ORIGIN OF FISSURE FILLINGS IN A PENNSYLVANIAN SHALE IN VERMILION COUNTY, ILLINOIS

W. ARTHUR WHITE
Illinois State Geological Survey, Urbana

ABSTRACT. — The top 15 feet of the marine shale above the Summum (No. 4) Coal of Illinois contains vertical fissures that could not have been formed by regional jointing. Some of the fissures are filled with siderite, dolomite, and calcite in various proportions. The fissures were developed by synaeresis, and the fillings contain two additional generations of synaeresis cracks.

A Pennsylvanian shale, mottled maroon and green at the top and grading to gray below, crops out in the bed and along the valley walls of a tributary of the Vermilion River, on the northeast side of a county road in SW¼ NE¼ SW¼ sec. 14, T. 18 N., R. 11 W., in Vermilion County, Illinois. The shale is above the Summum (No. 4) Coal (J. A. Simon, personal communication, 1964) and occurs in the marine portion of the cyclothem (Weller, 1930, p. 102).

Figure 1 shows the columnar section at the above location.

Data on the mineralogy and textural and structural characteristics of this shale are presented here, and conclusions are drawn regarding the depositional environment of the shale and the origin of its fissures and fissure fillings.

DESCRIPTION OF SEDIMENTS

The top inch of the shale is bright red, and the next 15 to 20 feet is mottled maroon and green. It contains vertical fissures that enclose polygons of noncalcareous shale. The polygons have from 3 to 6 sides and vary in size (Figs. 2-3). The outer inch of the shale bounded by the fissures is completely green, even after weathering, and outlines the polygons with green bands. The largest polygons are bounded by the widest fissures, which have calcareous, hard, greenish brown fillings. Some of the large polygons are divided into smaller polygons by smaller fissures. The fissure fillings vary vertically (Fig. 2) from a small fraction of an inch to as much as three to four inches thick. The fillings apparently become less numerous from the top of the shale down. One filling was not vertical but diagonal. The vertical fissures extend down almost to the first horizontal siderite layer.

The shale has no visible fissures below the siderite layer and is sandy near the base. The lower shale contains at least three more siderite bands below the top one. One marine fossil was found in the shale above the top horizontal siderite layer.

The clay above the shale is dark gray in the upper 18 to 24 inches and contains red stains along randomly oriented fractures. Below this lies 12 inches of light gray, sandy clay with red staining along diagonal fissures, which is underlain by 10 inches of light gray laminated shale with red and pink stains along the fissure surfaces.

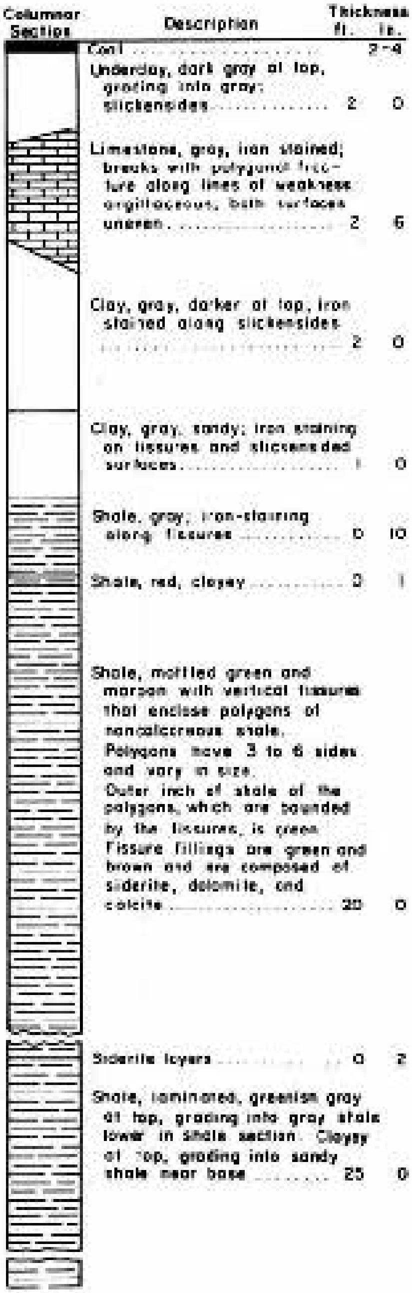

FIGURE 1.—Columnar section of the rocks exposed in a series of outcrops in SW¼ NE¼ SW¼ sec. 14, T. 18 N., R. 11 W., Vermilion County, Illinois.

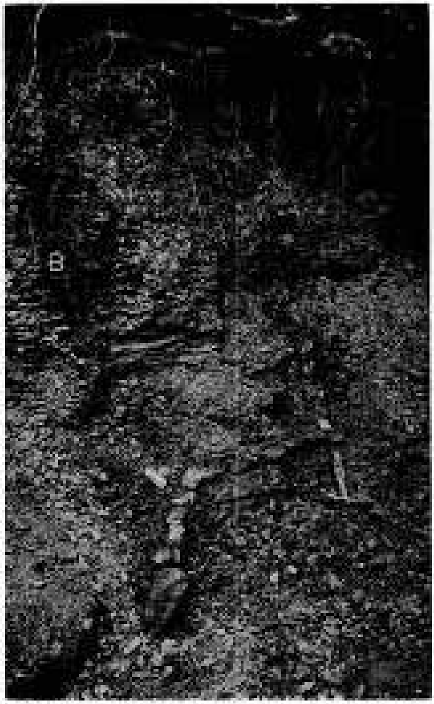

FIGURE 2.—Outcrop of shale with fissure fillings. Fissure fillings can be continuous for several feet (A) or may thicken and thin rapidly (B). Note hexagonal pattern.

The "fresh-water" limestone above the clay is gray, has splotches of iron staining, and its top and bottom surfaces are irregular. The limestone fractures easily along lines of weakness which form polygonal patterns.

The clay above the limestone is a normal gray to dark gray under-

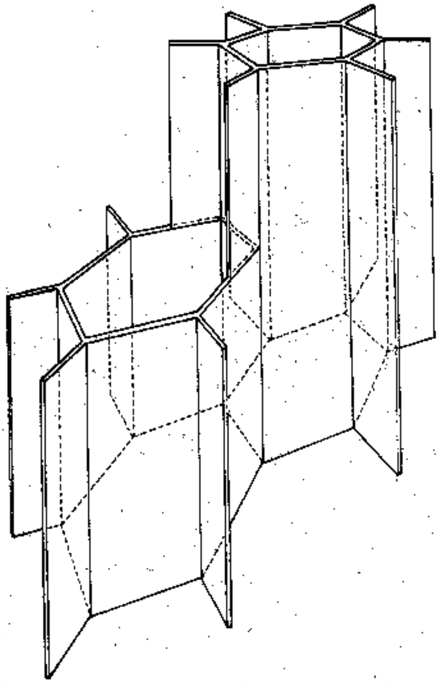

FIGURE 3.—An idealized fissure pattern for the upper 15 to 20 feet of the shale above Summum (No. 4) Coal.

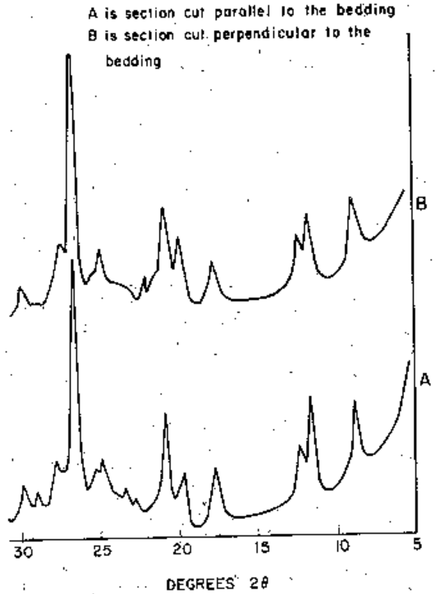

FIGURE 4. — X-ray diffractograms of the shale cut parallel (A) and perpendicular (B) to the bedding.

clay with no iron staining along the fissures.

Mineralogy of the Shale

The chief nonclay mineral in the shale is quartz. Pyrite, gypsum, and siderite also are present. The distribution of the clay minerals found in the shale is reported in Table 1.

The orientation of the clay minerals (Fig. 4) of the upper 15 to 20 feet of the shale is 0.47, which indicates a random orientation (Odom, 1963, p. 55). The equation used for determining orientation is

$$\text{Orientation} = \frac{\text{counts illite 001} \perp \text{to bedding}}{\text{counts illite 001} \perp \text{to bedding} + \text{illite 001 parallel to bedding}}$$

The shale evidently contains very little calcium carbonate, but it does have some gypsum, which is produced when sulfates formed by the weathering of pyrite or marcasite react with calcite or the exchangeable cations on the clay minerals.

TABLE 1. — Clay Mineral X-Ray Diffraction Intensities (parts in ten)

Samples	Illite	Mixed-layer	Chlorite	Kaolinite
Clay between shale and limestone	3-4	3	2	1-2
Upper 15 feet of shale	4	2	2	1
Shale below first siderite bed	4	1	3	1
Shale 40 feet below top	6	1	2	1

DESCRIPTION OF FISSURE FILLINGS

The fissure fillings are greenish gray but on the outside surfaces, which are uneven and contain reflecting crystal faces of calcite, they are mottled with maroon and brown. A broken or sawed surface shows a honeycomb network of veins in a greenish gray or brownish gray groundmass (Fig. 5). Close observation reveals that the veins are split lengthwise and crosswise and contain a transparent filling.

The filling in the vein was studied by both x-ray and microscope. The x-ray diffraction data showed that the filling is chiefly siderite, dolomite rich in iron, calcite, and a small percentage of quartz. The percentages of clay minerals are so low they do not show on the x-ray trace of the whole sample. When the carbonate was removed, illite, chlorite, and mixed-layer clay minerals showed up on the x-ray trace; illite made up over 50 percent of the clay minerals.

FIGURE 5.—Photograph of a piece of fissure filling cut and polished perpendicular to the fissure. Two generations of filled synaeresis cracks can be seen. The first is lighter than the background and the second is the darker pattern extending along and across the light fillings.

Investigation by microscope showed that the siderite and dolomite were very fine grained. The siderite had evidently formed first as a colloidal gel of very tiny crystallites with random orientation. The gel had then split into masses of various sizes and shapes, and the periphery of these masses had partially oxidized, making dark brown rims (Palache et al., 1951, p. 168) around the greenish gray siderite interiors. After the oxidation had taken place, some of the masses had been sheared by local movement. These masses are surrounded by a light yellowish brown mineral, probably the iron-rich dolomite, that transmits considerably more light than the siderite. The dolomite is fine grained, and it either has been cracked or the veins growing from each side did not quite meet. In some of the larger veins, a series of bands surround the siderite masses in the following order: an iron-rich dolomite; either calcite or a dolomite poorer in iron; iron-rich dolomite; pockets of calcite where the vein is widest; iron-rich dolomite; a layer of less-yellow dolomite or calcite; and a thin layer of high-iron dolomite adjacent to the next siderite mass. In some areas there are irregular stringers of siderite in the dolomite, indicating that the dolomite may have replaced the siderite. The dolomite veins have cross-breaks that are filled with calcite.

Table 2 gives percentages of minerals in 7 samples taken from fissure B. Fissure A is located about 100 feet from fissure B and about 2 feet higher in the shale. Table 3 gives the carbonate percentages for fissure A and the average from Table 1 for fissure B. Tables 2 and 3 show that the carbonate mineralogy can vary several per cent within a fissure and between fissures.

TABLE 2.—Carbonate Percentage in Seven Samples from Fissure B.

Sample	Siderite	Dolomite	Calcite
B-1	38	49	13
B-2	36	37	27
B-3	48	26	26
B-4	38	41	21
B-5	44	39	17
B-6	39	41	20
B-7	36	51	13
Range	36-48	26-51	13-27
Average	40	40	20

TABLE 3.—Carbonate Percentage in Fissure Filling.

Fissure	Siderite	Dolomite	Calcite
A	72	7	21
B average	40	40	20

Origin of Fissures and Cracks

Kallstenius (1963, p. 20) described two zones of fissures in Swedish postglacial clays, one seasonal and the other permanent. He stated that cracking in the first clay, which lies above the water table, occurs in the dry seasons; in the second clay, below the top of the water table, the cracking is permanent. He decided that the permanent fissures are shrinkage cracks caused by synaeresis, or chemical "drying" (1963, p. 21). His figures 41a, b, and c (1963, p. 95) show a fissured clay below a nonfissured clay in a scar left by a landslide in 1961.

Rosenqvist (1955, p. 63) and Kallstenius (1963, p. 21) suggested that the postglacial clays of the Scandinavian Peninsula were deposited in marine waters and that since uplift there has been a leaching of the sodium salts and an increase in the potassium content of the pore water. They assumed some weathering because oxidation has occurred on the fissure surfaces below the water table. Kallstenius (1963, p. 21) stated:

> The changes cause shrinkage of the clay due to decrease in michelle size and increase in strength. It should also tend to induce vertical fissures in the soil. Such effects have been observed by the present author [Kallstenius] in clay lying immediately below an area treated with lime to increase its bearing capacity.

In a fresh-water marsh, about half a mile north of Bayou Bienvenue in the Mississippi River Delta and on the east side of Louisiana Highway 47, polygonal mudcracks were developed. The polygons were about 1 foot in diameter and the fissures surrounding the cracks were from 1 to 2 inches wide. The cracks were found to extend several feet below the water table. According to Gould and Morgan (1962, p. 293), the surface of the swamp is about sea level. The water-table level was visible about a foot below the top of the cracks. That the mud had been deposited in a flocculated state was shown by the random orientation of the clay minerals in the clay (Odom, 1963, p. 79, 82). The fissures were the result of synaeresis.

Van Straaten (1954, p. 75) discussed mudcracks of subaqueous origin that result from processes active under permanent water cover. He suggested that the cracks formed after the muds were in a more or less advanced state of compaction because of the changes in the salinity of the water with each successive tide.

In Colorado, montmorillonite clay containing sodium as the exchangeable cation was used to line some of the irrigation ditches. According to R. D. Dirmeyer, Jr., of the Civil Engineering Department of Colorado State University (personal communication, 1962), when fresh irrigation water containing soluble salts of calcium and magnesium was passed through the ditches, the montmorillonite clay developed synaeresis cracks under the irrigation water.

The shale in Vermilion County appears to have polygons and fissures similar to those in the Mississippi River Delta except that the fissures in the shale are filled with carbonates instead of water. The origins of the polygons and fissures were probably more closely related to the synaeresis cracks formed in the clay in the irrigation ditches.

If the shale had been cracked by subaerial dessication, the fissures would have been filled with sand or clay—probably clay because it is the overlying sediment. However, less than 10 per cent of the filling is clay and sand. The greatest bulk of the filling is chemical precipitate.

If the cracks had been formed by subaerial drying, the sides of the fissures would have been parallel, or almost parallel. Some of the fissures do have straight walls, but others have walls that are 3 inches apart at one point and almost come together at other points (Fig. 2A-B).

The cracks or fissures could not have been formed by regional jointing, because some of the fissures meet at an angle of 120°, and the fissures are only about 1½ to 2 feet long (Fig. 2). Six-sided polygons could be made by three sets of regional joints, but the joints would have to continue through, also making triangular polygons with 60° angles next to the 120° angles. Figure 1 shows neither the triangles nor the 60° angles. Three 120° angles originate at one point.

The hypothesis drawn from the results of the study is that the polygons and fissures were produced by synaeresis. The shale probably was deposited as a normal marine shale, except for the top 15 to 20 feet. Instead of having a sufficient percentage of clay minerals deposited with their long dimensions parallel to the bedding to produce a shale with a fissility having a normal fabric index of 0.3 or less (Odom, 1963, p. 55), the top 15 to 20 feet of clay minerals was deposited with almost completely random orientation. Even though the clay has been compacted since Pennsylvanian time, the fabric index is reduced to only 0.47, which signifies almost complete random orientation. The chemical environment could have changed from a sodium-rich environment to one rich in calcium, magnesium, and iron. If such a change had occurred, the shale would be calcareous. Since the shale is noncalcareous, evidently there was a change in the chemical environment, a change in the sedimentation rate, or both.

The top 15 feet of shale exhibiting the polygons contains 10 per cent or less of quartz, whereas the part of the shale 35 to 40 feet below the top contains considerably more quartz. When the top 15 feet of shale was deposited, most of the sediment was composed of clay-size particles.

The velocity of transport and the rate of deposition probably had slowed down by the time the top of the shale member was formed. The clay was deposited in a flocculated state in water with a salt content nearly that of marine waters 15 to 20 feet below the top, as indicated by the marine fossil. The waters could have become less saline as further deposition occurred, but there is no proof of this.

After the deposition of the shale and before the deposition of the underclay above the limestone, the character of the water changed from dominantly sodium chloride to one dominated by ferrous iron, magnesium, and calcium. The change to waters containing a dominance of divalent ions probably began with deposition of the underclay. When the waters containing divalent cations began to replace the sodium chloride waters, the stability of the clay-water system was changed and synaeresis began to pull the particles closer together, forming the polygons and fissures.

Formation of Fissure Fillings

The filling of the fissures began with the precipitation of iron as very tiny crystals of siderite. The crystals were of colloidal size — a tenth, a hundredth, or a thousandth of a micron—and they formed a gel. At the same time, or perhaps a little later, an iron-rich dolomite began to precipitate with the siderite. The latter precipitate seemingly fractured into polygons and cracks. The cracks probably resulted from a change to a water content with more calcium and magnesium and less iron, which is suggested by the fine precipitate in the vein fillings around the siderite polygons. These veins cracked and were later filled with calcite. The cracking may have been the result of the change from waters containing little iron but high in calcium and magnesium to waters high in calcium.

Literature Cited

GOULD, H. R., and J. P. MORGAN. 1962. Coastal Louisiana swamps and marshlands. Field trip No. 9, 1962 G.S.A. Annual Meeting, Houston Geol. Soc. —Geol. Soc. America: 287-341.

KALLSTENIUS, T. 1963. Studies on clay samples taken with standard piston sampler. Swedish Geotechnical Inst. Proc. 21.

ODOM, I. E. 1963. Clay mineralogy and clay mineral orientation of shales and claystones overlying coal seams in Illinois. Univ. Illinois Ph.D. thesis. 143 pp.

PALACHE, CHS., H. BERMAN and C. FRONDEL. 1951. Dana's system of mineralogy. II, 7th ed. New York, John Wiley and Sons, Inc. 1124 pp.

ROSENQVIST, I. TH. 1955. Investigations in the clay-electrolyte-water system. Norwegian Geotechnical Inst., Pub. 9. 125 pp.

VAN STRAATEN, L. M. J. U. 1954. Composition and structure of Recent marine sediments in the Netherlands. Leidse Geologische Mededelingen Deel 19. 110 pp.

WELLER, J. M. 1930. Cyclical sedimentation of the Pennsylvanian Period and its significance. J. Geol. 38 (2): 97-135.

Manuscript received June 1, 1964.