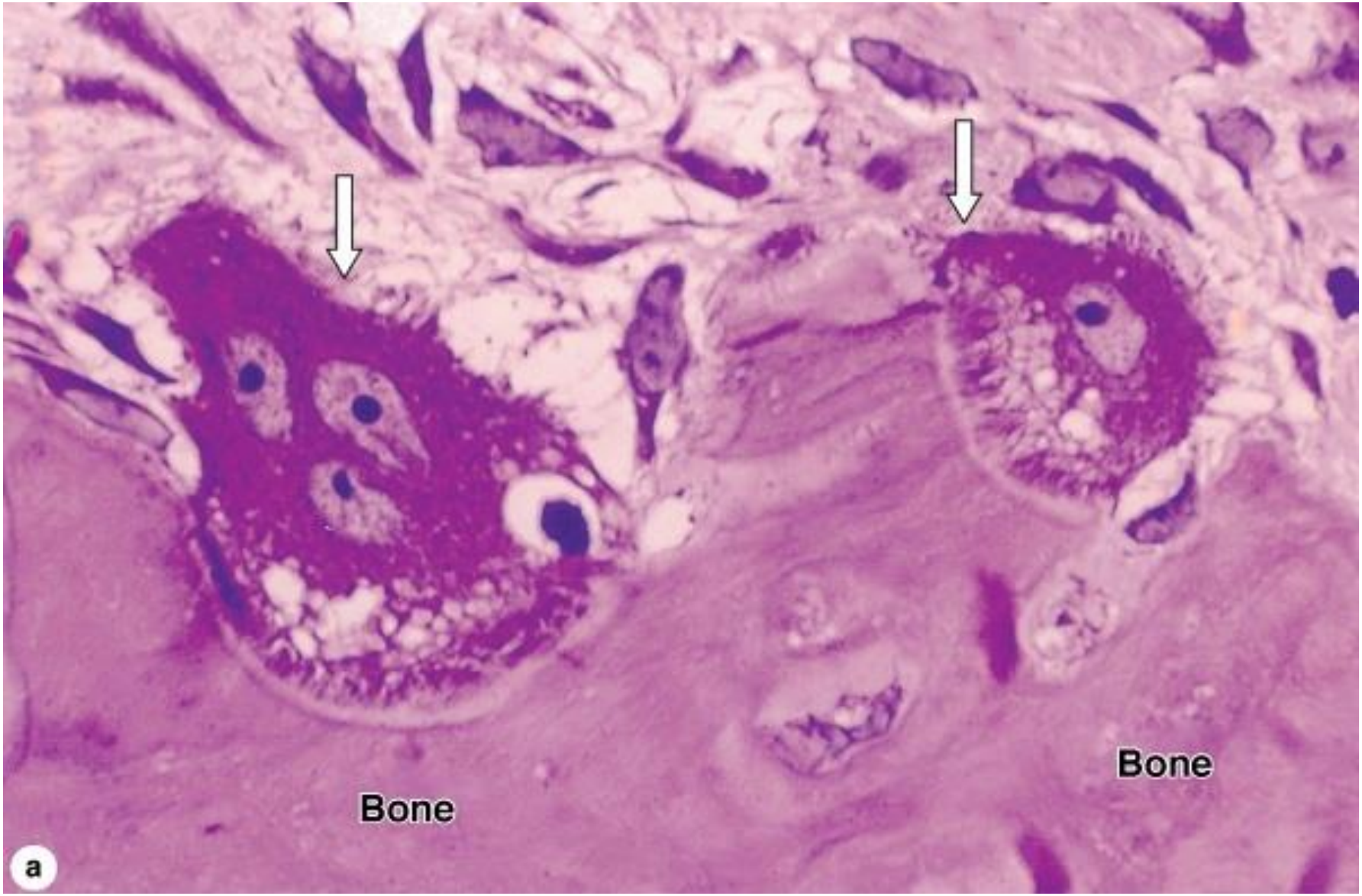

periosteum
osteoblasts
osteocytes
medullary spaces


periosteum
osteoblasts
OSTEOID
osteocytes
medullary spaces

OSTEOCLASTS

- Multinucleated cells originating from fusion of monocytes.
- Large, branched motile cells.
- Play a role in bone resorption and remodeling.
- Occupy shallow depressions, called **Howship's lacunae,** that identify regions of bone resorption.


cartilage
bone-lining cells
(periosteal cells)
osteoblasts
osteoprogenitor
cells
mesenchymal
stem cell
osteocytes
active
osteoclasts
inactive
osteoclast
granulocyte/monocyte
progenitor
(GMP, CFU-GM)
endosteal cells


Bone
Bone
a

- Osteoclast activity is controlled by local signaling factors and hormones:

- Osteoclasts have receptors for:

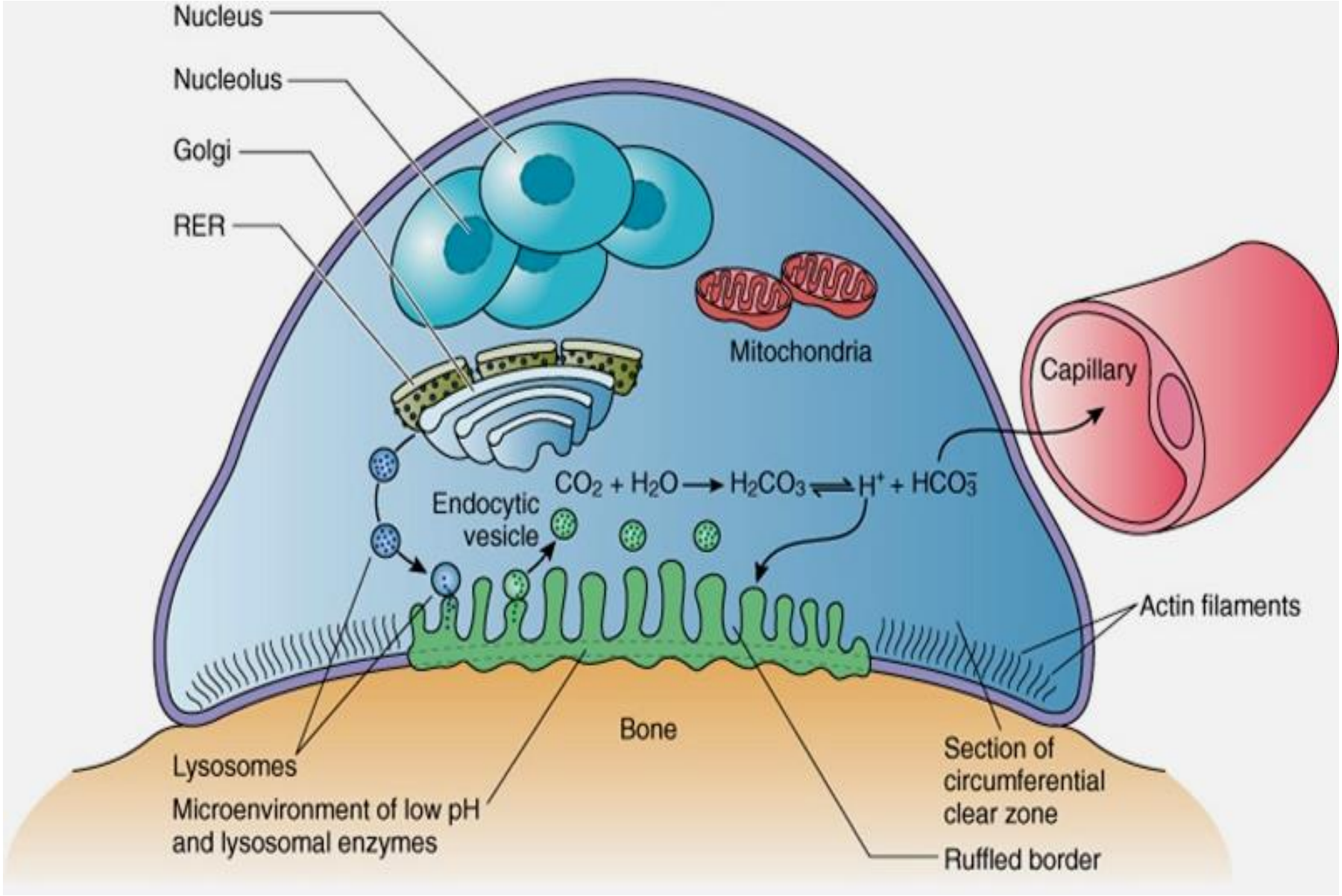
  Calcitonin, a thyroid hormone.

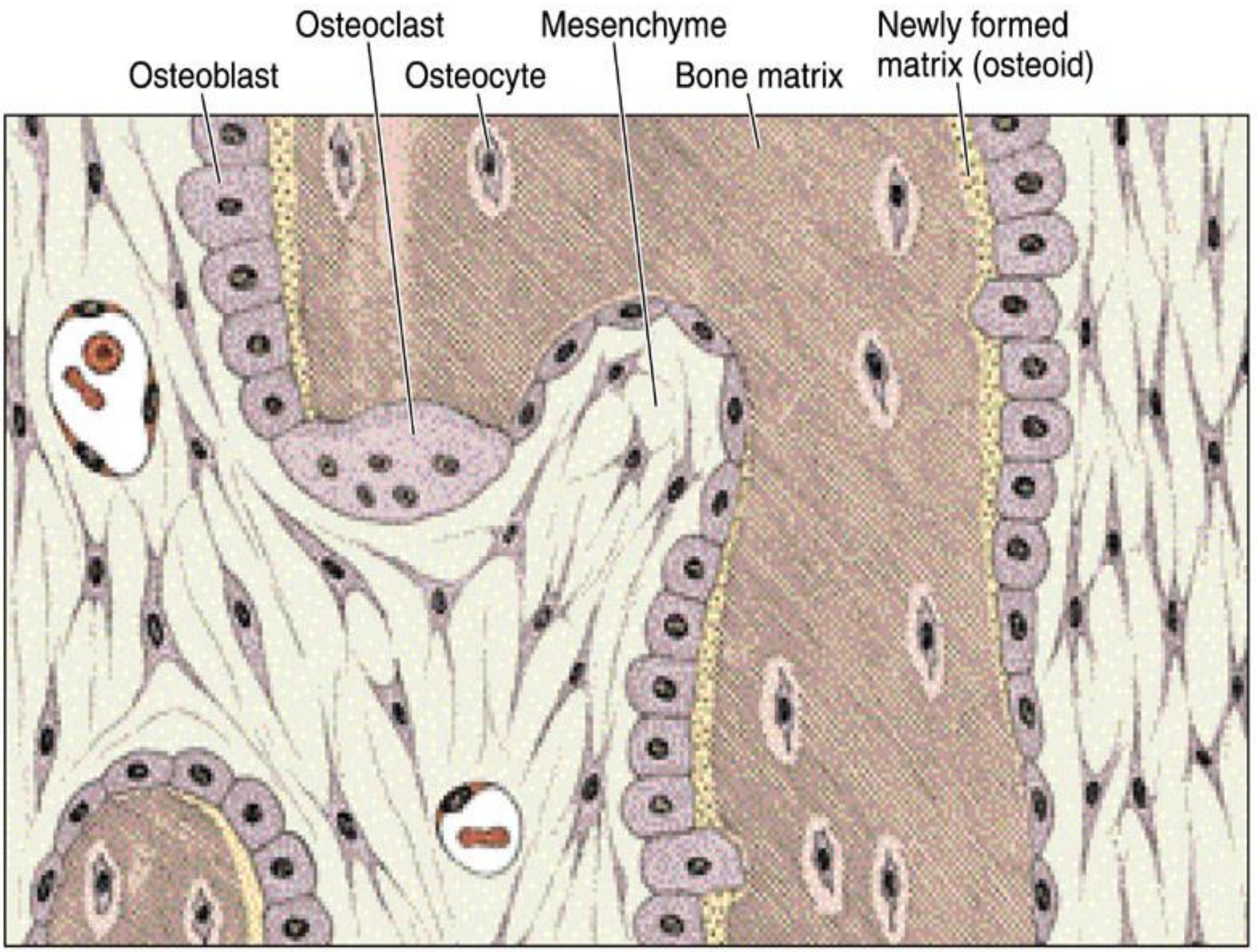
- Osteoblasts activated by parathyroid hormone (PTH) produce M-CSF, RANKL, and other factors that regulate the formation and activity of osteoclasts.

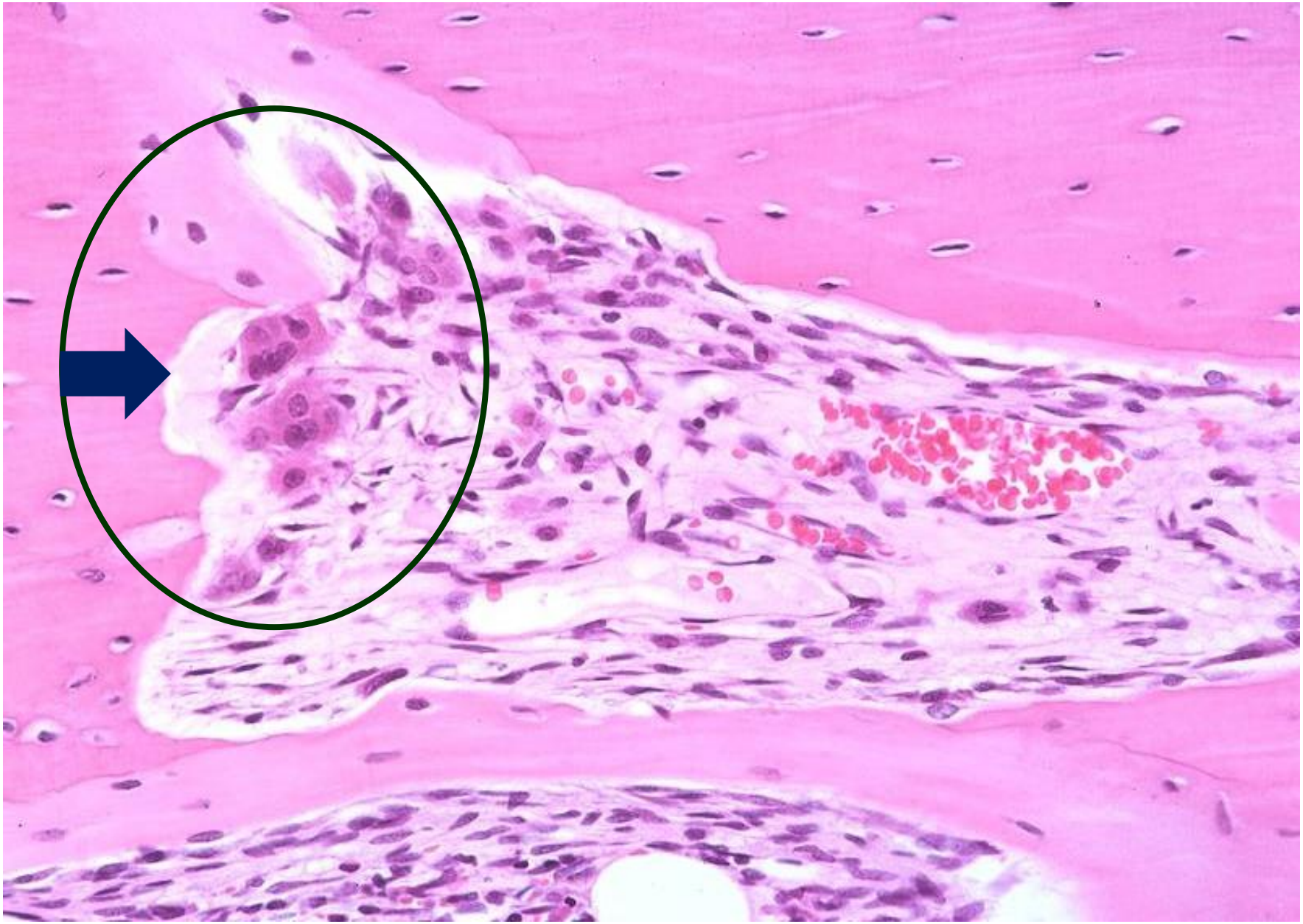
- Secretes collagenase and some enzymes.

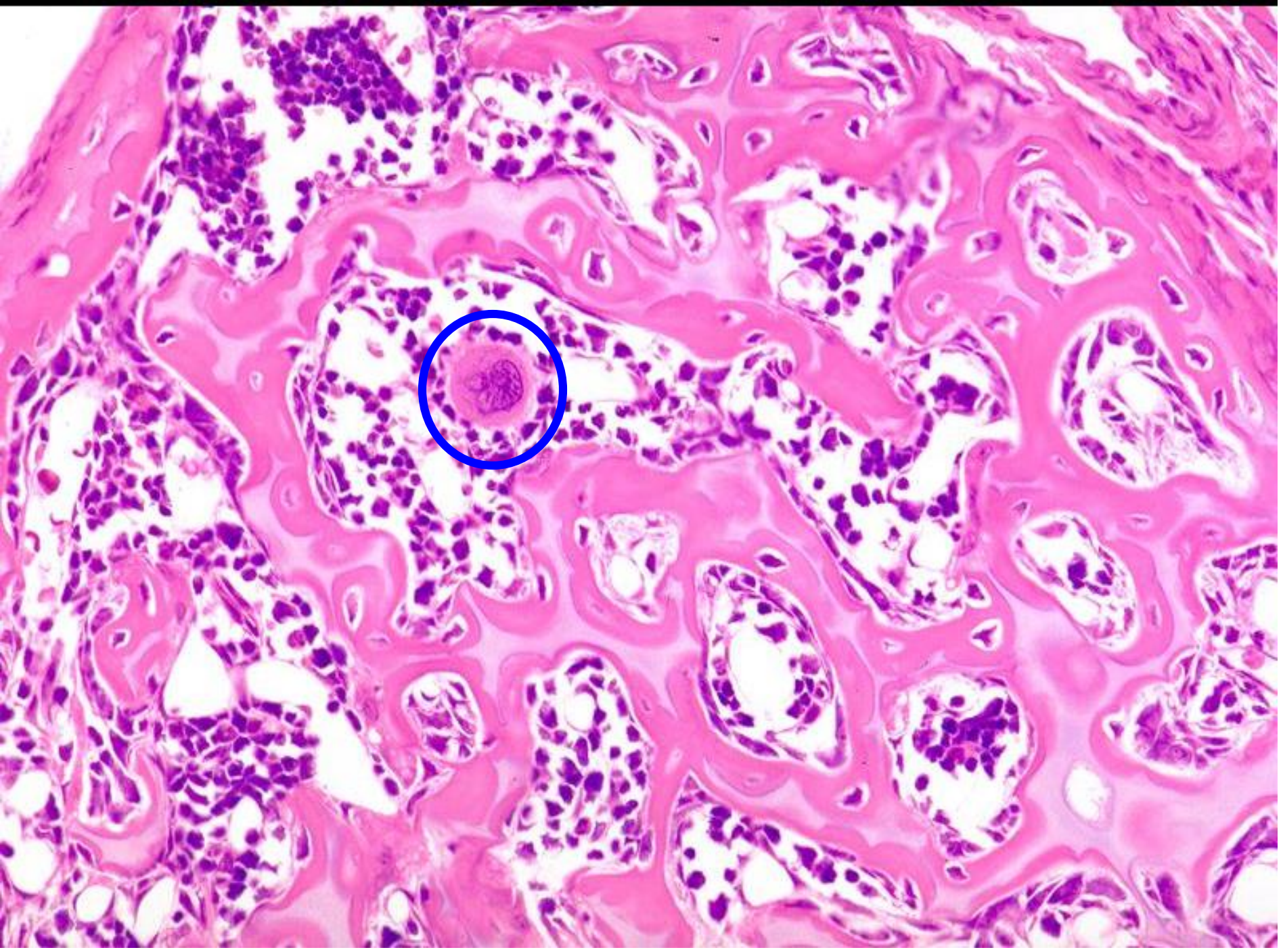
- **When active**, they lie in Howship's lacuna (resorption cavities):
  - Enzymatically etched depression on the surface.

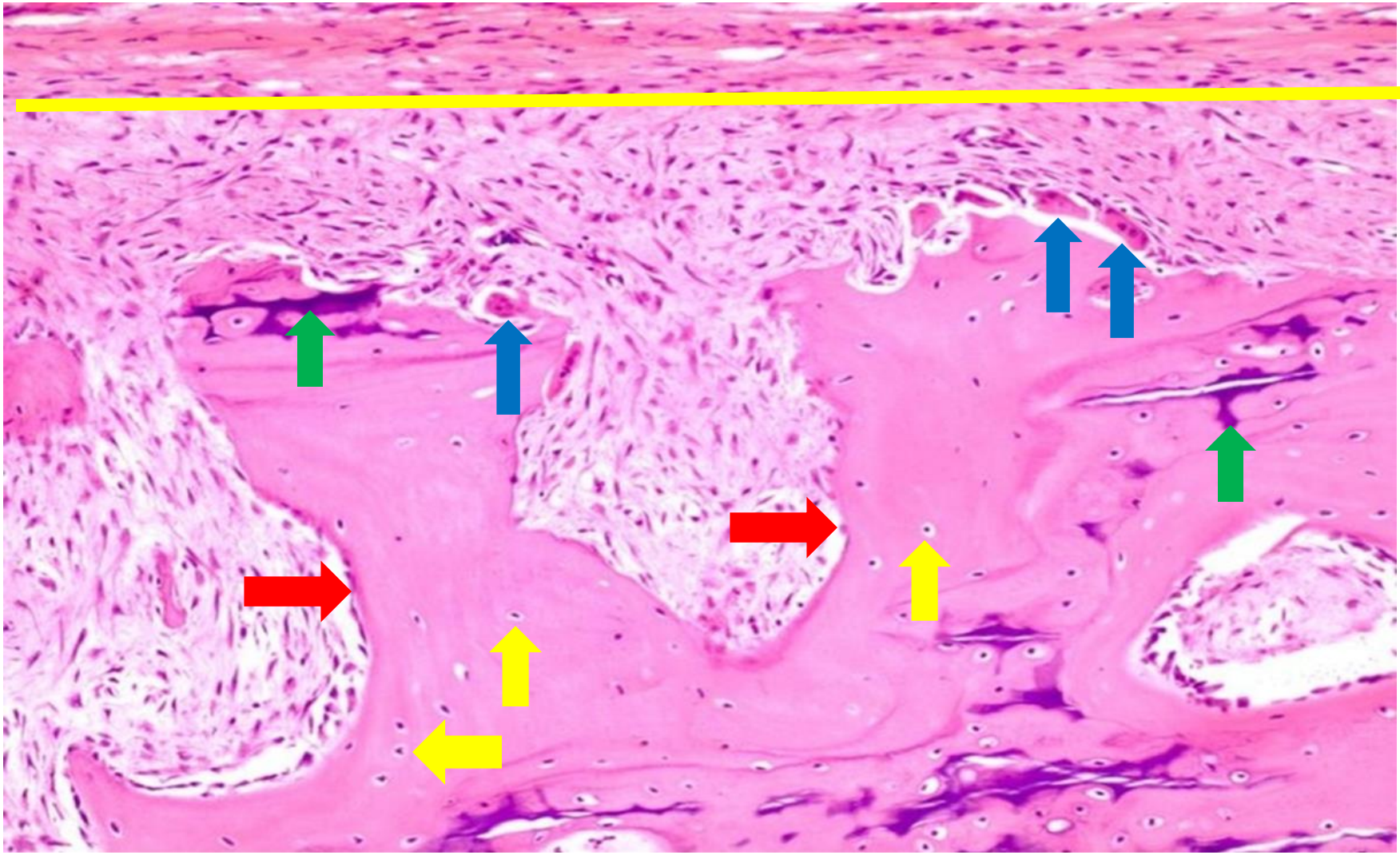
- The surface facing the matrix shows irregular foldings; **ruffled border**.
  - The ruffled border is surrounded by **clear zone**:
    - Clear of organelles, rich in actin filaments.
    - Creates microvironment for bone resorption.


Nucleus
Nucleolus
Golgi
RER
Mitochondria
Capillary
$CO_2 + H_2O \rightarrow H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$
Endocytic vesicle
Actin filaments
Bone
Lysosomes
Microenvironment of low pH and lysosomal enzymes
Section of circumferential clear zone
Ruffled border

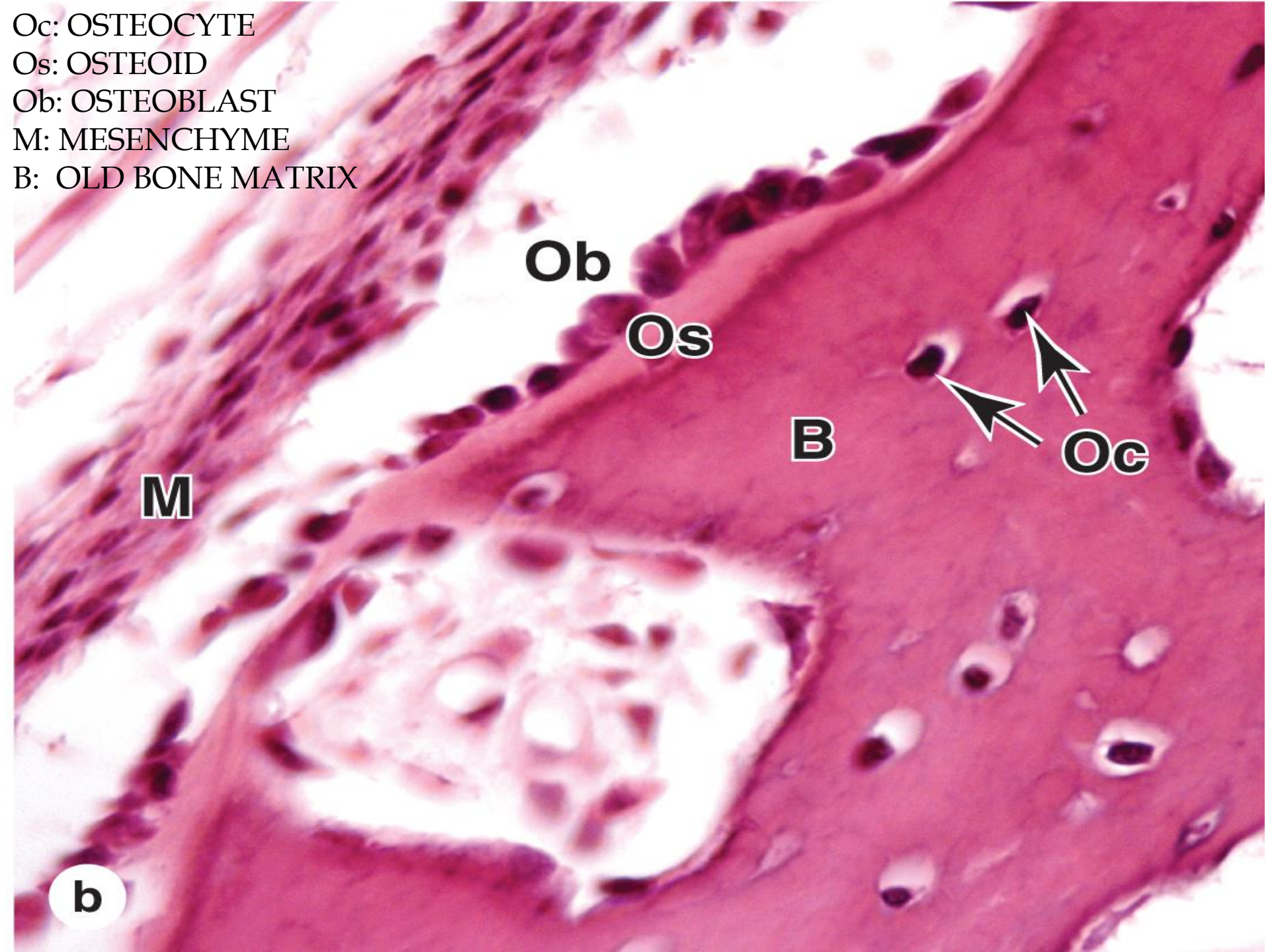

Osteoclast
Mesenchyme
Newly formed
matrix (osteoid)
Osteoblast
Osteocyte
Bone matrix

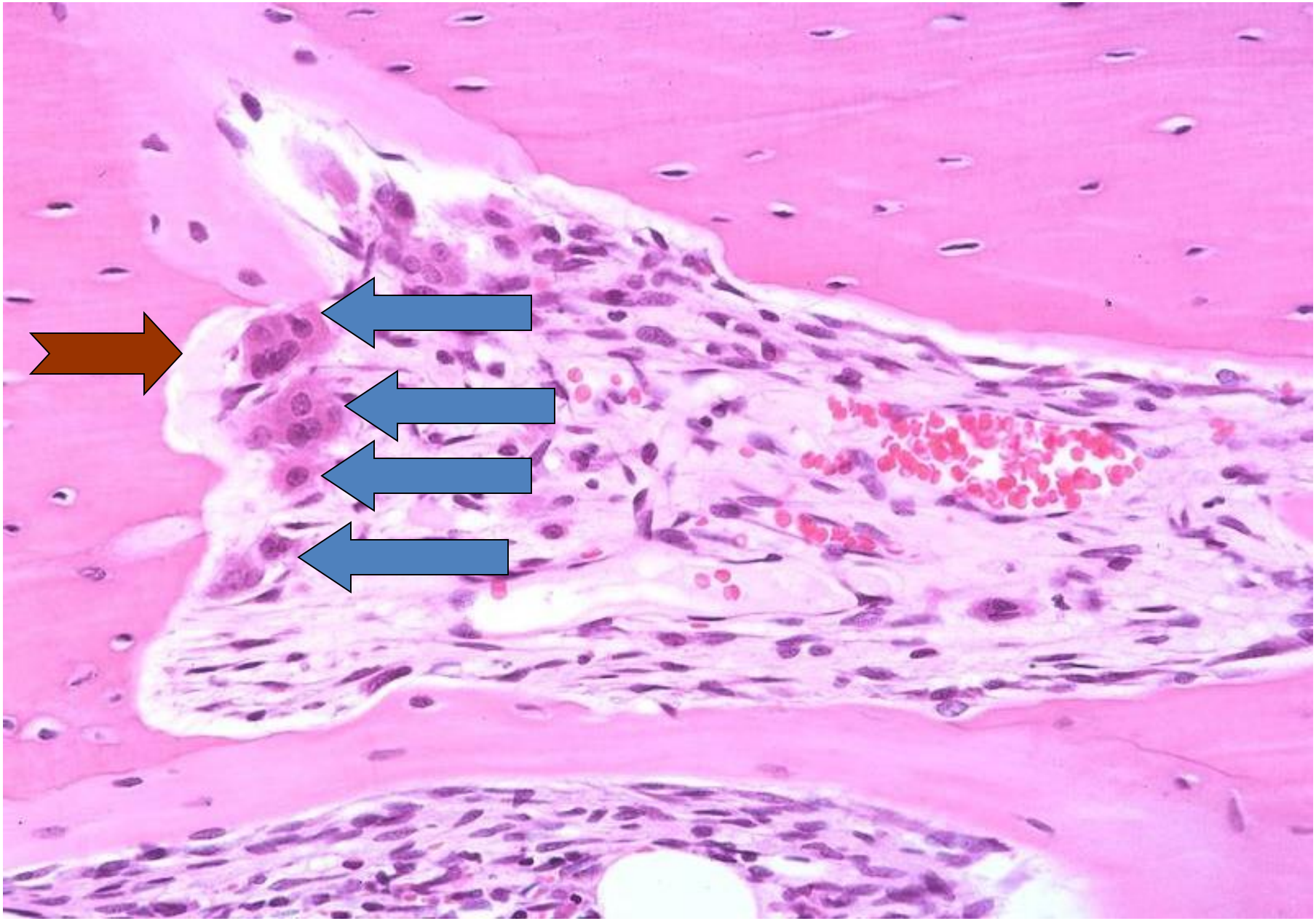


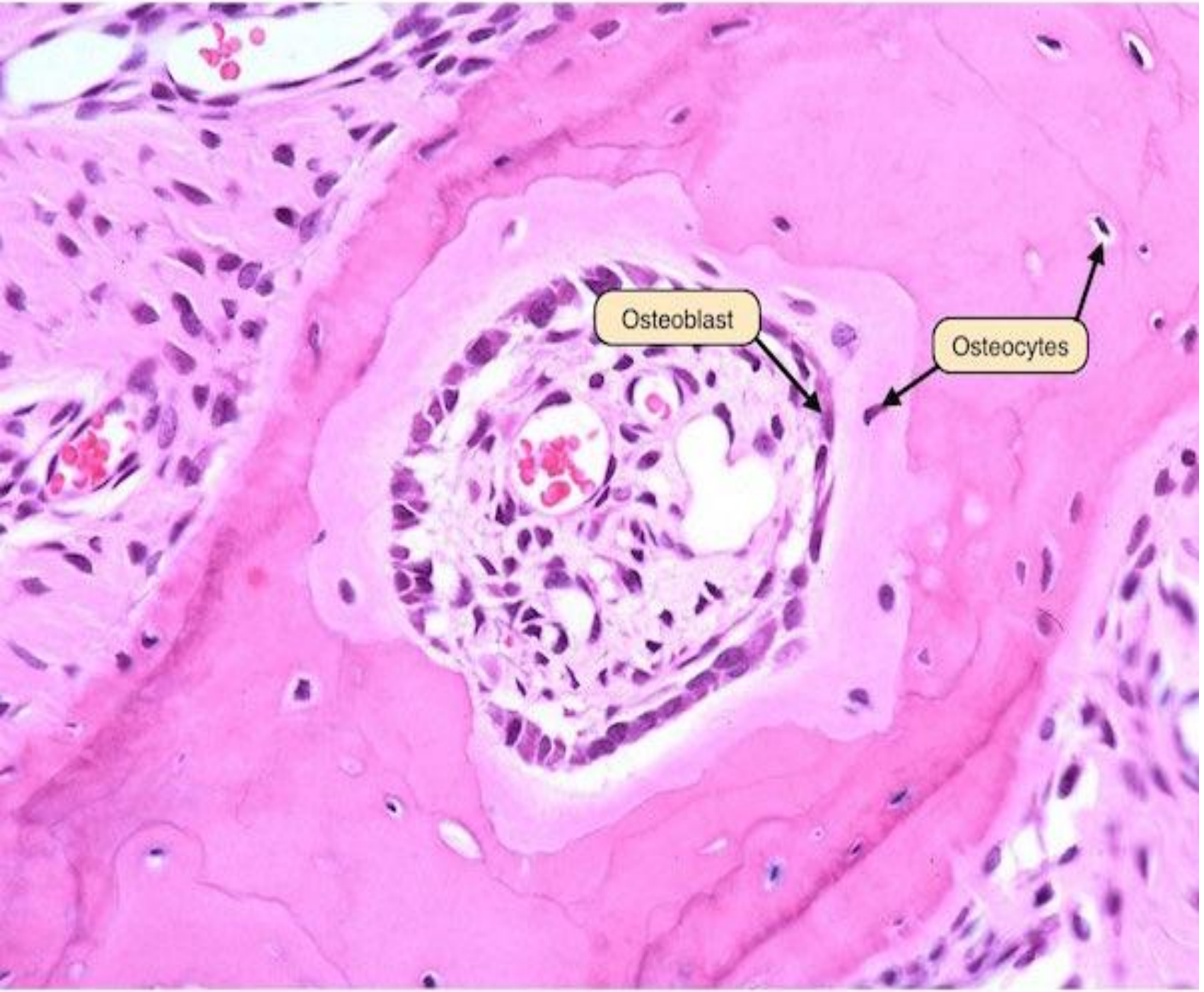


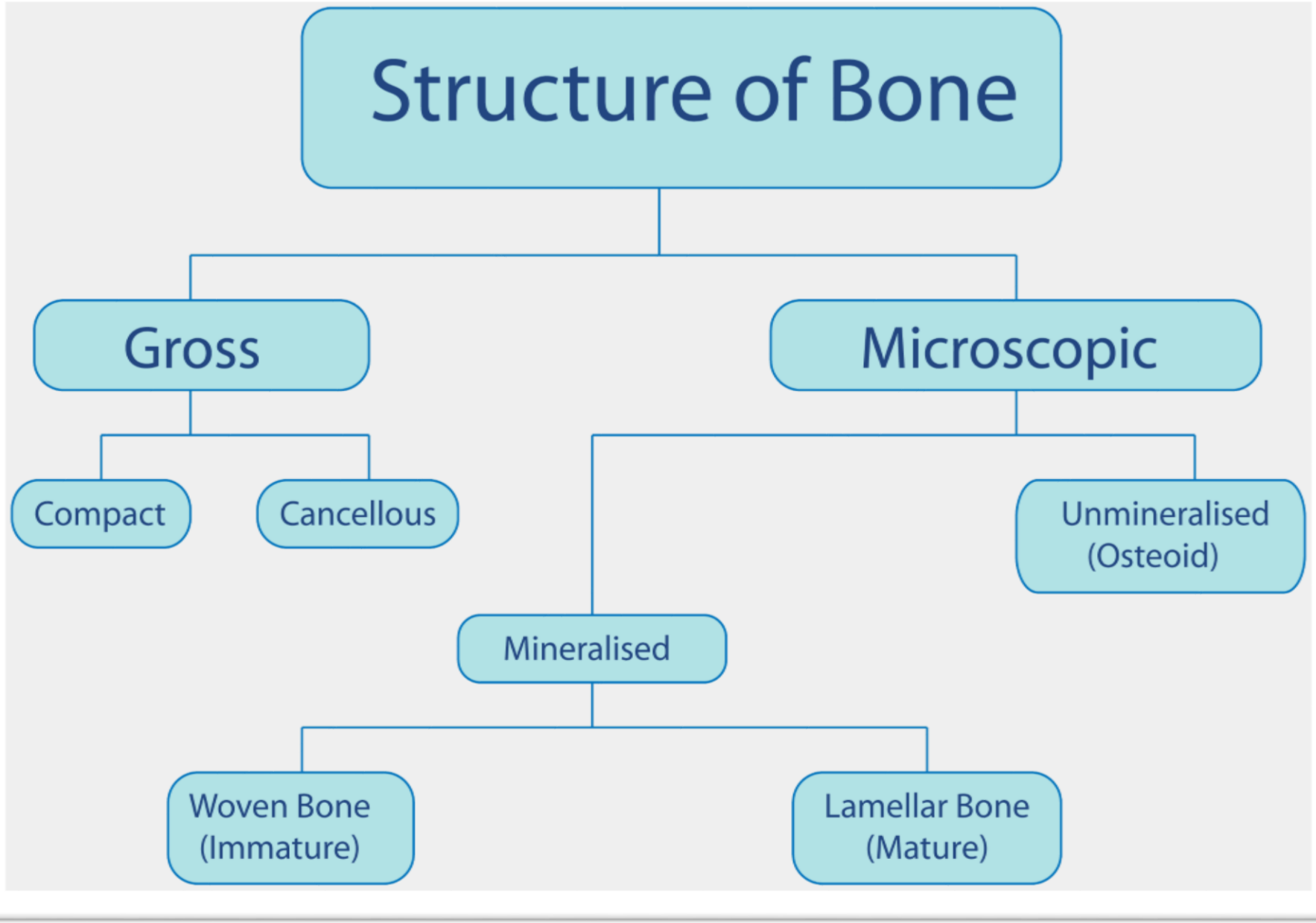


- **Periosteum**: an outer fibrous above the yellow line and inner cellular below the yellow line.
- **Blue arrow**: osteoclast.
- **Red arrow**: osteoblast
- **Green arrow**: calcified cartilage.
- **Yellow arrow**: Osteocyte


Oc: OSTEOCYTE
Os: OSTEOID
Ob: OSTEOBLAST
M: MESENCHYME
B: OLD BONE MATRIX
Ob
Os
B
Oc
M
b




Osteoblast
Osteocytes


Structure of Bone
Gross
Microscopic
Compact
Cancellous
Unmineralised (Osteoid)
Mineralised
Woven Bone (Immature)
Lamellar Bone (Mature)

Types of bone

- **Microscopic examination** of bone tissue shows two types of organization **:**

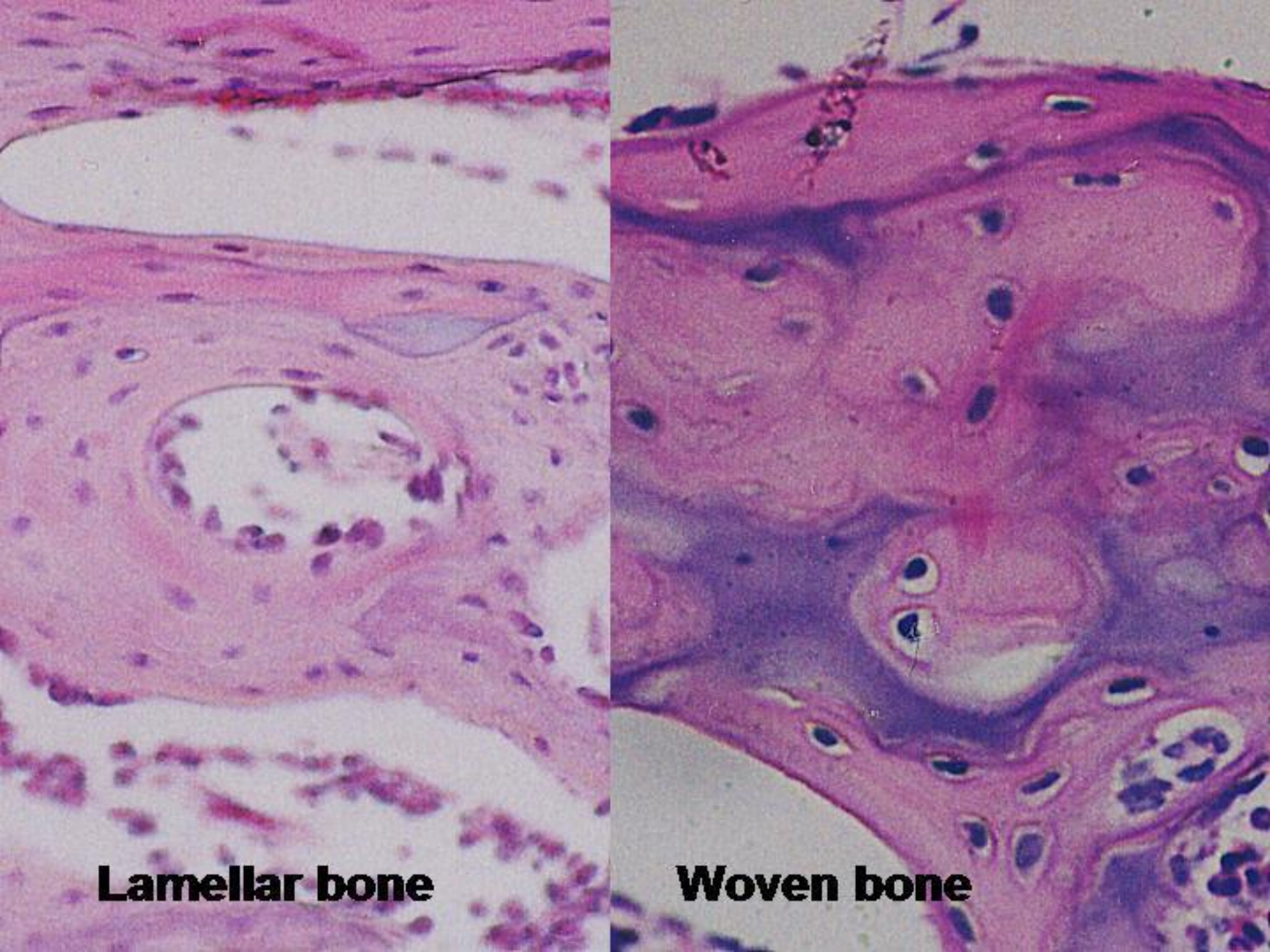
    1. **Lamellar bone (mature/ secondary).**
    2. **Woven bone (immature/ primary).**

Lamellar Bone

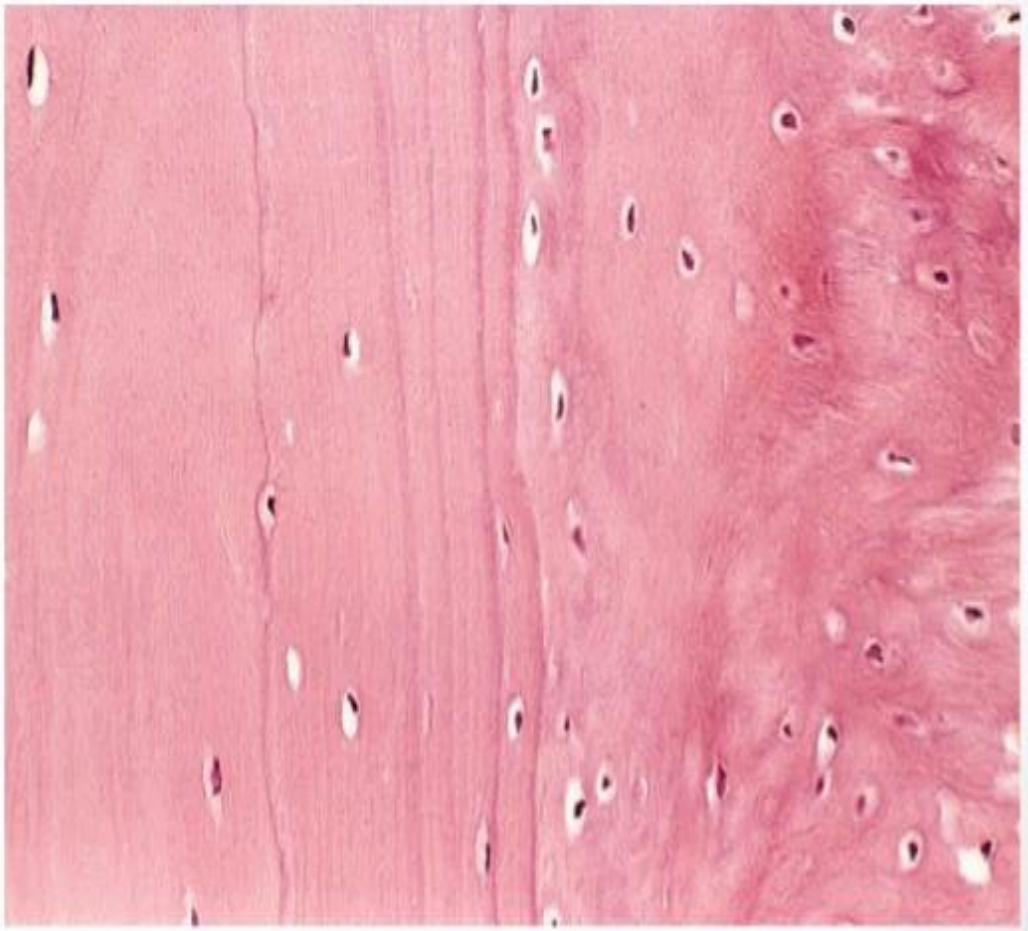
- Most bone in adults, **compact or cancellous** , is organized as **lamellar bone**.
- Is multiple layers or lamellae of calcified matrix.
- The lamellae are organized either parallel to each other (cancellous) or concentrically around a central canal (compact).
- In each lamella = mainly collagen fibers type I

Woven Bone

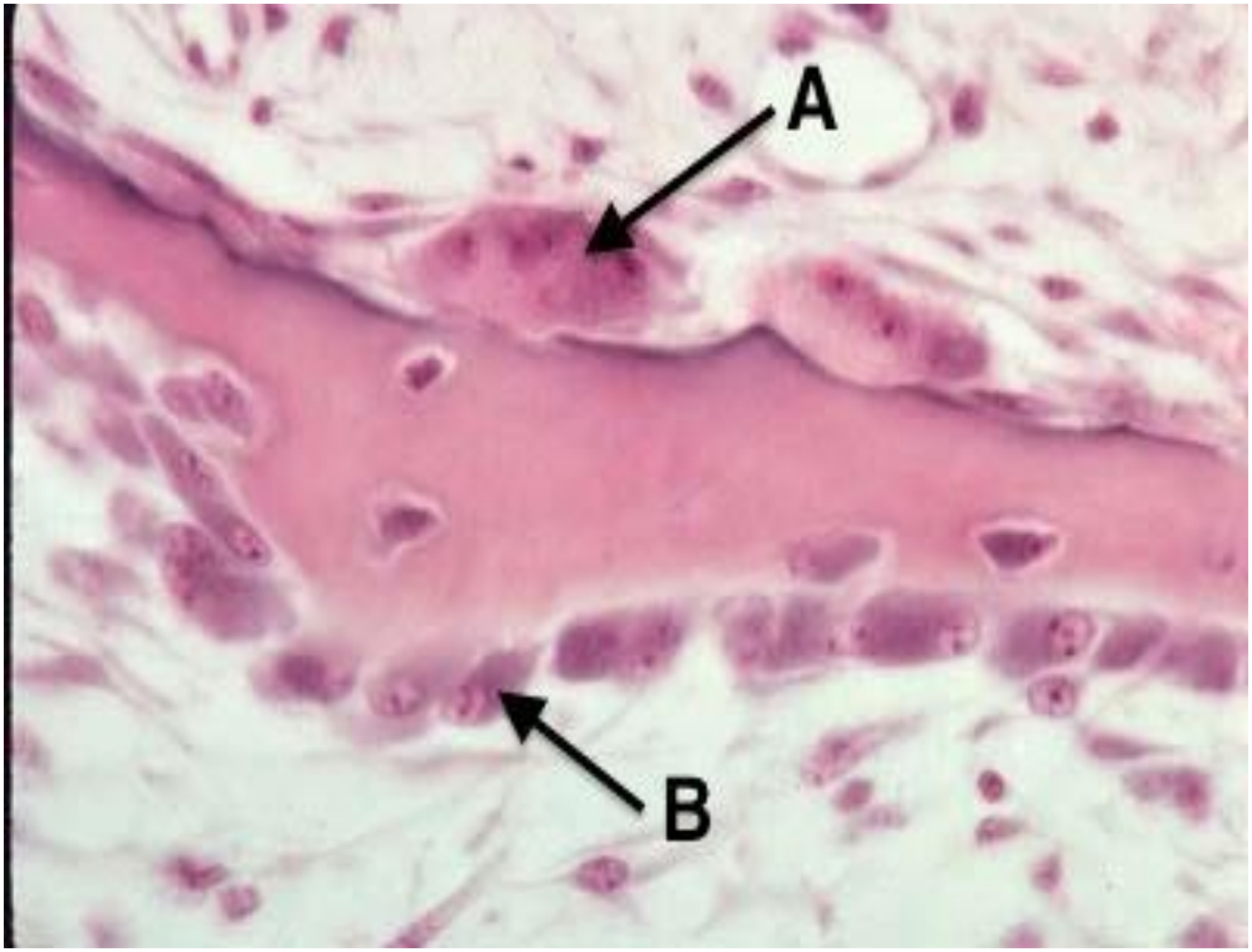
- Is nonlamellar.
- Is the first bone tissue to appear in embryonic development and in fracture repair.
- Temporary, is replaced by in adult by lamellar bone.
- Random disposition of type I collagen fibers
- Lower mineral content.
- Easily penetrated by x-ray.
- Number of osteocytes is relatively high.


Lamellar bone
Woven bone

Woven vs. Lamellar bone



Identify



A: OSTEOCLAST
B: OSTEOBLAST