Clays and Clay Minerals, 1973, Vol. 21, pp. 9–13. Pergamon Press. Printed in Great Britain

TIOGA BENTONITE (MIDDLE DEVONIAN) OF INDIANA

JOHN B. DROSTE and CHARLES J. VITALIANO
Department of Geology, Indiana University, Bloomington, Indiana 47401, U.S.A.

(*Received* 3 *July* 1972)

Abstract—The petrography of shale partings in carbonate rocks from eleven cores in the Illinois (Jeffersonville Formation) and Michigan Basins (Detroit River Formation) of Indiana indicates the presence of a *K*-bentonite which is interpreted as the Tioga Bentonite, an important stratigraphic marker in the middle Devonian rocks throughout the central and eastern United States. The clay mineral composition of the Tioga Bentonite of Indiana is interstratified illite and smectite, usually with admixed kaolinite. This composition stands in striking contrast to the simple illite suite without kaolinite in the normal terrigenous shale partings in the Devonian rocks of Indiana. Euhedral sanidine, high temperature albite, zircon, apatite, and the angularity of quartz grains found associated only with the interstratified clay mineral suite support the volcanic origin of these clay partings.

INTRODUCTION

THE TIOGA Bentonite is the best known, wide spread, sedimentary accumulation of volcanic ash in middle Devonian rocks of the Appalachian Basin. Johnson, Milton and Dennison (1971) recently reviewed the occurrence of this stratigraphic marker and proposed an area in central Virginia as the possible location of the volcanic vent(s). Oliver *et al.* (1968) show the Tioga Bentonite between Ulsterian and Erian Series, the Onesquethaw and Cazenovian Stages, and the Moorehouse and Seneca Members of the Onondaga Limestone in the New York outcrop. These workers located the Tioga Bentonite between the Columbus Limestone and Dundee Limestone at Sandusky, Ohio and Janssens (1970) stated that a 3 in. shale bed between the Columbus Limestone and overlying Delaware Limestone at Marble Cliff Quarry, Franklin County, Ohio, was identified as the Tioga Bentonite by D. A. Textoris and T. M. Dennison.

Collinson and others (1968) identified the stratigraphic position of the Tioga Bentonite in the subsurface from geophysical logs in more than one hundred wells in Illinois, Iowa, and southwestern Indiana. Becker (1973) traced the Tioga bentonite on geophysical (mainly sonic) records from 60 wells in southwestern and west-central Indiana, and he obtained a single sample of the bed from a core in Gibson County (extreme southwestern), Indiana.

MATERIALS AND METHODS

During the past five years the mineralogy of over 400 shale partings from cores cutting middle Devonian carbonates has been determined. These cores, many of which are available for study in the Core Library of the Survey, have been taken by the Indiana Geological Survey and several industrial groups. Twenty-seven cores, about equally divided between the Illinois and Michigan Basins and cutting the Jeffersonville or Detroit River Formations, were carefully sampled at shale partings.

Laboratory preparation for X-ray study (General Electric XRD-5 and copper radiation) included grinding, and disaggregation and fractionation in water. About three dozen thin sections were made from shale partings not possessing the X-ray characteristics of a *K*-bentonite. An attempt was made to produce thin sections from each shale parting which did show X-ray characteristics of a *K*-bentonite. However, only five of these eleven shale partings (Fig. 1) were coherent enough to impregnate and cut successfully.

CLAY MINERAL COMPOSITION

The clay mineral composition of the normal terrigenous material in middle Devonian rocks in Indiana is the simple 10 Å mica (illite) suite showing very little mixed-layering, containing on rare occasions a small amount of chlorite, and never (so far as we know now) containing kaolinite. The clay mineral composition of the devitrified ash beds stands in striking contrast and possesses a composition very similar to Paleozoic metabentonites, or *K*-bentonites, as described for example by Weaver (1953, 1956); Huff (1963); Mossler and Hayes (1966).

We are using two terms with respect to "purity"

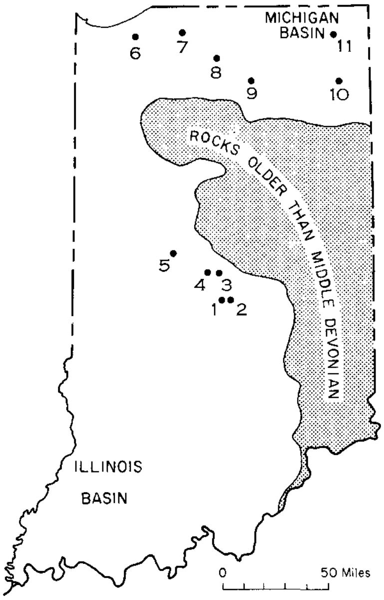

Fig. 1. Index map showing the locations of the cores containing the Tioga Bentonite.

of the Tioga bed and will substantiate this use later in the paper. Five of the Tioga Bentonite beds shown in Table 1 are designated "pure ash", six are indicated as being "impure ash". The pure ash beds contain only clay and non-clay mineralogy of a *K*-bentonite. The impure ash beds contain these pyroclastic components admixed with the normal middle Devonian terrigenous suite of illite and subrounded to rounded quartz grains. The clay mineralogy of the Tioga bed is mixed-layered illite and smectite, usually with lesser amounts of kaolinite. The $< 2\,\mu m$ material of the Tioga sample at Location 11, for example, with untreated, oriented mounting gives moderately broad diffraction peaks at 10·7, 5·0, 3·25 and 1·99 Å. After glycolation broad peaks or shoulders appear at 11·8, 9·7, 5·15, 4·9, 3·33 and 2·01–1·93 Å, and heating to 500°C produces peaks at 10·1, 5·0, 3·29 and 1·89 Å. K^+ saturation moves the moderately broad first order peak to 10·45 Å and Mg saturation does not produce clearly recognizable differences of the natural untreated, $< 2\,\mu m$ fraction. Random powder mounts of the $< 2\,\mu m$ fraction give (060) peaks between 1·49 and 1·50 Å indicating that the layered silicates are dioctohedral. A small amount of kaolinite, up to approximately 10 per cent of the $< 2\,\mu m$ fraction, is present in all but one sample (Location 11).

THIN-SECTION PETROGRAPHY

Thin sections were made successfully from Tioga partings in cores from Locations 1, 5, 7, 10 and 11 (Table 1). The thin sections of the pure ash show very find grained material with little or no evidence of internal stratification. At Location 7 the impure ash is clearly a quartz–carbonate rock with very fine grains distributed along well developed stratification planes.

The mineralogy of the pure Tioga beds consists of clay minerals, quartz, feldspar, zircon, apatite, pyrite and carbonates. The illitic clay occurs as flakes or fibers, less than $1\,\mu m$ wide and up to 10–$20\,\mu m$ long, and in either parallel alignment or braided depending upon whether or not other minerals are present. Kaolinite, identified by X-ray, is not surely recognized by optical examination.

Quartz occurs either as grains that are clear to partly dusty, sharply wedged shaped to subangular, and not over $150\,\mu m$ in dia., or as grains that are well rounded, clear and silt to sand sized. The former, interpreted as pyroclastic in origin, are intimately mixed with the illitic clay and uniformly distributed throughout the field of view with the other minerals described below. The subrounded to rounded grains of the impure beds are clearly sedimentary in origin because they form distinct layers and lenses with or without incorporated illitic and other minerals.

Albite and sanidine are the feldspars present in the Tioga beds. Albite with polysynthetic twinning occurs as angular to subangular grains not exceeding $75\,\mu m$ in dia. and with a negative 2V, facts which suggest it is the high temperature variety. Albite constitutes up to 5 percent of total mineralogy, and the grains show some clay-like alteration around the edges. The mineralogy of the alteration rims could not be surely determined by optical means, and the kaolinite known to be present in the samples from X-ray diagrams could not be located anywhere in the thin sections. Sanidine forms wedge and rectangular shaped grains not over $50\,\mu m$ in largest dimensions. Sanidine constitutes up to 3 per cent of the rock and is uniformly distributed along with albite and quartz throughout the clay fraction.

Apatite occurs as tiny crystals in clusters measuring not more than $25 \times 150\,\mu m$ in area. Excellent euhedra show typical hexagonal cross-section and hemimorphic form with basal parting. Zircon in slightly rounded to sharply angular euhedra 75–125 μm long are present in all slides examined. Apatite and zircon are approximately equal in abundance and make up to three per cent of rock.

DISCUSSION

The diffraction data from the pure Indiana Tioga Bentonite most closely matches the data of Reynolds and Hower (1970) which they designate

https://doi.org/10.1346/CCMN.1973.0210103 Published online by Cambridge University Press

Table 1. Location of cores containing the Tioga Bentonite shown on Fig. 1. Survey file cores are available for study in the Core Library. Indiana Geological Survey, Bloomington, Indiana. The two Northern Indiana Public Service Company cores and the American Smelting core have been used in the insoluble residue conodont study. Colors given are for dry split core

Core	County	Depth below top of Jeffersonville or Detroit River Formation (ft)	Remarks
	Illinois Basin, Jeffersonville Formation		
1. Survey File Core #449 Sec. 15, 15N., 3E.	Marion	23	pure ash, 1·3 in. parting, dark olive gray
2. Survey File core #145 Sec. 18, 16N., 4E.	Marion	17	impure ash, 0·3 in. parting, grayish black
3. Survey File Core #310 Sec. 7, 17N., 3E.	Hamilton	15	impure ash, 0·2 in. parting, olive brown
4. Survey File Core #472 Sec. 5, 17N., 2E.	Boone	19	impure ash, 0·2 in. parting, olive brown
5. Survey File Core #100 Sec. 26, 19N., 2W.	Boone	18	pure ash, 1·3 in. parting, yellowish brown
	Michigan Basin, Detroit River Formation		
6. American Smelting; I-4 Sec. 33, 36N., 5W.	Porter	22	pure ash, 2·0 in. parting, dark olive gray
7. NIPSCO; Al-11 Sec. 8, 36N., 1W.	La Porte	24	impure ash, 0·2 in. parting, grayish black
8. Survey File Core #232 Sec. 18, 34N., 3E.	Marshall	18	impure ash, 0·25 in. parting, dark olive gray
9. Survey File Core #409 Sec. 12, 32N., 5E.	Kosciusko	22	impure ash, 0·15 in. parting, grayish black
10. Survey File Core #250 Sec. 33, 32N., 12E.	Allen	27	pure ash, 1·0 in. parting, olive gray
11. NIPSCO; HA-7 Sec. 27, 36N., 12E.	Steuben	37	pure ash, 0·75 in. parting, olive gray

as a structure consisting of a superlattice of smectite–illite randomly interstratified with illite. Most of our glycol treated samples produce diffraction patterns almost identical to the lower curve shown on their Fig. 2, p. 30, for the Kalkberg bentonite with a 10 per cent smectite layer IMII superlattice. Our patterns from impure *K*–bentonite are not so clearly matched with those of Reynolds and Hower (1970) because of the discrete illite which may be present in amounts up to 50 per cent of the $< 2\ \mu m$ fraction. Two of our impure samples resemble a discrete illite component admixed with an illite and IM-ordered illite–smectite having a smectite abundance of about 20 per cent (see their Fig. 9G).

Weaver (1956) reported that six samples of the Tioga Bentonite from the outcrop of New York, Pennsylvania, and West Virginia contain randomly interstratified illite and smectite in the approximate ratio of 4:1 to 3:1 and heavy minerals including euhedral biotite, euhedral zircon, and euhedral to subhedral apatite. Evaluation of his X-ray data using the work of Reynolds and Hower (1970) seems to show a clay mineral composition very similar to that of the Tioga Bentonite of Indiana.

Johnson, Milton and Dennison (1971, see Appendix V, Dennison and Textoris) described the "Devonian Tioga Tuff" in northeastern United States. The most complete exposure of tuffaceous beds in Virginia is 203 ft thick, and the pure tuff beds are separated by strata lacking any detectable ash content. These workers reported that the vitric tuffs originally were glass dust that devitrified mainly to illite.

Kaolinite is present along with the mixed-layered mineral in 10 of the 11 samples we have studied. We have been unable to identify positively the kaolinite in thin section. Byström (1954) described thoroughly-kaolinized plagioclase in the Ordovician bentonites of Sweden, and was able from diffraction data to determine their composition to be quartz and a kaolin mineral. We have not been able to separate enough albite grains in our material to obtain X-ray data.

At the present time we feel that the most logical explanation for the kaolinite is that it is at least one of the minerals in the albite alteration rims. The albite grains in the one sample not containing kaolinite have almost no alteration rims, and the X-ray powder patterns of this whole sample show the most intense feldspar peaks. Certainly the higher peak intensities may be only the result of a greater abundance of feldspar in this sample, but even though the quality of our thin sections is not very high, we are not able to measure more feldspar in the thin section of this sample than in any of the other pure samples of the Tioga bed. On the assumption that the albite alteration rims do contain kaolinite, the alteration is considered to have occurred after deposition and during or after devitrification in the environment of diagenesis.

The strong igneous non-clay minerals present in the pure Tioga beds certainly support the pyroclastics origin of the clay mineral K-bentonite suite. The sanidine, high temperature albite, silvers of quartz, and euhedral zircon and apatite are particularly useful in identifying the impure Tioga beds. We have not found a single clay parting containing only the normal 10 Å illite suite and characteristic pyroclastic igneous minerals.

Except in one case, Location 11, we have found only one shale parting in each core containing K-bentonite components. The first shale parting 3 ft above the pure Tioga Bentonite in the core at Location 11 is 0·07 in. thick. Its composition is approximately 20 per cent K-bentonite admixed with normal terrigenous material. In all other cores the nearest shale break with normal mid-Devonian epiclastic mineralogy occurred no more than two feet above or below the Tioga position. We do not recognize any significant unconformity in that part of the Jeffersonville and Detroit River Formations where the Tioga Bentonite is found. We consider the layers we designate "impure ash" to have formed essentially contemporaneously with layers we designate "pure ash". The original ash may have settled in a place where normal epiclastic material was accumulating simultaneously, or the ash may have been transported to its depositional position along with other terrigenous material very shortly after the ashfall. The recognition of the Tioga Bentonite in stratigraphic analysis in Indiana already has led to a better understanding of the age of the Detroit River in northern Indiana and has permitted correlation of fossil-barren rocks in northern and southern Indiana (Droste and Orr, 1973). The Indiana Geological Survey now recognizes the Tioga Bentonite as having the stratigraphic rank of a Bed in Indiana.

CONCLUSIONS

The Tioga Bentonite of Indiana is recognized by its clay mineral content of smectite–illite interstratified with illite and generally admixed kaolinite, by the very angular quartz grains, and by euhedral sanidine, high-temperature albite, zircon and apatite. Other terrigenous shale partings in the middle Devonian carbonates of Indiana contain a clay mineral suite of normal 10 Å illite, rarely a small amount of chlorite and no kaolinite, rounded quartz grains, and no euhedral feldspar, zircon, or apatite. The Tioga bed in six of the eleven cores studied contains a recognizable mixture of the K-bentonite and epiclastic suites. The pure and impure beds are considered essentially isochronous with the Tioga Bentonite throughout central and eastern United States, and will permit correlation of Michigan and Illinois Basin geology within Indiana and with Appalachian Basin events in middle Devonian time.

REFERENCES

Becker, L. E. (1973) Silurian and Devonian rocks in Indiana southwest of the Cincinnati Arch: *Indiana Geol. Survey Bull.* 50.

Byström, A. M. (1954) Mineralogy of Ordovician bentonite beds at Kinnekulle, Sweden: *Sveriges Geol. Undersökn. Arsbok* **48**, 62.

Collinson, C. (1968) Devonian of the north-central region, United States. In *Intern. Symposium on the Devonian System*, Calgary, Alberta, September 1967, Vol. 1, pp 933–971. Alberta Soc. Petroleum Geologists.

Droste, J. B. and Orr, R. W. (1973) The age of the Detroit River Formation in Indiana: *Indiana Geol. Survey Spec. Report.*

Huff, W. D. (1963) Mineralogy of Ordovician K-bentonites in Kentucky: *Clays and Clay Minerals* **11**, 200–209.

Janssens, A. (1970) Guidebook to the middle Devonian rocks of north central Ohio: *Ohio Geol. Soc. Annual Field Trip*, 1–30.

Johnson, R. W., Jr., Milton, C. and Dennison, J. M. (1971). Field trip to the igneous rocks of Agusta, Rockingham, Highland, and Bath Counties, Virginia: Virginia Div. of Min. Resources Info. Circ. **16**, 1–68.

Mossler, J. H. and Hayes, J. B. (1966) Ordovician potassium bentonites of Iowa: *J. Sed. Petrol.* **36**, 414–421.

Oliver, W. A., Jr., DeWitt, W., Jr., Dennison, J. M., Hoskins, D. M. and Huddle, J. W. (1968) Devonian of the Appalachian Basin, United States. In *Intern. Symposium on the Devonian System*, Calgary, Alberta, September, 1967, Vol. 1, pp. 1001–1040, Alberta Soc. Petroleum Geologists.

Reynolds, R. C., Jr. and Hower, J. (1970) The nature of interlayering in mixed-layer illite-montmorillonites: *Clay and Clay Minerals* **18**, 25–36.

Weaver, C. E. (1953) Mineralogy and petrology of some Ordovician K-bentonites and related limestones: *Geol. Soc. Am. Bull.* **64**, 921–943.

Weaver, C. E. (1956) Mineralogy of middle Devonian Tioga K-Bentonite: *Am. Mineralogist* **41**, 359–362.

Résumé—L'étude pétrographique des filons de schiste dans les roches carbonatées provenant de onze carottages dans les bassins de l'Illinois (Formation de Jeffersonville) et du Michigan (Formation de Detroit River) dans l'état d'Indiana, indique la présence d'une bentonite K, qu'on interprète comme la bentonite de Tioga; cette argile est un marqueur stratigraphique important dans les roches du Dévonien moyen dans tout le centre et l'est des Etats-Unis. La composition en minéraux argileux de la Bentonite de Tioga de l'Indiana est celle d'un interstratifié illite et smectite, comprenant généralement en mélange de la kaolinite. Cette composition présente un contraste frappant avec celle de la série simple de l'illite, qui ne comporte pas de kaolinite dans les filons de schiste détritique des roches dévoniennes de l'Indiana. La présence de sanidine holoédrique, d'ablite haute température, de zircon, d'apatite et le caractère angulaire des grains de quartz trouvés seulement en association avec la série du minéral argileux interstratifié, constituent des arguments pour l'origine volcanique de ces filons argileux.

Kurzreferat—Die Petrographie der Schiefertonschieferungen in Karbonatgestein von elf Punkten der Illinois (Jeffersonville Formation) und Michigan Becken (Detroit River Formation) von Indiana weist darauf hin, daß ein K-Bentonit vorhanden ist. Dieses wird als Tioga Bentonit betrachtet und bildet eine wichtige stratigraphische Markierung in dem mitteldevonischen Gestein, das in den mittleren und östlichen Teilen der Vereinigten Staaten weit verbreitet ist. Was die Tongesteinzusammensetzung des Tioga Bentonits von Indiana anbelangt, finden wir Einlagerungen von Illit und Smektit, in der Regel mit Beimischungen von Kaolinit. Diese Zusammensetzung unterscheidet sich auffällig von dem einfachen Illit ohne Kaolinit in den normalen terrigenen Schiefertonschieferungen der devonischen Gesteine von Indiana. Idiomorphes Sanidin, gegen hohe Temperaturen beständiges Albit, Zirkon, Apatit und die winkelige Beschaffenheit der Quarzkörner, die sich nur bei dem Tongestein mit Einlagerungen finden, erhärten die Auffassung, daß diese Tonschieferungen von vulkanischem Ursprung sind.

Резюме — Петрография прослоек одиннадцати колонок глинистого сланца в карбонатной горной породе в Иллинойс (формация Джефферсонвилл) и в бассейне Мичиган, Индиана (формация реки Детройт), указывают на присутствие К-бетонита, расшифровываемого как тиога-бетонит, являющимся важным стратиграфическим напластованием в горных породах центральных и восточных Штатов Америки. Строение глинистого минерала тиога-бетонита Индианы — это переслаивающийся иллит и смектит, обычно с примесью каолинита. Это строение резко отличается от простого иллита без каолинита в нормальных терригенных прослойках глинистого сланца в девонских горных породах Индианы. Санидин, высокотемпературный альбит, цикрон, апатит и скосы зерен кварца, находимые в ассоциации только с переслаивающимися глинистыми минералами подтверждают вулканическое происхождение этих глинистых прослоек.