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WHAT IS GERM PLASM?[1]

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THE term germ plasm has become a common term. It is used by laymen as well as biologists with such diverse connotations that one can never be sure just what is meant. Weismann[2] developed a definite and specific meaning for germ plasm. As a result of his study of acquired characters and from his attempt to find an explanation of development and heredity which would be more satisfactory than the physiological units of Spencer or the gemmules of Darwin, he worked out an elaborate and logical hypothesis. Whether acceptable or not, his hypothesis merits high praise as an outstanding biological contribution which has stimulated observation, experiment and enormous discussion.

Weismann's germ plasm theory may be briefly outlined in the following points: Hereditary characters are produced by specific particles or substances called determinants, located in the chromosomes of the nucleus. Each independently variable character of an organism is due to a single kind of determinant, whether in a single cell or a group of similar cells. The germ cells alone contain all the determinants of a species needed at any and all periods of the life history of an organism, including complete or partial determinants of ancestors.

At the first cleavage of the egg two cells are produced, one of which is the primordial germ cell which takes no part in ontogeny, but remains unchanged to produce the germ cells of the individual at the appropriate time. This primordial germ cell is therefore a sample of the fertilized egg and its products will be exactly like it. The other cleavage cell is the starting point for the rest of the complex organism. During continued divisions the determinants are gradually

[1] Address of the vice-president and chairman of the Section on Zoology of the American Association for the Advancement of Science, Cleveland, September 13, 1944.

[2] A. Weismann, "The Germ Plasm." Translated. New York, 1893.

sorted and distributed to different cells as a result of qualitative nuclear divisions, until each histologically differentiated cell or group of cells in the organism has only a single kind of determinant. The determinants do not have any effect while within the nucleus, they must pass into the cytoplasm and form biophors and in this condition are active in producing specific characters.

De Vries's "Intracellular Pangenesis"[3] had been published in 1889 and Weismann was familiar with it; he accepted some of the views presented but rejected the theory. He thought de Vries had failed to consider the arrangement of the hereditary particles which Weismann designated as the "architecture of the germ plasm." According to de Vries each hereditary character is represented by a particle, the pangen, located in the chromosomes of the nucleus. Each nucleus of an organism is alike in containing every kind of pangen, all of which, at each nuclear division, are divided and passed equally into each daughter nucleus. Within the nucleus pangens are inactive, except for their ability to divide; they may pass into the cytoplasm where they grow, multiply and become active permanently or for a time or when stimulated, and produce their specific characteristics. Not all pangens of any one cell pass into the cytoplasm and become active, and the structure and behavior of a cell depends on what pangens and how many are present in the cytoplasm.

The germ plasm, according to Weismann, is the complete complex or assortment of all the determinants of the organism or species. This is found only in the nuclei of germ cells, for the nuclei of all other cells are unlike, containing only the particular determinant which is their characteristic. The gradual distribution of the determinants through qualitative nuclear divisions during ontogeny results in cell differentiation. Since only germ cells contain all the determinants it is only such cells which can produce a new organism; tissue cells can produce only their own type.

De Vries believes the nuclei of all cells in the body are alike in containing a complete assortment of all the species pangens, each of which divides and passes into the two daughter nuclei at each division, thus maintaining the completeness of the nuclear pangen complex. But pangens may divide within the nucleus at other times than at division and some of these migrate into the cytoplasm. Hence the differentiation of the cytoplasm is determined by the kind and number of pangens in it. While de Vries did not use the term germ plasm, it would be present in every cell of the body, according to Weismann's definition. Indeed de Vries says that in plants potential germinal tissue is often everywhere, producing both somatic and sex organs, and in some plants almost any cell might produce a new organism, even from highly specialized epidermal cells, as in Bryophyllum.

The opinion held at present is that the hereditary materials, or genes, are located in the chromosomes of the nucleus and every cell is alike in possessing a complete chromosome and gene complex. At each division each chromosome and gene is exactly divided and the daughter nuclei are identical. Our modern studies have been so concentrated on the nucleus and the genes that we have no definite theory of how differentiation and cytoplasmic determination is produced. Nor can one find any clear statement of how the nuclear and cytoplasmic constituents interact.

The de Vriesian, Weismannian and modern opinions agree in postulating the presence of material particles, substances or hereditary materials in the chromosomes of the nucleus which determine the characters of organisms and their parts. It is precisely this complete hereditary material of the species which Weismann called the germ plasm. In his theory it was present in only a few cells (germ cells), all others containing a part of this material; and eventually each histologically differentiated cell or group possessed a single kind of determinant or gene. His scheme involved the sorting out and distribution of genes by qualitative nuclear divisions; presumably the chromosomes would persist but all chromosomes in one cell would contain many genes of a single kind. This qualitative division was never acceptable and has long been abandoned. De Vries's theory, and our own present one, agree that both chromosomes and genes divide equally at each division. All three of these theories seem to agree that the hereditary material present in the nucleus is inactive and must pass into the cytoplasm before it can become active in producing definite characteristics.

If we retain the term germ plasm for the hereditary substance or genes we then say that all cells of the body, irrespective of the degree of differentiation or specialization, contain germ plasm. This would seem to imply that any cell potentially may produce a new organism. While botanists usually have not used the term germ plasm this implication has been more or less acceptable to them; on the other hand, zoologists generally do not believe that differentiated cells can produce a new organism. To Weismann the difference between germ cells and tissue cells was due to differences of their nuclei. Since we hold that nuclei are identical in all cells of an organism, what determines the structure, behavior and fate of cells in the organism? Genes are active, and perhaps determinative, not only in heredity but in ontogeny, but there

[3] Hugo de Vries, "Intercellular Pangenesis." Translated. Chicago: Open Court Publishing Company, 1910.

appears to be no differential element in the nucleus, and any distinction between cells would seem to be due to cytoplasmic differences. What a strange reversal: from the view that germ cells differ from tissue cells because of diverse nuclear composition to the view that all nuclei contain complete hereditary material of the species, and the differences between cells are due to the kind of cytoplasm in which the nuclei are located!

At the time it was proposed the germ plasm theory was a significant one, compatible with the facts then known. The stimulus given by it to new discussions and investigations has enormously increased our knowledge and opened many fields not then considered. The significant point at that time was the assumed distinction between germ cells and tissue cells and the relation of this to the production of new organisms. Since then the question has so broadened that it is more one of the determination of the regions of the developing organism, the factors concerned in the differentiation and organization of organs, and the capacities or potencies of cells. Is a cell determined once for all and irreversibly, or may it change? If change may occur what are the factors or conditions leading to the change and how great a modification may take place?

All cells of an organism come from the fertilized egg and theoretically it should be possible to trace the lineage of any cell from the egg. However, in practice, it is impossible to trace the lineage of one cell in any organism with a large number of cells. Weismann's theory implies that the first cleavage should produce one primordial germ cell and one primordial body cell, whose products thereafter are separate and distinct. This has never been observed. Probably the nearest approach to such an early separation of a germ cell is in the fly Miastor in which at the 8-nuclear stage a single cell is cut off. Hegner[4] traced this single cell into the 64 ova of the animal; all other nuclei and cells produced the body. Somewhat similar lineages have been traced, but never so definitely, in some flies, beetles, crustacea and few other animals. In Ascaris at the 32-cell stage Boveri[5] believed one cell with undiminished chromatin was the primordial germ cell. In the majority of animals no such germ tracks have been established, and only after most organ systems have been laid down have germ cells been identified. As a rule no specific or characteristic differences can be found to distinguish one cell from another in cleavage and early ontogeny. In vertebrates it is only by the large size of cells located in or near the developing gonad that we can distinguish germ cells.

[4] R. W. Hegner, "The Germ Cell Cycle of Animals." New York: Macmillan, 1914.

[5] T. Boveri, *Sitz. Gesell. Morph. Phys.* München. 8: 1892.

In many mammals the earliest identified germ cells begin growth early and reach their maturity before the animals are sexually mature. A period of profound degeneration of many of the early germ cells is a common thing and new, enlarged cells appear in the germinal epithelium of the ovary. Edgar Allen[6, 7, 8] and co-workers concluded that the germinal epithelium of mammalian ovaries is active throughout the mature life, producing new ova at each oestrus, some of which mature but most degenerate and die.

In most animals removal of gonads is not followed by regeneration and very commonly x-ray treatment of gonads results in ultimate death of the germ cells, which usually are not replaced from other cells. Transplantation of embryonic gonad regions into the chick allantois or mammal kidney have given varying results, the most common being that if the transplant be made before germ cells can be identified, no germ cells will be present in the transplant. However, Everett[9] recently found that if the germinal epithelium of mouse ovaries was not destroyed when transplanted in a kidney, new ova would develop from the epithelial cells.

In mammals, then, there is not shown any great capacity for germ cells to arise from other cells, except from the germinal epithelium of ovaries. But neither the observational nor the experimental studies are quite sufficient as yet to warrant a final decision on this point.

Another source of evidence on the potencies of cells is supplied from regeneration. It may be recalled that Weismann explained regeneration as due to the presence of cells with partial germ plasm situated at strategic places in the organism. In flatworms and some other invertebrates regeneration has often been ascribed to the presence of "formative" or pleuripotential cells scattered through the parenchyma; and by some, annelid regeneration is referred to similar "neoblasts." But others believe a dedifferentiation occurs and all needed replacements are derived from the mass of dedifferentiated tissue. Wilson and Penny[10] macerated sponges by squeezing through fine bolting cloth. By this method the morphological arrangement was completely destroyed; certain types of cells were held in the net and others passed through as scattered and isolated cells. Out of this mass developed a new sponge. This involved two factors: the complete reformation and integration of the morphological pattern; and the production of the missing types of cells from the isolated cells of the mass.

[6] Edgar Allen, *Am. Jour. Anat.*, 31: 439–482, 1923.

[7] Edgar Allen, W. B. Kountz and B. F. Francis, *Am. Jour. Anat.*, 34: 445–468, 1925.

[8] Edgar Allen and R. N. Creadick, *Anat. Rec.*, 69: 191–196, 1937.

[9] N. B. Everett, *Jour. Exp. Zool.*, 92: 49–92, 1943.

[10] H. V. Wilson and J. T. Penny, *Jour. Exp. Zool.*, 56: 73–148, 1930.

Butler and Puckett[11] amputated a leg of a salamander and after the wound surface had healed observed the production of a blastema derived by dedifferentiation of local tissues. From this, and not from adjacent differentiated cells, all the tissues of the regenerate were produced. Hertwig[12] had earlier shown that the newly developed regenerate came from the wound surface and not from the whole leg. This was demonstrated by transplanting a haploid arm on a diploid body; after healing, the leg was amputated through the haploid arm close to the diploid stump and the regenerate contained only haploid cells. Umanski[13] grafted the skin of a non-x-rayed limb on an x-rayed limb, allowed this to heal, and amputated through the graft region. The tissues of an irradiated limb are incapable of regeneration, yet a normal limb regenerated, showing that the non-irradiated skin had been able to supply everything needed for the regeneration of skin, muscle, cartilage and other tissues.

In such results it is clearly shown that specialized and functional tissues and parts may possess latent capacities to change their structure and behavior in various directions. While we do not know much about the limits of this, nor precisely what factors are involved in the dedifferentiation and modified parts produced, it seems to be clear enough that cell potency is not fixed. Needham[14] says that regeneration "is a repetition of ontogenesis so far as the organ districts involved are the same, but the processes involved are of necessity somewhat different . . . but within the limits of the organ district in question the material is certainly undetermined."

Recalling that we consider the gene complex of the nuclei of all cells of any one species as identical, the question arises in how far the cytoplasm is responsible for, or determines, the character of cells, organs or regions. Long ago Conklin discussed the question of different sorts of cytoplasm in the egg, the segregation of these in different blastomeres during early cleavage, and their significance as possible organ-forming substances. This seems to have been generally accepted by embryologists and much of recent experimental embryology is concerned with the matter of organ determination and cytoplasmic differentiation. But of necessity there is also involved interaction between cytoplasm and nucleus. Harrison[15] says the egg is composed of protoplasm characteristic of the species "and different from that of any other species." Differentiation which takes place in the cytoplasm "is accompanied and controlled by the genic complex in the chromosomes. Since the latter is presumably the same for all cells of the organism, differences between cells must arise through interaction between the constant genom and the locally variable cytoplasm, in which they ultimately become visible."

Our ideas of what is involved in development and differentiation have undergone great changes as a result of experimental and biochemical investigations by embryologists and geneticists. Needham's[14] "Biochemistry and Morphogenesis" is a stimulating survey and analysis of this field. He says that determination occurs and may explain structure and behavior through the action of biochemical agents called organizers, inductors, evocators, inhibitors and the like. What a part becomes may be due to the inducing substance itself or to the ability of the part to react to the inductor. Behavior may vary under different conditions; several substances, related chemically, may be able to accomplish the same result or the same inductor will act on quite unlike regions, the result depending on the character of the reacting region. The determination may be permanent or temporary, may involve the whole system or only a small region, it may be revocable if and when new inductors become active. "It is thus clear that at some stage or other, which may be different for each tissue, all the tissues and organs will take on inductive power, *i.e.*, the inducing substance in them will be liberated from its inactive precursor." "The process of liberation of the active substance must be connected with the process of determination and histological differentiation." If the genes fundamentally determine what is to appear, the organizers and inductors must be related to them and Needham believes that, "Organizers must indeed be regarded to a large extent as the intermediary mechanisms between the gene equipment and the final form and properties of the developing animal." ". . . genes act in development by producing, inhibiting the production of, or masking and unmasking hormones, catalysts or inhibitors in more or less diffusible states."

These quotations indicate that the experimental embryologist is getting a new picture of some of the factors concerned in development and differentiation. The processes are complex, the details are vague and the causal relations can not always be specified. Embryological changes seem to be due to definite chemical substances which in turn are somehow related to interaction of nucleus and cytoplasm. To the embryologist determination has meant a definite morphological fixation of structure; to the biochemical embryologist it seems to mean a series of biochemical reac-

11 E. G. Butler and W. O. Puckett, *Jour. Exp. Zool.*, 84: 223–239, 1940.

12 G. Hertwig, *Arch. f. Ent.-mech. d. Organ.*, 111: 292–316, 1927.

13 E. Umanski, *Bull. Biol. Med. Exp., U.S.S.R.*, 6: 141–, 1938.

14 J. Needham, "Biochemistry and Morphogenesis." Cambridge University Press, 1942.

15 R. G. Harrison, "Cellular Differentiation and Internal Environment." In: "The Cell and Protoplasm," 77–97. Publ. 14, A.A.A.S., 1940.

tions resulting in the production of a definite molecular pattern in the cytoplasm. One thing in this recent type of experimental work which is of great interest is the discovery of the plasticity which is sometimes found, and the ability of a part to change while the whole organism is maintained as a unit.

Sonneborn[16] described an interesting cytoplasmic-genic relationship in Paramecium aurelia. Both a gene and a cytoplasmic substance are necessary if a particular hereditary character is to appear. "When some of the cytoplasmic substance is present, the gene controls its continued production; but when the cytoplasmic substance is absent the gene can not initiate its production." If the organism has the gene but not the cytoplasmic substance the character does not appear, but when the cytoplasmic substance is added the character does develop, and since the gene then controls this substance the character is maintained in succeeding generations. Sonneborn thinks this sort of relationship may be significant in development and determination generally. He says: "All that is required to account for the production of different characters in different cells with the same genes is to have differential segregation of these cytoplasmic determiners at cell division . . ." This suggestion seems to imply a cytoplasmic origin of the particular substance independent of any genic or nuclear cooperation.

De Vries's theory provided for a nuclear-cytoplasmic interchange since his pangens could leave the nucleus and enter the cytoplasm where they became active. Several or many pangens could enter the cytoplasm and multiply there; some of these might be correlated in action or opposed, but the structure and behavior of the cytoplasm was the resultant of the influence of all the pangens present in it. Thus far our modern theory has not provided us with any clear idea of how the genes in the nucleus can influence the properties of the cytoplasm and thus determine its character. Probably we could assume that chemical substances might be made in, or be contained in, the gene and these could diffuse out of the nucleus much like de Vries's pangens. Caspersson and Schultz[17] demonstrated the presence of nucleic acids in both nucleus and cytoplasm. Mirsky and Hollister[18] give us a hint of possible means of interaction of nucleus and cytoplasm. Chromatin is "largely, if not entirely, composed of a unique substance, nucleohistone," and the chromosomal properties are really the properties of this chemical substance. Interactions might function in this way: "From the massive, indiffusible particles of nucleohistone small quantities of histone (a protein of relatively small size) are apparently constantly dissociating. If this process occurs in the living cell, and we have good reasons to believe it may, it could play an important part in the mechanisms of gene action, for it would mean that a protein component of the chromatin is diffusing out to other parts of the cell."

With our increasing knowledge of the chemistry and physics of protein, and of the biochemical aspects of biological processes new light is being thrown on old facts. But it is also compelling us to change our point of view and to speak in more specific terms than we often use. Words like germ plasm, cells, cytoplasm, chromosomes, genes suggest morphological entities, units or behavior, and may keep us from understanding or appreciating the underlying molecular phenomena which are fundamental and significant. Biological phenomena are not just chemical and physical. The question of arrangement and organization is involved but molecular patterns and groupings may be back of biological organization. Sponsler and Bath[19] point out that a considerable amount of orderliness occurs in proteins, the amino acid residues occupying definite positions in the chains of protein molecules. Since definite patterns can thus be demonstrated chemically it is possible that this may be the basis for what we think of as protoplasmic organization. We must somehow correlate the molecular and morphological aspects if we are to have the opportunity to test the behavior and significance of definite chemical substances in protoplasm.

Chromatin (and genes) are nucleoproteins which reproduce themselves. Stanley[20] states that all viruses are, or contain, nucleoproteins and "all viruses have in common the ability to reproduce or multiply when placed within living cells." Whether viruses are living or not they are close to the borderline between living and non-living proteins. Claude[21] says, ". . . it is noteworthy that, so far, organic structures found to exhibit the property of self-duplication have been shown to contain nucleic acid of the one type or the other." Might it be permissible to speculate further that substances containing nucleic acids or nucleoproteins are capable of reproducing themselves? If certain types of proteins are capable of self-repro-

[16] T. M. Sonneborn, *Proc. Nat. Acad. Sci.*, 29: 329–343, 1943.

[17] T. Caspersson and J. Schultz, *Proc. Nat. Acad. Sci.*, 26: 507–515, 1940.

[18] A. R. Mirsky and A. W. Hollister, *Trans. N. Y. Acad. Sci.*, II, 5: 190–198, 1943.

[19] O. L. Sponsler and Jean D. Bath, "Molecular Structure in Protoplasm." In: "The Structure of Protoplasm," 41–80. W. Seifriz, editor, Iowa State College Press, 1942.

[20] W. M. Stanley, "The Structure of Viruses." In: "The Cell and Protoplasm," 120–135. Publ. 14, A.A.A.S., 1940.

[21] Albert Claude, "Distribution of Nucleic Acids in the Cell and the Morphological Constitution of Cytoplasm." In: "Biological Symposia," X, 111–130. J. Cattell Press, 1943.

duction we may have the basis for the duplication and perpetuation of molecular patterns.

It may not be acceptable much longer to claim that reproduction is a unique biological property as contrasted with non-biological substances believed to be devoid of this property.

POST-WAR GEOLOGY

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IMMEDIATE PROSPECT

REDUCED civilian teaching schedules and smaller classes, even though partially supplemented by the introduction of ASTP, FAL, lately, ASTRP instruction, leave me time to ponder the status of post-war geology. Shall earth sciences flourish or languish, shall we have an influx of students for whom employment awaits only graduation, will the "G.I. Bill of Rights" return many of our students now in uniform? Personally, I think we shall have plenty of students. I believe curricula in geology and allied sciences will see, if not a boom, a considerable increase over prewar registration. If so, must course content be revised? Will spcialization be stressed? I believe changes must be made, particularly at graduate level because specialization will assuredly be stressed far more than in the past. Initial employment and subsequent advance in geology will go more and more to the man with the Ph.D. There may be so great an immediate demand that anybody who has rubbed elbows with geology in college can find employment, but I am looking beyond such a period to more settled conditions, steady employment. If this be so, what field or fields will have the accent; which may remain unaccented, what may drop from the picture? Where will curricular emphasis fall? What must we plan for undergraduate preparation and post-graduate specialization?

With such questions in mind, I commenced fact-gathering through correspondence and conferences with teachers of geology, geologists with the state and federal surveys, at museums, private consulting and industrial positions. In each case I tried to find out the individual's opinion on post-war geology and proper preparation of men for the work to be. Since some of the answers are confidential, I refrain from specific citations but shall summarize opinions and even have the temerity to introduce suggestions of my own.

EMPHASIS, WHERE?

Among those interrogated, optimism dominates. Geologists are generally hopeful that the science has an immediate, luminous if not scintillating future. Agreement is less general as to where greatest development will come. Nevertheless, two developments of earth science were most often mentioned: applied geology in engineering and economic geology, including mineral fuels.

Closer bonds between applied geology and certain types of engineering, particularly civil and mining, appeal to reason. How often has the civil engineer been accused of too little familiarity with the earth into which he digs, upon whose surface his structures rise? Conversely, many a geologist, called in on a construction job, has been baffled by ignorance of engineering terminology and practise. Though a man trained in neither field need master fully the other, he can have a basic knowledge thereof. A civil engineer or geologist with extra study can acquire enough knowledge to function intelligently in the complementary science. The super-highway, railroads, dams, water supply, flood control, foundations, harbor and shore installations are among civil engineering projects where geology must serve. To prepare for work on such projects, can we not, at the expense of one or two extra study years, create a civil-engineering geologist? I have had students who "split majors" in these fields even though their years in college were crowded to meet the added load. Their professional success fully justifies the preparation. While such a hybrid-trained student might split his major as suggested, he could achieve the objective if he took his bachelor's degree in geology, followed with a degree in civil engineering or *vice versa*.

There was a time a generation ago when mining engineers had a tolerable geologic training. To-day, the trend seems to be to prepare a man to lay track and string wires underground, to get out coal or ore regardless of its geologic nature and occurrence. I have no argument with this type of training, if it follows the trends of the time and fills a need of our civilization. Yet, if the old concept of the mining engineer is to be discarded, why not develop in his stead the newer concept of a mining geologist? If his education followed a program of the pattern suggested for the civil-engineering geologist, it would turn out a man capable of giving correct geologic interpretations to mining problems.

One could propose more applications of geology to engineering and allied fields. I have often felt that the metallurgist to-day is going the way of the mining