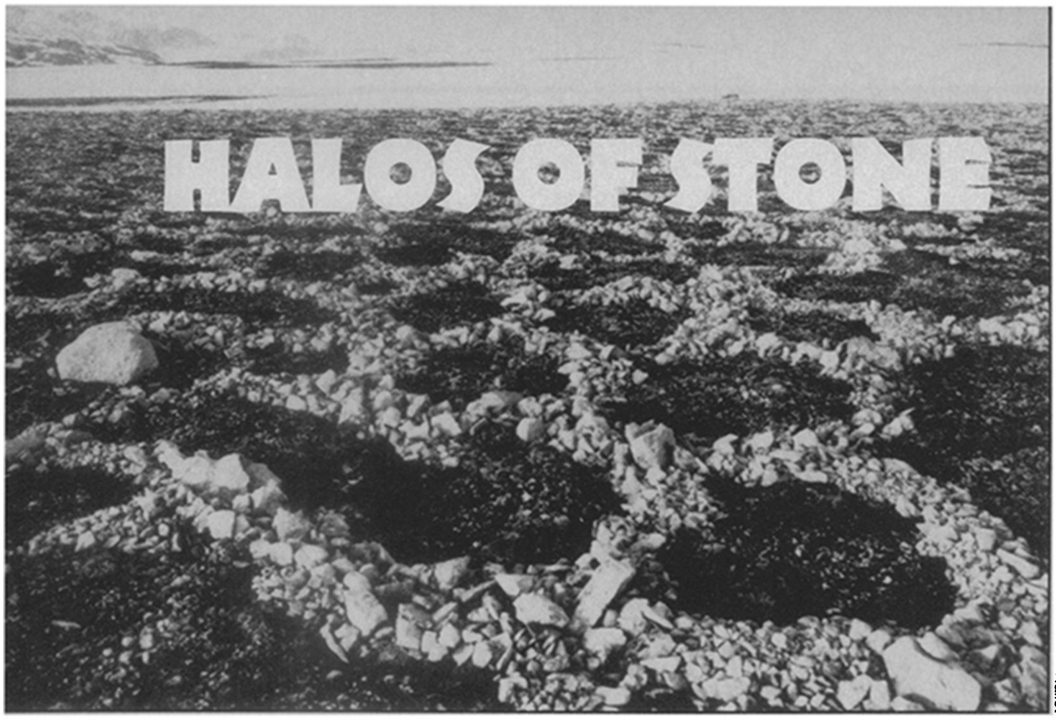

Hallet

HALOS OF STONE

How soil and rocks are fashioned into strikingly beautiful and orderly patterns is a mystery that has confounded scientists for over a century

"Stones have been known to move"
—Shakespeare, *Macbeth*

By STEFI WEISBURD

It looks as if someone with a good eye for design or, at the very least, a mischievous urge to baffle unwary geologists spent the entire afternoon in a desolate part of Spitsbergen, an island north of Norway, rearranging the rocks. The pattern of large stones lying in protective rings around mounds of soil is too distinct and remarkably regular to suggest anything but a human creator. And yet, it is *nature's* hand, not a person's, that sorts and arranges these stones into a honeycomb-like network that is unveiled every summer as the snow retreats and the arctic ground thaws.

Geologists have known about these so-called sorted circles for over a century. They grace periglacial and alpine regions worldwide from Antarctica to North Wales and Greenland — wherever the silty or clay soil exposed to moisture is seasonally frozen and thawed. The circles range in size from a fraction of a meter, where they are surrounded by pebbles, to several meters in diameter, where boulders sometimes mark their borders.

Sorted circles are just one example of a larger class of natural surface designs called patterned ground. Other geometric shapes include polygons, nets (forms between circles and polygons), steps and stripes. These shapes can be either sorted (in which case the rocks are separated from, and border, finer soil) or nonsorted (borders are commonly made by vegetation or cracks in the soil). These other forms are just as ubiquitous as circles and can reach sizes up to 50 meters in diameter. Relics of ancient surface patterns measuring up to 150 meters have been found in former permafrost regions.

Geologists believe that the patterns must be caused by some of the forces associated with cyclic freezing of the soil, and that this process can occur fairly rapidly; at one locale, scientists disrupting the pattern in one season have returned the next to find the rocks replaced neatly in the borders. But beyond that there is little consensus on the actual mechanics of pattern genesis and maintenance (see sidebar). "The patterns are just begging to be addressed in terms of an interesting problem in geology, and it is amazing to me that no one has really [solved] it yet," exclaims Bernard Hallet, a geomorphologist with the Quaternary Research Center at the University of Washington in Seattle.

Hallet is among a number of contemporary scientists who are reviving interest in the study of these intriguing patterns by trying to unravel the detailed physical forces that create them. With co-workers Suzanne Prestrud, Carrington Gregory and Christopher Stubbs, also at the University of Washington, Hallet has installed an extensive array of instruments near Ny-Ålesund, Spitsbergen, to monitor temperature, water content, pressure and soil movement. Recent advances in electronic recording technology enable the researchers for the first time to log data throughout the entire year, and not just during the summer months.

"We felt that the reason very little was known and no one could really say which of the hypotheses was the most likely is that we have never been able to document very well the physical properties of the soil and especially those that change with time," Hallet says. But by the end of next summer, his group should have some answers.

In the meantime, Hallet's working hypothesis is that sorted circles are formed by the movement, or convection, of the soil up toward the center of the mound and then down under the stone borders. "One of the attractive aspects of this idea is that it would mean that this material would be moving down under the gravel, very much like a subduction zone," says Hallet. This movement would keep the troughs around the mounds clean and free of rocks, maintaining a sharp angle between the mounds and borders, just as is observed at Spits-

On the left is one frame of a computer simulation of the pattern evolution of a liquid contained in a circular vessel and heated from below to cause an effective density inversion. Black areas indicate downward motion of the liquid and white areas show upward movement. The pattern strongly resembles the aerial map, shown on the right, of sorted designs on Cornwallis Island in Canada. In this map, the long plumes of soil are made on hills where the soil moves not only in cells but also down the slope. The circles form on the level ground.

M. Bestehorn, H. Haken/PHYSICS LETTERS 12/12/83

A. L. Washburn

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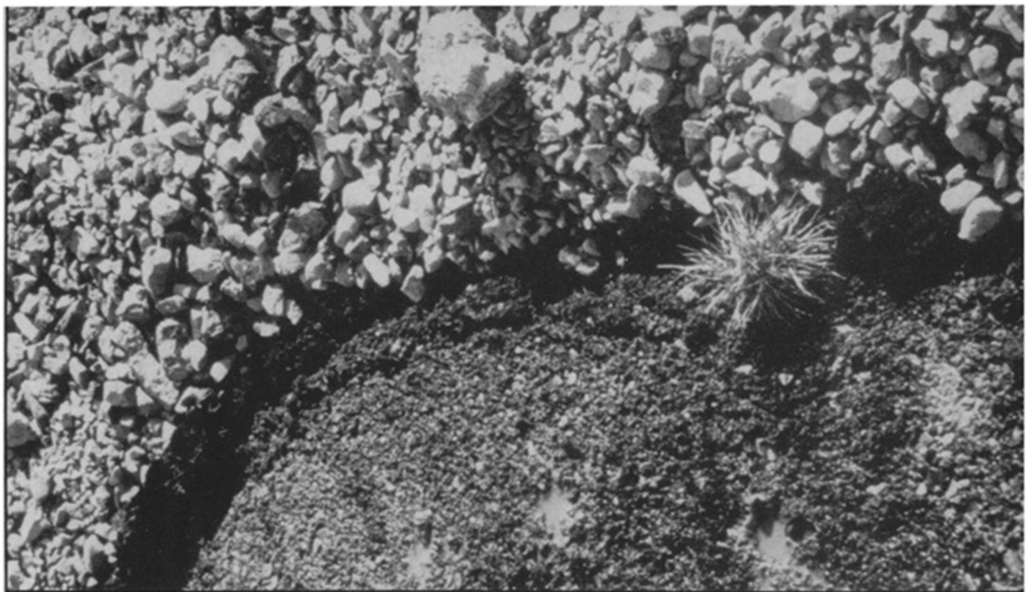
bergen. The convection theory is also supported by the observation that the earth in the center of the mound often appears churned up.

The soil convection model stands up to the preliminary data obtained so far by Hallet's group. Over three months of summer, the researchers recorded 1 degree of tilt with a tilt meter buried deep within a mound. Hallet suspects that the soil convects a little bit each summer so that the patterns form after a number of freeze-thaw cycles.

The researchers have also noticed that at the beginning of the thaw season the height differential between the mound and the bordering rocks drops by about 6 centimeters. Hallet interprets this to mean that the soil region is the first to thaw, lose water and consolidate. "One of my hunches is that it consolidates first near the surface, and as the thaw front propagates down, the consolidation takes place at deeper and deeper horizons," he says. The upper consolidating layers would then be more dense than the underlying ones. And Hallet's group has in fact measured such a density inversion in the soil near the rock border.



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Above, close-up of one of the sorted circles at Spitsbergen shown in an aerial view on the facing page. The border between the soil mound and surrounding rocks is kept so clean and sharp, presumably by the motion of soil down under the border, that a plant is able to grow in relative peace.

What happens to a system once a density inversion has formed is a classic problem in fluid dynamics — called a Rayleigh-Taylor instability—that has been applied to phenomena ranging from the evolution of rising plumes of magma (SN: 11/24/84, p. 324) to the fingers of gases that shoot out of the grasp of black holes (SN: 4/7/84, p. 220). The problem, essentially, is how the heavier material on top gets to its more comfortable position below the less dense matter. The two layers can't just flip over one another like acrobats. Instead, small instabilities, or perturbations, develop along the boundary between the two regions, creating flow pathways. Mathematically, the distance between these instabilities, and hence the size of the resulting convection cell, can be shown to measure a little more than twice the thickness of the convecting layer, regardless of the specific properties of the material.

At Spitsbergen, Hallet's group found just this relationship: The diameter of a sorted circle was 210 centimeters while the active soil layer measured about 1 meter deep. What's more, Hallet calculated for sorted circles the so-called Rayleigh number that gives an indication of how easy or difficult it is for convection to occur. "We actually get a number that is vastly greater than what is critical for convection," he says.

But the real icing on the cake occurred when Hallet saw a series of computer simulations by two German physicists of the convection pattern of a liquid with an unstable density profile. Although the boundary conditions and type of material are different, the fundamental physics is the same. The similarity between sorted circle patterns and these computer designs was striking, Hallet notes.

Convection explains the size and regularity of the sorted patterns, but it doesn't

From earthquakes to weather: Other models for molding the ground

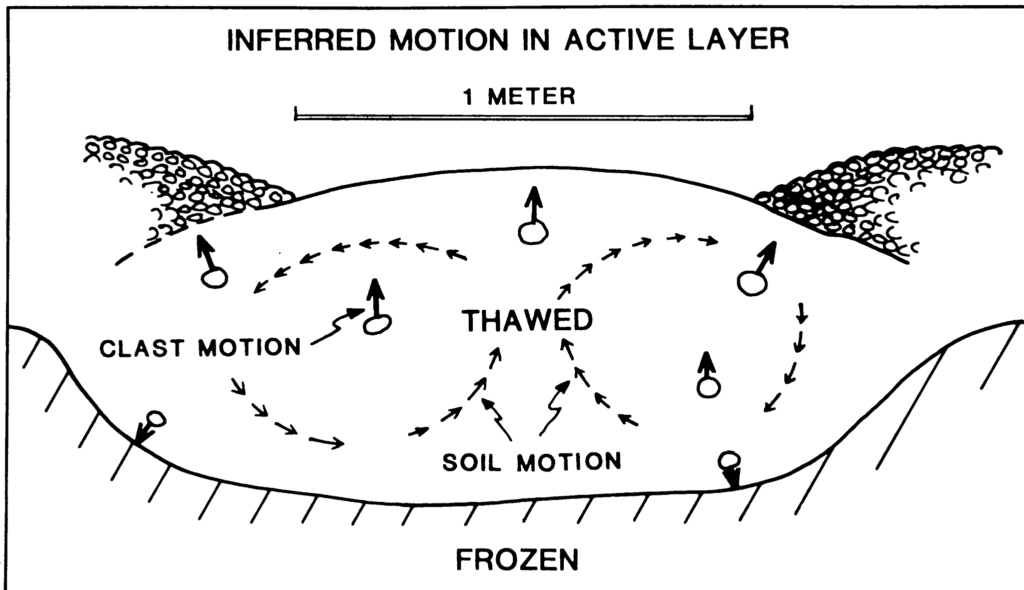
Since the natural mosaics of stone and earth called patterned ground were first discovered over a century ago, more than a dozen models of the pattern-forming process have been put forth and debated. Scientists do agree that more than one mechanism may be involved and that the variety of patterned group types will not necessarily be explained by one universal model. One of the earliest ideas, for example, involving the contraction of a material upon rapid drying, may well explain how polygonal shapes are created in desert muds and even coats of paint, but it does not address how patterns are formed in which rocks are sorted from the finer soil.

As for sorted circles, theories range from the increased wearing down of coarse grains in isolated cracks in bedrock to the sorting of the rocks by earthquake vibrations. Many scientists think that frost heaving—in which water migrates and freezes into ice lenses in the soil that then push up on the overlying earth—is involved. With frost heaving, the soil is expanded considerably because the ice chemically attracts more water. This might account for the mounds of soils that are seen at Spitsbergen, since fine soil is thought to be more susceptible to frost heaving than are coarse grains or rocks. But frost heaving does not explain why the troughs around the mounds are not littered with large rocks or what keeps the angle between the soil mound and the coarse border so sharp. And, like many other ideas proposed in the past, it does not explain the characteristic size and regularity of sorted circles.

That's where the concept of convection has come in. If a material starts out with a density inversion, with heavier layers on top of lighter matter, individual convection cells will be created that have a characteristic size and shape. Bernard Hallet at the University of Washington in Seattle believes that sorted circles are created in this way by the movement of soil. Nel Caine at the University of Colorado in Boulder and coworkers have revamped and improved on an older idea in which water convects through the soil. Caine's group thinks that the circulating water, which transfers heat from one region to another as it moves, causes some parts of the thawing front to thaw (or some parts of the freezing front to freeze) sooner than others. This results in a wavy pattern in the thawing and freezing fronts, which, they believe, ultimately leads to a similar pattern forming on the surface.

One advantage of this theory is that it might explain the occurrence of patterns that form in sediments underwater. The main disadvantage, Caine admits, is that it requires that soil always contain water, a condition that is not always met in every situation. Moreover, his group has yet to actually show that a wavy thawing or freezing front creates the surface patterns. Hallet believes that water convection could be occurring and could in fact contribute to the initiation of the pattern-forming process, but he is skeptical about its playing an important role once the pattern has begun to form.

In any event, says Caine, both the soil and water convection ideas have "revived discussion in an area of earth sciences that has been in the doldrums for about 40 years." —*S. Weisburd*



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This vertical cross section of a sorted circle shows schematically Hallet's theory of soil convection. The soil at the top of the mound thaws first and becomes more dense than the soil beneath it. This density inversion causes the soil to move in cells as shown. The larger clasts, or large rocks, are separated out from the soil by a combination of two motions: the soil movement and a process called upfreezing in which the clast moves relative to the soil. The end result after many seasons is a sorted circle.

really address the question of how the larger stones are sorted from the fine soil. According to Hallet, large rocks, or clasts, commonly freeze up through the soil. "Farmers find boulders in their fields and people who build highways find that rocks go right up through the base of the road and through the pavement," he says.

Hallet's group has examined this "upfreezing" process in the laboratory. After four cycles of thawing and freezing in the laboratory, they found that a stone buried in the soil moved 3 centimeters above its original position. The researchers believe that the top of the rock freezes first and is pulled up by the inflated frozen soil. When the soil thaws, the rock settles down, but not quite as far, so that after a number of seasons the combined action of the soil convection and the clast movement results in a sorted pattern.

In the coming months at Spitsbergen the researchers want to verify and map the density profile as it changes, chart the freezing and thawing fronts that are thought to move through the soil mounds and search for soil motion that might accompany freezing as well as thawing. They are also interested in seeing if some motions they observed, such as the border rings appearing to shrink slightly, are erased or enhanced during a complete freeze-thaw cycle.

"Our study of gravitationally sorted patterns is far from being finished," says Hallet. "But I think we're on the right track."□

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conjunction with theories on the origin of the solar system, extends from 35 to 70 AU. From 70 to 130 AU, Planet X would have cleared a gap in the belt, which then resumes beyond 130 AU. While this comet belt has never been seen, says Whitmire, it is widely thought to exist, especially the section of the belt closest to the sun. The gravitational pull of Planet X would dislodge comets near the gap when either the perihelion (point on the orbit closest to the sun) brushes by the inner edge of the gap, or the aphelion (point farthest from the sun) graces the outer gap edge, although Whitmire believes the former effect is stronger than the latter since the comet belt is most dense closest to the sun.

Whitmire sees two major advantages of the Planet X approach over the competing Nemesis theory, of which Whitmire was in fact one of the original creators. Nemesis is the name of the proposed sister star to the sun that is envisioned to intrude on the so-called Oort cloud of comets at distances much farther from the sun than the proposed orbit of Planet X (SN: 4/21/84, p. 250).

With Planet X, "we're not postulating the existence of anything that hasn't already been postulated before for other reasons," says Whitmire. The idea that there could be an extra planet cruising the periphery of the planetary system has been put forth a number of times over the last 100 years in order to account for the observed deviations in the motions of the known outermost planets from their predicted courses (SN: 1/31/81, p. 68). While other suns are known to have companion stars, there is no independent astronomical evidence that Nemesis exists, Whitmire says. Moreover, past studies have concluded that the "missing planet" should have 1 to 5 times the mass of the earth and should be found 50 to 100 AU from the sun, characteristics consistent with Whitmire and Matese's Planet X theory for comet impacts.

The second advantage, according to Whitmire, is that the orbit of Planet X, being much closer to the sun than Nemesis, would be very stable. Recent calculations on the orbit of Nemesis, on the other hand, indicate that its period has changed by 15 percent over the last 250 million years because of the gravitational nudges from other bodies (SN: 11/3/84, p. 279). "This is not necessarily a fatal objection to Nemesis, but it's the one that's most often raised," he explains.

Both the Planet X and Nemesis ideas can accommodate a range of values for the period, which is an asset at present because there is some uncertainty and disagreement over the exact period for the fossil, crater and other geological records. But this flexibility is also a disadvantage, says Richard B. Stothers at the NASA Goddard Institute for Space Studies in New York, because the period can't be used to make testable predictions with either theory.

Stothers and co-worker Michael R. Rampino prefer a model in which the solar system oscillates through the galactic plane at the known time interval of 33 million years — corresponding to periodicities the researchers claim to see in geological records (SN: 1/12/85, p. 24).

All of the scientists involved in the debate do agree that the solution will depend on more accurate dating of the geological and fossil records. Astronomers have also been looking for Nemesis. And, according to Ray Reynolds at NASA Ames Research Center in Moffett Field, Calif., who with co-workers had been planning to search for Planet X for a number of years, the data from the Infrared Astronomy Satellite (IRAS) have just been put in a form that can be analyzed to look for Planet X.

One of the reasons why Planet X may not have been found in the past, says Whitmire, is that previous surveys concentrated on the Northern Hemisphere while recent calculations show that Planet X, if it exists, is more likely to be found in the Southern Hemisphere. The IRAS data cover both hemispheres.

In the meantime, comments Stothers, "I think we haven't seen the last of the astronomical mechanisms. I have a stack of preprints related to all this on my desk.... The field is full of flowers." —*S. Weisburd*