

CONTACT TEMPERATURE OF A PERIDOTITE DIKE WITH PENNSYLVANIAN SHALE DETERMINED BY CLAY MINERAL ALTERATIONS

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Basic igneous rocks have been encountered in coal mines and in drill holes from time to time in southern Illinois (Clegg and Bradbury, 1956). One such occurrence uncovered in a coal stripping operation near Absher, Illinois, (Clegg, 1955) is of two mica peridotite dikes and their associated stringers. The dikes vary from 8" to about 10' in thickness and cut through sedimentary rocks of Pennsylvanian age extending upward into the shale that directly overlies the Harrisburg (No. 5) Coal. Natural coke was formed at the dike contact during intrusion and contact metamorphism of the coal extends only 18"-20" from the dike.

Clegg (1955) described the dike rock as a mica-peridotite having a seriate-porphyrific texture. The rock is specular in overall appearance, and the only minerals macroscopically recognizable are olivine, pyroxene, biotite, pyrite, and calcite. The phenocrysts are more-or-less equant and consist of stubby, doubly terminated euhedra of olivine and pyroxene as much as 1 to 2 mm in diameter. Along the dike contact a few biotite crystals are 10 to 15 mm across, and olivine and pyroxene may reach lengths of 10 mm. The phenocrysts are enclosed in a blue-gray matrix in which grain size is

too small to permit identification of individual minerals.

In thin section the microcrystalline matrix appears to consist mainly of finely shredded biotite, various quantities of chlorite, and some epidote. Serpentinization of olivine and pyroxene has proceeded to the extent that differentiation is often impossible except by crystal form. Accessory minerals include apatite, garnet, magnetite, ilmenite, chromite, and perovskite (?). Secondary minerals are serpentine, chlorite, magnetite, pyrite, calcite, epidote, and leucoxene.

Clegg studied the natural coke by petrographic microscope techniques and by differential thermal analyses (DTA) and concluded that the coal at the contact had been heated to not more than 600° C and that the temperature may have been lower. Sosman (1938) considered the coke inclusions in a similar mica peridotite dike cutting a Pennsylvanian coal bed in western Pennsylvania to have been heated at least to 480° C but not above 550° C. He studied the kinds and amounts of volatiles in the coke and unaltered coal to arrive at his estimate and suggested that the coking temperature had been close to 520° C \pm 30° C.

In the present study an estimate of the temperature of the contact



FIGURE 1.—Location of Absher Dike area in southern Illinois, SE $\frac{1}{4}$ Sec. 34, T. 9 S., R. 4 E., Williamson County.

zone between one of the dikes at Absher, Illinois, and the shale and underclay associated with the No. 5 Coal is based on the clay mineral differences between the unaltered country rock and the contact zone. Laboratory heating of the unaltered clay minerals was used to aid in estimating the contact temperature.

STRATIGRAPHY

The area of study is located in SE $\frac{1}{4}$ sec. 34, T. 9 S., R. 4 E., Wil-

liamson County, Illinois (Fig. 1). Here the Harrisburg (No. 5) Coal has been strip-mined and the pit abandoned several years ago. The Pennsylvanian rocks exposed in the pit floor and in the high walls belong to the Carbondale Formation of the Kewanee Group (Kosanke *et al.*, 1960). The rocks throughout this area for the most part have a slight dip to the north toward the deeper portion of the present Illinois Basin.

SAMPLING AND SAMPLE TREATMENT

Figure 2 is a generalized diagram of the field relationships of the various sedimentary rock types and the peridotite dike selected for study. Four samples of the top 1 foot of the underclay were taken at varying distances from the dike; (sample D-1) 30 feet from the dike, (sample D-2) at 20 feet, (sample D-3) at 10 feet, and (sample D-4) 6 inches to 1 foot from the contact. (The actual contact of the underclay and the dike was not observed because of slumping of the spoil bank at that point. The position of D-4 was in-

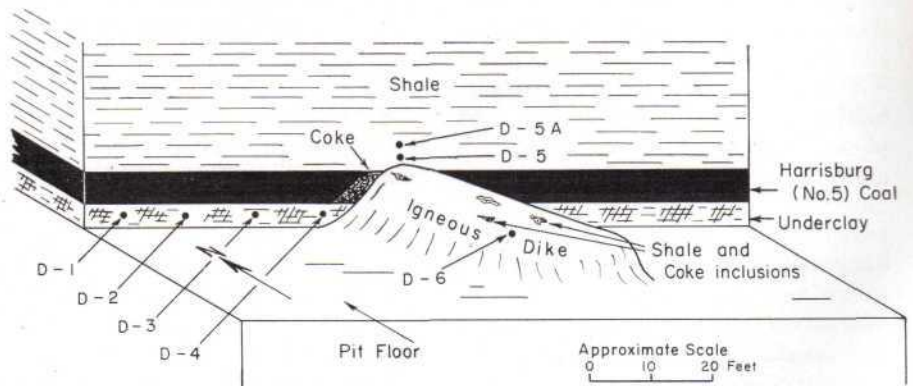


FIGURE 2.—Generalized field relationships of the Absher Dike, Pennsylvanian rocks exposed in the abandoned stripmines, and sample locations.

ferred from the line of intersection of dike with the bed of underclay.) Three samples of the shale above the coal were taken from directly over the dike. (Sample D-5A) at 1½ feet, (sample D-5) at 3 inches, and (sample D-6) was taken from shale pieces partly enclosed in the top of the dike. No chill zone was noted at the contacts with the country rock or on sample D-6. The shale samples were taken from a position where the top of the dike had penetrated only a foot or less into the shale. The dike at this point is approximately 5 feet wide.

Oriented aggregates were made of the $< 2 \mu$ fraction of each sample and were identified by x-ray diffraction techniques. Some of the samples were placed in an ethylene glycol atmosphere for at least 12 hours to facilitate the identification of any expansible clay mineral present. Sample D-5A was later heated for various times at different tem-

peratures in a small electric furnace in an effort to reproduce a clay mineral suite as much like the D-6 suite as possible.

Figure 3 shows the x-ray traces of the underclay samples D-1, D-2, D-3, and D-4. Each sample contains illite, chlorite, mixed-layer clay material and a trace of kaolinite. Samples D-1, D-2, D-3 are all essentially the same in clay mineral composition and in the quantities of the clay minerals present. Only sample D-4 shows some slight differences from the other three underclay samples. This sample is slightly harder than normal underclay, yet very similar in color and appearance to the other three. D-4 disaggregated and dispersed fairly easily in water during slide preparation, suggesting only slight thermal alteration at best.

The first order illite peak at $8.8^\circ 2\theta$ of the unglycolated D-4 trace is more pronounced than in the other three underclay samples and appears

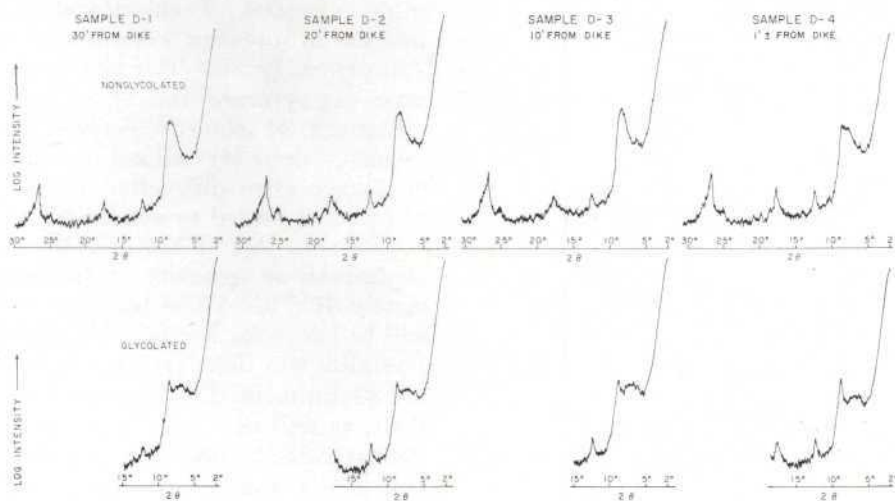


FIGURE 3.—X-ray traces of the < 2 micron fraction of top one foot of underclay of Harrisburg (No. 5) Coal.

as if some of the mixed-layer material has collapsed to a 10 Å spacing as a result of the heat of the intruding dike. The x-ray trace of the glycol treated sample D-4 shows a definite increase in the intensity of the first order illite peak when compared to the same illite peak of D-1, D-2, and D-3. The thermal effect of the dike on the clay minerals of the underclay at a distance of about 6" to 1' from the contact is very slight.

Figure 4 shows the effect of the temperature of the intruding dike on the clay minerals of the overlying shale. The 002 basal plane reflection of kaolinite and the 004 basal plane reflection of chlorite of the

shale samples have been plotted in Figure 5 from x-ray diffraction intensity measurements taken at regular intervals over the $25^\circ 2\theta$ region for samples D-5, D-5A, and D-6 in order to more clearly resolve these reflections. Sample D-5A, $1\frac{1}{2}$ feet above the top of the dike, shows no alteration effects of the dike. The clay minerals of this sample are illite, kaolinite, chlorite, and mixed-layer clay material. Sample D-5, taken 3 inches above the dike-shale contact, shows some differences in the clay minerals when compared with D-5A. The first order illite and chlorite peaks of D-5 are seen to be sharper on both the untreated and glycol treated sample. The sharpening of the illite peak is due to the collapse of the mixed-layer clay material and the sharpening of the chlorite is due to the shift of the same mixed-layer material away from the $5^\circ 2\theta$ area of the curve. Weiss and Rowland (1956) have demonstrated the following relationships: the 001 of chlorite should increase in intensity when heated to approximately 560°C while at the same temperature the other basal reflections of chlorite decrease in intensity; well crystallized kaolinite no longer gives diffraction maxima after being heated to approximately 525°C ; the 002 of kaolinite begins to decrease in intensity at approximately 475°C . These temperatures will be lower for kaolinite of poorer crystallinity. The crystallinity of the kaolinite in this Pennsylvanian shale, as well as that of many other Pennsylvanian clays and shales in Illinois, is somewhat poorer than that referred to by Weiss and Rowland (1956). If the sharpening of

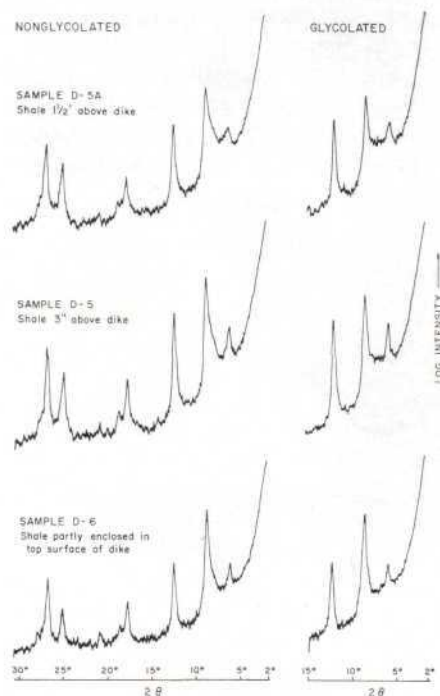


FIGURE 4.—X-ray traces of the <2 micron fraction of the shale overlying Harrisburg (No. 5) Coal.

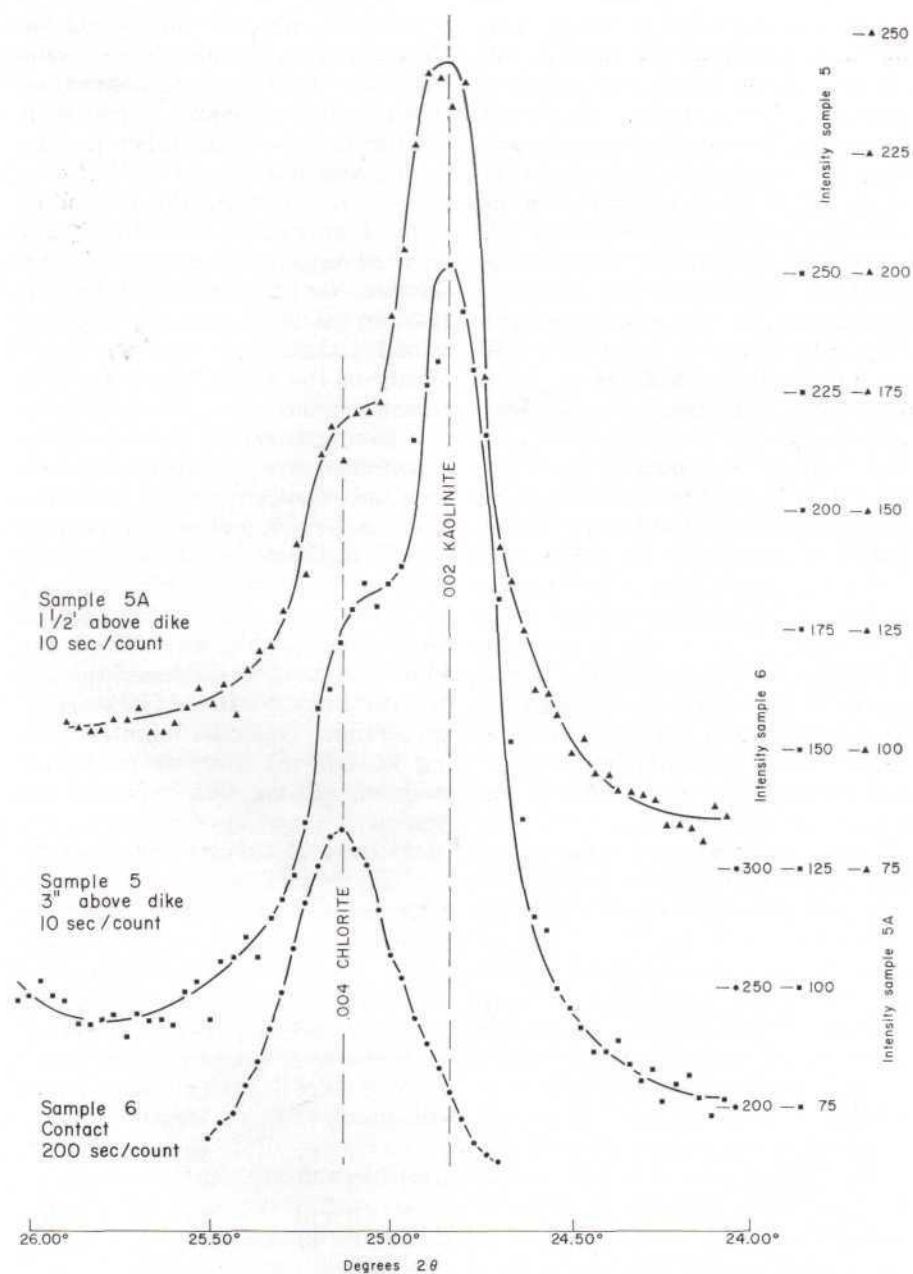


FIGURE 5.—X-ray intensity measurements of the <2 micron fraction of 002 kaolinite and 004 chlorite of shale above Harrisburg (No. 5) Coal.

the 001 chlorite peak of sample D-5 had been caused by temperature, the 002 reflection of kaolinite would have decreased in intensity. Figure 4 shows that this is not the case. Therefore, the maximum temperature to which sample D-5 was subjected is estimated at approximately 400° C.

The clay fraction of D-6 is composed of only illite and chlorite, kaolinite being no longer present (Fig. 5). The 001 of chlorite has not increased in intensity and its other basal reflections do not show a decrease.

A contact temperature of about 525° C to 550° C would seem to be compatible with the findings of Weiss and Rowland if the kaolinite and chlorite in the shale react in the same way as did theirs at elevated temperatures.

Portions of the unaltered shale sample D-5A were heated at various temperatures and times as follows: 400° C for 30 and 140 minutes, 430° C for 30 and 60 minutes, 450° C for 30 and 60 minutes, 450° C for

30 and 110 minutes, and 480° C for 15, 45, and 60 minutes. The intensities for the basal reflections of chlorite and kaolinite after each heating are listed in Table 1. The heatings at 400° C and 430° C produced no changes in the intensities of the basal reflections of the < 2 μ oriented aggregates of kaolinite or chlorite for the times indicated. Heating at 450° for 30 minutes caused a slight reduction in the intensity of the kaolinite 001 and 002 reflections and after 110 minutes at this temperature the basal kaolinite reflections were subdued even further but were still easily recognizable. After 15 minutes of heating at 480° C, the x-ray diffraction trace was very similar to that produced by 110 minute heating at 450° C. Continued heating at 480° C for 45 minutes further decreased the 001 of kaolinite and left the 002 scarcely perceptible. After 60 minutes heating at 480° C, there is no longer evidence of the 002 reflection of

TABLE 1.—X-ray Intensities of Basal Reflections of Chlorite and Kaolinite After Heating at Various Temperatures for Different Times.

C°	Times in minutes	Chlorite				Kaolinite
		001	002 C + 001 K	003	004	002
400	30	35	90	15	25	40
400	140	35	80	10	25	40
430	30	30	100	15	30	45
430	60	35	95	10	30	40
450	30	35	75	10	25	35
450	110	35	40	10	15	20
480	15	35	45	10	20	25
480	45	35	35	15	20	15
480	60	45	20	15	20	0

kaolinite and the small, poorly defined peak at $12.4^{\circ} 2\theta$ that remains is attributed to the 002 of chlorite.

The basal reflections for chlorite are not as well developed in the artificially heat treated sample as from those naturally heated. This difference might be expected since there are a number of factors that may have influenced the natural reactions that are not acting in the laboratory heat treatment of the same material.

First, the laboratory heating was in an oxidizing atmosphere, whereas the natural heating probably was under neutral or reducing conditions as is evidenced by the dark gray color of the shale inclusions in the dike and the salmon color of the laboratory heated samples.

Secondly, in the natural heating water probably was present in the system but in the laboratory the heatings were dry.

Third, perhaps at the time of intrusion the chlorite in the shale at the dike contact was able to accept magnesium from the igneous material into its structure at the expense of iron. The resulting more magnesium-rich chlorite would give more intense basal reflections. Analysis of the magnesium content of the chlorite in sample D-6, using the technique of Schoen (1963), showed there to be between 8 and 9 magnesium atoms per 12 octahedral positions.

Fourth, all of the temperature estimates in this study have been made on the assumption that the effect of pressure near the contact of the dike and the shale resulting from their possible deep burial at the time of intrusion was of little

consequence. Clegg (1955) states . . . "Field evidence indicates that pressure was not excessive at the time of igneous activity. The conspicuous jointing above the coal and the dike in the southeast highwall points to a release of pressure as a result of tension-fracturing prior to the advance of the rising igneous material. The manner in which the small dike stringers are controlled by fractures in the country rock also indicates that fracturing had opened avenues in advance. It is difficult to understand how a stringer of material less than one-half inch thick could advance for several feet into country rock unless crevices were already present. An apophyseal dike nearby consists of amygdaloidal rock, showing that, at least locally, confining pressure must have been almost entirely absent. The planar arrangement of vesicles in the natural coke and the manner in which the drag folds of the middle zone are deformed suggest that lateral pressure was greater than vertical." and "(therefore) pressure is not considered to be of major importance in the Absher area." Perhaps, though, even a slight pressure change at the contact would play some part in the behavior of the chlorite at elevated temperatures.

Lastly, the difference between the rate of heating of the shale in the laboratory and the time the shale was held at a given temperature in nature must be of significance in accounting for differences in their diffraction effects. This can be seen in the results of the laboratory heating for, as mentioned earlier, heating for 110 minutes at 450°C produced an x-ray diffraction trace very

similar to one obtained from a 15 minute heating at 480° C. Clegg (1955) also stated that the dike probably cooled relatively slowly due to the low conductivity of the country rock. Had the dike been intruded at a lower temperature and cooled very slowly, the same clay mineral changes in sample D-6 might still have been produced. Clegg's D.T.A. data, though, show that the coal within 6 inches of the dike contact was heated to at least 480° C, yet the same D.T.A. effects would probably be produced if the coal were heated to a slightly lower temperature and held for some time. Rogers *et al.*, (1962) have shown that at and below 400° C lignite held at fixed temperatures will show a decrease in volatile content and an increase in B.T.U.'s with time. D.T.A. changes of the material would also be expected with time.

Sosman (1938) also places a lower limit of temperature at 480° C. on a similar dike in Pennsylvania based on laboratory coking experiments. Clegg (1955) has shown that most of the olivine of the dike has been altered to serpentine. Bowen and Tuttle (1949) stated that the water necessary to convert olivine to serpentine must come from outside of the igneous body and that water will be driven in from the country rock as the olivine cools to approximately 500° C and lower. Clark and Fyfe (1961) stated, "It has been noted frequently that ultrabasic rocks seldom show thermal effects at their contacts, which might be anticipated from their melting temperatures." ". . . the demand for water im-

posed by the serpentine reaction in chilled marginal phases may cause flow of water into the cooling magma and an abnormally low heating effect at contacts. This situation is in direct opposition to that with granitic rocks where internal water requirements are small, and transfer of water out from the magma may heat contact rocks." Whether the serpentine formed at the time of intrusion or later is not known in this case. If it had been formed at the time of intrusion, though, the inflow of water into the dike would probably have cooled the contact rock rapidly, thus diminishing the possibility of long-term low temperature alteration of the contact zone. If the serpentine formed later and if the dike cooled slowly, approximately 450° C would seem to be the minimum contact temperature from the clay mineral evidence.

Based on the clay mineral changes noted in the partly included shale pieces and in the laboratory heated samples of the unaltered shale, and on the field relationships of the rocks in question, the suggested contact temperature for the dike with the country rock at the time of intrusion is estimated at approximately 450° C to 480° C.

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