

REGULARLY INTERSTRATIFIED CHLORITE— DIOCTAHEDRAL SMECTITE IN DIKE-INTRUDED SHALES, MONTANA

C. L. BLATTER and H. E. ROBERSON

Department of Geology, State University of New York at Binghamton, New York 13901, U.S.A.

and

G. R. THOMPSON

Department of Geology, University of Montana, Missoula, Montana, U.S.A.

(Received 18 December 1972)

Abstract—Corrensite or 'corrensite-like' minerals occur in dike-intruded shales and siltstones of the Montana Group and Colorado Group (Early Cretaceous) in Western Montana. The $< 1 \mu\text{m}$ size fraction of one specimen of this "corrensite-like" material has been studied in detail. X-ray diffraction data and chemical analysis indicate that this specimen is a regular or nearly regular interstratification of chlorite and *dioctahedral* smectite. Also described are other samples, which contain corrensite and additional phases. These samples were taken at several localities where basic dikes have intruded these shales and siltstones.

INTRODUCTION

CORRENSITE or 'corrensite-like' minerals occur in rocks of widely different character and mode of origin, but they are commonly associated with carbonate and evaporite deposits as is indicated by the number of reported occurrences in these environments (Bradley and Weaver, 1956; Martin-Vivaldi and MacEwan, 1960; Peterson, 1961; Lippmann, 1956; Grim, Droste and Bradley, 1960; Bodine, 1971). Corrensite has been observed also in argillaceous siltstone (Earley, Bradley, McVeagh and Vanden Heuval, 1956); as a hydrothermal alteration product of andesitic and chloritic rocks (Harvey and Beck, 1960); as an alteration product of a deuterically altered beryl (Heckrodt and Roering, 1965); in metalimestones (Wilson and Bain, 1970) and in hydrothermal deposits (Sudo, Takahashi and Matsui, 1954).

The main purpose of this paper is to describe a pure corrensite that occurs in dike-intruded shales and siltstones (Lower Cretaceous) outcropping in Western Montana. The chemical analysis along with the X-ray diffraction data lead us to believe that this 'corrensite material' is different in character from most corrensite that has been reported in the literature. That is, the material described in this paper is believed to be composed of an ordered or nearly ordered 1:1 interstratification of dioctahedral smectite and trioctahedral chlorite, rather than an ordered interstratification of trioctahedral vermiculite or smectite with trioctahedral

chlorite. The other layer silicate assemblages found in these intruded shales and siltstones are also briefly noted.

In this paper corrensite is considered to be a regular mixed-layer mineral having approximately a 29 \AA *c*-axis *d*-spacing in the air-dried state which swells to $\sim 31 \text{ \AA}$ when treated with ethylene glycol. The term *corrensite* will be used indiscriminately to describe those minerals possessing such layering and swelling characteristics.

SAMPLE LOCALITIES AND METHODS OF SAMPLING

Most of the samples containing corrensite which are described herein were taken at the Dearborn River (DBR) locality (No. 1 in Fig. 1) midway between Bowman's Corner and Wolf Creek. Four sampling traverses from a 40–50 ft wide dike to distances up to 1800 ft were made. Samples were collected at approximately the same stratigraphic level along each traverse. In addition, a 58 ft stratigraphic section was sampled here (No. 1 on map).

Samples from four other localities (Nos. 2–5 on map) were obtained, but many did not contain corrensite, and only brief mention of the mineralogy of these samples is made.

X-RAY DIFFRACTION STUDY OF SAMPLES COLLECTED ALONG TRAVERSES

Samples to be studied by X-ray diffraction were suspended in demineralized water and centrifuged

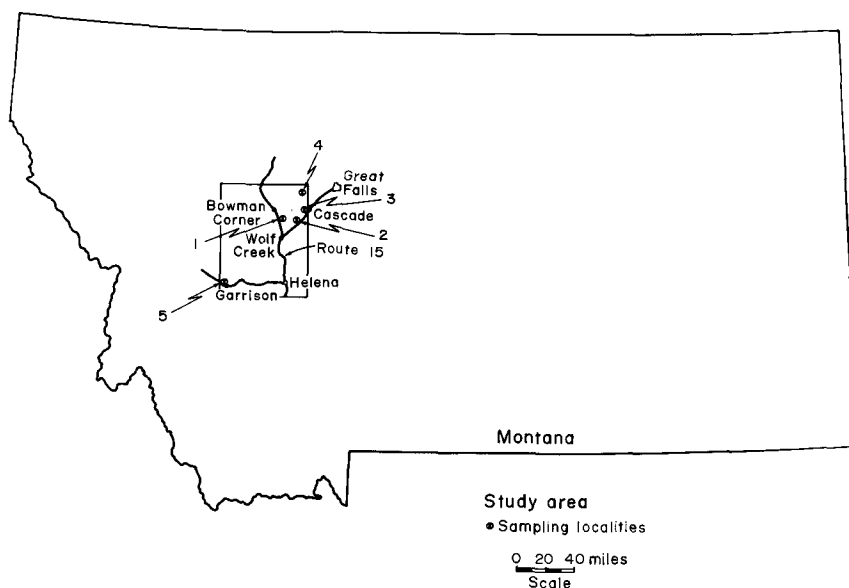


Fig. 1. Study area showing locations of sampling sites.

to remove particles coarser than $2\mu\text{m}$ (equiv. spherical dia.). Oriented aggregates of the $< 2\mu\text{m}$ fraction were prepared by the technique described by Kinter and Diamond (1956).

At two localities (Nos. 1 and 3 in Fig. 1) corrensite is the predominant or only clay mineral in the intruded shales. Figure 2 (DBR #3C, one traverse

at Locality No. 1) shows that all the samples collected up to 1400 ft from the dike contact along this traverse contained a relatively pure corrensite. The sedimentary rocks in this locality are sandwiched between two dikes, approximately 1800 ft apart, running perpendicular to the strike of the bedding. Corrensite in this 1800 ft span is the dominant mineral in the shales as well as in the dike rock. Figure 3 shows diffraction patterns obtained from samples along another sampling traverse (Locality No. 1 in Fig. 1) where corrensite is the main constituent of shales near the dike contact. However, at this locality the X-ray diffraction patterns show that well-ordered corrensite near the contact gives way to a more poorly ordered corrensite within a few feet. Farther out, this material grades into an expandible mixed-layer phase and discrete chlorite.

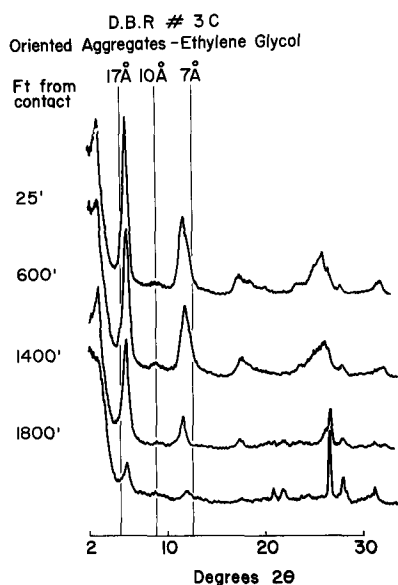


Fig. 2. Corrensite along one traverse (DBR #3C) at Sampling Locality No. 1.

At locality DBR # 3 (No. 1 in Fig. 1), a stratigraphic section of 58 ft was sampled at 3 ft intervals to determine if the composition of the corrensite and/or other materials varied in a vertical as well as a lateral direction. The variation of lithologies in the vertical section ranged from coarse-medium grained sandstone to fine grained siltstone to very fine grained, compact shales. The diffraction patterns showed no appreciable mineralogical change throughout the section.

At some sampling localities no corrensite was found in the intruded siltstones or shales. At two different localities (Nos. 4 and 5 in Fig. 1) the

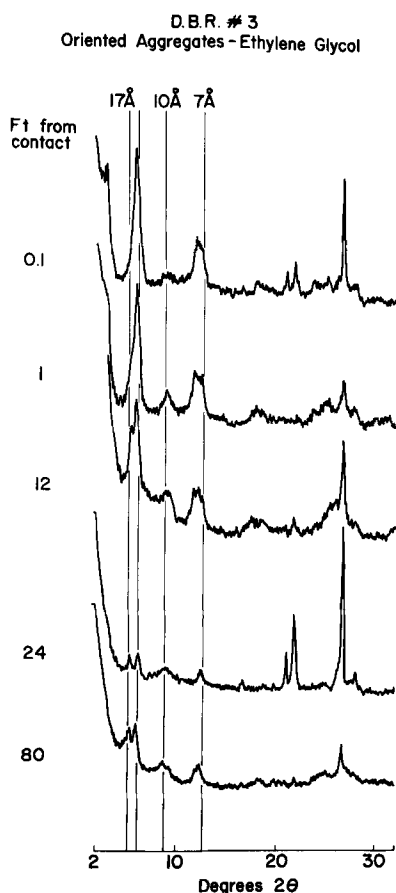


Fig. 3. Variations in corrensite material and other clays as a function of distance from dike along one traverse (DBR #3) at Sampling Locality No. 1.

predominant phase near the dike contact is a mixed-layer illite/smectite; the proportion of smectite layers in the mixed-layer illite/smectite decreases and the amount of discrete illite increases away from the dike contact. Along two traverses (Nos. 2 and 3 in Fig. 1) a highly expandible mixed-layer phase is the major clay mineral constituent in the intruded sedimentary units.

MINERALOGY AND CHEMISTRY OF THE CORRENSITE

It was possible by size fractionation to obtain two relatively pure corrensites. These samples have been subjected to several treatments in order to characterize this material as fully as possible.

Figure 4 (DBR #2A) shows diffraction patterns obtained from one of the samples after various treatments. X-ray patterns of the air-dried and the glycol-solvated samples show an *almost* regular series of 001 reflections with a fundamental period-

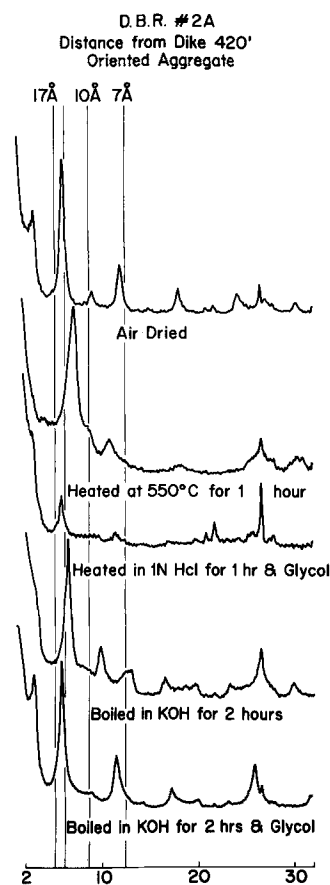


Fig. 4. X-ray diffraction patterns obtained using $\text{CuK}\alpha$ radiation showing changes after several different treatments.

icity of 29 and 31 Å, respectively. This observation appears to indicate that the material is composed of a nearly regular alternation of 14 and 15 Å units in the air-dried state and 14 and 17 Å units in the glycol-solvated state. After heating to 550°C, a weak peak at about 23–24 Å and a strong peak at about 12 Å appeared, which indicates a regular alternation of 10 and 13–14 Å units. As can be seen from Fig. 4, the series of 001 reflections was no longer integral after the material had been treated with 1 N KOH for 1 hr. Apparently, the expandible layers ceased to be uniformly expanded, i.e. some layers may have had thicknesses of 10 Å while others had thicknesses up to about 12 Å, dependent on the state of hydration of the K-treated layers. After glycolation, however, the regular 31 Å periodicity again appeared indicating that K⁺ had not caused any of the layers to collapse irreversibly. This re-expansion, and the fact that the expandible

layers absorbed two layers of glycol and collapsed to around 10 Å after heating to 550°C, suggest that these layers are more like smectite than vermiculite in composition and charge density. Other samples subjected to the same treatment produced similar results.

Figure 5 (DBR # 3) shows X-ray diffraction patterns after HCl treatments. The relative solubility of the corrensite, indicated by the increase in intensity of the quartz peak relative to the corrensite peaks, would be expected for a chloritic type mineral. However, the superlattice structure was still intact after one hour of acid treatment although the relative intensities of the basal reflections changed and some of the peaks were now broader and more diffuse.

X-ray diffraction powder data

X-ray diffraction powder data were obtained using a 114.6 mm dia. Debye-Scherrer camera with

filtered Cu K α radiation. The results for the < 1 μ m fraction of sample DBR#3C-8 are shown in Table 1. There are two main points to be made concerning these data. First, the pattern of DBR #3C-8 has no lines that can be ascribed to mica, quartz, calcite, or any other mineral that might be

Table 1. X-ray powder data of < 1 μ m fractions of DBR#3C-8 (filtered Cu K α radiation)

d (Å)	I (Est.)
14.5	10
9.73	3
7.26	7
5.81	$\frac{1}{2}$
4.81	1
4.60	6
3.61	5
3.21	3
2.90	3
2.57	8
2.44	5
2.28	2
2.01	1
1.69	1
1.54	9
1.51	4
1.32	2
1.31	1

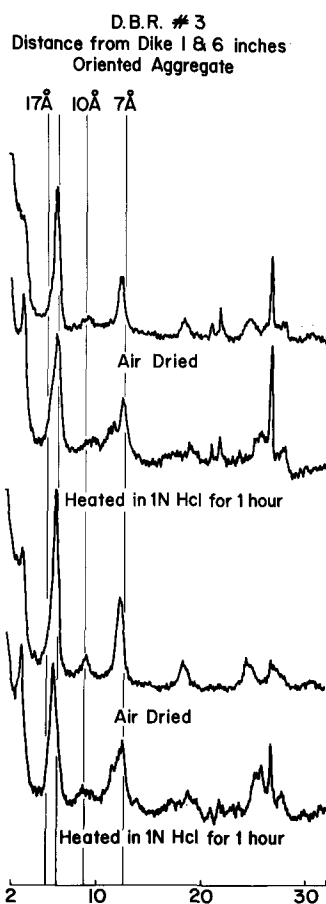


Fig. 5. X-ray diffraction patterns obtained using CuK α radiation showing changes after HCl treatments.

expected to occur in rocks of this type. The other point worthy of consideration is the presence of reflections at 1.54 and \sim 1.50 Å. The strong line at 1.54 Å suggests a trioctahedral character for some or all of the 2:1 silicate layers. The medium intensity line at 1.50 Å could be interpreted as resulting solely from 062 reflections from the chlorite layers, or 060 reflections from dioctahedral 2:1 expandable layers regularly interstratified with the trioctahedral chlorite layers. We will show that the chemical analysis indicates that the expandable layers are dioctahedral rather than trioctahedral.

Chemical analysis

The < 1 μ m size fraction of DBR#3C-8 was analyzed by methods similar to those of Shapiro and Brannock (1962). Before analysis, the sample was ignited at 850°C for 1 hr. Ignited samples should give more reliable information for recasting chemical formulas because air-dried samples can contain varying amounts of water depending on sample preparation and ambient conditions. The precision is approximately \pm 1 per cent of the amount indicated. The chemical analysis and the recast formula are shown in Table 2. We would like to place special emphasis on the number of octahedral

Table 2. Chemical analyses and unit formula of $< 1\mu\text{m}$ fraction of DBR#3C-8 (ignited weight basis)

SiO ₂	42.19
Al ₂ O ₃	17.00
Fe ₂ O ₃	8.98
FeO	7.43
MnO	0.20
MgO	21.38
CaO	1.98
Na ₂ O	0.32
K ₂ O	0.51
Total 99.99	

Distribution of ions calculated on basis of 50 oxygen atoms:

Interlayer ions	Octahedral ions
$\text{Ca}_{0.32}\text{Na}_{0.10}\text{K}_{0.10}$	$\text{Mn}_{0.02}\text{Mg}_{4.82}\text{Fe}_{0.94}^{2+}\text{Fe}_{1.02}^{3+}\text{Al}_{1.98}$
	Total = 8.18
Tetrahedral ions	
	$\text{Si}_{6.36}\text{Al}_{1.64}$

cations in this sample. The number of octahedral cations is approximately 8 per 50 oxygens (ignited basis). If both the 2:1 expansible layers and the regularly interstratified chlorite layers were trioctahedral, there would be 9 octahedral cations per unit cell. Obviously, we are assuming that the analyzed sample is pure corrensite. We have shown already that the X-ray diffraction data from the $< 1\mu\text{m}$ fractions of these two samples show no lines that can be attributed to phases other than corrensite. For this reason and because the number of octahedral cations is so close to 8 per 50 oxygens. We believe there is a strong possibility that either the 2:1 expansible layers or the regularly interstratified chlorite layers are dioctahedral. We have already pointed out that the expansible layers sorb two layers of ethylene glycol, which probably indicates a rather low charge density characteristic of a smectite rather than a vermiculite. Also, since dioctahedral chlorite is quite rare it is more probable that the 2:1 expansible layers are dioctahedral. This probability is further strengthened by the observation that the shales altered by the intrusions are highly aluminous and predominantly composed of dioctahedral smectites or mixed-layer illite/smectites.

PETROGRAPHIC DESCRIPTION OF THE CORRENSITE IN THE INTRUDED SHALE AND IN THE DIKE

(Thin sections of the dike rock and shale material collected 25 ft from the dike) at locality DBR #3, in which corrensite was detected by X-ray powder

techniques, were studied in an attempt to determine what textural relationships, if any, the corrensite displayed with respect to the other minerals in the rock. The dike rock was composed of 8–10 per cent pyroxene, approximately 50 per cent plagioclase, 3–4 per cent opaques, with the remainder of the rock, sometimes fractured and veined by calcite, groundmass and corrensite. In contrast, the shale material contained no pyroxene, calcite, or opaques. However, phenocrysts and slender laths of plagioclase were present, as in the dike rock, and comprised approximately 50 per cent of the rock with the remainder being fine-grained groundmass and corrensite. The yellowish spherulitic intergrowths, believed to be corrensite, are shown in Fig. 6. The corrensite spherulites are much finer

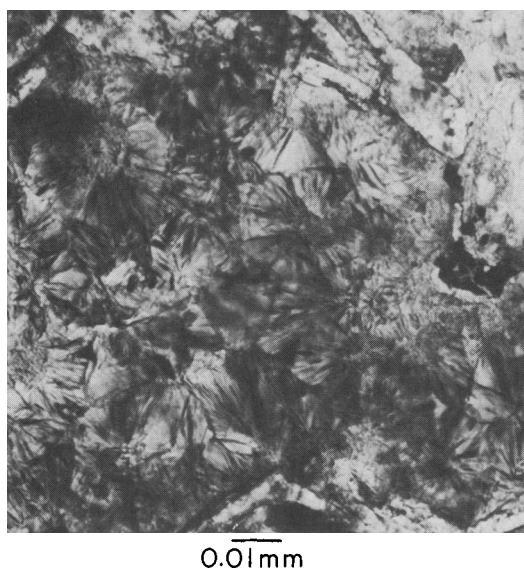


Fig. 6. Photomicrograph of spherulitic intergrowths.

grained in the shale than in the dike rock. However, in both instances the spherulites occurred as interstitial irregular masses between slender laths of plagioclase, or sometimes as apparent partial replacement of plagioclase phenocrysts and groundmass laths.

The calcite in the dike rock also appears to be partially replaced by corrensite in some cases. It may be plausibly inferred, therefore, that the development of corrensite post-dates or is synchronous with the main stage of carbonate veining and alteration.

CONCLUSIONS

In this locality, corrensite appears to be a product of alteration of shale and siltstones caused

by fluids accompanying intrusions. Fine fractions are pure enough to allow us to characterize the material in detail. The chemical analysis and X-ray powder data suggest that the corrensite or 'corrensite-like' mineral is a regular or nearly regular interstratification of chlorite and *dioctahedral* smectite layers. Most other corrensites described in the literature had impurities which caused difficulty in accurately re-casting chemical formulas. It is possible that corrensites similar in chemical composition to the one we have described here may be more abundant than recognized previously.

Acknowledgements—We thank Max Budd for the chemical analysis. One of us, G. R. T., wishes to acknowledge partial support for this study from a University of Montana Summer Session Research Grant.

REFERENCES

- Bodine, M. W. (1971) Alteration of basic volcanic rocks by hypersaline brines: *Geol. Soc. Amer. Abs.* **3**, 509.
- Bradley, W. F. and Weaver, C. E. (1956) A regularly interstratified chlorite-vermiculite clay mineral: *Am. Mineralogist* **41**, 497–504.
- Earley, J. W., Brindley, G. W., McVeagh, W. J. and Vanden Heuval, R. D. (1956) A regularly interstratified montmorillonite-chlorite: *Am. Mineralogist* **41**, 258–267.
- Grim, R. E., Droste, J. B. and Bradley, W. F. (1960) A mixed-layer clay mineral associated with an evaporite: *Clays and Clay Minerals* **8**, 228–267.
- Harvey, R. D. and Beck, C. W. (1962) Hydrothermal regularly interstratified chlorite-vermiculite of tobermorite in alteration zones at Goldfield, Nevada: *Clays and Clay Minerals* **9**, 343–354.
- Heckroodt, R. O. and Roering, C. (1965) A high-aluminous chlorite-swelling chlorite regular mixed-layer clay mineral: *Clay Minerals* **6**, 83–90.
- Johnson, L. J. (1964) Occurrence of regularly interstratified chlorite-vermiculite as a weathering product of chlorite in a soil: *Am. Mineralogist* **49**, 556–573.
- Kinter, E. B. and Diamond, S. (1956) A new method for preparation and treatment of oriented-aggregate specimens of soil clays for X-ray diffraction analysis: *Soil Sci.* **81**, 111–120.
- Lippmann, F. (1956) Clay minerals from the rot member of the Triassic near Gottingen, Germany: *J. Sediment. Petrol.* **26**, 125–139.
- Martin-Vivaldi, J. L. and MacEwan, D. M. C. (1960) Corrensite and swelling chlorite: *Clay Minerals Bull.* **4**, 173–181.
- Peterson, M. N. A. (1961) Expandable chloritic clay minerals from carbonate rocks: *Am. Mineralogist* **46**, 1245–1269.
- Shapiro, L. and Brannock, W. W. (1962) Rapid analysis of silicates, carbonate, and phosphate rocks: *U. S. Geol. Surv. Bull.* **1144-A**, 56 pp.
- Sudo, T., Takahashi, H. and Matsui, H. (1954) On X-ray properties of the Kurota mine. Yamsyuchi prefecture: *Japan J. Geol.* **24**, 71–85.
- Wilson, M. J. and Bain, D. C. (1970) The clay mineralogy of the Scottish Dalradian meta-limestones: *Contributions Mineral. Petrol.* **26**, 285–295.

Résumé—La corrensite ou les minéraux 'du type corrensite' se rencontrent dans des schistes et des siltstones traversés par des dikes, dans le Groupe du Montana et le Groupe du Colorado (crétacé inférieur), du Montana de l'Ouest. La fraction $< 1 \mu\text{m}$ d'un échantillon de ce matériau 'du type corrensite' a été étudiée en détail. La diffraction des rayons X et l'analyse chimique indiquent que cet échantillon est un interstratifié régulier ou presque régulier de chlorite et de smectite *dioctaédrique*. On décrit aussi d'autres échantillons qui contiennent de la corrensite et des phases additionnelles. Ces échantillons ont été prélevés dans plusieurs localités où des dikes basiques traversent les schistes et les siltstones.

Kurzreferat—Corrensit oder 'Corrensit-ähnliche' Minerale kommen in adernführenden Schiefer-tonen und Schluffgesteinen der Montana- und Colorado-Gruppe (Unterkreide) im westlichen Montana vor. Die Korngrößenfraktion $< 1 \mu\text{m}$ einer Probe dieses "Corrensit-ähnlichen" Materials wurde im einzelnen untersucht. Röntgenbeugungswerte und chemische Analyse zeigen, daß diese Probe eine regelmäßige oder nahezu regelmäßige Wechsellagerung von Chlorit und dioctaédrischem Smectit aufweist. Andere Proben, die Corrensit und zusätzliche Phasen enthalten, werden ebenfalls beschrieben. Diese Proben wurden an verschiedenen Stellen entnommen, wo basische Adern in die Schiefertone und Schluffgesteine eingedrungen sind.

Резюме— Корренсит или корренситообразные минералы залегают в глинистом сланце с внедренными дайками и в алевроите групп Монтана и Колорадо (ранний меловой период) в Западной Монтане. Детально изучалась фракция образца размером $< 1 \mu\text{m}$ этого корренсито-образного материала. Рентгенографические данные и химический анализ показывают, что этот образец является регулярным или почти что регулярным впластованием хлоритного и *диоктаэдрального* смектита. Также описываются другие образцы содержащие корренсит и добавочные разновидности. Эти образцы собрали в разных местонахождениях, где основные дайки внедрились в глинистые сланцы и алевроиты.