and the cessation of all growth. The increased radiosensitivity appears to be chiefly associated, then, with the advanced developments induced in the partially germinated, dormant seeds. These developments may be identified with certain chemical and structural changes within rapidly dividing cells—namely, the initiation of nuclear divisions and the exposure to irradiation of enlarged and possibly oversensitized chromosomes, just prior to, or during mitotic activities.

Inasmuch as the water content of both lots of seeds was about the same, it would seem that increased seedling injury in the case of partially germinated, dormant seeds is related primarily to direct absorption of energy from ionizing radiations rather than to indirect chemical action of active radicles produced in the presence of water.

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3. This work is a part of a study to determine more effective ways of utilizing radiation techniques in connection with breeding oats for disease resistance and other qualities.
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5. I am indebted to Seymour Shapiro of the Brookhaven National Laboratory for performing the irradiations.
6. The role of salts, oxygen, temperature, and other factors besides water on lowering or hastening the initial rate of development should be taken into consideration in interpreting radiation effects on biological material.

27 December 1955

Ability of Thais haemostoma to Regenerate Its Drilling Mechanism

The odontophoral process of the prosobranch gastropods is situated at the distal end of the proboscis, which is essentially a very extensible and maneuverable tube extending from the esophageal region, with the mouth at the end. The odontophore consists of a cartilaginous carriage, which licks back and forth while the radular band moves back and forth over it like a belt over a pulley (*1, 2*). Possibly the radula can also be held stationary at times, with the sole movement being made by the cartilaginous carriage. This may account for the differences in observations made by some famous zoologists in the past century (*1*). With its attendant muscles and nerves, the odontophore is a very complicated mechanism (*2*) and efficiently operates in drilling as if it were a small rotary drum covered with spikes (*1*).

Hundreds and possibly thousands of species of predatory gastropods drill holes through the shells of other mollusks and extract the meat. It is generally stated that this ability is possessed only by the Naticidae and Muricidae. It should be noted, however, that the Thaisidae have been separated from the Muricidae. In addition, Moore (*3*) has shown that three species of the Cassidae bore through the calcareous tests of sea urchins and sand dollars.

The odontophore is certainly mechanically efficient, but whether it functions in this manner alone (*4*) or is sometimes assisted by acids or enzymes is not yet settled (*5*). Furthermore, *Thais haemostoma,* the Gulf oyster borer, which is at times a very serious oyster pest, can open oysters without leaving any sign of shell damage whatsoever. This raises the question of whether the animal makes use of some paralytic agent.

In an attempt to answer this question, we cut off the proboscis of several *Thais* with a razor blade. This was done after the hungry animals had been induced to extend the proboscis through a small hole in a plate of plastic to reach a piece of oyster meat placed to one side. The cutting movement had to be swift, for the proboscis is very sensitive and can be retracted with the speed of a rubber band. It was noted that "conchs" that had the proboscis cut cleanly survived, while those suffering jagged cuts did not. Only the distal portion of the proboscis containing the odontophore was cut off. These were preserved in formalin. The supposition was that these "aradulate" gastropods might open oysters by use of a paralytic agent, if they possessed one.

The planned experiment was a complete failure, but the results were nonetheless startling. Within 3 weeks, the surviving gastropods all regenerated the complete odontophoral process, as good as new, and without abnormalities as far as we can determine. The odontophore, consisting as it does of muscle, nerves, cartilage, and chitinous teeth in a band, which undergo a complex but coordinated set of movements, may well be the most complicated organ any animal is able to regenerate. The complexity of the odontophore has been shown best by the detailed anatomical studies of Carriker (*2*) on *Urosalpinx.* The anatomy of *Thais* has not been described, but it is very similar.

The morphogenetic processes involved in the regeneration of this complicated organ may or may not yield easily to analysis. The apparatus lies in a tube, but it probably will not be extruded by the animals while healing. In any case, some interesting questions are raised and other workers may wish to take advantage of this type of material.

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30 January 1956

New Evidence for Reversal of the Geomagnetic Field Near the Pliocene-Pleistocene Boundary

It has been shown (*1*) that, almost without exception, undisturbed Cenozoic lava flows are magnetized roughly in the direction of the present geomagnetic field or at 180° to this direction, termed normal (N) and reversed (R), respectively. There are two conflicting interpretations of how this thermoremanent magnetization was acquired.

1) The geomagnetic field has two stable configurations, those of an axial geocentric dipole of either polarity. Change from one polarity to the other happens in a time of the order of some thousands of years and occurs a number of times in the Cenozoic period, the last occasion being about the Pliocene-Pleistocene boundary. The total time during which the field was reversed in Cenozoic times appears to be roughly the same as that during which the field was normal.

2) In about 50 percent of the lava flows, the iron oxide minerals responsible for the magnetization possess the anomalous property of spontaneously reversing the magnetization acquired during the first stages of cooling below the Curie point. This occurs either during the final stages of cooling or slowly through the time between the eruption and the present day. In the former case, certain interactions between two lattice sites or two phases must be assumed; in the latter case, diffusion of ions between lattice sites or chemical changes or exsolution must be postulated.

No simple decisive test of these hypotheses has so far been proposed. Geologic time correlation is not sufficiently good to allow the magnetization of lava flows of the same age in different places to be compared, nor can any laboratory tests entirely exclude the possibility that the anomalous properties required for the second hypothesis were not present during the time when the present magnetization was acquired. Apparently, the best procedure is to continue to accumulate field evidence.

It was possible (2) last summer to make a survey of the remanent magnetization of some of the lava flows of the San Francisco Mountain, Verde Valley, and Mormon Mountain volcanic fields in northern Arizona. It was thought sufficient to determine the polarity rather than the exact direction of magnetization of the specimens. For this it is possible in the majority of cases to use a Brunton compass. Assuming that the specimen is magnetized normally or reversely, the poles of the specimen are brought near the poles of the compass, and repulsion or attraction is noted. Increased sensitivity can be obtained by moving a pole of the specimen from side to side over one end of the compass needle and noting whether the needle moves in phase or antiphase with the specimen.

Occasionally, a few specimens in a single flow were found to be magnetized differently from the rest, but, as these specimens were usually very intensely magnetized and had been collected from exposed points, it was assumed that lightning strokes were responsible.

From the extent of the erosion of the lava tops and fronts, Colton (3) has arranged the lavas of the San Francisco volcanic field in order of age, stage I being the oldest, stage V the youngest. Sharp (4) considers stage III lavas to be younger than about 60,000 years and stage II lavas probably older. Robinson (5) considers the earliest flows in this region to be Pliocene. Work done by Childs (6) on pediplane surfaces of the Colorado plateau shows that the stage I flows rest on a late Pliocene surface and that the stage II flows occurred before the first glaciation in the San Francisco peaks, probably in the early Pleistocene.

Nine stage III flows, one stage IV, and one stage V flow were examined and found to be normally magnetized. This is in accord with the evidence from the New England varved clays which cover a fair proportion of this time. The data from Iceland and France would indicate that stage II covers the Pliocene-Pleistocene boundary. One out of six lavas examined in the Verde Valley volcanic field was reversely magnetized, and 13 out of 21 in the Mormon Lake volcanic field were reversely magnetized.

All these flows were of stage I or II. In these fields, one normally magnetized lava and two reversely magnetized flows have been found overlying baked clay horizons. The latter were found to be magnetized concordantly with the respective lavas. The clay was thus heated by the lava and, on cooling, acquired a magnetization in the same direction as the lava. If the second hypothesis were true, this would not always occur.

The results that very recent flows are always found to be normally magnetized and baked clays have the same magnetization as the lava which bakes them are in accord with evidence from other lava series. It must be concluded that this evidence from northern Arizona lends support to the first hypothesis. If this hypothesis is correct, the earlier flows in this region must be at least about 1 million years old (7).

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1 February 1956

Ecosystem as the Basic Unit in Ecology

The term *ecosystem* was proposed by Tansley (1) as a name for the interaction system comprising living things together with their nonliving habitat. Tansley regarded the ecosystem as including "not only the organism-complex, but also the whole complex of physical factors forming what we call the environment." He thus applied the term specifically to that level of biological organization represented by such units as the community and the biome. I here suggest that it is logically appropriate and desirable to extend the application of the concept and the term to include organization levels other than that of the community.

In its fundamental aspects, an ecosystem involves the circulation, transformation, and accumulation of energy and matter through the medium of living things and their activities. Photosynthesis, decomposition, herbivory, predation, parasitism, and other symbiotic activities are among the principal biological processes responsible for the transport and storage of materials and energy, and the interactions of the organisms engaged in these activities provide the pathways of distribution. The food-chain is an example of such a pathway. In the nonliving part of the ecosystem, circulation of energy and matter is completed by such physical processes as evaporation and precipitation, erosion and deposition. The ecologist, then, is primarily concerned with the quantities of matter and energy that pass through a given ecosystem and with the rates at which they do so. Of almost equal importance, however, are the kinds of organisms that are present in any particular ecosystem and the roles that they occupy in its structure and organization. Thus, both quantitative and qualitative aspects need to be considered in the description and comparison of ecosystems.

Ecosystems are further characterized by a multiplicity of regulatory mechanisms, which, in limiting the numbers of organisms present and in influencing their physiology and behavior, control the quantities and rates of movement of both matter and energy. Processes of growth and reproduction, agencies of mortality (physical as well as biological), patterns of immigration and emigration, and habits of adaptive significance are among the more important groups of regulatory mechanisms. In the absence of such mechanisms, no ecosystem could continue to persist and maintain its identity.

The assemblage of plants and animals visualized by Tansley as an integral part of the ecosystem usually consists of numerous species, each represented by a population of individual organisms. However, each population can be regarded as an entity in its own right, interacting with its environment (which may include other organisms as well as physical features of the habitat) to form a system of lower rank that likewise involves the distribution of matter and energy. In turn, each individual animal or plant, together with its particular microenvironment, constitutes a system of still lower rank. Or we may wish to take a world view of life and look upon the biosphere with its total environment as a gigantic ecosystem. Regardless of the level on which life is examined, the ecosystem concept can appropriately be applied. The ecosystem thus stands as a basic unit of ecology, a unit that is as important to this field of natural science as the species is to taxonomy and systematics. In any given case, the particular level on which the ecosystem is being studied can be specified with a qualifying adjective—for example, community ecosystem, population ecosystem, and so forth.

All ranks of ecosystems are open systems, not closed ones. Energy and matter continually escape from them in the course of the processes of life, and they must be replaced if the system is to continue to function. The pathways of loss and replacement of matter and energy