bodies. If, however, the "igneous" rocks are actually metasomatic, then the current theory of the origin of these deposits is no longer valid.

A number of writers have discussed the magnetite deposits of the eastern United States, in particular Bayley, Miller, Colony, and Alling, and more recently Buddington, Leonard, Postel, Hotz, and Sims. The following discussion is restricted to the Scott Mine, but the concepts developed may have application to other mines (*1*).

The Scott Mine is in a region of metamorphic rocks where quartz-oligoclase gneiss, quartz-monzonite gneiss, and pegmatite have replaced pyroxene amphibolite. Evidence of metasomatism includes the following. (i) Foliation in the gneiss passes uninterruptedly into amphibolite inclusions. (ii) Amphibolite inclusions often contain microcline and other minerals of the gneisses or pegmatite. (iii) Thin section analyses of the quartz-monzonite gneiss made by Offield (*2*) show a considerable variation in mineral percentages along the strike. This is more characteristic of different degrees of replacement of amphibolite than it is of intrusive magmatic rock. (iv) Undisturbed long thin layers of amphibolite are present in the gneiss. (v) Evidence of squeezing or displacement to accommodate intrusion of magmatic material is absent. (vi) No *boudinage* structure around amphibolite inclusions was found that would indicate regional plastic deformation rather than metasomatism. (vii) Foliation and lineation of the gneisses have been inherited from the amphibolite; there is no evidence that these gneisses are metamorphosed igneous rocks. (viii) Microtextures are present that are commonly ascribed to replacement processes. Following the metasomatism, magnetite partly replaced the amphibolite layers in a 250-foot-thick ore-bearing zone.

Microscopic studies suggest that the ferromagnesian minerals within the ore-bearing zone were formerly richer in iron than they are now. The refractive indices of biotite, hornblende, augite, and orthopyroxene in the amphibolite decrease with nearness to the ore-bearing layers. This relationship suggests a decrease in iron content of these minerals. Specimens from diamond drill cores through relatively thick ore bodies show, in general, greater decreases in index than do specimens from core with smaller and fewer magnetite concentrations. The indices of orthopyroxene correspond to a composition of from 57 to 100 molecular percent enstatite. A lowering of refractive indices in most mafic minerals is commonly related to a decrease in iron content; however, other elements may be involved. In the Scott Mine the amounts of ferric iron and titanium may be especially significant, but they have not yet been determined.

The relative amounts of each mafic mineral differ somewhat from place to place in the cores. In most specimens, all four ferromagnesian silicates exist together. Therefore, the systematic decrease in indices toward the ore-bearing zones apparently does not reflect a decrease in iron content of one ferromagnesian mineral because of the presence of other mafic minerals, as Nockolds (*3*) found in a study of biotites.

Loss of iron from the ferromagnesian silicates is believed to have been sufficient to supply that necessary for the magnetite bodies. Since chemical analyses have not yet been made, it is not possible to estimate the amount of iron removed from the minerals. However, the ore-bearing zone in which the refractive indices are lowered is sufficiently extensive to warrant this tentative conclusion. From his study at Lyon Mountain in the Adirondacks, Miller (*4*) came to the conclusion that the magnetite was formed in part by a change of hornblende and hypersthene to diallage of lower iron content and in part by solution of magnetite from the country rock. He felt that this was accomplished by late stage intrusive pegmatites. Miller did not substantiate his ideas by sufficient petrographic and chemical data, but the results we have obtained at the Scott Mine suggest that some of Miller's conclusions may have been justified.

Ramberg (*5*) has shown that iron and magnesium ions substitute in different proportions in different types of silicate structures. This may be the result of the fact that the electronegativity of iron is somewhat greater than that of magnesium. Ramberg has further shown that the electronegativity of oxygen in a silicate is less than that of oxygen in an oxide, and accordingly iron will be preferentially taken up in the oxide (magnetite, in this case) and magnesium in the silicate.

If this process took place at the Scott Mine, the iron in the mafic minerals was expelled and became fixed as replacement magnetite. Such a process, controlled by structural features, is believed to have formed the concentrations of magnetite. During metamorphism and metasomatism, differential movement along planar and linear structures produced high and low pressure zones, and iron migrated to the low pressure zones. Plagioclase is the principal mineral that is replaced by magnetite, and each marked increase in magnetite percentage is accompanied by a comparable decrease in plagioclase percentage. The ore bodies are thought to be a phase of the metamorphism and metasomatism of the region.

Other magnetite deposits in metamorphic regions in the eastern United States and elsewhere may have had a similar origin.

A. F. HAGNER
L. G. COLLINS

Department of Geology, University of Illinois, Urbana

References and Notes

1. This investigation was supported by a grant from the Research Board of the University of Illinois. We are indebted to C. A. Chapman and D. M. Henderson of the University of Illinois for helpful discussions and for reading the manuscript.
2. T. W. Offield, master's thesis, Univ. of Illinois, 1955.
3. S. R. Nockolds, *Am. J. Sci.* 245, 401 (1947).
4. W. J. Miller, *Econ. Geol.* 14, 509 (1919).
5. H. Ramberg, *J. Geol.* 60, 331 (1952).

21 July 1955

"Swimming" Anemone from Puget Sound

Extensive dredging operations have been carried out in recent years by the department of oceanography of the University of Washington in a study of the distribution and assemblage patterns of plants and animals in Puget Sound. While dredging was being carried out in an area north of Seattle, collections were made of several specimens of an anemone identified by Cadet Hand of the University of California as *Stomphia coccinea* (*1*). These animals were placed in aquariums that are provided with a constant flow of filtered sea water maintained at a temperature of 10°C, the approximate mean surface water temperature in Puget Sound.

By accident it was discovered that the attached anemones would free themselves and exhibit a spasmodic "swimming" motion in response to immediate contact with certain starfish. Preliminary experimentation showed that the swimming response occurred when one of the following starfish—*Crossaster papposus, Hippasteria spinosa,* or *Dermasterias* sp.—was placed in contact with the anemone, whereas no swimming response occurred when one of the asteroids *Solaster* sp., *Mediaster aequalis, Henricia leviuscula, Pisaster* sp., *Evasterias* sp. or any ophiuroid, was used.

Further investigation showed that the spasmodic swimming response could be produced by placing electrodes one on each side of the column and stimulating the animal with alternating current at 15 to 25 v and 7.5 amp. Sea water containing the mucoid slime of *Dermasterias* sp. also elicited the same response. However, parts of other asteroids gave no positive results—for example, direct contact with the amputated arm of *Crossaster* elicited no response. The swimming action has been photographed on 16-mm Kodachrome film (*2*). Figure 1 is a schematic representation of the pertinent activities involved in the swimming response; Fig. 2 is a series of single frames from the film. Briefly described, the swimming procedure is as follows.

1) When the starfish is placed on the oral disk, the anemone partially contracts. This contraction is concentrated in the oral disk and occurs very rapidly (Fig. 1*B*).

2) In 2 to 3 seconds the oral disk, column, and tentacles extend fully.

3) After complete extension, the anemone begins a series of whirling motions, with the oral disk circling around the oral-aboral axis (Fig. 1*C*). One complete rotation takes approximately 1 second. After one or two rotations, the movement changes to a spasmodic, side-to-side movement of the oral disk and the upper part of the column.

4) Detachment from the substratum then generally occurs.

5) The swimming motions of the anemone involve a combination and intensification of undulatory movements of the oral disk, the column, and the base (Fig. 1*D* and Fig. 2*A,B,C*). Considerable thrashing is needed for any extensive progressive movement, suggesting that this mode of "swimming" is very inefficient. The direction moved appeared to be random. The longest distance traveled in a straight line that was observed during one swimming operation was 80 cm. Since this movement lasted 58 seconds, the anemone moved through the water at a rate of about 1.5 cm/sec. While the organism is actively swimming, the base is considerably distended and dome-shaped. At the center of the base is a conspicuous papillalike structure that appears to be important in facilitating quick detachment (Fig. 2*D*). Serial sections are being prepared to reveal whether there is a possible connection between the coelenteron and the underside of the basal disk through an aperture at the end of the papilla.

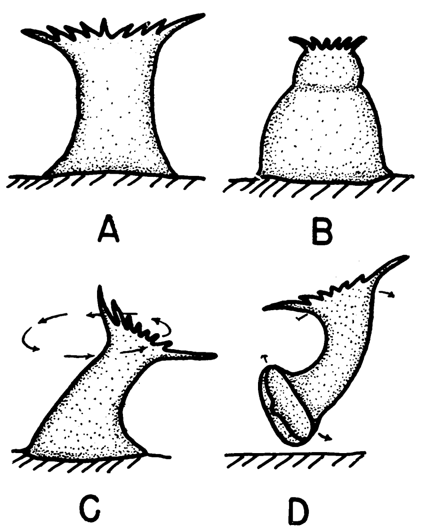

Fig. 1. Pertinent activities involved in detachment and "swimming" by the actinian *Stomphia coccinea.* (*A*) Anemone before contact with the starfish; (*B*) contact with starfish with the anemone partially contracting and a conspicuous sphincter constriction occurring near the oral end of the animal; (*C*) "whirling" motion of the anemone just prior to detachment; (*D*) complete detachment.

6) During swimming operations, the base of the anemone will sometimes touch the substratum, evoking an increase in the activity so that the animal may make several such momentary contacts before coming to rest.

7) With the cessation of the swimming motions, the anemone settles to the bottom, still fully extended, and comes to rest on its side. After a minute or two the elongated column flexes, the base attaches to the substratum, the animal rights itself, and the normal resting posture is resumed.

It is interesting to note that the immediate contact of the starfish apparently stimulates the swimming response to completion—there are no partial modifications. It may be that this complex reflex behavior is initiated by the anemone's chemoreceptors after stimulation by some substance from the starfish. This dramatic swimming reaction might be interpreted as an escape mechanism, since it is known that *Crossaster papposus* has been observed to feed on anemones (*3*). However, in the aquariums, during the course of these experiments, none of the species of starfish studied have been observed to feed on this or any other anemone. In addition Stevenson (*4*) observed that *Stomphia* became "restless, jerked and detached" when subjected to adverse conditions, such as the warming of the water within the aquarium.

Periodic locomotion involving creeping motions of portions of the pedal disk is rather common among actinians. Pantin and coworkers have shown that this type of locomotion, termed "walking," may be correlated with some stimulus in *Metridium.* Usually the walking response ensues after the animal has been stimulated adversely (*5*). Because of the long time periods required for this and other actinian responses, Batham and Pantin have termed them phasic.

The swimming response of *Stomphia* has obvious contrasts. (i) The activity is of a much shorter duration. (ii) The swimming activity requires the specific stimulus of the immediate presence of certain starfish or some substance from the starfish. (iii) The site of greater sensitivity of this stimulus appears to be in the region of the oral disk. Electric shocks applied midway on the column evoked the swimming response, but the means by which the sensory apparatus in the oral

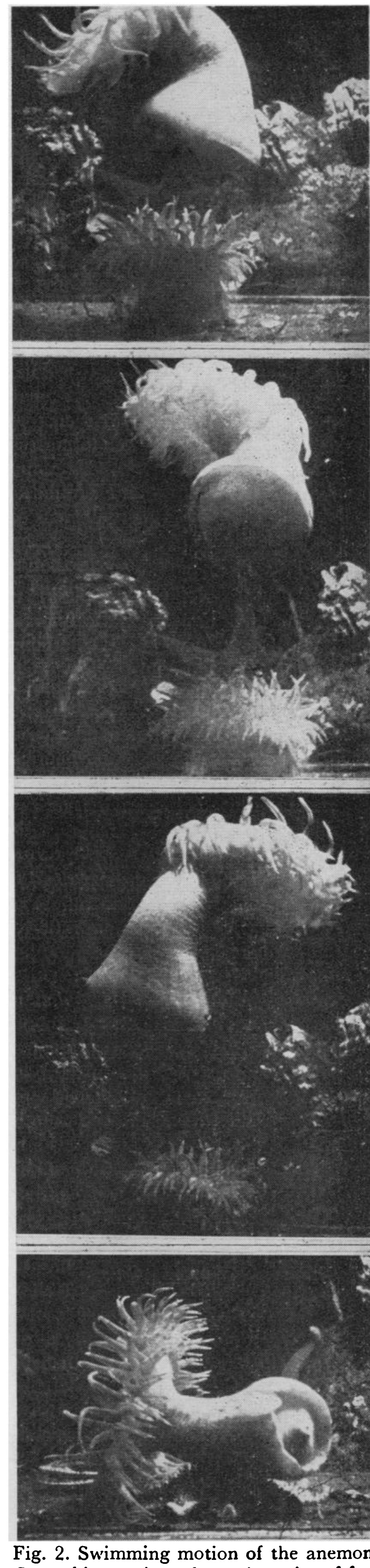

Fig. 2. Swimming motion of the anemone *Stomphia coccinea* shown in series of four frames from a motion picture (*2*). The time lapse between the first and third frame is approximately 40 seconds. In bottom frame note protruding pore in the basal disk.

end of the animal is excited by the electric impulse is not understood. (iv) The swimming response appears to have a rather specific threshold of stimulation. But to divorce this response completely from all phasic activity one would have to establish the existence of a specific receptor-effector mechanism for this response that could operate independently of phasic activities. The existence of such a mechanism in the simple actinian nervous system does not seem probable. A possible answer might be that the swimming response is a combination of accelerated phasic activities.

Figure 1 shows that the general motions of *Stomphia* are the same motions found in slower phasic activity. Likewise, this sequence of movements closely resembles that of the feeding activities of *Metridium senile* as described by Batham and Pantin. Therefore, the swimming response may be all the typical phasic activities in sequence accelerated to a high degree by the presence of the starfish or the starfish substance.

Further work is in progress at these laboratories; special emphasis is being placed on the description of the neuromusculature system of this anemone.

C. S. YENTSCH
D. C. PIERCE

Department of Oceanography, University of Washington, Seattle

References and Notes

1. This work was partly supported by Office of Naval Research contract N8onr-520/III with the University of Washington (Contribution No. 190 from the Department of Oceanography.) Acknowledgment is extended to Richard H. Fleming, executive officer, for the use of the departmental facilities; to M. P. Wennekens and E. E. Collias for their technical assistance, and to L. M. Passano and D. L. Ray for their many helpful suggestions during the preparation of this report.
2. Four copies of this film are available, two at the Department of Oceanography and two at the Department of Zoology, University of Washington, Seattle.
3. H. M. Milligan, *Nature* 96, 619 (1916).
4. T. A. Stephenson, *The British Sea Anemones* (Ray Society, London, 1935), vol. 2.
5. E. J. Batham and D. F. A. Pantin, *J. Exptl. Biol.* 27, 377 (1950).

22 July 1955

Variations of Nitrogen-15 Abundance in Naturally Occurring Substances

It has been shown that the isotopic abundances of many of the lighter elements are not constant (*1*). This paper is a report of some measurements on the variation of the N^{15} abundance in a number of naturally occurring substances. The absolute abundance of N^{15} in atmospheric nitrogen has been measured to be 0.365 percent (*2*). The N^{15} to N^{14} ratio in the N_2 isolated from the samples has been compared directly with the ratio in standard atmospheric N_2, and the results are expressed as parts per 1000 difference from the N^{15} to N^{14} ratio in the standard:

$$\frac{(N^{15}/N^{14})_x - (N^{15}/N^{14})_{\text{std.}}}{(N^{15}/N^{14})_{\text{std.}}} \times 10^3$$

Protein nitrogen was reduced quantitatively to ammonium salts by the standard Kjeldahl digestion, followed by oxidation to N_2 by sodium hypobromite (*3*). Since this procedure alone did not yield sufficiently pure samples, the N_2 was purified by repeated passage over Cu–CuO at 700°C in a carefully outgassed quartz furnace attached to a liquid nitrogen trap.

Inorganic nitrates were quantitatively reduced to ammonium salts by reduction with iron in dilute sulfuric acid (*4*), followed by oxidation to N_2 and purification. The N_2 from natural gas was isolated by passing the gas through a liquid nitrogen trap and then cycling the noncondensable fraction over hot CuO–Cu at 700°C until a constant value for the N^{15} to N^{14} ratio was obtained. In several cases, the sample was separated from a large excess of helium by trapping the N_2 in charcoal at liquid nitrogen temperature and pumping off the noncondensed helium with a Toeppler pump.

The N_2 from rocks and minerals was obtained by heating 100-g portions of the

Table 1. Variations in N^{15} abundance compared with standard atmospheric N_2 of local origin.

Sample	Origin	Difference in N^{15}/N^{14} ratio from standard (parts per 1000)
	Plant protein	
Leaves, white clover	Local	− 6.5
Leaves, dandelion	Local	− 2.8
Leaves, red oak	Local	− 0.9
Leaves, cedar	Local	1.3
Leaves, American elm	Local	1.9
Weeds	Local	4.3
Oats	Unknown	6.2
Seaweed	Tokyo Bay, Japan	8.1
	Animal protein	
Egg, domestic chicken	Local	5.8
Clam flesh	Atlantic Ocean	7.3
Lamb flesh	Unknown	5.0
Milk	Local	5.1
White rat, brain tissue	Local	5.4
White rat, lung tissue	Local	7.5
White rat, liver tissue	Local	4.5
White rat, blood	Local	6.2
White rat, skin and hair, thorax	Local	5.0
	Peat and coal	
Peat	Eire	1.9
Peat	Junius, N.Y.	− 2.8
Lignite	Bowman, N.D.	− 1.2
Bituminous coal	Pittsburgh, Pa.	− 0.9
Cannel	Cannel City, Ky.	1.6
Anthracite	Gunnison, Colo.	− 1.2
Anthracite	Lehigh, Pa.	− 1.4
	Oil and gas wells	
Ella Well	Hunton Lime Formation, Okla.	− 8.1
Plaisted No. 1	Marchand Formation, Okla.	− 3.5
Steve No. 1	Upper Bradley Formation, Okla.	− 8.2
Steve No. 1	Lower Bradley Formation, Okla.	2.9
Fletcher No. 10	Marchand Formation, Okla.	− 7.6
Bitt No. 1	Hart Formation, Okla.	−11.5
Matheson 96-percent methane	Unknown	−13.0
Natural gas	Washington County, Ark.	− 5.9
	Rocks and Minerals	
Granite	Chelmsford, Mass.	− 0.2
Granite	Milford, Mass.	− 0.9
Pitchblende	Great Bear Lake, Canada	− 2.3
	Inorganic nitrogen	
Chile nitratite	Tarapaca, Chile	− 2.6
Sal ammoniac	Paracutin, Mexico	13.0