Bone

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Quit

Bones main functions:

• **Protection** — Bones can serve to protect internal organs, such as the skull protecting the brain or the ribs protecting the heart and lungs.
• **Shape** — Bones provide a frame to keep the body supported.
• **Blood production** — The marrow, located within the medullary cavity of long bones and interstices of cancellous bone, produces blood cells in a process called haematopoiesis.
• **Mineral storage** — Bones act as reserves of minerals important for the body, most notably calcium and phosphorus.
• **Fat Storage** — The yellow bone marrow acts as a storage reserve of fatty acids
• **Movement** — Bones, skeletal muscles, tendons, ligaments and joints function together to generate and transfer forces so that individual body parts or the whole body can be manipulated in three-dimensional space. The interaction between bone and muscle is studied in biomechanics.
• **Acid-base balance** — Bone buffers the blood against excessive pH changes by absorbing or releasing alkaline salts.
• **Detoxification** — Bone tissues can also store heavy metals and other foreign elements, removing them from the blood and reducing their effects on other tissues. These can later be gradually released for excretion.
• **Sound transduction** — Bones are important in the mechanical aspect of hearing.

Bone

- A **rigid** form of CT
- Consists of matrix and cells
- Matrix contains:
  - **organic component** 35% collagen fibres (95% **collagen type I**)
  - **Inorganic salts** 65% #Calcium phosphate (58, 5%) (**Hydroxyapatite**)
    #Calcium carbonate (6,5%)
    (responsible for hardness and rigidity)

2 types of bone

- **spongy (cancellous) (trabecular) (medullary) bone**
- **compact (dense) (cortical) bone**

- Microscopic elements are the same
- Spongy bone consists of bars **(trabeculae)** which branch and unite to form a meshwork
- Spaces are filled with **bone marrow**
- Compact bone appears solid but has microscopic spaces
- In long bones the shaft (**diaphysis)** is compact bone
- And the ends (**epiphysis)** consists of spongy bone covered with compact bone
- Flat bones consists of 2 plates of compact bone with spongy bone in-between
- **Periosteum** covers the bone
- **Endosteum** lines marrow cavity and spaces
- These 2 layers play a role in the nutrition of bone tissue
- They constantly supply the bone with new osteoblasts for the **repair** and **growth** of bone

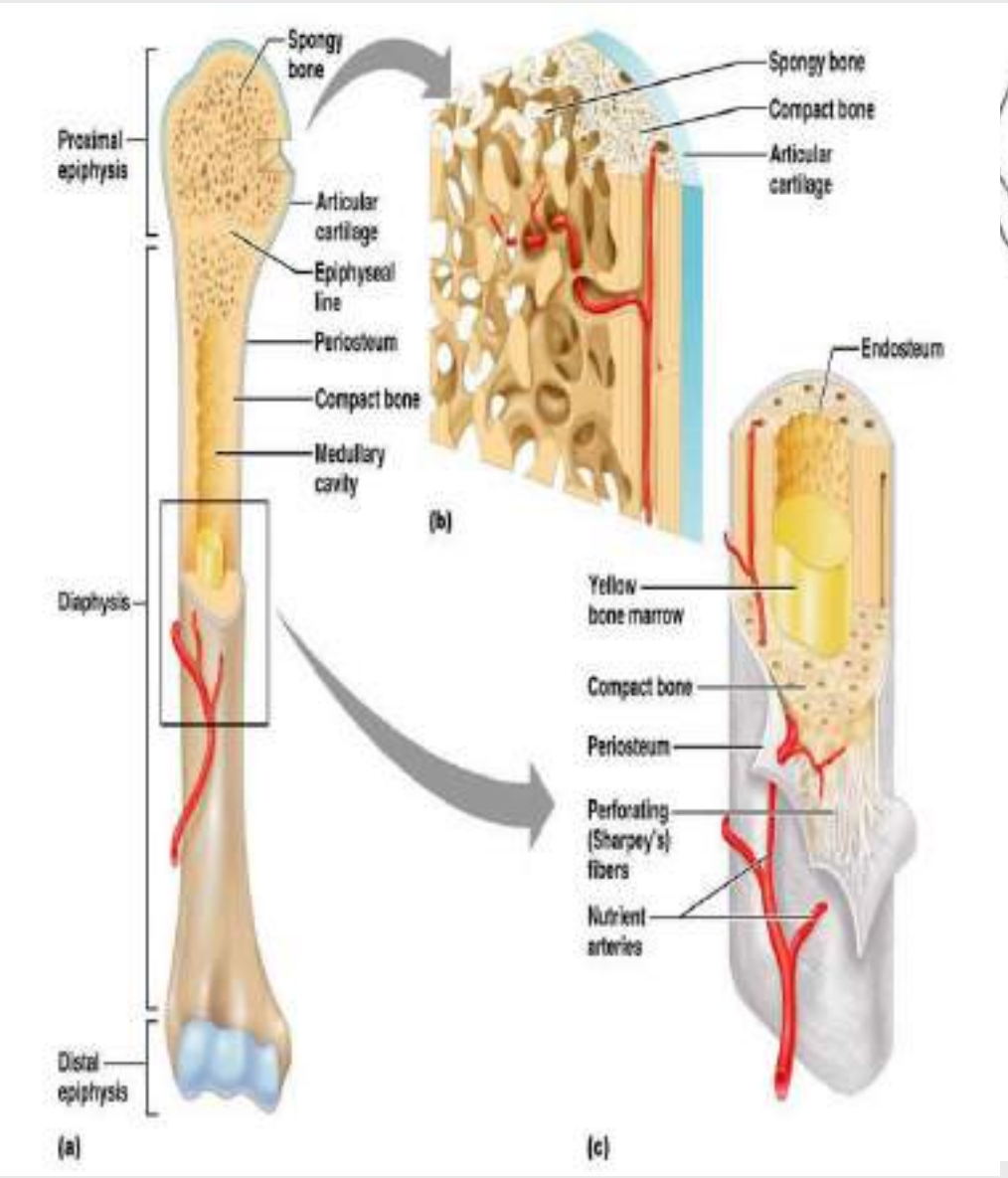
(a)

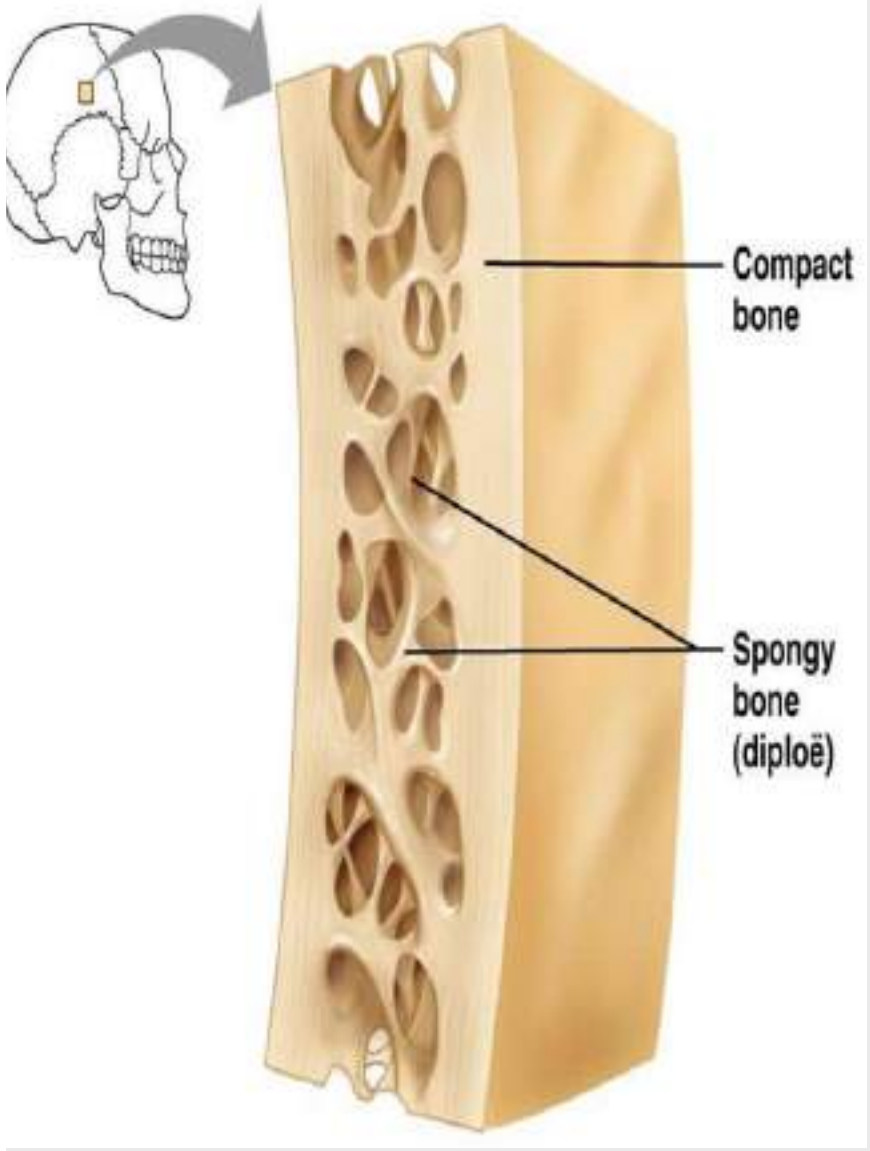
Without mineral

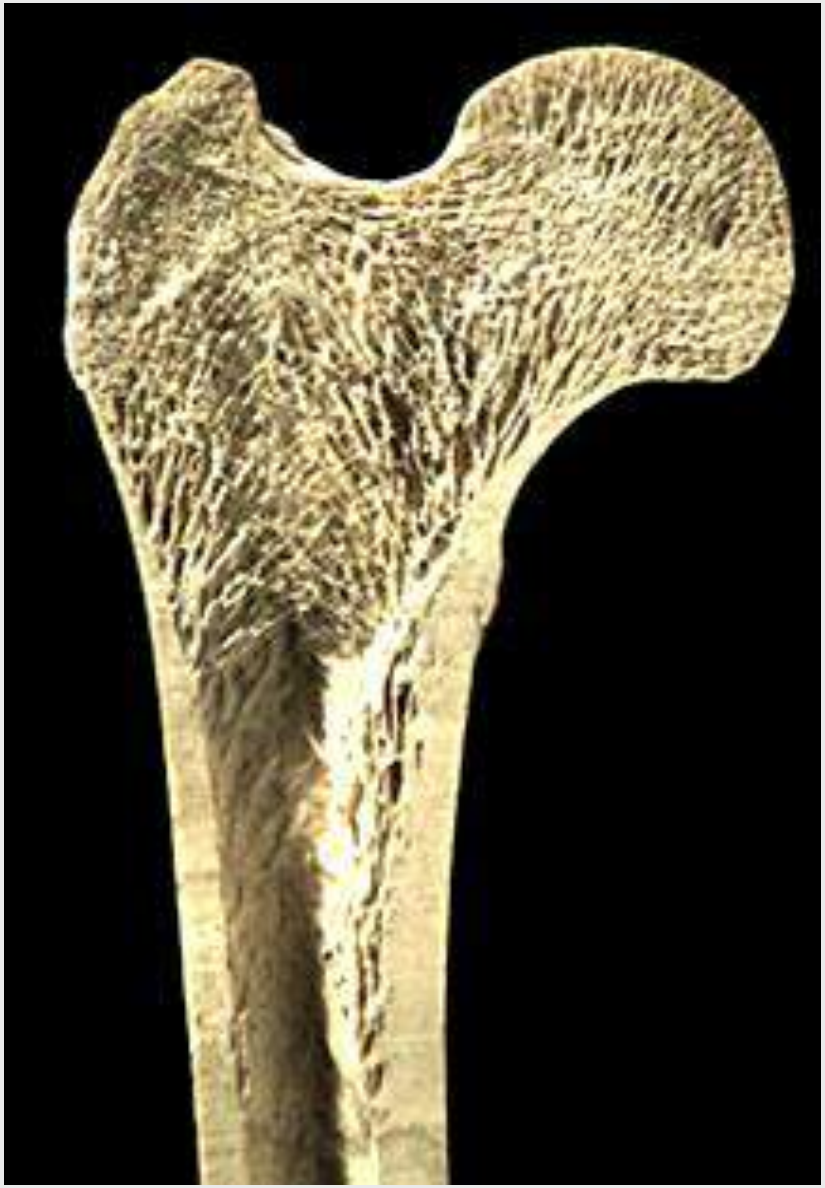
Without collagen

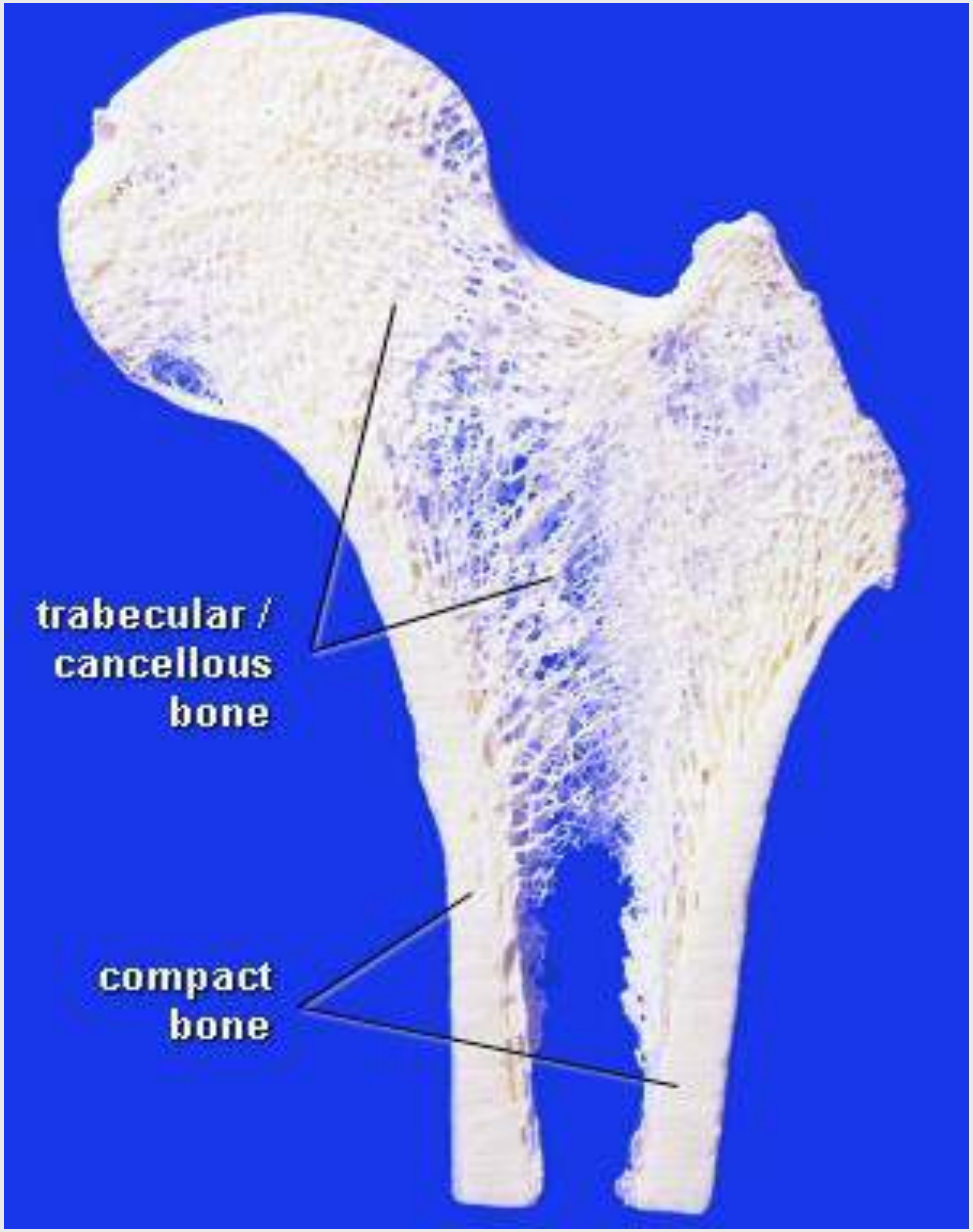
(b)

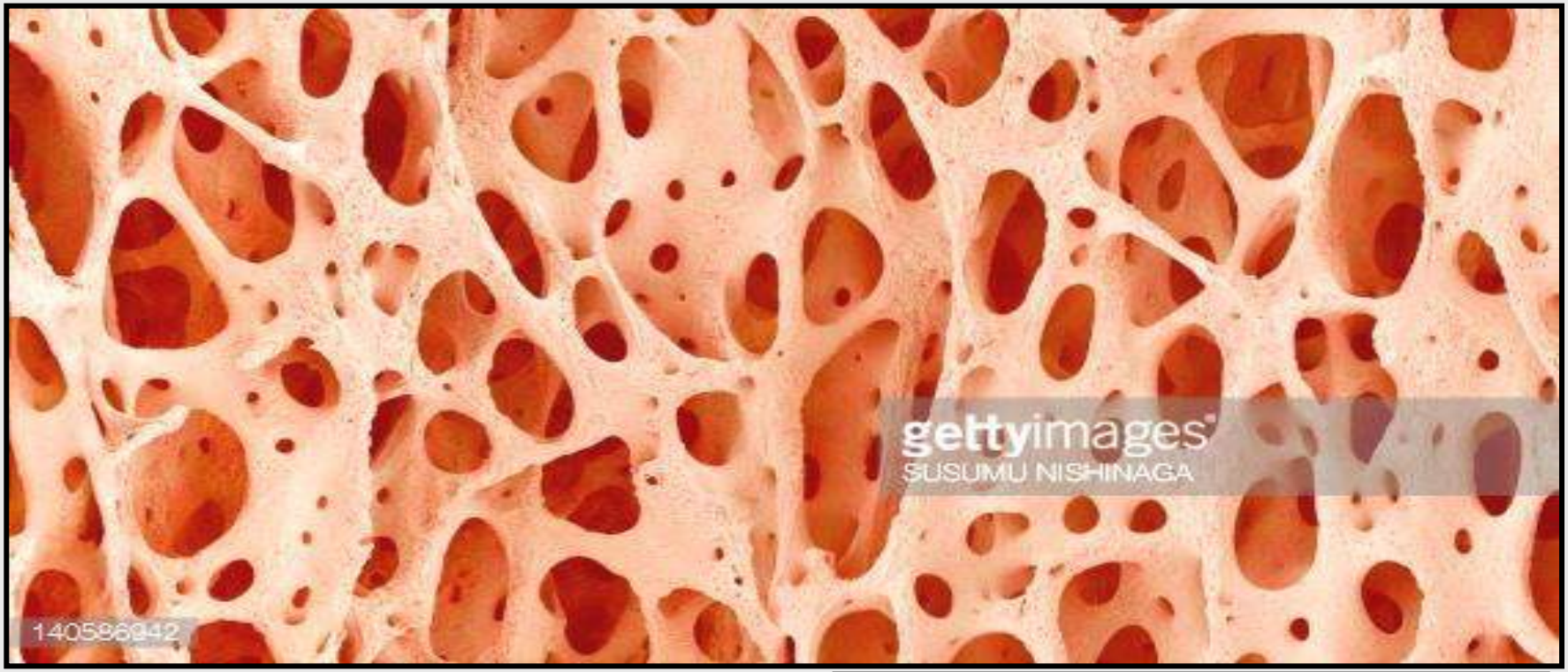
(c)


Spongy bone
Proximal epiphysis
Articular cartilage
Epiphyseal line
Periosteum
Compact bone
Medullary cavity
Diaphysis
Distal epiphysis
(a)
Spongy bone
Compact bone
Articular cartilage
(b)
Endosteum
Yellow bone marrow
Compact bone
Periosteum
Perforating (Sharpey's) fibers
Nutrient arteries
(c)


Compact bone
Spongy bone (diploë)




trabecular /
cancellous
bone
compact
bone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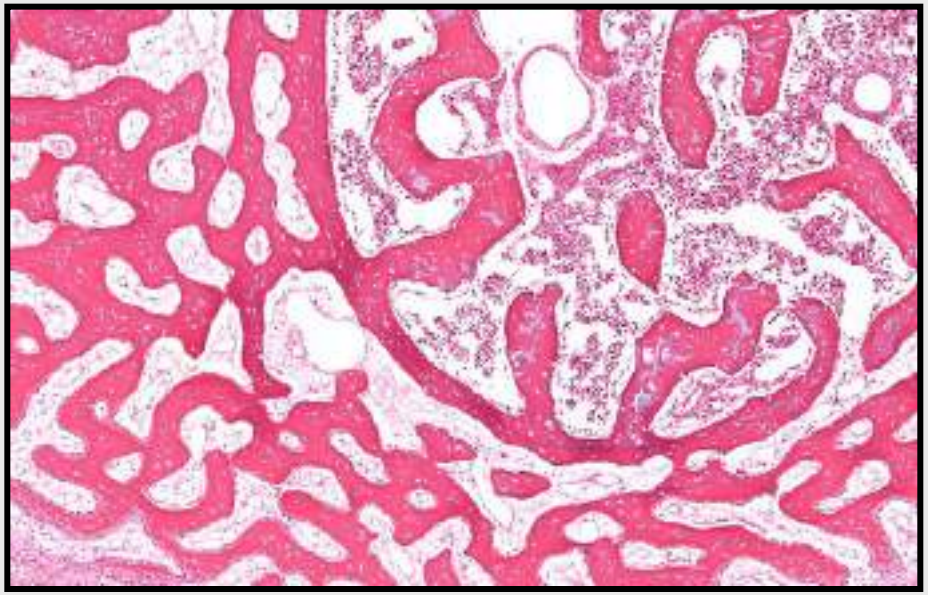

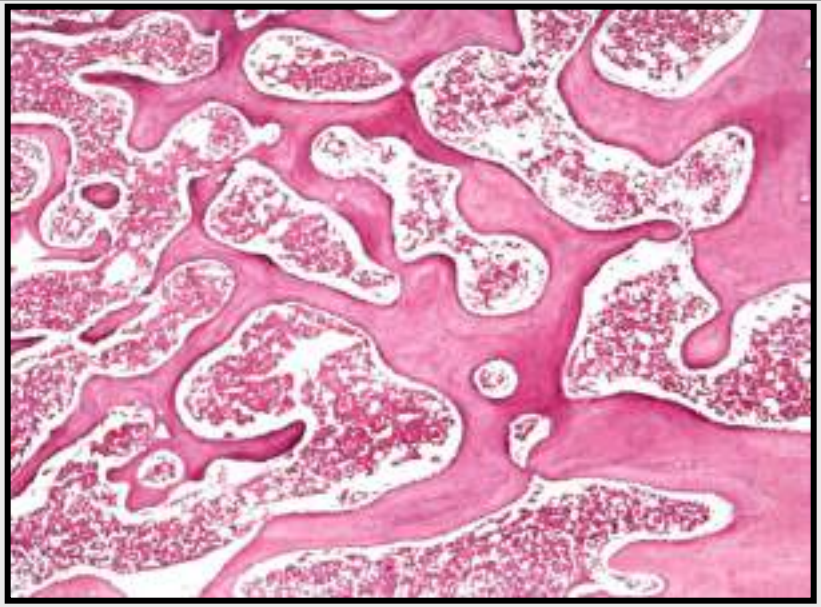

This is spongy or cancellous bone. This type of bone is found in the ends of long bones and between flat bones. The ↑↑ indicate trabeculae. The microscopic elements in spongy bone are the same as in compact bone.

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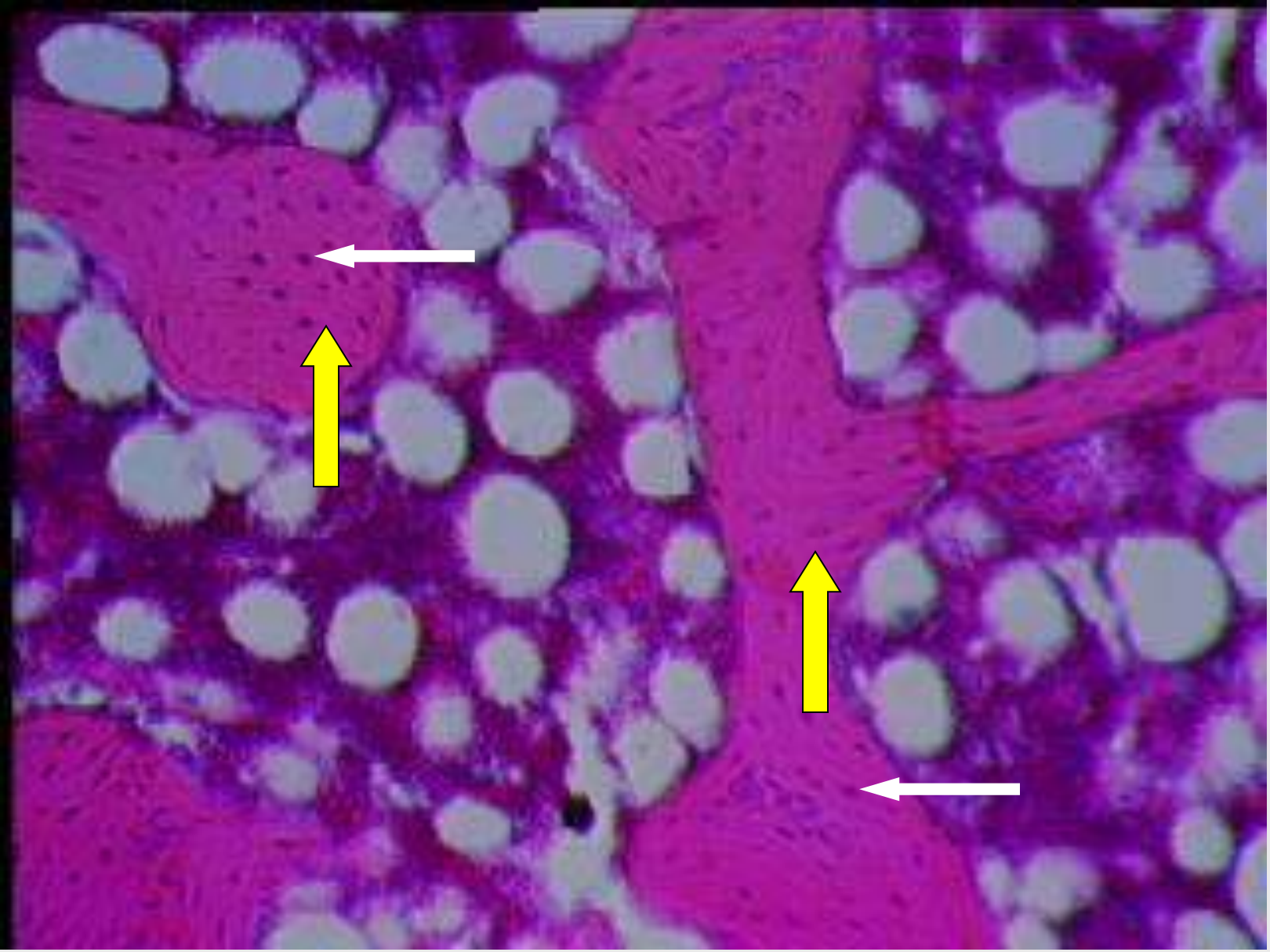

This is again spongy bone ↑↑ indicate trabeculae. The black dots ⇇ are lacunae.

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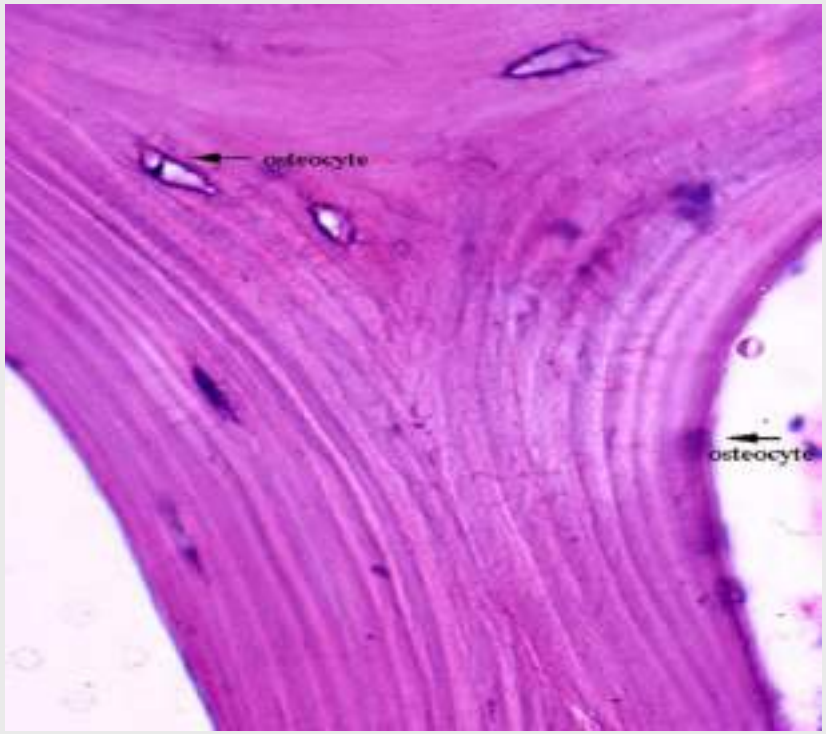
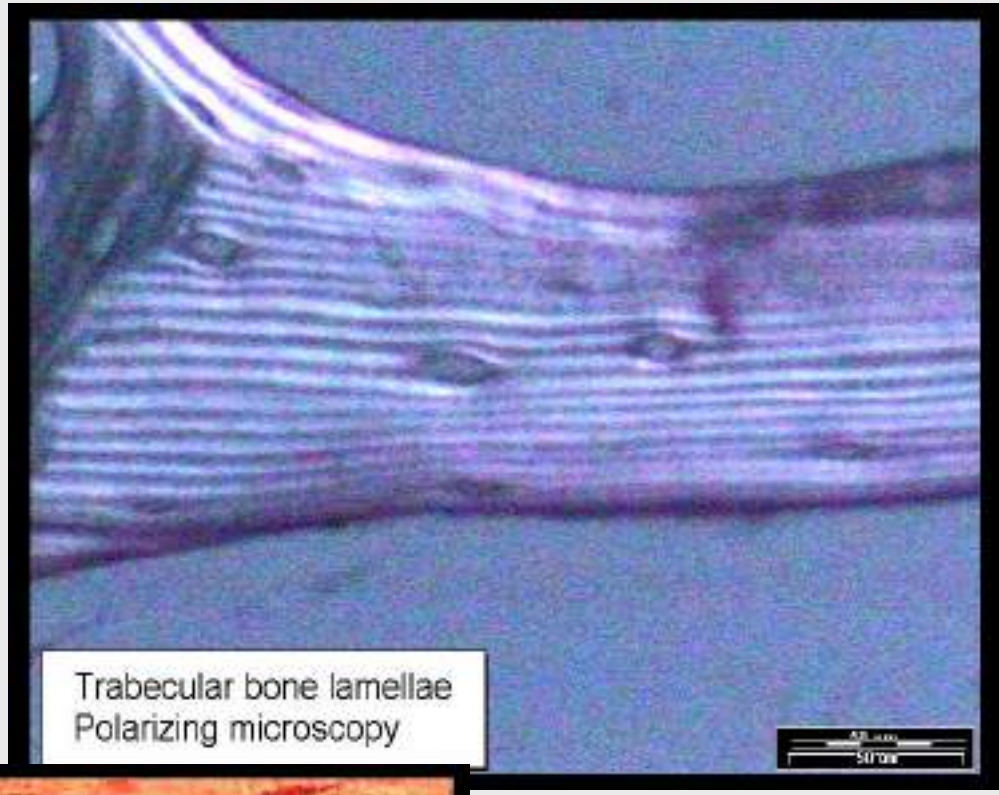
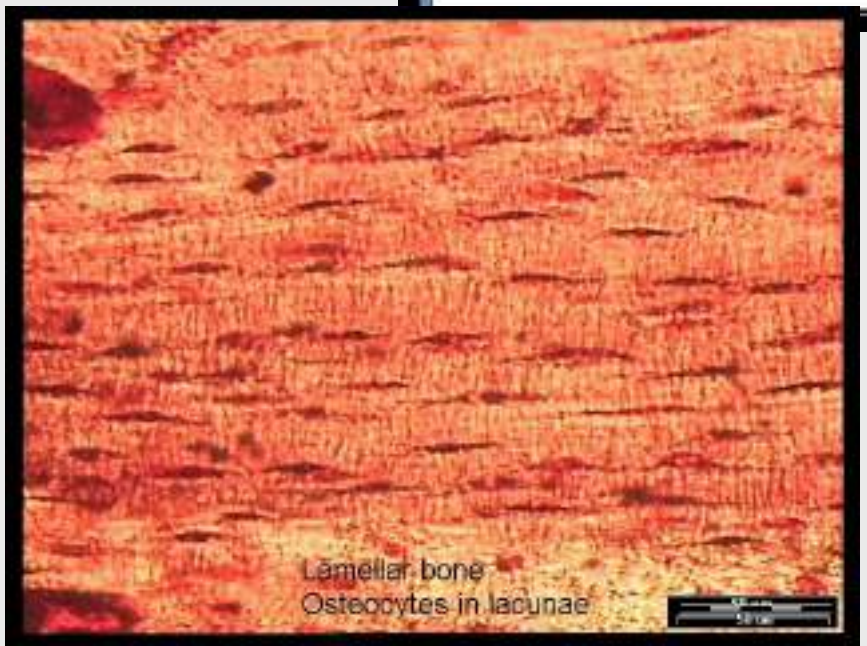




Cancellous bone



Microscopically

- Bone (cortical and cancellous) all over the body is composed of units called **lamellae** with osteocytes lacunae embedded in between
- In **cortical bone** these lamellae arranged in concentric configuration the **Haversian system** or **osteon** (the basic structural unit)
- An osteon consists of a **central Haversian canal**
- In which lies vessels nerves and loose CT
- Around the central canal lies rings of **lacunae**
- A lacuna is a space in the matrix in which lies the osteocyte
- The lacunae are connected through **canaliculi** which radiate from the lacunae
- In the canaliculi are the processes of the osteocytes
- The canaliculi link up with one another and also with the Haversian canal
- The processes communicate with one another in the canaliculi through **gap junctions**
- Between two adjacent rows of lacunae lie the lamellae, 5-7μm thick
- In three dimensions the Haversian systems are **cylindrical**
- The collagen fibres lie in a spiral in the lamellae
- Perpendicular to the Haversian canals are the **Volkman's canals**
- They link up with the marrow cavity and the Haversian canals
- Some lamellae do not form part of a Haversian system they are the:
    - **Inner circumferential lamellae** - around the marrow cavity
    - **Outer circumferential lamellae** - underneath the outer surface of the bone
    - **Interstitial lamellae** - between the osteons

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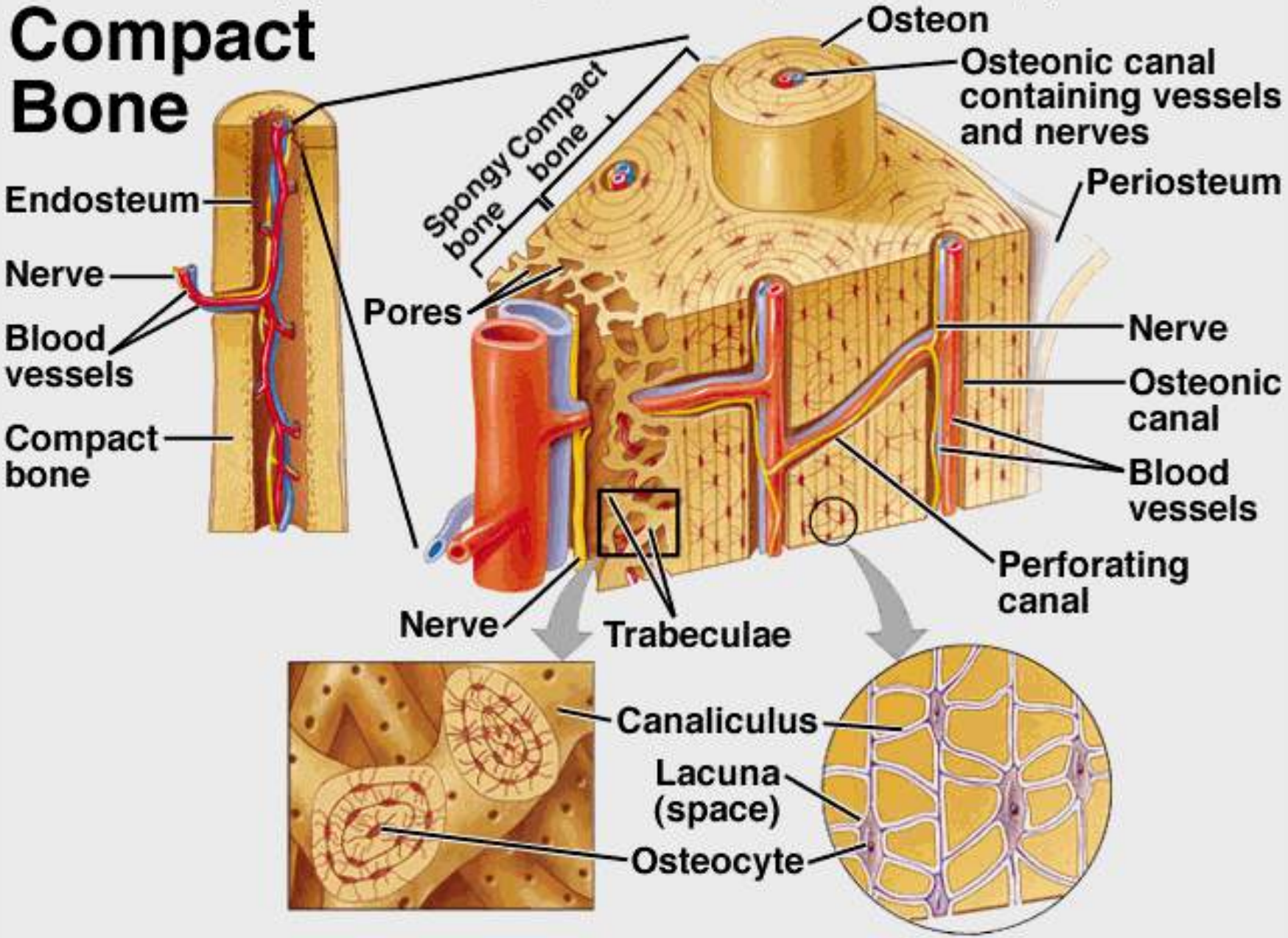
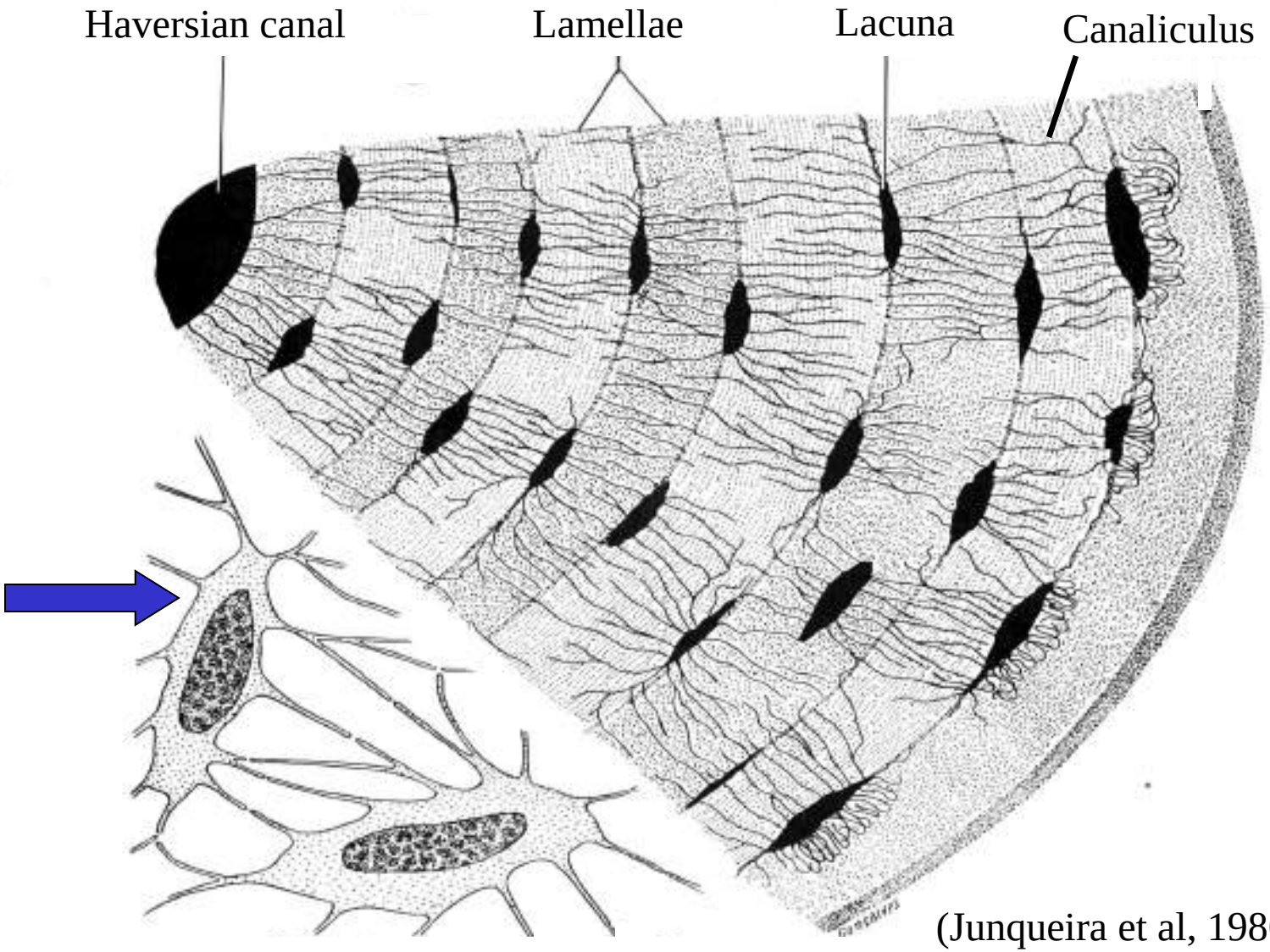
Compact Bone





(Junqueira et al, 1986).

This is at Δ section through a haversian system. The different parts of the haversian system has been annotated. The → indicate an osteocyte with it's processes that lie in the canaliculi. Around the osteocyte, in the lacuna is some bone fluid.

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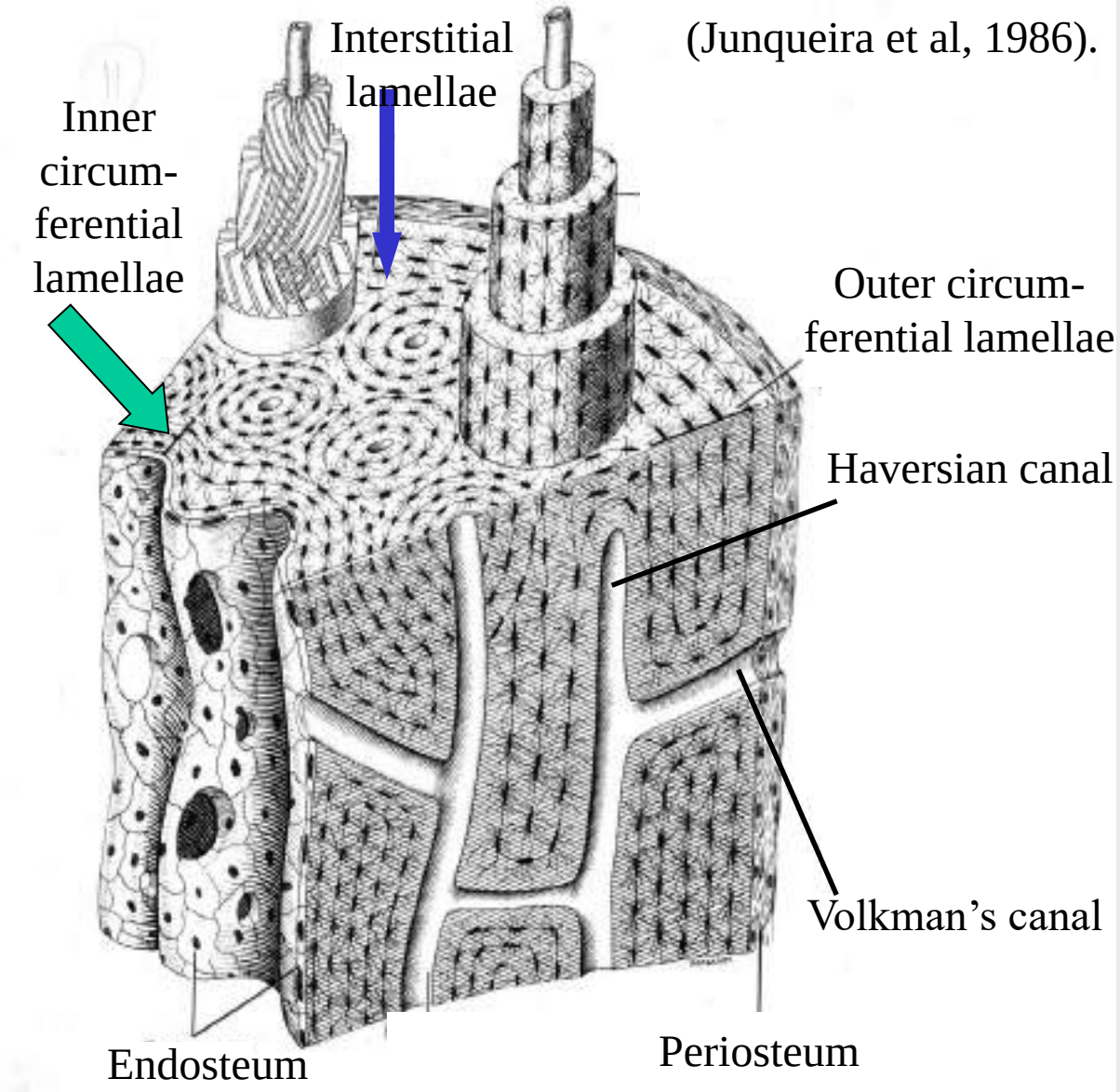
Cortical bone



This is a diagram of the structure of bone. Most of the elements are annotated. The ↓ = inner circumferential lamellae and the ↓ = the interstitial lamellae. The Endosteum lines the Volkman's canals and the Haversian canals and is continuous with the deepest layer of the periosteum.

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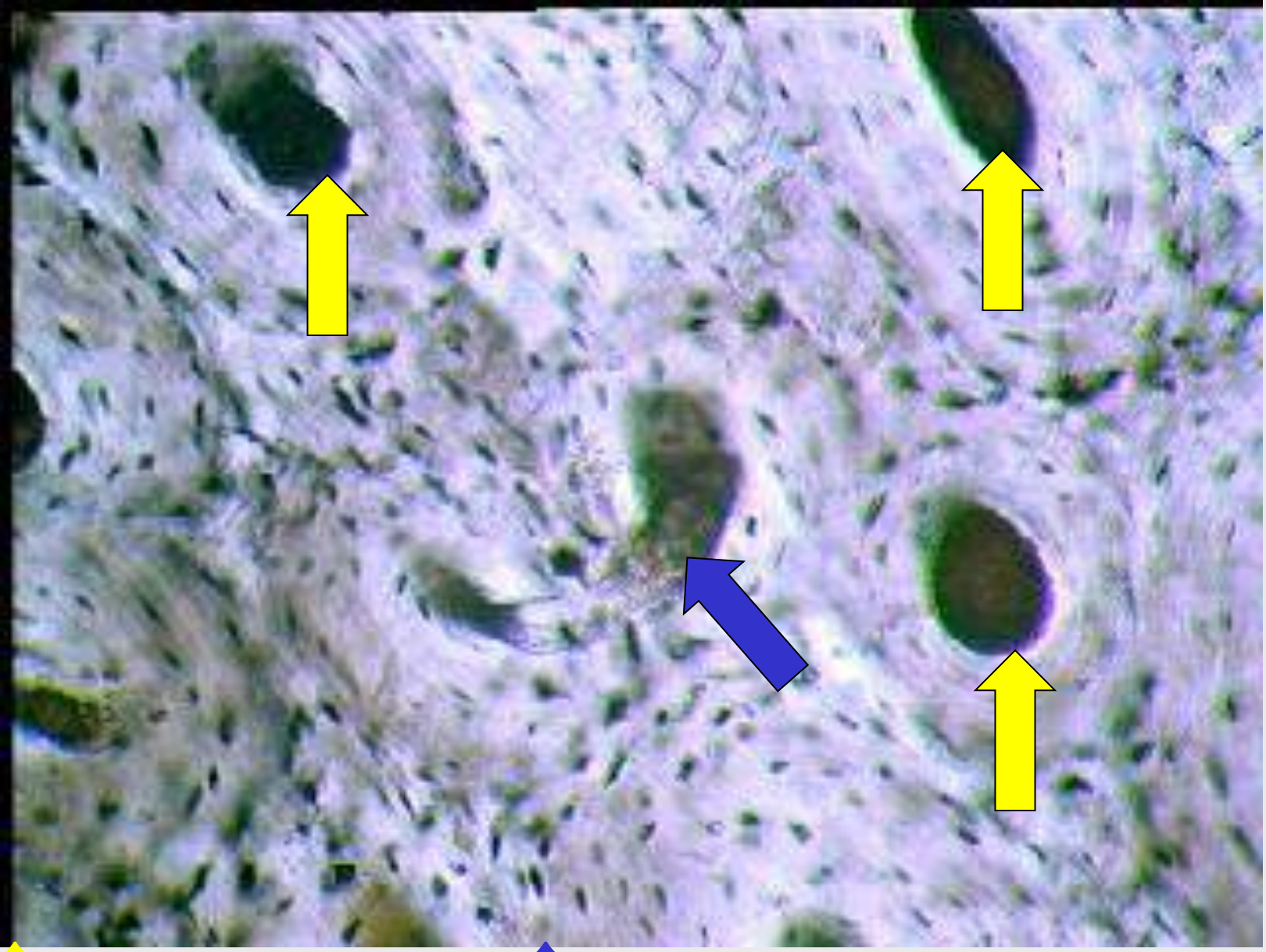

↑ = the haversian canals while the ↑ = Volkman's canal.

Ground section in compact bone

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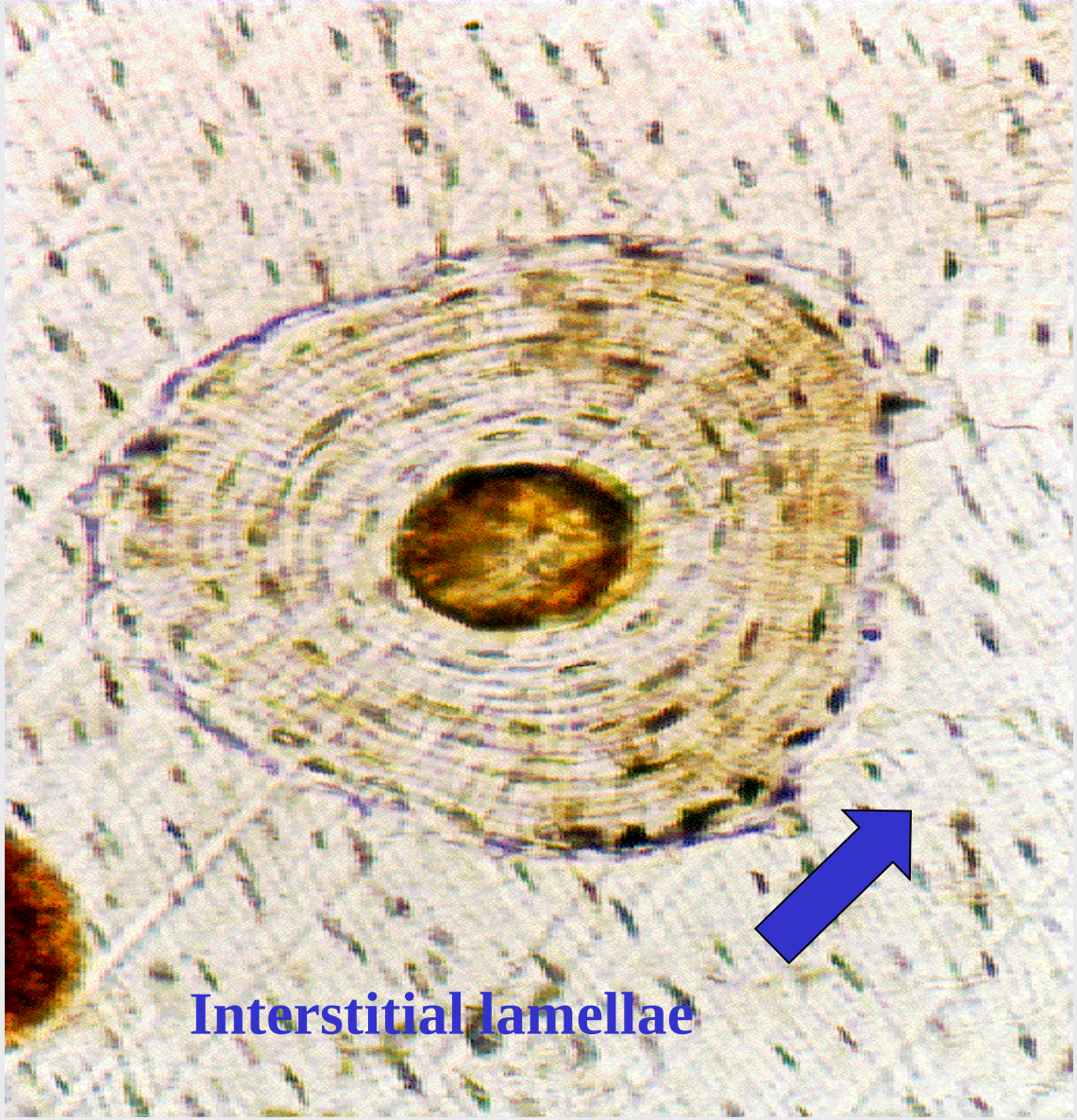

In this slide one can see a haversian system. The ↑ = interstitial lamellae that lie around the haversian system.

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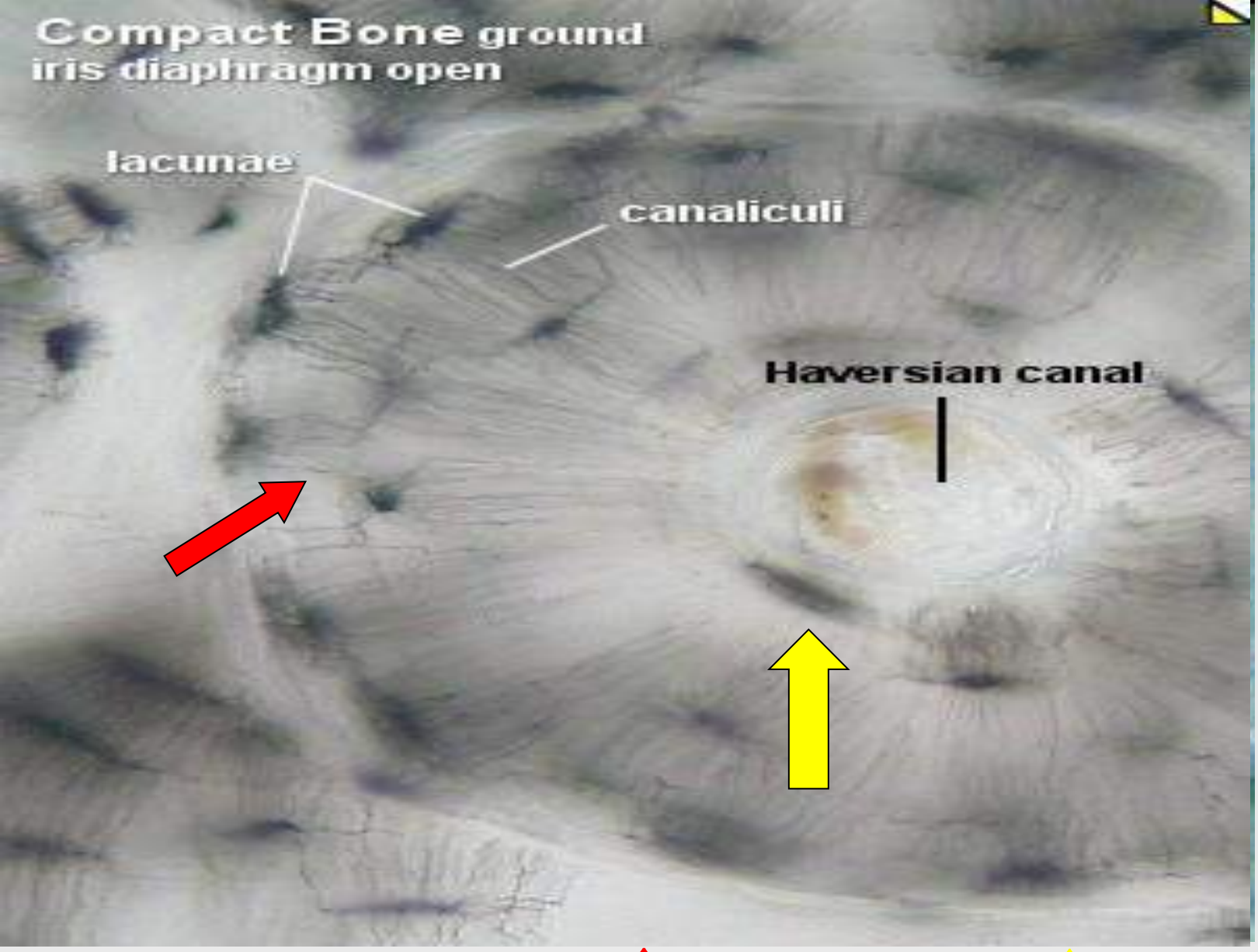

This is a high powered view of bone. The ↑ = the canaliculi while the ↑ = a lacuna. In the lacuna lies an osteocyte with some bone fluid around it while the processes of the osteocyte lie in the canaliculi.

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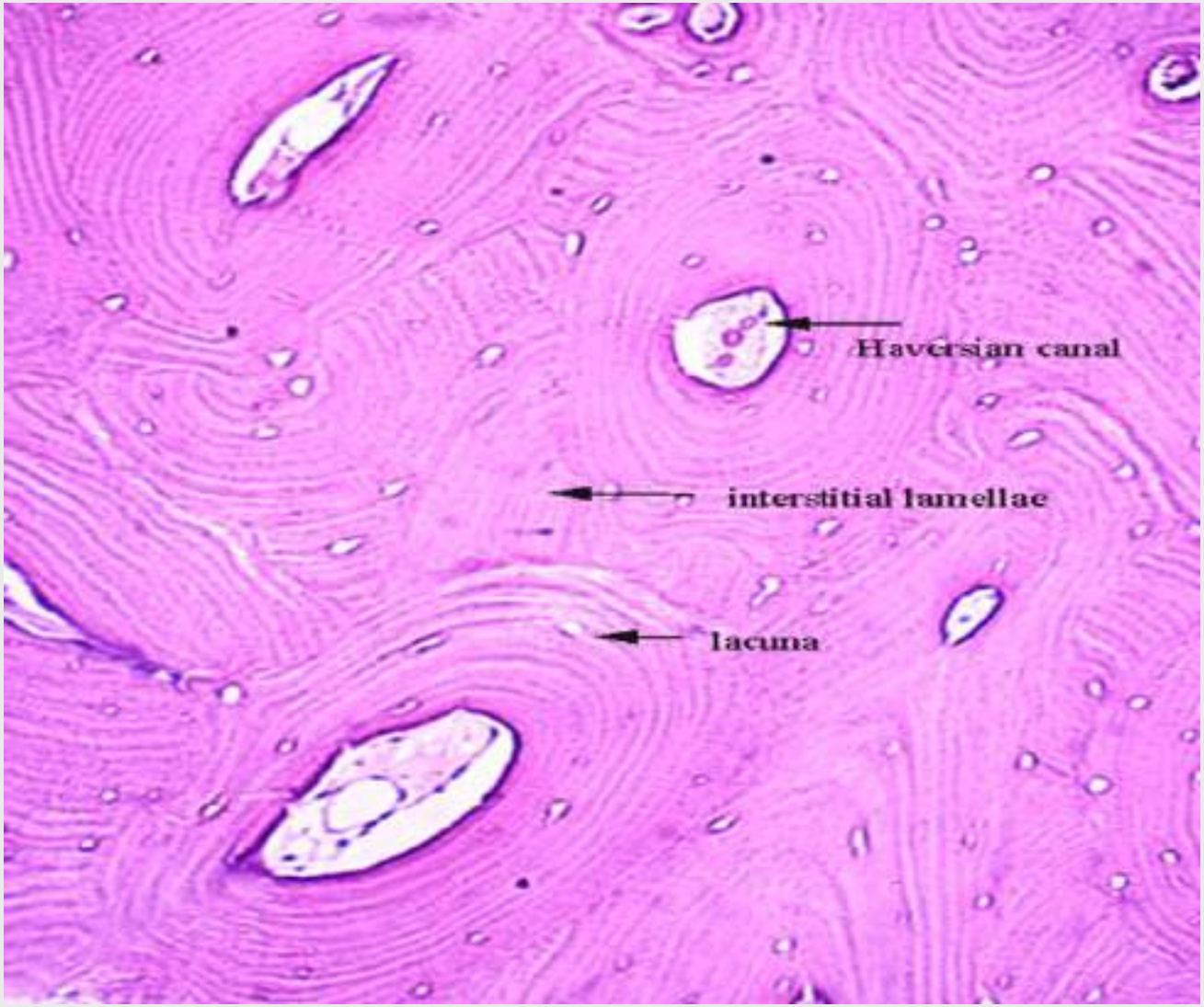


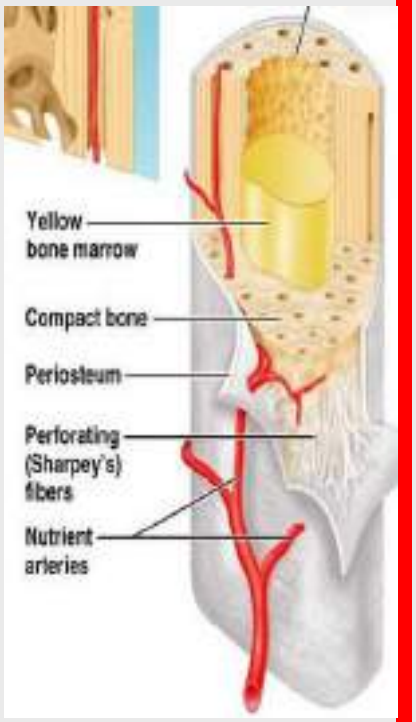
Decalcified section in compact bone

Periosteum

- Formed by tough CT, a vascular fibrous sheath covering flat and long bone's shaft (diaphysis) but not the **articulating surfaces**.

2 layers

- ***Outer fibrous layer***
  - Thickest
  - Contains collagen fibres
  - Some fibres enter the bone - called **Sharpey's fibres**
  - Contains blood vessels.
  - Also fibrocytes and the other cells found in common CT
- ***Inner cellular layer***
  - Flattened cells (continuous with the endosteum)
  - **osteoprogenitor cells** which divide and differentiate into osteoblasts
  - spindle shaped
  - little amount of rough EPR
  - poorly developed Golgi complex
  - play a prominent role in bone growth and repair



Endosteum

- Lines all cavities like marrow spaces, Haversian- and Volkman's canals
- Consists of a **single** layer of squamous osteoprogenitor cells with a thin reticular CT layer underneath it
- Continuous with the inner layer of periosteum
- Covers the trabeculae of spongy bone
- Cells differentiate into osteoblasts (like the cells of the periosteum)

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Bone cells

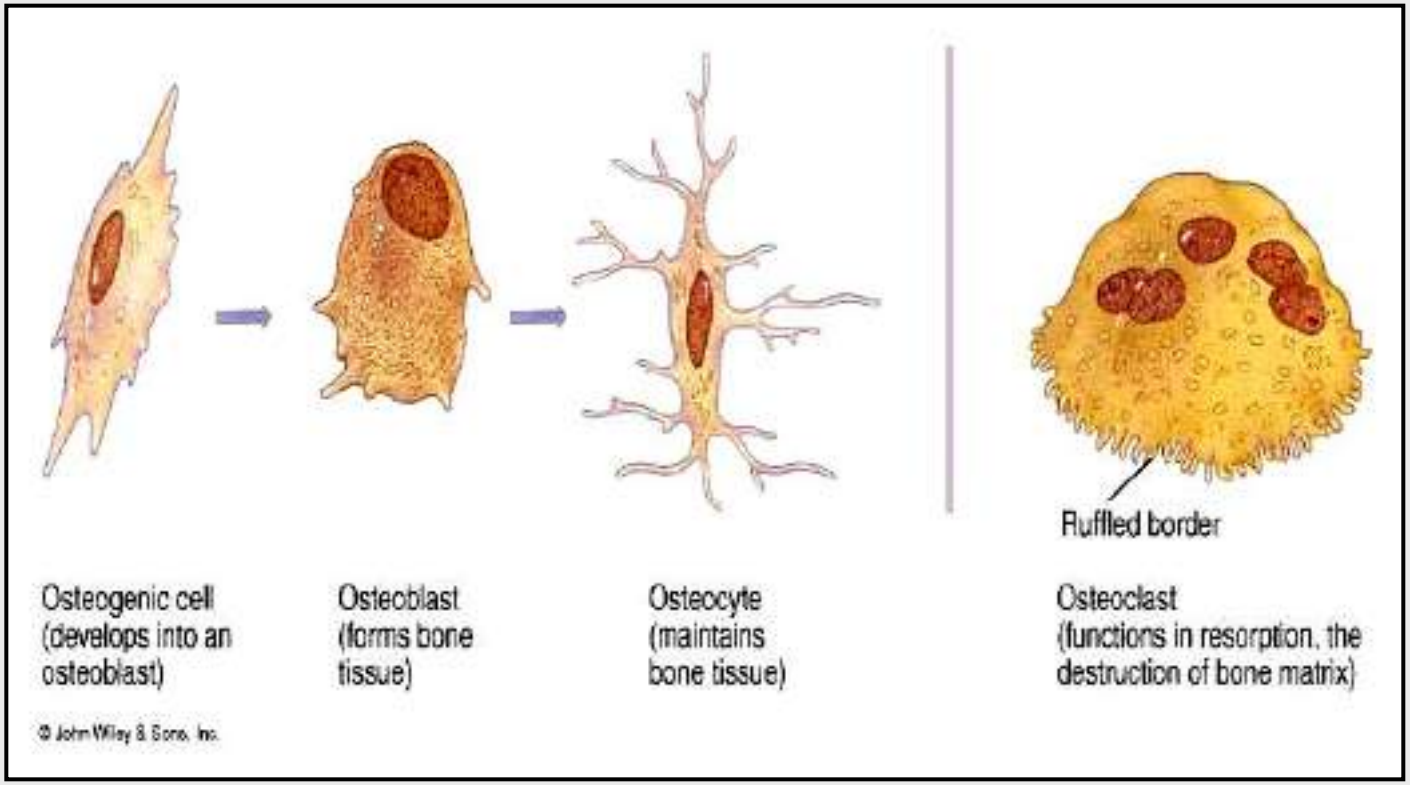
1. Osteogenic cells 2. Osteoblasts 3. Osteocytes 4. Osteoclasts

Osteogenic cells (osteoprogenitor cells)

spindle shape cell with oval nucleus and basophilic cytoplasm

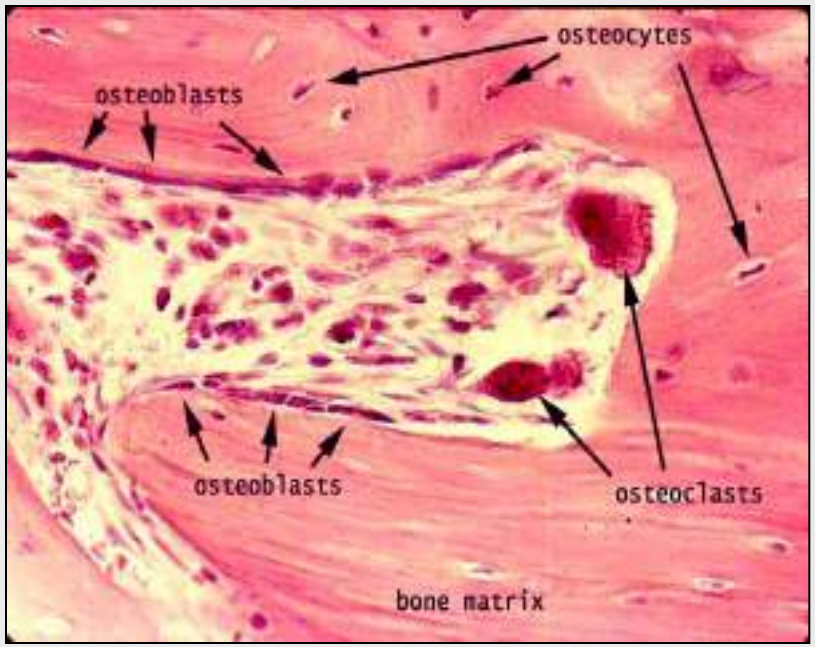
essentially inactive osteoblasts which become active during bone growth and fracture (differentiate to osteoblasts)

present in periosteum and endosteum



Osteoblasts (bone forming cells)

- Oval in shape
- Have thin processes
- Rough EPR in one part of the cell (**basophilic**)
- On the other side is the nucleus
- Golgi and the centrioles in the middle
- Form **matrix**
- Become trapped in the matrix to give osteocytes
- Synthesise **organic matrix** and **secrete alkaline phosphatase**
- Responsible for the **calcification** of the matrix
- The matrix closest to the osteoblasts is not yet calcified and is known as **osteoid** or **prebone**. This osteoid is rich in collagen fibers.



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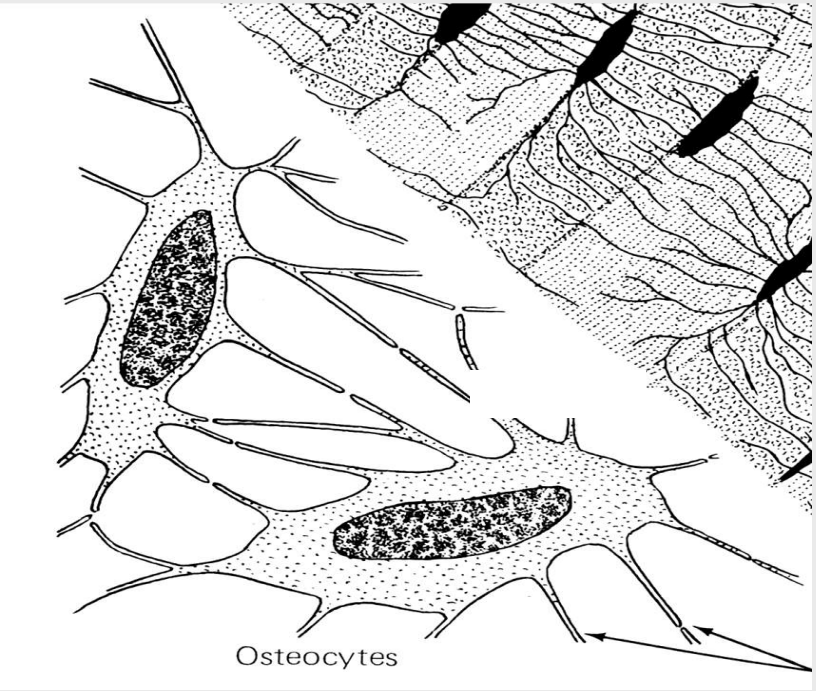
Osteocytes (bone maintenance cells)

- Basically, an osteoblast that has been enclosed within the bony matrix in a space called the **lacuna**
- Mature cells with single nucleus
- Less basophilic than the osteoblasts
- Lie trapped in the lacunae
- Their processes lie in the **canaliculi**
- Processes communicate with one another through **gap junctions**
- Substances (nutrients, waste products) are passed on from cell to cell
- Aid in the **maintenance** of bone (**not** completely inert cells)



(Junqueira et al, 1986).

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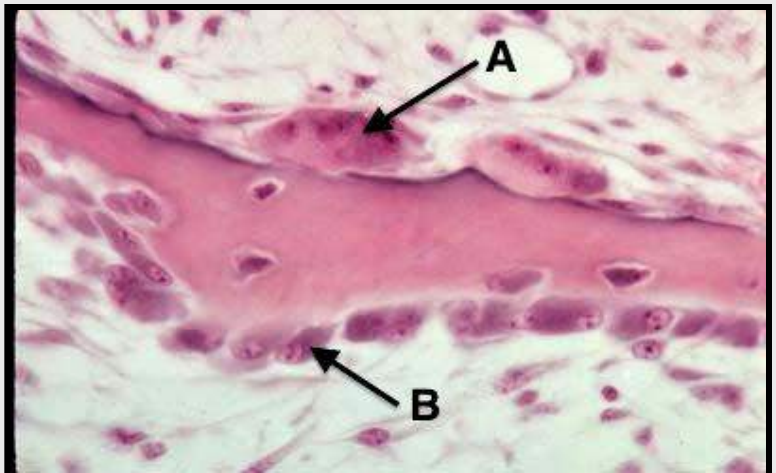
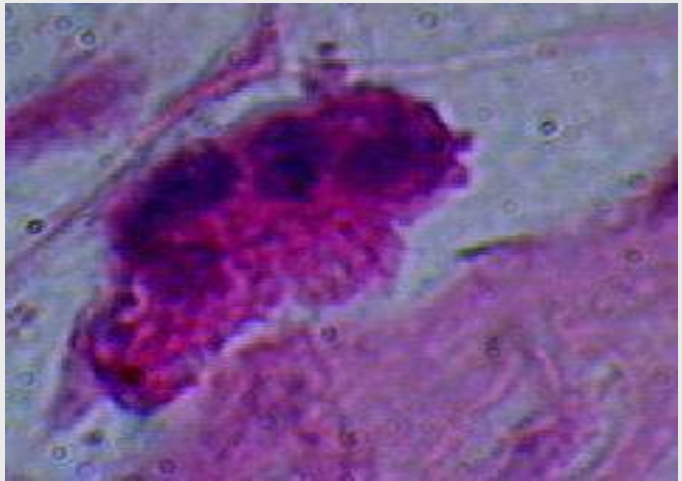
Osteoclasts (bone breaking cells)

- Very **large** which vary greatly in shape
- **Multinucleate** (up to 50)
- On inner and outer surface of bone
- Lie in depressions on the surface called **Howship's lacunae**
- The cell surface facing the bone has short irregular processes **microvilli** called **ruffled border**
- **releases H ions** to provide acidic media
- Has many **lysosomes**, polyribosomes and rough EPR
- Lysosomal enzymes are secreted to digest the bone, like **acid phosphatase and collagenase**
- Resorb the **organic part** of bone
- It is thought that osteoclasts arise by fusion of **uninucleated osteoprogenitor** cells or from fused **monocytes** which emigrate from the blood.

- **Bone resorption** is the process by which osteoclasts **break down organic** part of bone and release the minerals, resulting in a transfer of calcium from bone fluid to the blood.





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Histogenesis (OSTEOGENESIS)

Osteogenesis is the name given to the development of bone tissue. The first bone to develop is a form of spongy bone known as **woven bone (immature bone or primary bone or bundle bone or non-lamellar bone).**

Woven bone is **not** usually found in people aged over 14 except for some specific locations including the vicinity of **sutures** of flat bones of the skull, in **tooth sockets**, and some **tendon insertions**. Woven bone also develops temporarily in cases of bone **fracture** and **repair**.

Lamellar bone (Mature bone, Secondary bone)

Most bone tissue is lamellar bone in which the tissue is well organized and regular.

Mature and immature bone

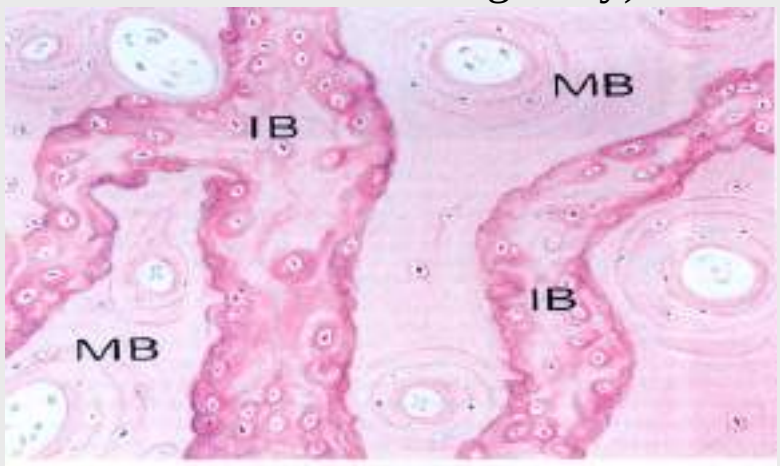
Most of the compact and spongy bone from adult skeleton display the pattern of lamellar bone which classified as adult or **mature bone (lamellar bone** or **secondary bone).** On the other hand, the bony tissue initially deposited on the skeleton of developing fetus is called **immature bone (woven bone** or **primary bone** or **nonlamellar bone** or **bundle bone).**

It differs from adult bone in several aspects

- No organized **lamellated** appearance (called nonlamellar or woven bone)
- It contains more **cells** per unit area than the mature bone
- The cells tend to be randomly **arranged**
- The matrix of immature bone has more **ground substance**
- It **forms** more rapidly than mature bone
- The **mineral** content is lower in immature bone
- It is the major bone type in **developing fetus** while mature bone is the major type in **adult** (although in remodeling areas the immature bone is seen regularly)

MB Mature Bone

IB Immature Bone



Histogenesis

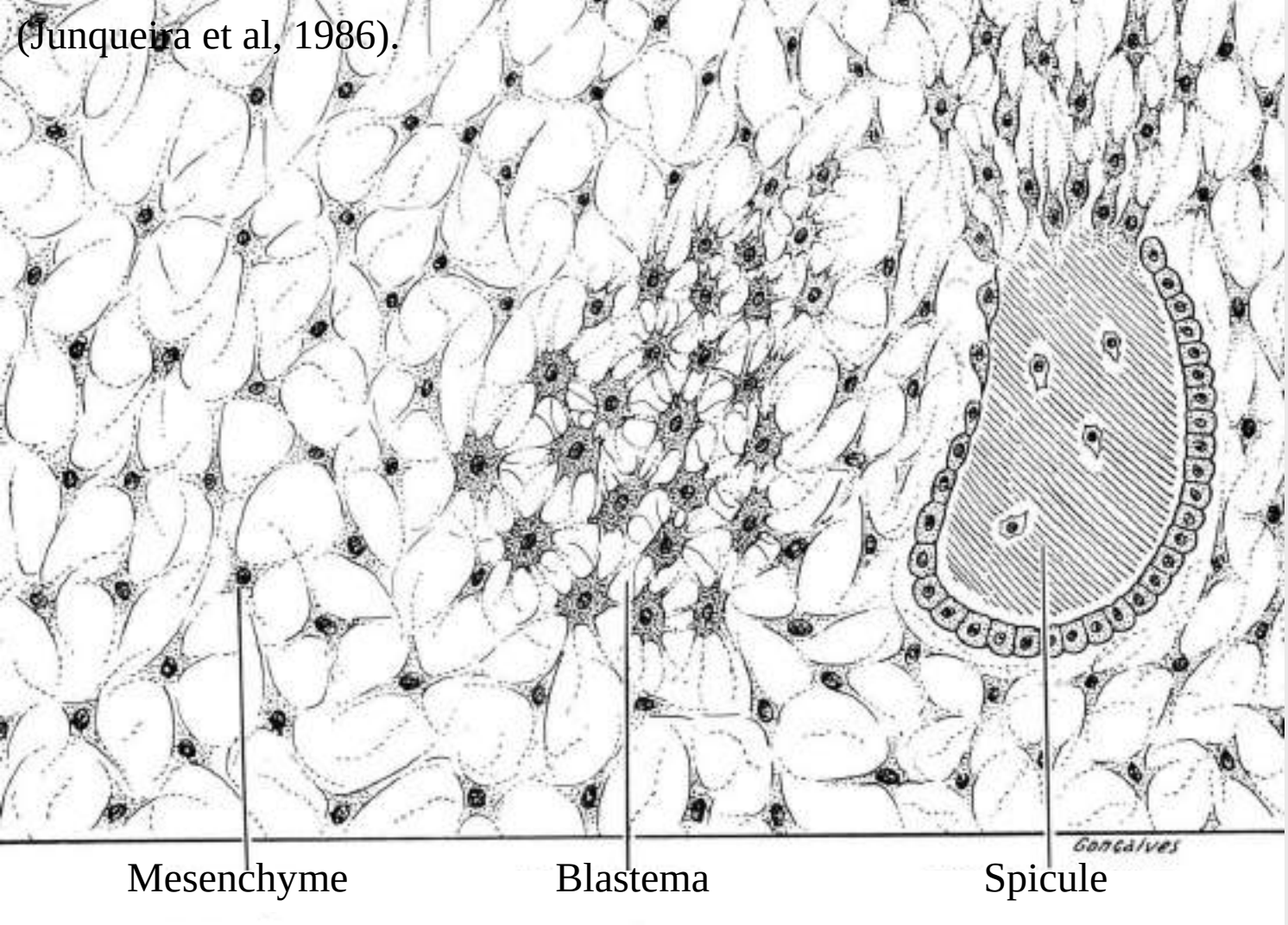
Two types of bone development.

- **intramembranous ossification**
- **endochondral ossification**

Intramembranous ossification

- Intramembranous ossification occurs during the embryonic development of many **flat bones** of the **skull** ("membrane bones") and **jaw**.
- This type of bone development takes place within a membranous, condensed plate of **mesenchymal cells**
- Mesenchymal cells condense to form a **primary ossification centre** (**blastema**)
- Some of the condensed mesenchymal cells change to **osteoprogenitor cells**
- Osteoprogenitor cells change into **osteoblasts** which start to deposit bone
- As the osteoblasts deposit bone some of them become trapped in lacunae in the bone and then change into **osteocytes**
- Osteoblasts lie on the surface of the newly formed bone
- As more and more bone is deposited more and more osteocytes are formed from mesenchymal cells
- The bone that is formed is called **a spicule**
- This process takes place in **many places** simultaneously
- Osteogenic cells in the **outer** and **inner** surfaces will proliferate to form **periosteum** and **endosteum** respectively
- The osteogenic cells in the periosteum will differentiate to form compact bone
- The **spicules** fuse to form **trabeculae**
- Blood vessels grow into the spaces between the trabeculae
- Mesenchymal cells in the spaces give rise to hemopoietic tissue

(Junqueira et al, 1986).



On the left hand side are mesenchymal cells. They condensate to form a blastema. The cells in the blastema change to osteoprogenitor cells which become osteoblasts that deposit a spicule of bone. Osteoprogenitor cells become osteoblasts that position themselves on the spicule and deposit bone. When an osteoblast becomes trapped in bone it is called an osteocyte. Around the spicule are osteoblasts and in the spicule are osteocytes.

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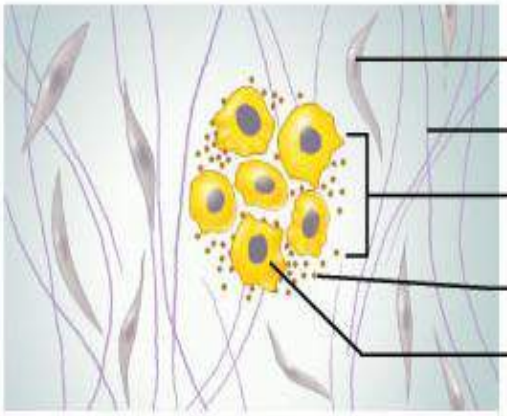
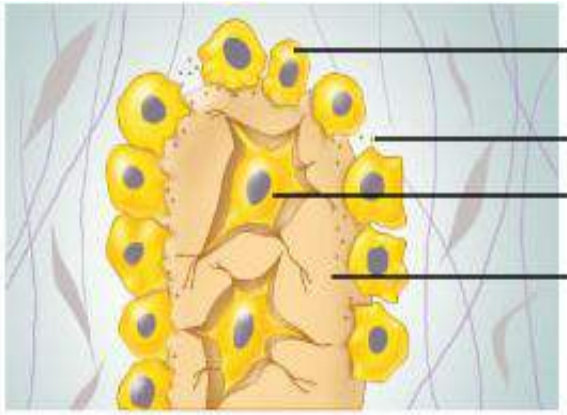


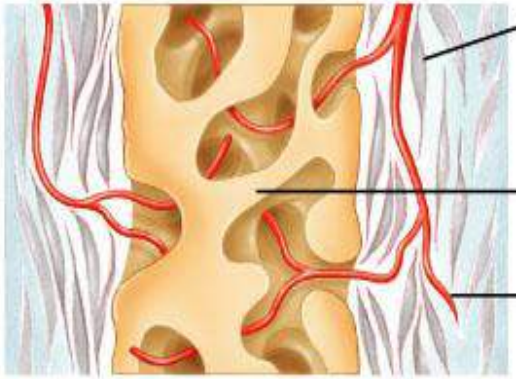
① An ossification center appears in the fibrous connective tissue membrane.

- Selected centrally located mesenchymal cells cluster and differentiate into osteoblasts, forming an ossification center.



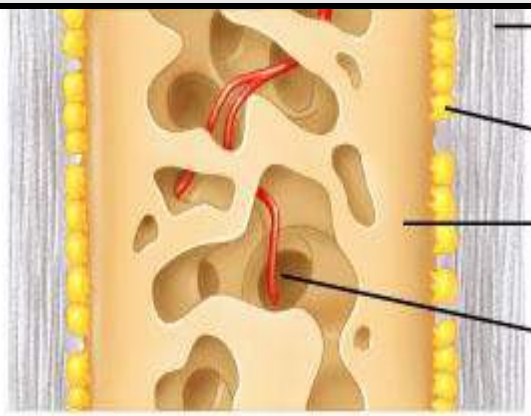
② Bone matrix (osteoid) is secreted within the fibrous membrane.

- Osteoblasts begin to secrete osteoid, which is mineralized within a few days.
- Trapped osteoblasts become osteocytes.



③ Woven bone and periosteum form.

- Accumulating osteoid is laid down between embryonic blood vessels, which form a random network. The result is a network (instead of lamellae) of trabeculae.
- Vascularized mesenchyme condenses on the external face of the woven bone and becomes the periosteum.



④ Bone collar of compact bone forms and red marrow appears.

- Trabeculae just deep to the periosteum thicken, forming a woven bone collar that is later replaced with mature lamellar bone.
- Spongy bone (diploë), consisting of distinct trabeculae, persists internally and its vascular tissue becomes red marrow.

Endochondral ossification

- A **cartilage model** exists this process begins during the **third month** of gestation and typically in the **long bones**.
- Through **intramembraneous ossification** a **collar of bone** (**periosteal collar**) forms around the middle part of the cartilage model
- The **perichondrium** change to a **periostium**
- The bone collar cuts off the nutrient and oxygen supply to the chondrocytes in the cartilage model. The **chondrocytes** then increase in **size and resorb** the surrounding cartilage matrix until only **thin vertical septae** of matrix are left over. These thin plates then calcify after which the chondrocytes die
- The **osteoclasts** make **holes** in the bone collar through which **blood vessels** can now enter the cavities left behind by the chondrocytes
- With the blood vessels **osteoprogenitor cells** enter the tissue
- They position themselves on the calcified cartilage septae, change into osteoblasts and start to deposit bone to form **trabeculae**
- In the mean time the periosteum is depositing bone on the outside of the bone collar making it thicker and thicker
- The trabeculae, consisting of a core of calcified cartilage with bone deposited on top of it, are eventually resorbed by osteoclasts to form the **marrow cavity**
- The area where this happens is the **primary ossification** centre and lies in what is called the **diaphysis** (shaft)
- This process spreads in **two directions** towards the two ends of the bone the epiphysis

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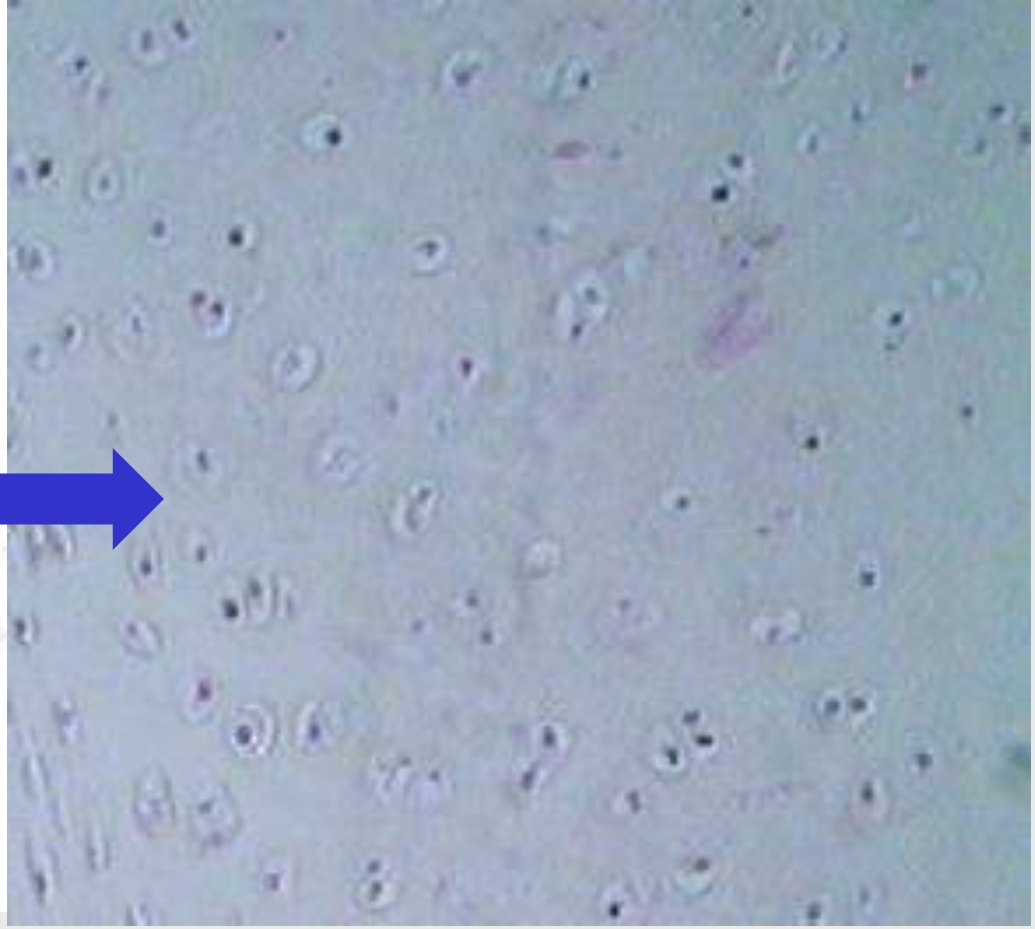
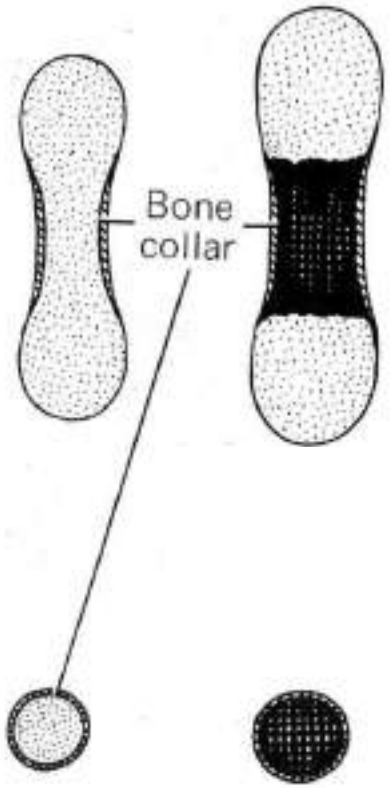
•At about the time **of birth**, **secondary centres (Epiphyseal centres)** of ossification appear in both ends of most long bones. A **secondary ossification** centre develops from where ossification spreads **radially**. Here **no bone collar** forms
•The outer layer of the original cartilage remains behind to form the **articulating cartilage**
•Between the primary and the secondary ossification centres **growth plates** (**epiphyseal plates**) of the **metaphysis** remain
•This is where the bone grows **in length**
•When the child reaches skeletal maturity (18 to 25 years of age), all of the cartilage is replaced by bone, fusing the diaphysis and both epiphyses together (**epiphyseal closure**).

(Junqueira et al, 1986).



On the left is the cartilage model of a long bone. On the right is hyaline cartilage.

(Junqueira et al, 1986).



Proliferation

On the left is shown how the perichondrium changes to a periosteum and lay down a bone collar around the shaft of the cartilage model. On the right is shown what is going on in the cartilage of the shaft. Chondrocytes proliferate to form stacks. Between the cells are horizontal septae ↑. Between the stacks are vertical septae ↓.

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Cell in the proliferation stage

Cell in the hypertrophic stage – cells get progressively bigger.

Vertical septum gets narrower.

Still the hypertrophic stage – cells get progressively bigger.

Cell is at its biggest and start to degenerate

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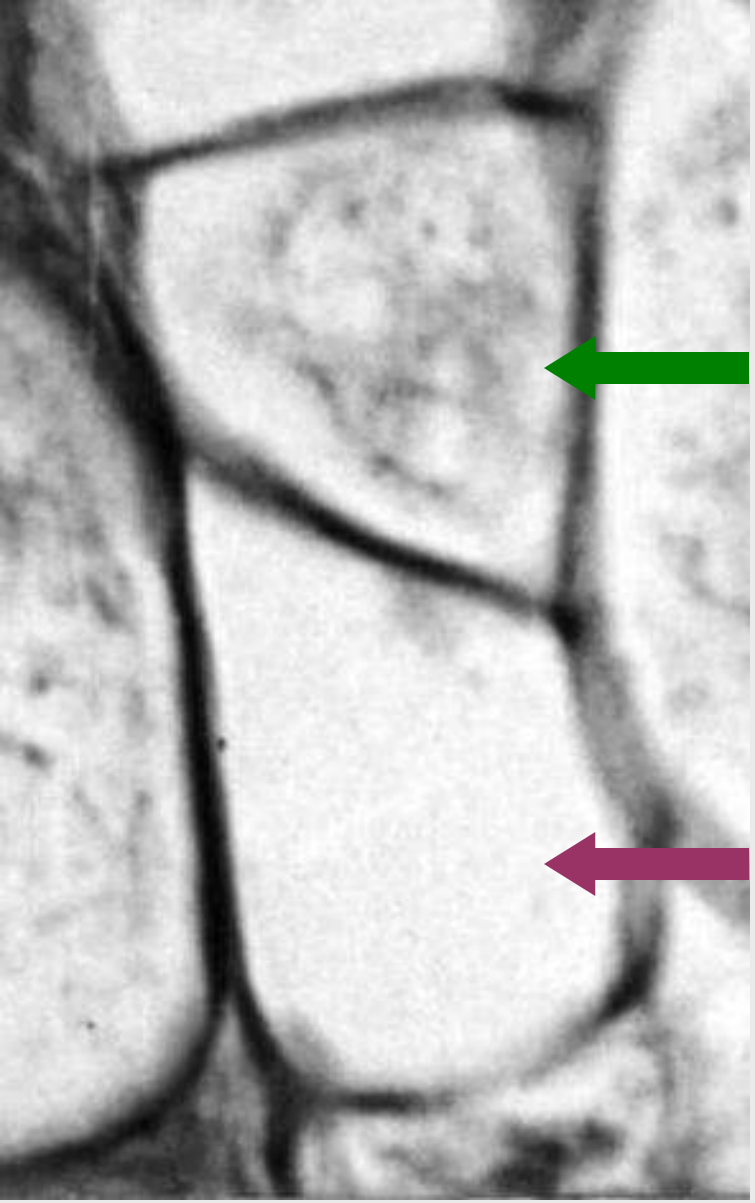

Degenerating cell (Chondrocyte)

Cell has died and only the empty space remains

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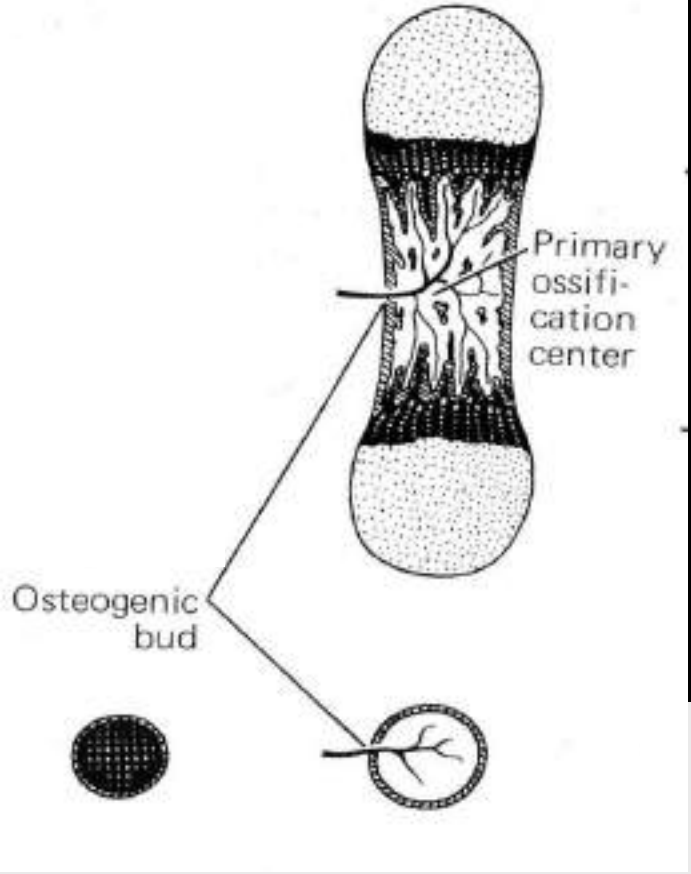
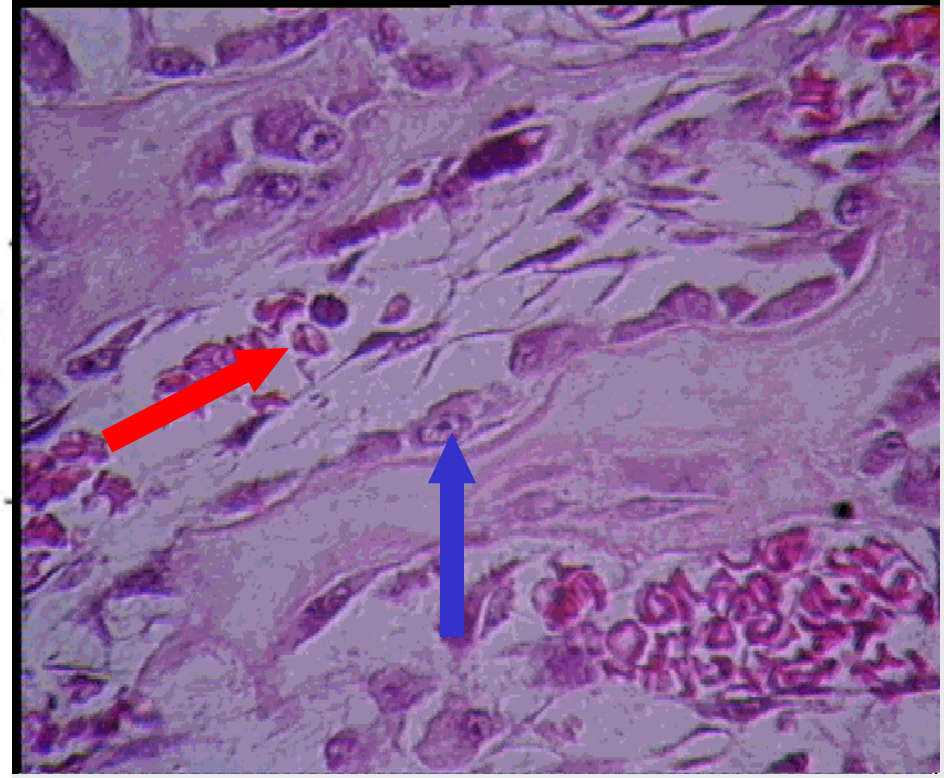
(Junqueira et al, 1986).





On the left is shown how blood vessels enter through the bone collar. One can also see that the bone that has formed in the center of the shaft has been destroyed to make the marrow cavity.

On the right the → indicate how blood enter the spaces left by the chondrocytes that had died bringing in osteoprogenitor cells. The ↑ shows an osteoblast that has positioned itself on the calcified cartilage septum and is now depositing bone.

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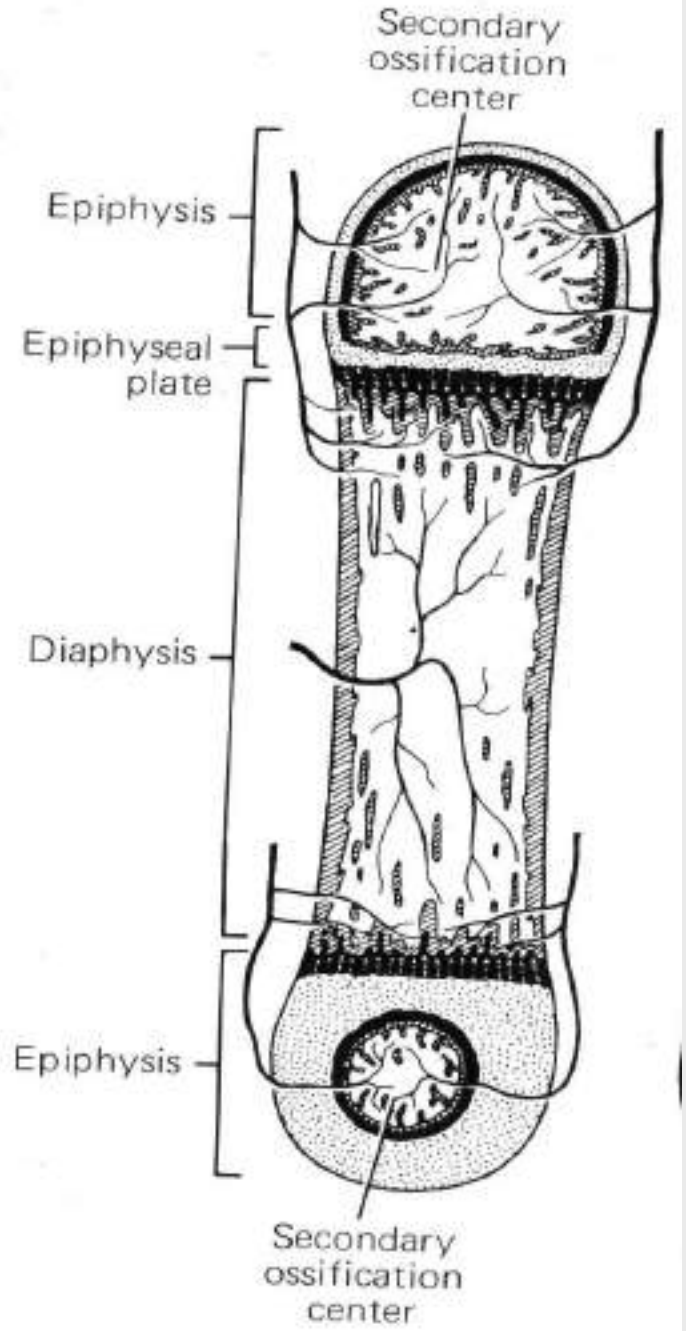

(Junqueira et al, 1986).

In this drawing the marrow cavity that has formed in the in the shaft (diaphysis) can be seen. In the epiphysis the secondary ossification center is shown. In this center all the previously shown processes have taken place:

Proliferation
Hypertrophy
Calcification
Ossification

Between the epiphysis and the diaphysis the **epiphyseal plate** remains. This is where **Growth in length** of bone takes place.

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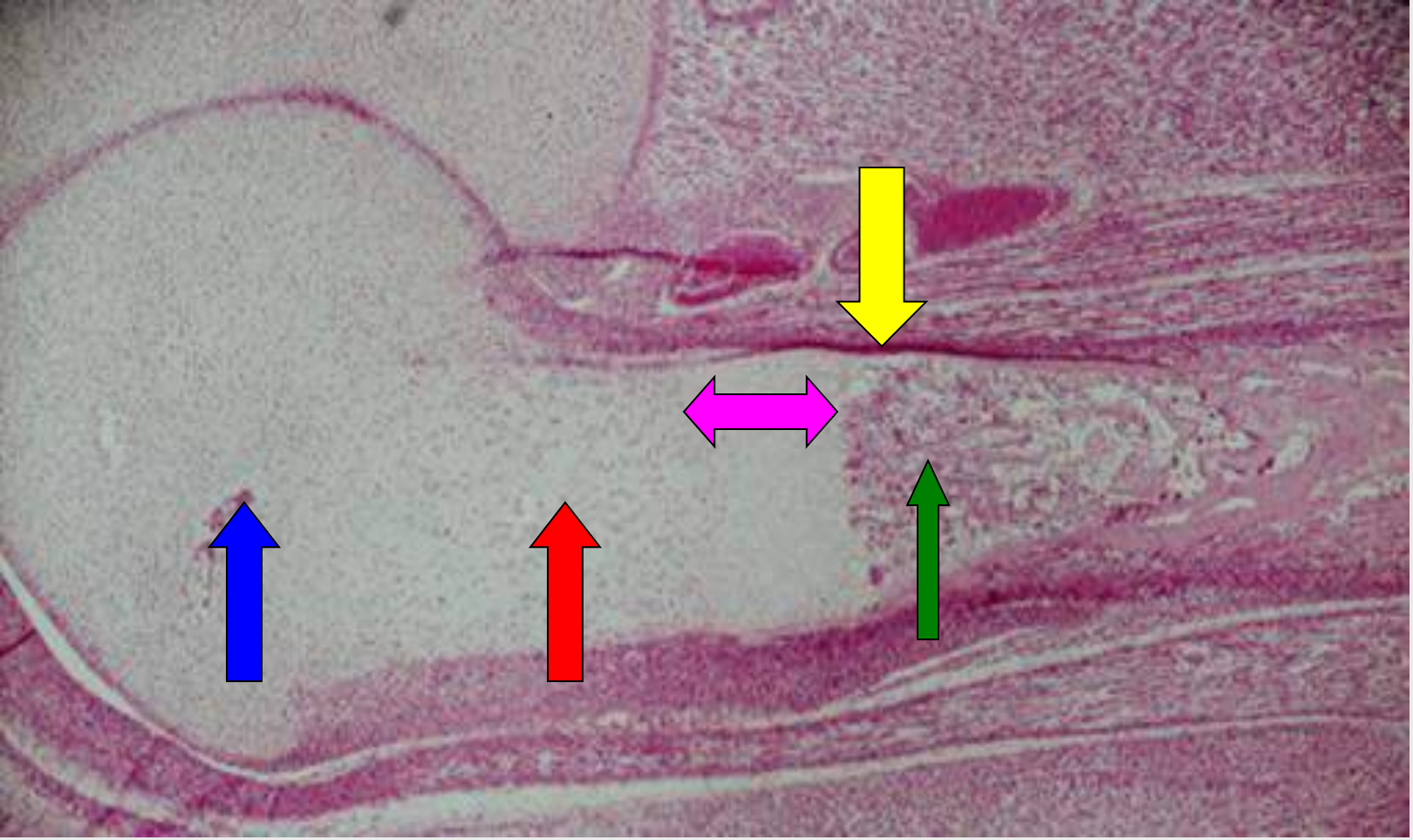

↑resting cartilage.
↑proliferation zone
↔epiphyseal plate (hypertrophic zone).
↑ossification zone
↓ bone collar.

The epiphyseal plate moves to the left and in the process the bone lengthen.

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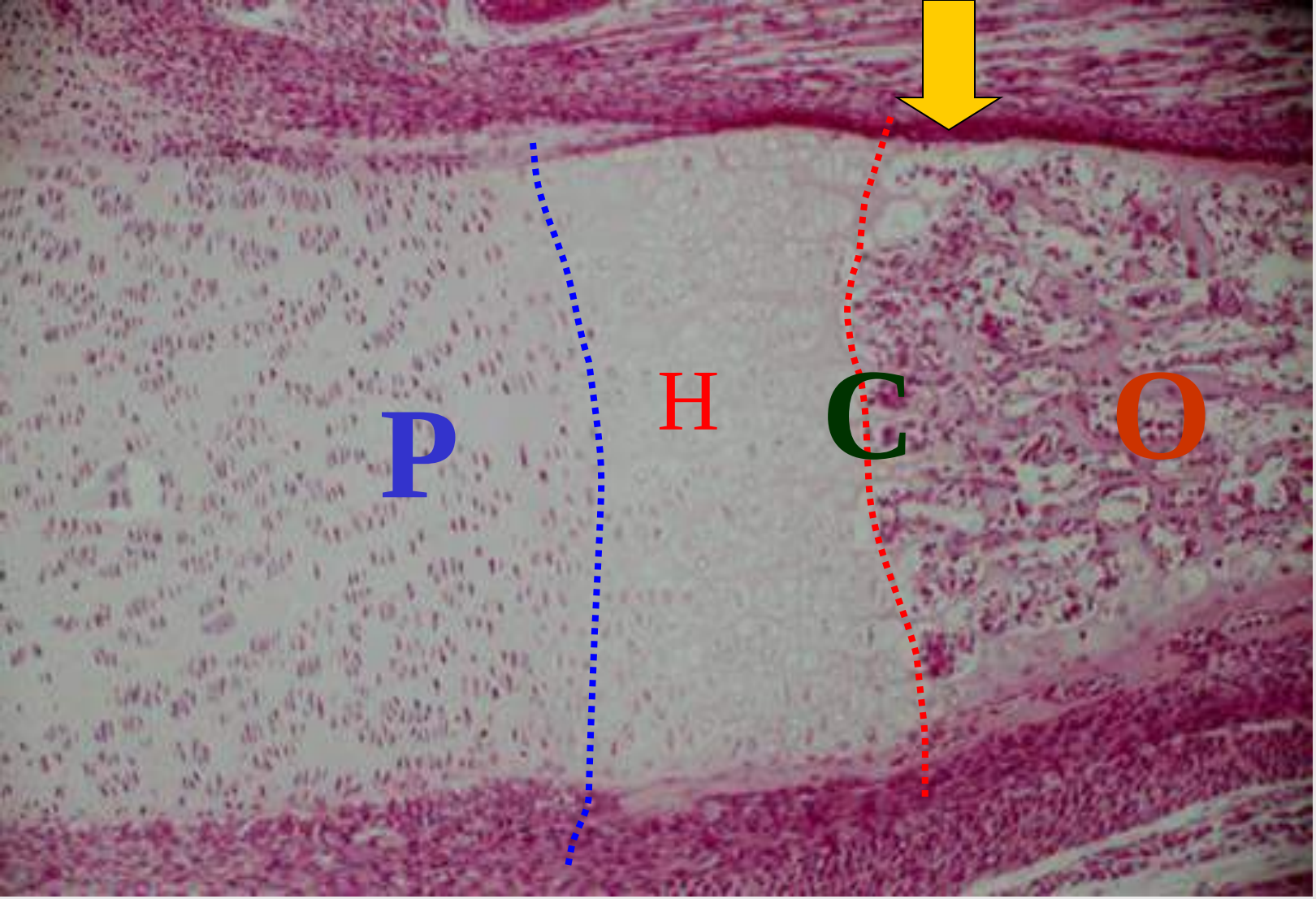

Chondrocytes proliferate P. Then they get bigger H (hypertrophy). Then the cartilage septae between the chondrocytes calcify and the chondrocytes die C. Bone is then deposited on the calcified cartilage septae by the osteoblasts O.

↓ bone collar.

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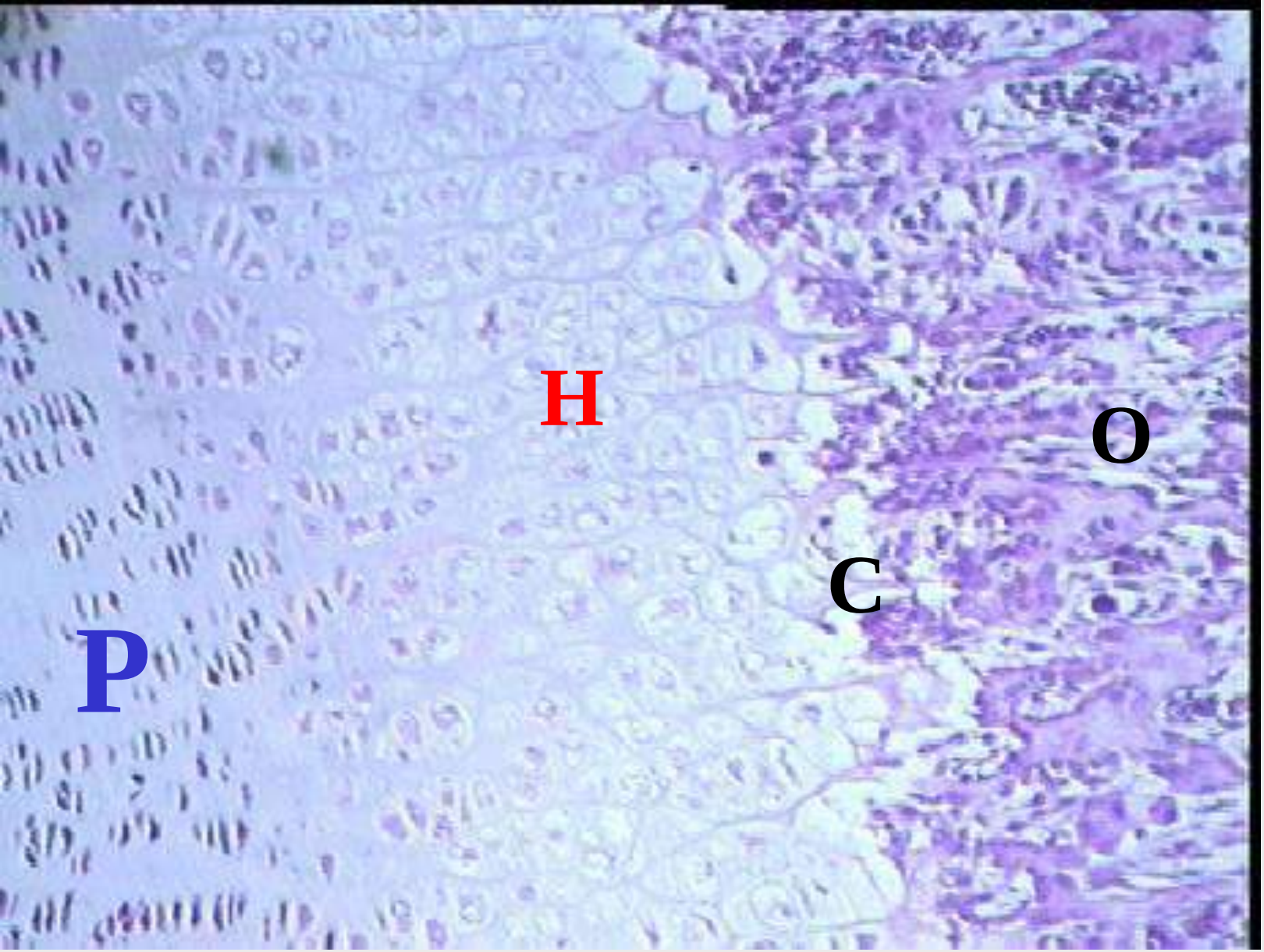

This is a closer look at the proliferation P, hypertrophic H, calcification C and ossification O zones.

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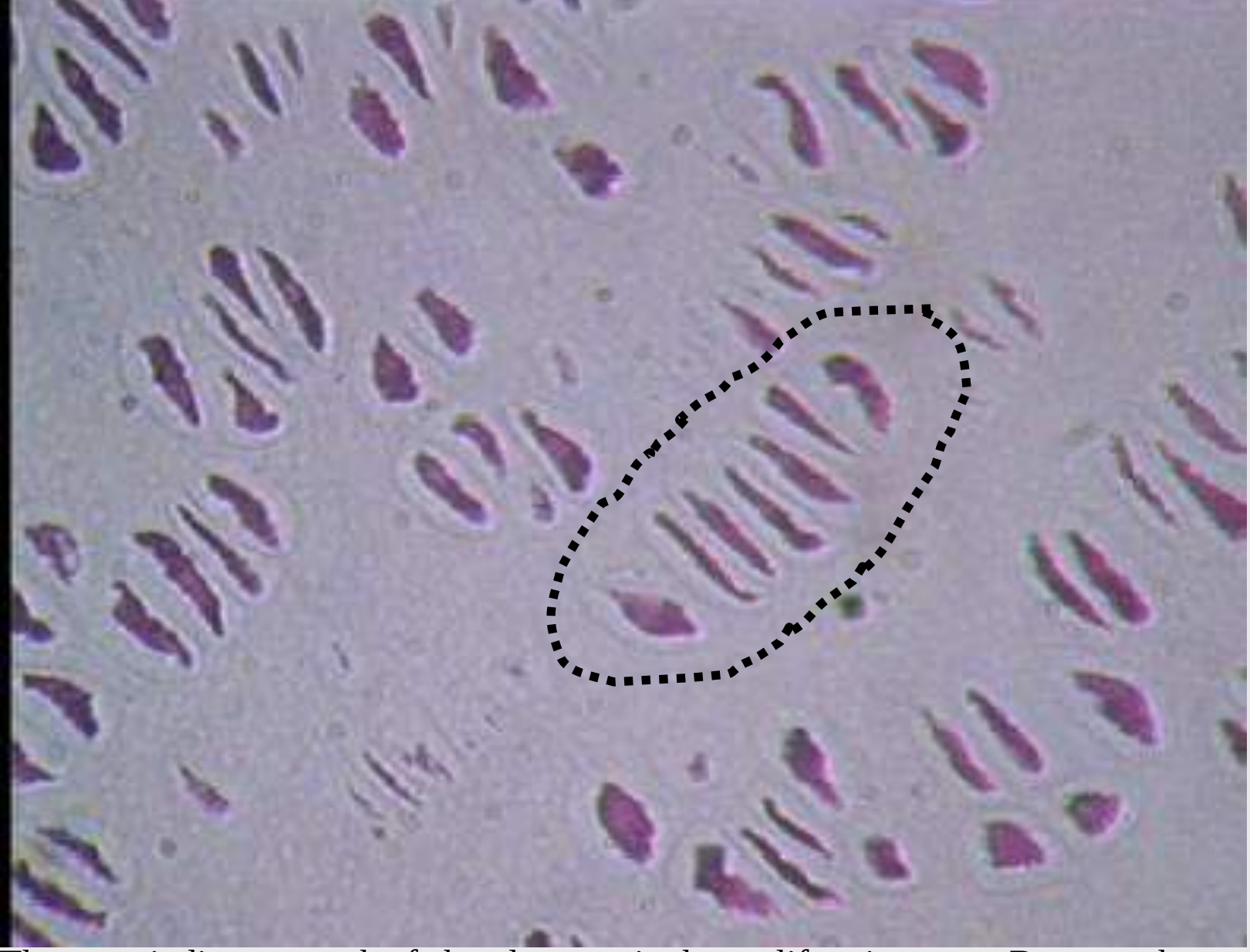

The ..... indicate a stack of chondrocytes in the proliferation zone. Between the stacks are vertical septae and between the chondrocytes are horizontal septae.

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The ..... shows where the proliferation zone change over into the hypertrophic zone. In the hypertrophic zone the chondrocytes get progressively bigger.

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The → shows a vertical septum which is calcifying. The chondrocyte indicated by the ..... is degenerating because the calcification cuts off its oxygen and nutrient supply. The ↑ indicate an empty space that forms because of the death of the chondrocyte. Blood invades these empty spaces bringing in osteoprogenitor cell that will change into osteoblasts, position themselves on the calcified cartilage plates and deposit bone.

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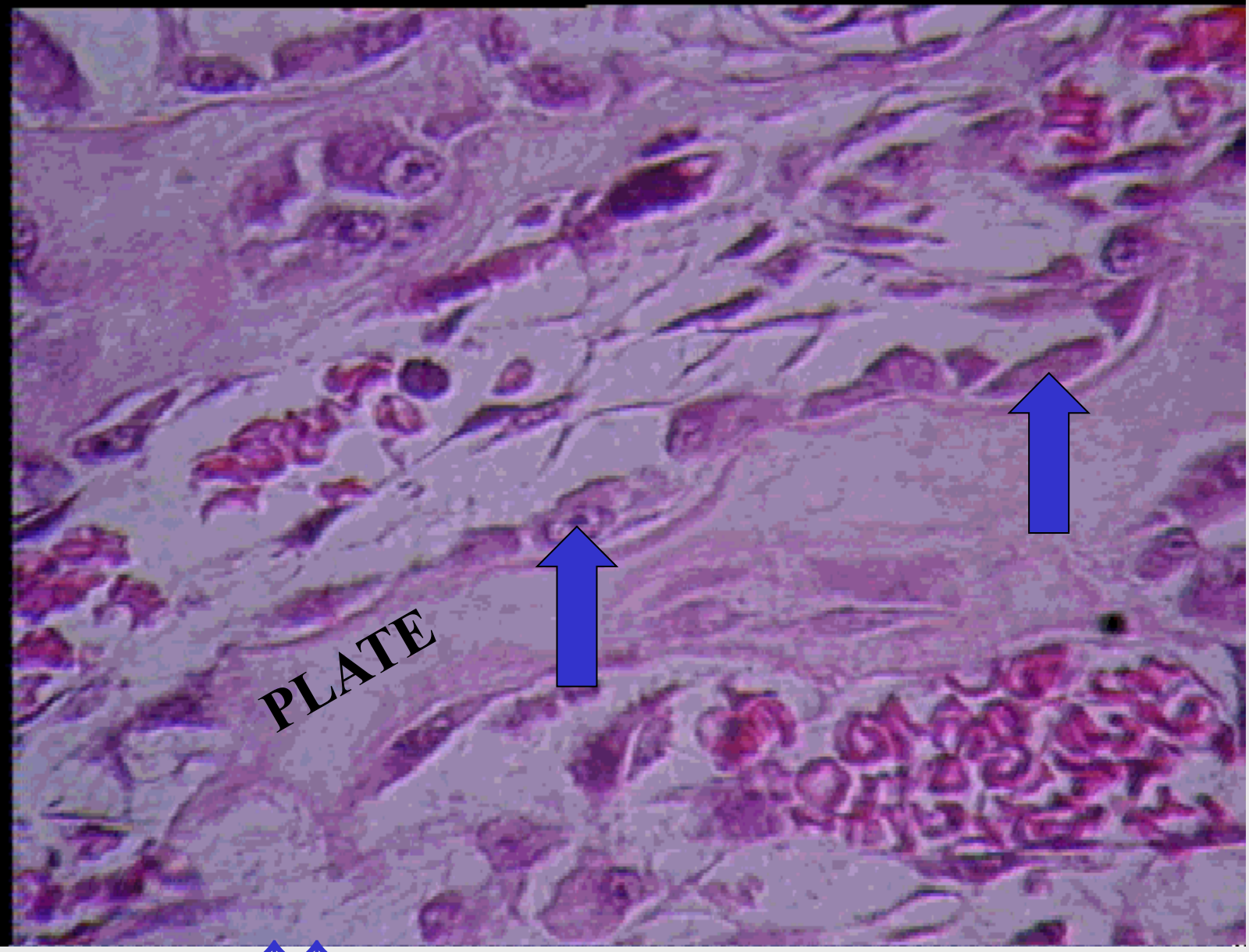

This slide shows ↑ ↑ osteoblasts lying on calcified cartilage plates, depositing bone.

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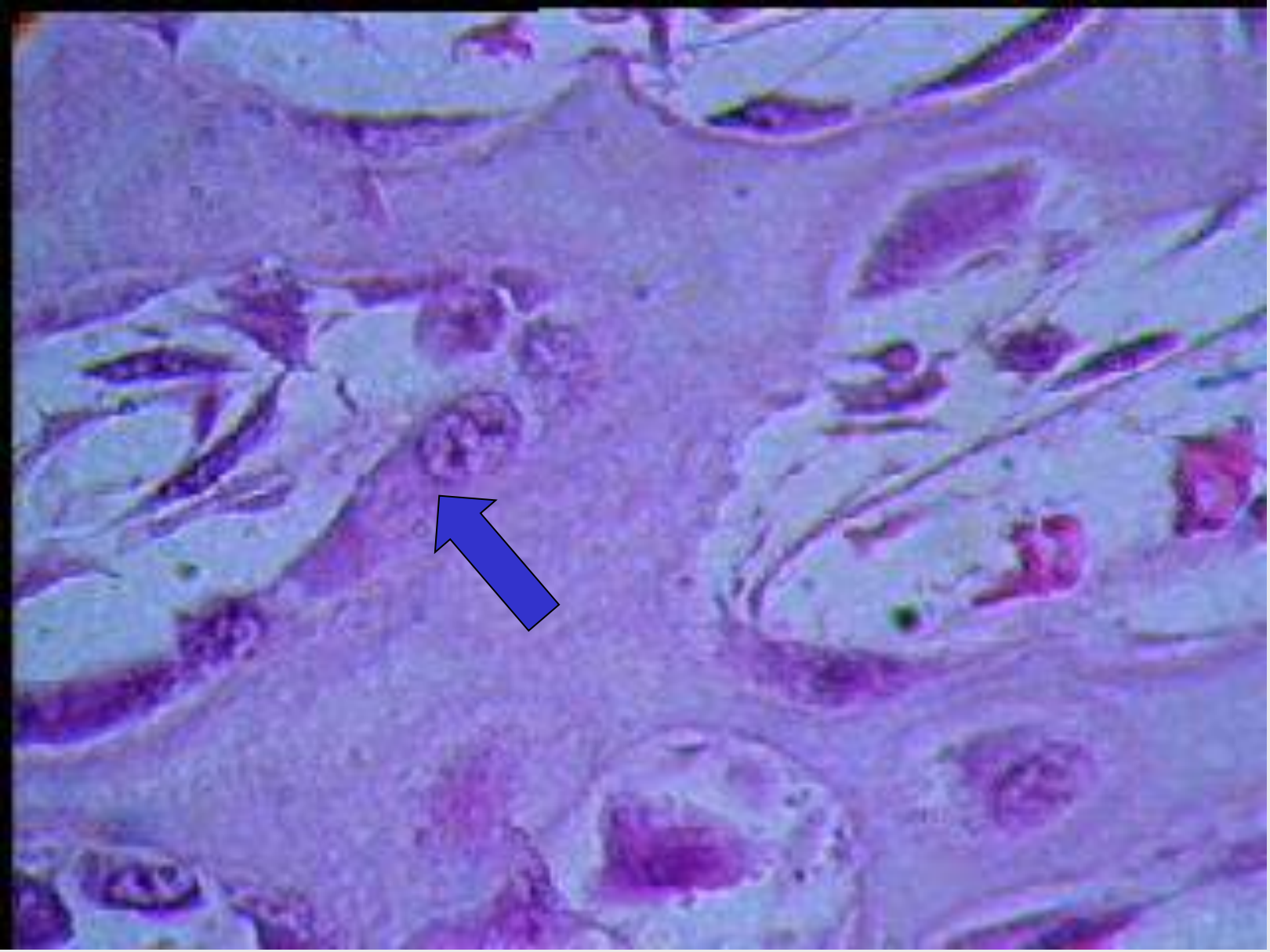

This is an osteoblast ↑ on a calcified cartilage plate, depositing bone.

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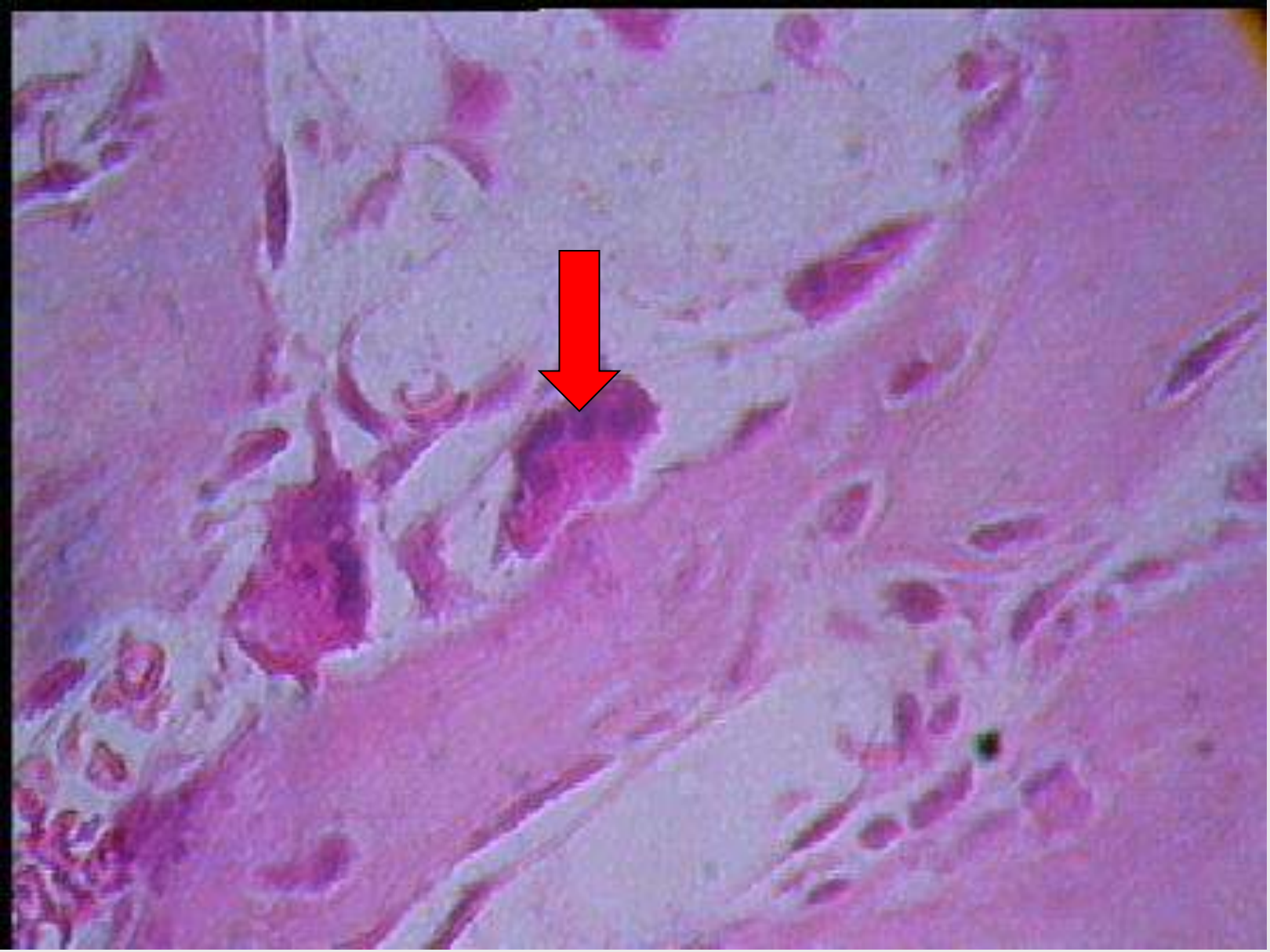

This is an osteoclast ↓. This cells breaks down some of the newly formed bone to make the marrow cavity.

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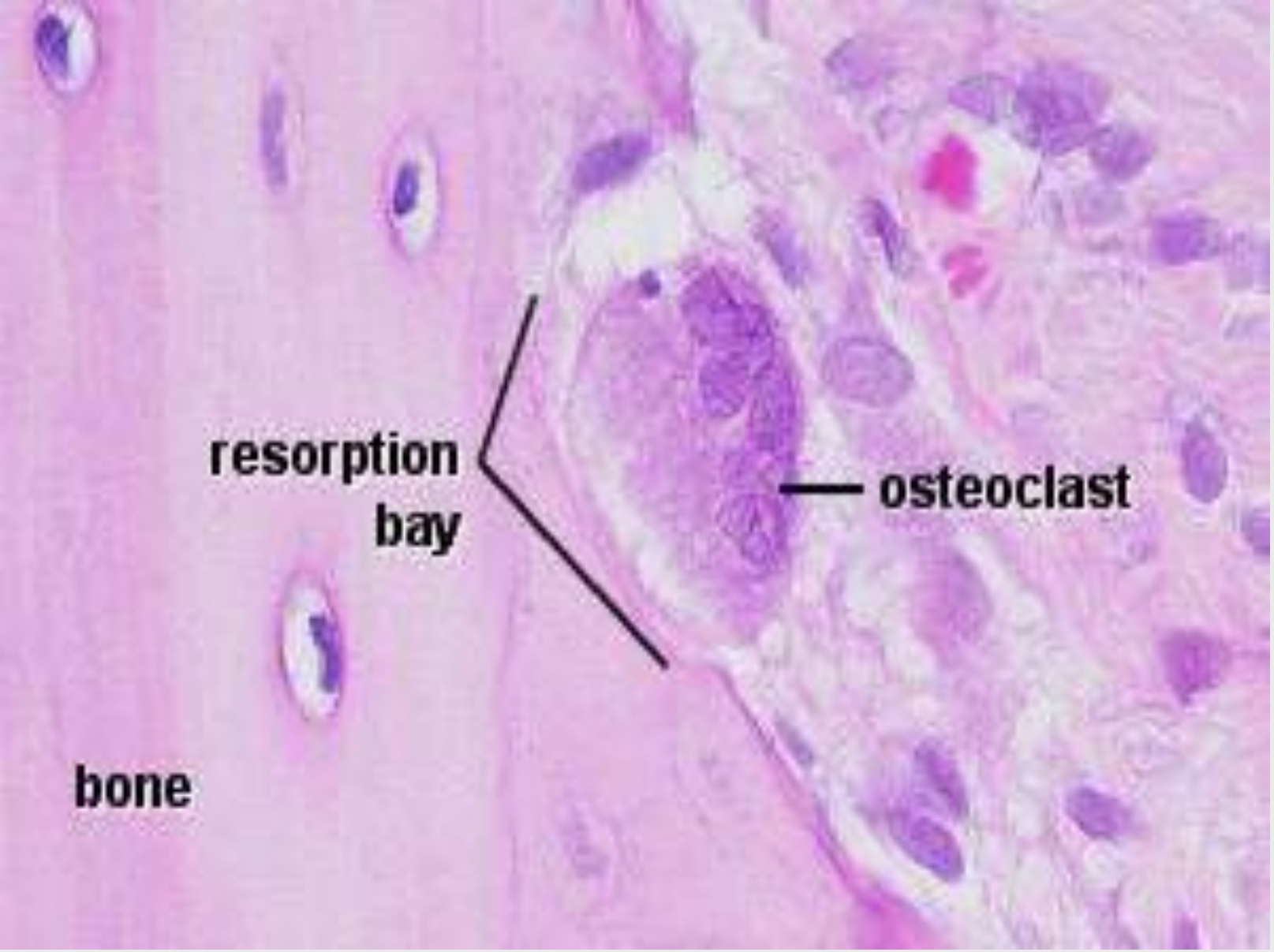

This is an osteoclast.

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Stages of Endochondral Ossification

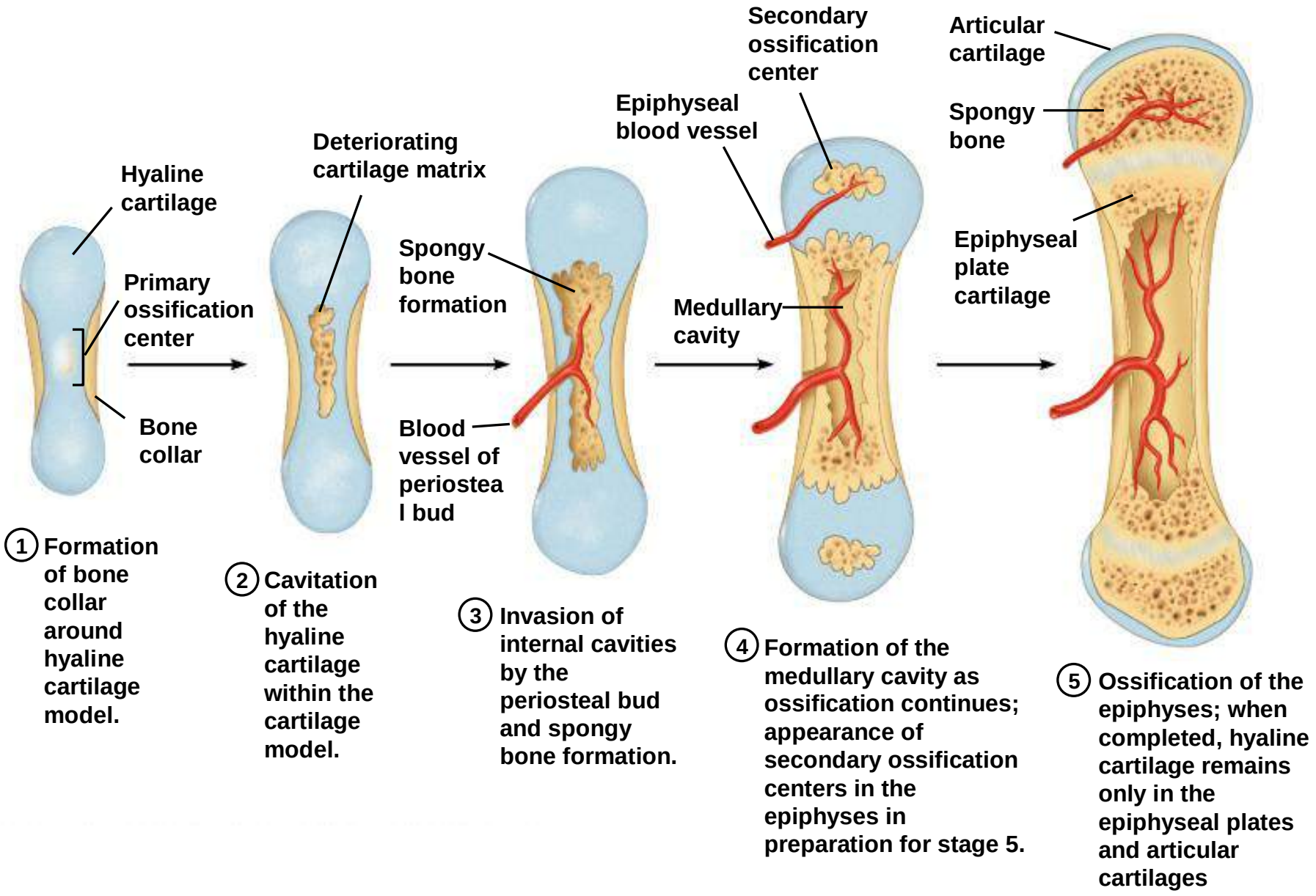

Figure 6.8

From the epiphyseal cartilage plate towards the diaphysis a number of zones can be identified:

(Bone grows in length)

- **Resting zone of cartilage**
  - Hyaline cartilage
- **Proliferation zone**
  - Chondrocytes divide to form columns of cells that mature.
- **Hypertrophic cartilage zone**
  - Chondrocytes become larger, accumulate glycogen, resorb the surrounding matrix so that only thin septae of cartilage remain
- **Calcification and degeneration zone**
  - The thin septae of cartilage become calcified.
  - The calsified septae cut off the nutrient supply to the chondrocytes so subsequently they die.
- **Ossification zone.**
  - Osteoclasts make openings in the bone collar through which blood vessels then invade the spaces left vacant by the chondrocytes that died.
  - Osteoprogenitor cells come in with the blood and position themselves on the calcified cartilage septae, change into osteoblasts and start to deposit bone.
  - When osteoblasts become trapped in bone they change to osteocytes.

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Growth and remodeling of bone

- Long bones become **longer** because of growth at the **epiphyseal plates**
- They become **wider** because of bone formed by the **periosteum**
- The marrow cavity becomes bigger because of resorption by the osteoclasts

-The architecture of bone is **not static.** Bone is constantly being destroyed and reformed in different regions simultaneously. It is a constantly reforming tissue (**bone remodelling**).

- **Bone remodeling** is a life long process where old bone is removed from the skeleton (a sub-process called bone resorption by osteoclasts) and new bone is added (a sub-process called bone formation by osteoblasts). These processes also control the reshaping or replacement of bone during growth and following injuries**.**

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Bone Fracture

Is a medical condition where the bone is cracked or broken, while many fractures are the result of high force impact or stress it also can result from pathological conditions e.g. osteoporosis, cancer and osteogenesis imperfecta.

Fracture healing

When bone is fractured a blood clot forms
Macrophages then remove the clot, remaining osteocytes and damaged bone matrix
The periosteum and endosteum produce osteoprogenitor cells that form a cellular tissue in the fracture area
Trabeculae connect the two ends of the broken bone to form a callus
fibrocartilaginous callus (soft callus**)** becomes hard (bony callus)
Remodelling then takes place to restore the bone as it was