Course Name- Developmental Biology
Paper code MZO(509)

Unit -11 Cleavage and Gastrulation

Dr. Mukta Joshi
Department of Zoology
Uttarakhand Open University,
Haldwani

Cleavage and gastrulation

Cleavage

- The development of multi-cellular organisms begins from a single-celled zygote, which undergoes rapid cell division to form the blastula. The rapid, multiple rounds of cell division are termed cleavage.
- The blastula is usually a spherical layer of cells (the blastoderm) surrounding a fluid-filled or yolk-filled cavity (the blastocoel). Mammals at this stage form a structure called the blastocyst, characterized by an inner cell mass that is distinct from the surrounding blastula. During cleavage, the cells divide without an increase in mass; that is, one large single-celled zygote divides into multiple smaller cells. Each cell within the blastula is called a blastomere.

- Cleavage can take place in two ways: holoblastic (total) cleavage or meroblastic (partial) cleavage. The type of cleavage depends on the amount of yolk in the eggs. In placental mammals (including humans) where nourishment is provided by the mother’s body, the eggs have a very small amount of yolk and undergo holoblastic cleavage. Other species, such as birds, with a lot of yolk in the egg to nourish the embryo during development, undergo meroblastic cleavage.

Characteristics of cleavage

- All division of cleavage are mitotic so that the daughter cells are provided with same number and types of chromosomes.
- During cleavage there is no growth in the resulting blastomeres. Consequently, there is increase in the number of cells during cleavage but the resulting blastomeres are only half the original size. Thus cleavage begins with a one large cell and ends in a large number of cells of very small size even smaller than the cells of adult.
- The size of the nucleus does not decrease with the decrease in the size of blastomeres. Therefore, the nuclear cytoplasmic ratio gradually increases. In the zygote the nuclear cytoplasmic ratio is very low because the size of nucleus is quite small in comparison to the size of ovum.

- The pace or rhythm of cleavage is determined by the cytoplasm rather than the nucleus. The quantity and pattern of distribution of yolk influences the pattern and pace of cleavage furrow.
- The reserve food present in the egg provides energy and the substance needed for the cell division.
- Although, the embryo does not grow during cleavage, the metabolic activities occur at a tremendous rate. It involves break down of substances stored in the egg cytoplasm into amino acids, monosaccharide's and lipid molecules and synthesis of nucleic acids and proteins that are used in the formation of spindle and duplication of chromosomes.

- For rapid nuclear divisions, there is great increase in the synthesis of DNA.
- Oxygen consumption is greatly increased during cleavage, showing the activeness of the embryo.
- Early cleavage division are synchronous because all the blastomeres of embryo divide simultaneously. However, this synchrony disappears after blastomeres have increased in number considerably.

Pattern of Cleavage

The patterns of cleavage due to organization of egg may be following types:

1. **Radial cleavage**

- The radial cleavage occurs when the successive cleavage planes cut straight through the egg, at right angles to one another and resultant blastomeres become symmetrical disposed around the polar axis. When such an egg is viewed from either pole, the blastomere are found to be arranged in a radially symmetrical form ,e.g., all animals having holoblastic cleavage such as *Synapta, Paracentrotus,* etc.

2. Bilateral cleavage:

- In bilateral cleavage the mitotic spindles and cleavage planes remain bilaterally arranged with reference to a plane of symmetry which coincides with the median plane of the embryo, e.g., Tunicate, Amphioxus, Amphibia and higher mammals.

3. Spiral cleavage:

- The spiral cleavage is found in which there is a rotational movement of cell parts around the egg axis.
- The cleavage plane does not pass straight through the axis of the egg but becomes oblique relative to the axis as well as to the equator of the egg. Therefore the blastomeres are disposed in regular tiers, which more or less alternate with one another.
- The turn of the spiral as seen from above may be in clockwise or anticlockwise direction or in couter- clockwise direction. In the first case the cleavage furrows are called dextral spiral cleavage and in the second case it is called sinistral spiral cleavage e.g., Turbellaria,

Nematoda, Rotifera, Annelida and all molluscs except cephalopods.

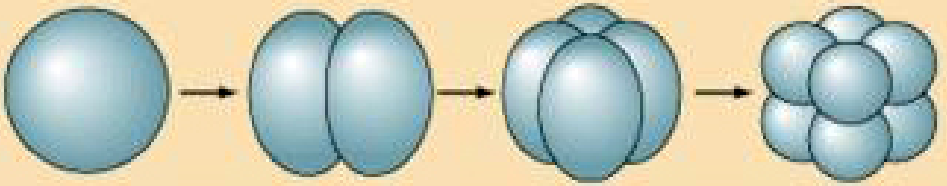
4. Determinate cleavage:

- In some animals (e,g., tunicate, molluscs, annelids, etc.), cleavage follows a precise pattern and each blastomere has its characteristic position and unalterable fate. Such type of cleavage is called determinate cleavage and it transforms a fertilized egg into a blastula which is mosaic, because its component blastomeres have received assignments according to an inflexible plan already completed at the time of fertilization.

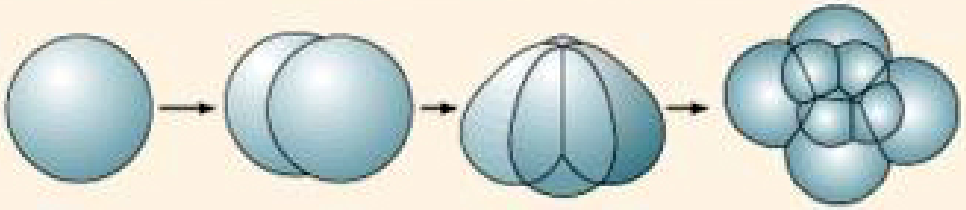
I. HOLOBLASTIC

A. **Isolecithal**

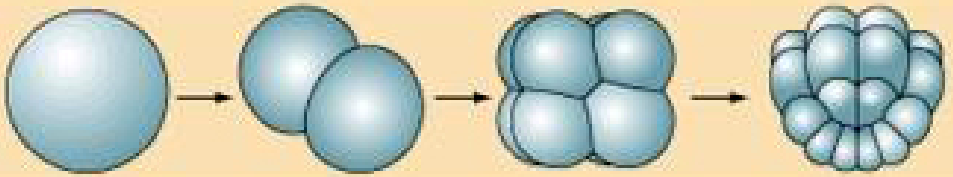
1. Radial
   Echinoderms, amphioxus



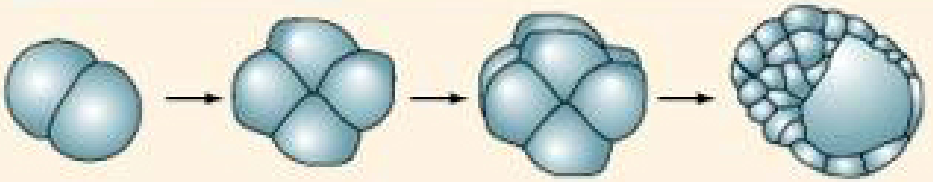
2. Spiral
   Annelids, molluscs, flatworms



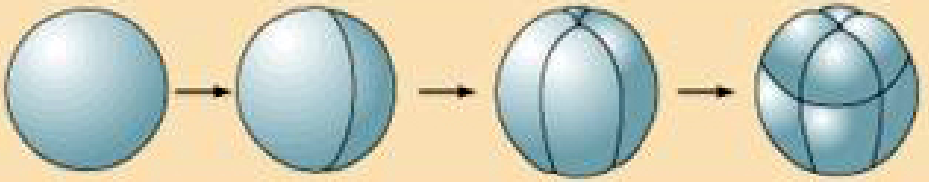
3. Bilateral
   Tunicates



4. Rotational
   Mammals, nematodes



B. **Mesolecithal**
   Radial
   Amphibians



Influence of yolk on cleavage

- The cleavage occurs more readily in the active cytoplasm than the yolk-laden cytoplasm or deutoplasm of the egg.
- The yolk is a non living component of the egg. It participates neither in cleavage nor in the formation of embryo.
- It provides nourishment to the developing embryo.
- The yolk is present in all animal eggs in little(e.g., microlecithal eggs) or larger (e.g., mesolecithal and macrolecithal eggs) amounts remains distributed evenly (e.g., isolecithal eggs) or unevenly (e.g., telolecithal eggs) in the ooplasm of different kinds of eggs. It has a profound deterring influence on cleavage and mechanics of moving the germ layers into their final positions.

The amount of yolk influences the course of cleavage by following ways:

1. When the amount of stored yolk increase, the amount of active cytoplasm gradually decreases, and the position of nucleus is variously affected. In mesolecithal eggs, such displacement of zygotic nucleus from the geometrical centre of the egg to the less yolky (active) cytoplasm is very common. The mitotic division of such a displaced nucleus result in unequal cytokinesis and unequal sized blastomere.
2. Every mitosis of cleavage involves movement of the cell components, the chromosomes, parts of the cytoplasm constituting the achromatic figure, the mitochondria and the surface layer of the cell, the activity of which along the equator of the maternal cell lead to the eventual separation of the daughter cells.

Thus amount and distribution of yolk may determine the cleavage following kinds:

A) **Total or holoblastic cleavage:** In total, complete or holoblastic type of cleavage the entire egg divides by each cleavage furrow. It is two types:

(i) Equal holoblastic cleavage: When holoblastic cleavage occurs in micrlecithal and isolecithal eggs, it produces blastomeres of equal or approximately equal size, e.g., *Amphioxus,* marsupials and placental mammals.

(ii) Unequal holoblastic cleavage: In mesolecithal and telolecithal eggs, the holoblastic cleavage produces unequal sized blastomeres, which include many small sized blastomeres called micromeres, and few large sized, yolk laden biastomeres called macromeres, e.g., lower fishes and amphibians.

B. Meroblastic cleavage: The partial, incomplete or meroblastic cleavage occurs in macrolecithal and centrolecithal eggs. In such a cleavage, the furrows divided the small amount of active cytoplasm of animal pole or periphery of egg and most of the yolky portion of vegetal pole or central area of egg remain undivided. The meroblastic cleavage following two types:

(i) Discodal: In the macrolecithal and highly teiolecithal egg, the cleavage, remains restricted to the disc shaped active cytoplasm of animal pole, and is called discodal meroblastic cleavage, e.g., elasmobranch fishes, bony fishes, reptile, birds and monotreme mammals.

(ii) Superficial: In centrolecithal eggs, the cleavage remain restricted to the peripheral cytoplasm investment of egg, e.g., arthropods.

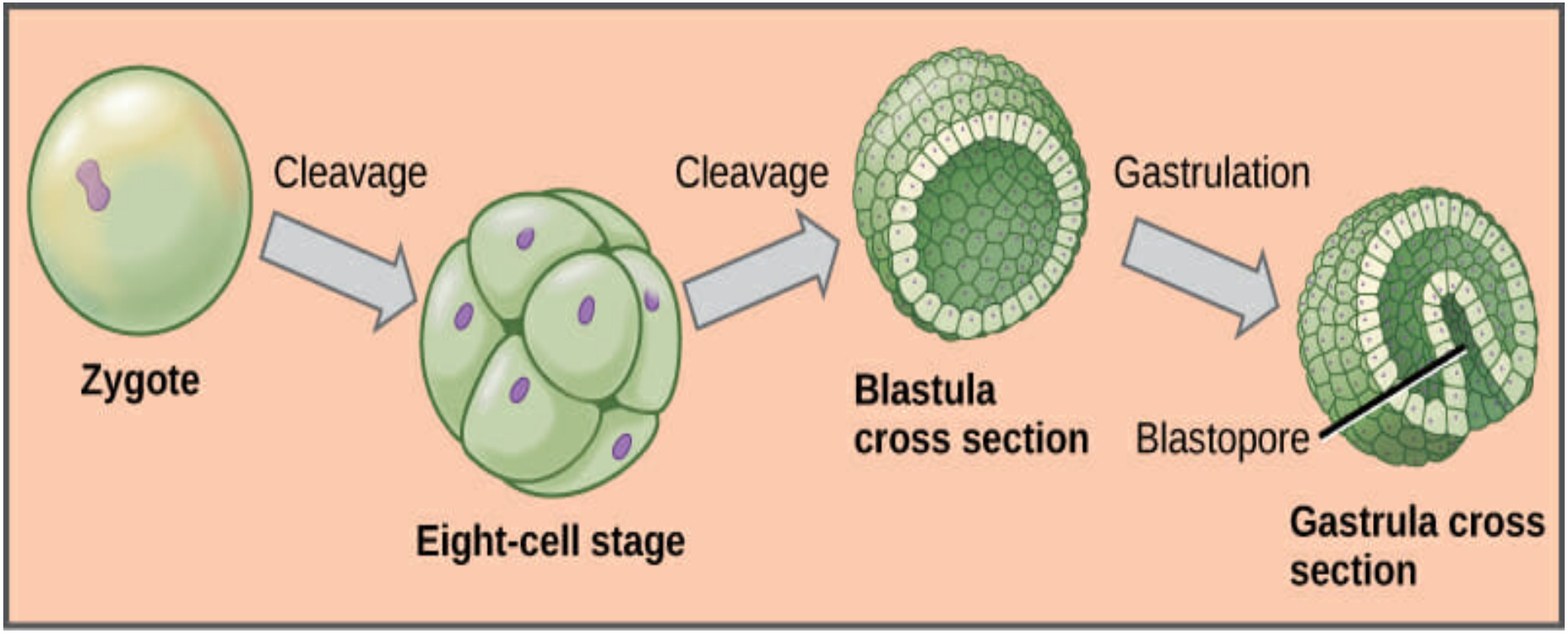
Significance of cleavage, morulation and blastulation

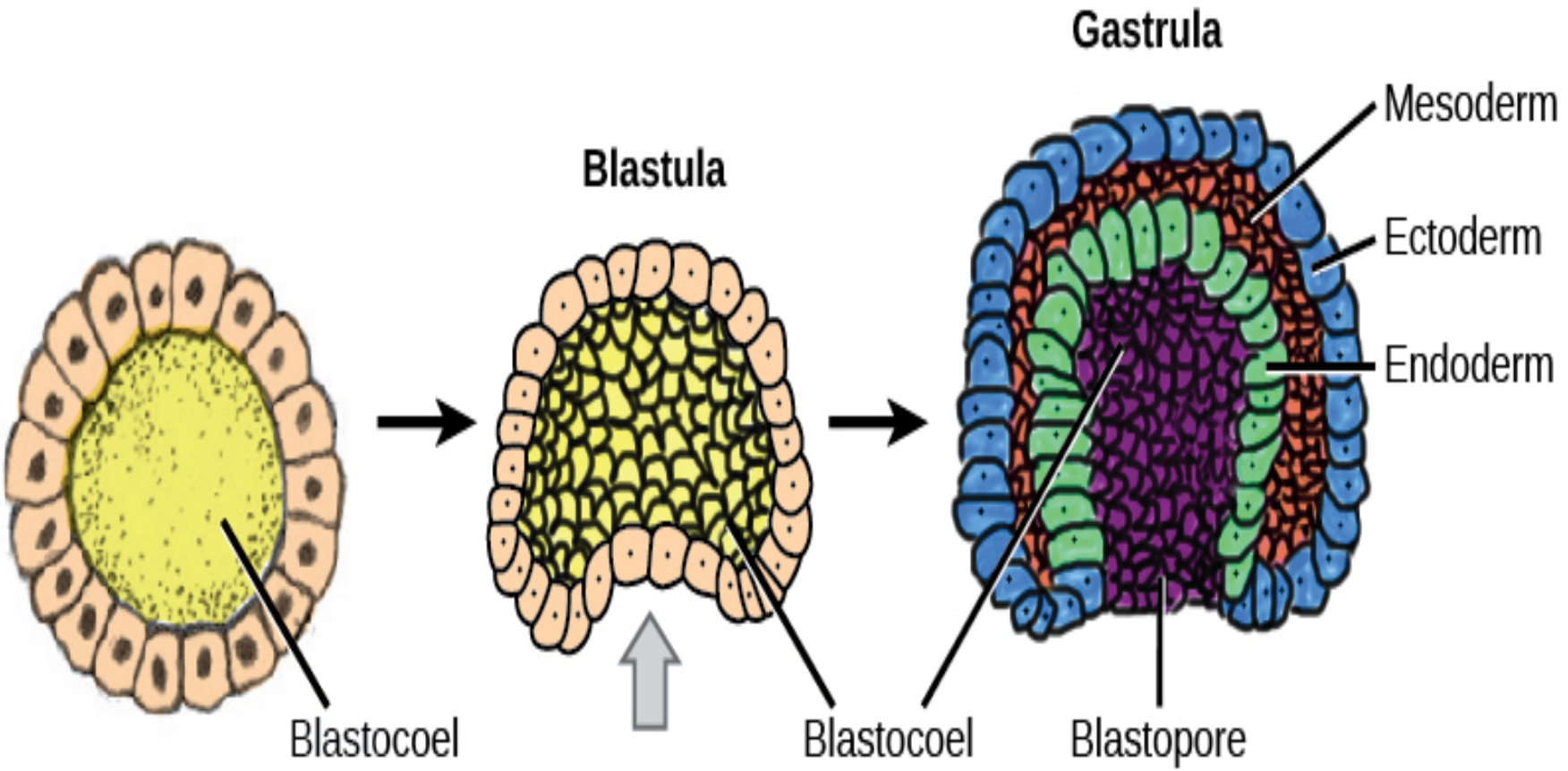
- The significance of cleavage, morulation and blastulation comprises three aspects- subdivision of the embryo genetic substrate into an array of cells, preparation for and occasionally even the initiation of the process of the cell differentiation or diversification and the creation of a cell aggregate which, through the activity of morphogenetic process, may be subjected to further morphological changes (gastrulation).
- Further, due to cleavage and blastulation the major presumptive organ forming area of the future embryonic body segregated into definite parts of the blastoderm.
- The blastocoele permits the migration and rearrangement of the major presumptive organ forming areas during gastrulation.

Gastrulation

- Gastrulation is the embryonic process brings about the reorganization and displacement of organ forming areas of a blastula.
- It converts a simple one layered (monodermic) blastula into a two layered (didermic, *Amphioxus)* or often a three layered (tridermic, e.g., all vertebrata) embryonic stage, called gastrula.
- The single layer of blastula is known as blastoderm, ectoblast or protoderm.
- The resultant three layers of gastrula- the outer **ectoderm,** the middle **mesoderm** and inner **endoderm** are commonly known as germ layers.

- The ectoderm gives rise to the nervous system and the epidermis; the mesoderm gives rise to the muscle cells and connective tissue in the body; and the endoderm gives rise to columnar cells found in the digestive system and many internal organs.
- During gastrulation, the cavity of the blastula is obliterated and a new cavity, called archenteron or gastrocoel (cavity of gastrula) enclosed by endoderm is formed. It is also during the gastrulation that the embryo acquires its clear cut antero-posterior polarity and bilateral symmetry.
- Through the process of gastrulation varies greatly in different groups, but in most cases basically it involves the same cellular mechanisms: large scale movement, called **morphogenetic movements** (e.g., invagination, involution, ingression, epiboly,etc.).


Cleavage
Cleavage
Gastrulation
Zygote
Eight-cell stage
Blastula
cross section
Blastopore
Gastrula cross
section


Gastrula
Mesoderm
Blastula
Ectoderm
Endoderm
Blastocoel
Blastocoel
Blastopore

Major events of gastrulation

The process of gastrulation involves the following main events:

1. A rearrangement of blastular cells or blastomere by means of formative or morphogenetic movements occurs.
2. The rhythm of cellular division (cellulation or cleavage) is slowed down or almost is inhibited.
3. Growth, if any, is insignificant.
4. The type of metabolism changes and the rate of oxidation is intensified.
5. The nuclei become more active in controlling the activities of the embryonic cells. The influence of the paternal chromosomes (genes) becomes evident during gastrulation.
6. During gastrulation chemodifferentiation is started by

Gastrular morphogenetic movement

- The movement of the blastomeres from one place of the embryo to another to establish a particular from or structure is a common embryological procedure. This type of cell movement is described as formative or morphogenetic movement.
- Morphogenetic movement occur in the embryo during blastulation, gastrulation, tubulation and organogenesis. They do not occur only during the embryonic stages but also in an adult animal.

  The two basic types of morphogenetic movement pattern are involved in gastrulation:

1. Epiboly 2.Emoboly

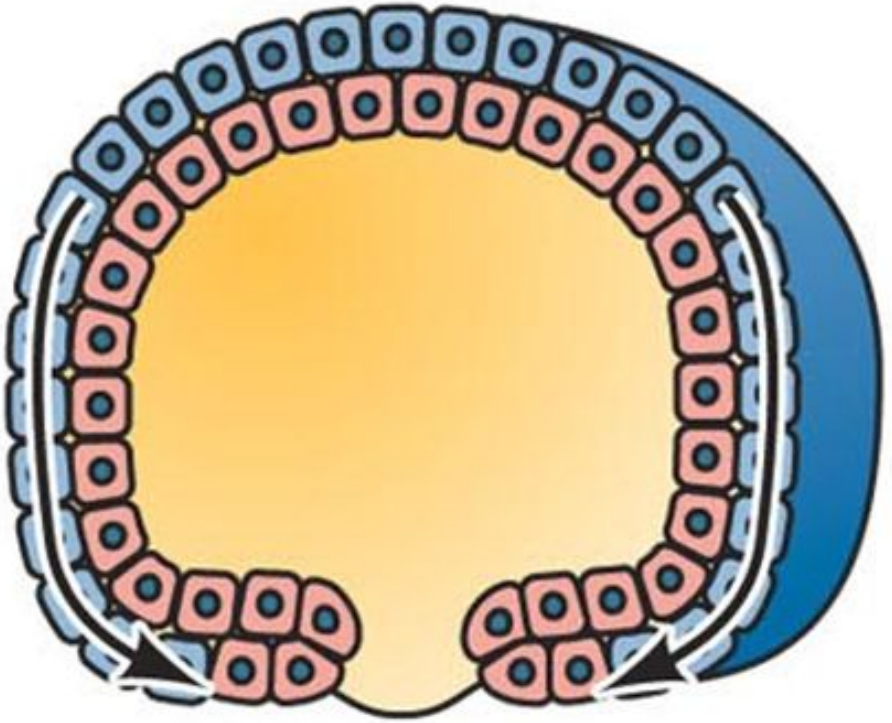
1. **Epiboly:**

   Epiboly is one of the cell movement that occurs in the early embryo during gastrulation. It is characterized by the thinning and spreading of cell layers.

2. **Emboly:**

   Emboly is the process in which there occurs an invagination of the blastula to form gastrula. Embolic movement include invagination, involution and ingression movements displacing future or prospective endoderm and mesoderm into the interior of the embryo.

Epiboly



Epiboly- the movement of epithelial sheets that spread as a unit to cover the embryo

Chemical changes during gastrulation

- The gastrulation is the most active phase of embryonic development during which extensive or profound morphogenetic activities of different types of blastomeres occur and rate of metabolism of gastrula as a whole becomes rapidly increased. Its metabolism can be studied under following headings:
- **(a) Catabolism-** The morphogenetic movements during gastrulation cause an increased expenditure of energy rich ATP molecules and consequently, an increase oxidation, an increase oxidation. It has been found that the oxygen consumption during the gastrulation of frog and sea urchin shows a further increase as compared with the blastula stage. During gastrulation the food reserves (e.g., glycogen and yolk) are oxidized for the manufacturing of ATP molecules.

- **(i) Oxidation of glycogen-** One of the substances particularly involved in the supply of energy during gastrulation in amphibians and other animals, is glycogen. It has been shown in frogs that amount of glycogen becomes considerably diminished in the invaginating cells of the dorsal lip of the blastopore. Rapid breakdown of the glycogen in the dorsal lip suggests a particularly active respiration in this area.
- **(ii) Breakdown of yolk-** Besides glycogen, the yolk of the blastomeres is broken down for energy metabolism or assimilation. The breakdown of yolk granules has been investigated in amphibian embryos both electron microscopically and biochemically.

(b) Anabolism-

- Throughout gastrulation, the volume of the embryo does not change appreciably. Every expansion in one direction occurs at the expense of contraction in another direction. Division of cells by mitosis continues throughout gastrulation and this mean, that there is an increase of nuclear material at the expense of the cytoplasmic substances.
- Anabolism mainly includes great amount of transcription (DNA- dependent RNA synthesis), small amount of DNA replication and biosynthesis of certain new types of proteins.

Significance of Gastrulation:

(a) Three primary germ layers are formed.

(b) It marks the beginning of morphogenesis and differentiation.

(c) Metabolic activities of the cells are increased due to great morphogenetic activities of the blasromeres.

(d) Blastocoel is obliterated and archenteron is formed.

Thank you