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MONTMORILLONITE DEPOSITS IN NEVADA*

KEITH G. PAPKE
Nevada Bureau of Mines, University of Nevada, Reno, Nevada 89107

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Abstract—Nevada has produced one-third million tons of montmorillonite clays; a major portion was natural adsorbent clay from the Ash Meadows district. Four properties, 3 with swelling and 1 with non-swelling montmorillonite, are currently producing.

Detailed geologic and laboratory studies were made of thirty Nevada montmorillonite deposits. Pyroclastic and other volcanic rocks, mainly Miocene and Pliocene in age, were the host for most of these. The montmorillonite deposits are believed to have been formed in four ways: (1) eleven deposits by alteration of volcanic ash shortly after it settled in lacustrine basins; (2) two deposits by deposition of fine-grained clastic materials; (3) eleven deposits by hydrothermal alteration of a variety of rock types near structural channelways; and (4) six deposits by partial leaching and alteration of glassy, rhyolitic volcanic rocks by ground water.

Montmorillonite is the predominant clay mineral in all the deposits except Ash Meadows, where saponite is present. Sodium is much more common as the exchangeable cation than calcium and/or magnesium. Kaolinite and illite are present in one-fifth of the samples; chlorite or mixed-layer material are rarely present. Quartz, cristobalite, feldspars, calcite, and gypsum are common impurities.

The tests performed on the clay samples were: color; texture; slaking reaction; percentage swelling in water; plastic viscosity, yield point and gel strength of clay-water slurry; colloid content; and pH. Some montmorillonites formed by incomplete alteration of pyroclastic rocks can be wet separated to yield a light-colored, $-2\,\mu$ fraction with superior viscosity and thixotropy.

INTRODUCTION

ALTHOUGH Nevada has produced one-third of a million tons of montmorillonite and many of the inactive deposits in the State are of possible economic interest, published information is limited to a few brief descriptions in bulletins by the Nevada Bureau of Mines, several short articles, and occasional references in U.S. government publications. For this reason a systematic study of the montmorillonite resources of Nevada seemed desirable, and the investigation summarized here was undertaken to obtain information on the distribution, production, geology, mineralogy, and physical properties of the principal deposits. Detailed descriptions of these data for the individual clay deposits, which are summarized here, can be found in a report by Papke (in press).

About 60 montmorillonite deposits that appeared to have possibility of commercial utilization were examined and sampled. Some shale formations of Paleozoic or Mesozoic age and the numerous dry lake beds, where montmorillonite occurs with other clay minerals and abundant impurities, were not included. Half of the deposits examined were judged to have inferior size, purity, or physical properties of the clay and were not studied further. Detailed geologic and laboratory examinations were made of the remaining 30 deposits which are in 11 of the State's 17 counties (Fig. 1). Field work on this project was done during 1967 and 1968.

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PAST PRODUCTION, PRESENT PRODUCERS, TREATMENT, AND USES

Production of montmorillonite clay was first reported from Nevada in 1918 (Middleton, 1921) and there has been production in most years since that time. In statistical summaries published annually by the U.S. government, tonnage information for individual states often was omitted and, prior to 1930, bentonite type of clay was included with miscellaneous clays. Based on the incomplete data available and field evidence, I estimate that 268,000 short tons of fuller's earth (all of which consisted of montmorillonite group minerals) and 50,000 short tons of other montmorillonite clay have been produced. A large part of the fuller's earth came from the Ash Meadows district in southern Nye County, which had intermittent production from 1918 to 1925 and continuous yearly production from 1925

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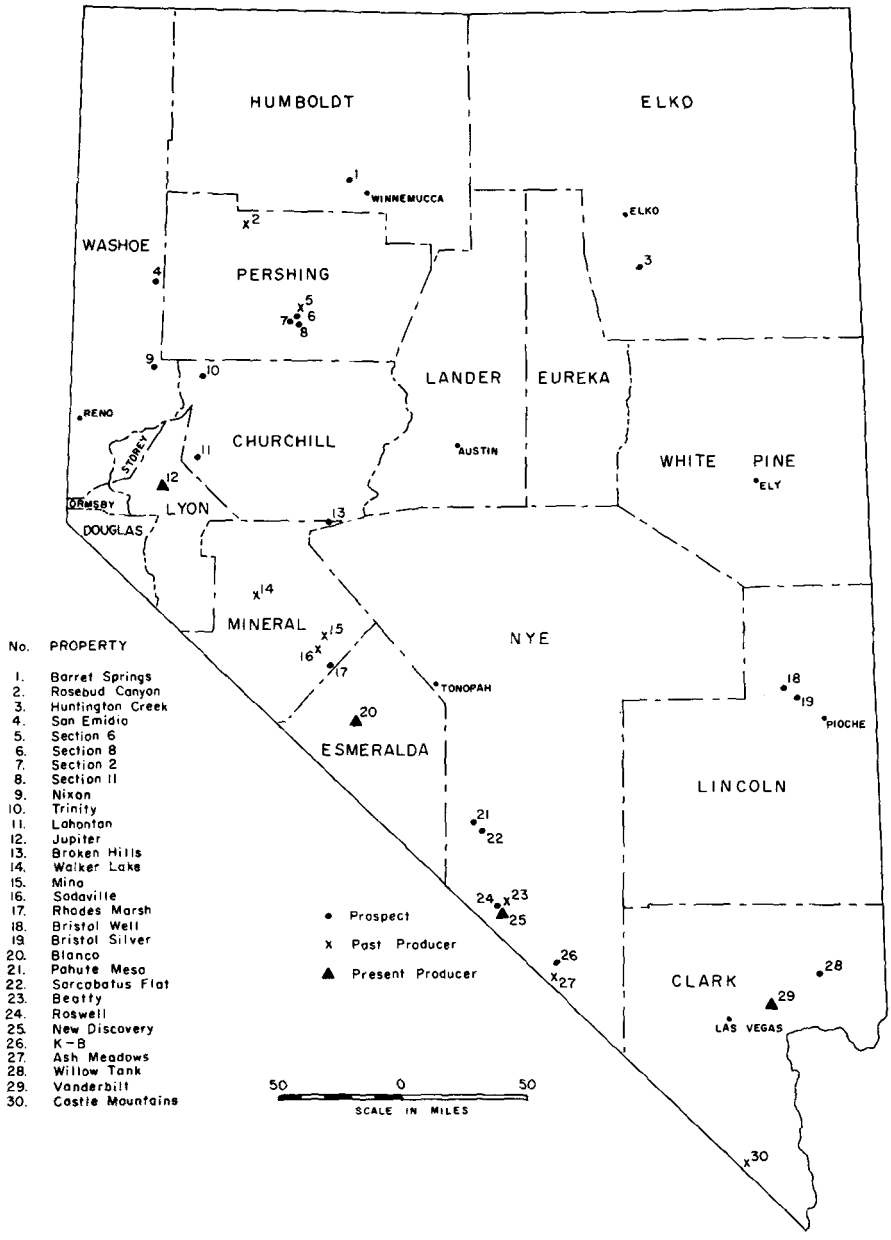


Fig. 1. Map showing montmorillonite deposits in Nevada.

through 1952. The swelling montmorillonite came mostly from 5 open-pit mines and 1 underground mine, whose total productions ranged from 1000 to 15,000 tons.

Montmorillonite clays are currently produced from four Nevada deposits. Industrial Minerals Co. mines a small tonnage of fuller's earth by open-pit method at the Jupiter property in Lyon County and processes it at a mill in northern California. The clay was once used to purify petroleum and vegetable oils but is now used chiefly as a binder in feed pellets.

All the swelling montmorillonite is produced by one company at three widely-separated mines. The Western Talc Co., a subsidiary of R. T. Vanderbilt Co., mines clays at the Blanco and Van-

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derbilt properties by open-pit method and at the New Discovery property by underground, square-set stoping. The Blanco and New Discovery ores contain abundant feldspar and quartz, but the $-2\,\mu$ fraction is white and has superior viscosity and thixotropy. The Vanderbilt clay is purer and has lower viscosity and gel strength than the clays from the other two properties. The selectively-mined materials from the three properties are crushed and ground in a southern California mill. At a plant in Connecticut, the clays are blended, slurried with water, and processed to recover a fine-size fraction. Various blends of clays from the three Nevada deposits and two out-of-state deposits are used in different grades of Veegum, a brand product of the parent company. The powder or flake is used in numerous consumer products such as toothpaste, paint, floor polish, pharmaceuticals, cosmetics, and ceramics.

GEOLOGY

General

Nevada is in the Basin and Range province, a region with north- to northeast-trending, elongated mountain ranges which are bordered by broad flat valleys. Almost all of the described montmorillonite deposits occur in the southern and western parts of the State (Fig. 1), where conditions apparently were favorable for the formation of these clays.

Most of the montmorillonite bodies were derived from volcanic rocks, usually pyroclastic materials, of Tertiary or Quaternary age. Volcanic glass was identified in 1 or more samples from 15 of the deposits, and an igneous texture is retained by the clay in about one-half of the samples examined.

The outcrop of a swelling montmorillonite in a dry climate usually has a distinctive, extensively cracked crust that results from repeated wetting and drying and consequent swelling and shrinking. In some Nevada deposits this crust is underlain by several inches of granular material that contains abundant soluble salts. Fragments of gypsum, or occasionally calcite, sometimes litter the surface. Many of the clay bodies are rather resistant to erosion and form low knolls or shoulders.

Types of deposits

The Nevada montmorillonite deposits have been divided into four genetic types: those formed by sedimentation and alteration in lakes; those formed by deposition of fine-grained clastics; those formed by hydrothermal alteration; and those formed by ground water alteration.

1. *Deposits formed by sedimentation and alteration in lakes.* The deposits in this group were formed by alteration of volcanic ash shortly after it fell into alkaline lakes. The montmorillonite beds are stratiform and are underlain and overlain by continental sedimentary rocks. The adjoining rocks usually are mudstone, shale, or siltstone; less commonly they are sandstone, conglomerate, or limestone. Most of the beds are nearly horizontal but dips as much as 45° have been observed. The montmorillonite beds range in thickness from 2 to 20 ft or more. The clays often contain small amounts of volcanic glass but residual tuffaceous textures are uncommon.

Montmorillonite clays formed by the alteration of volcanic ash *in situ* are found throughout the world, and are particularly abundant in Tertiary rocks (Grim, 1968). Glassy volcanic ash is very susceptible to alteration to montmorillonite. The presence of some alkalis and alkaline earths are necessary for the conversion, and in particular the presence or introduction of magnesia probably is necessary for the formation of montmorillonite. When in excess of that required to form the clay, silica, alkalis, and calcium are liberated during the hydrolysis and devitrification of the glass and crystallization of the montmorillonite.

Although it is believed that the ash settled directly in water prior to its alteration to clay, two other possibilities exist: (1) that the ash fell on land and was re-deposited in a lake before its conversion; (2) that pre-existing montmorillonitic clay was eroded and deposited in water, and the deposit more properly belongs to the clastic group described below. The small amount of detrital material in most of the samples is an argument against these possibilities, and especially against the second.

The deposits formed by sedimentation and alteration of volcanic ash in lakes are Rosebud Canyon, Huntington Creek, Trinity, Lahontan, Broken Hills, Walker Lake, K-B, Ash Meadows, and Vanderbilt. The Barret Springs and Nixon deposits probably are in this group; they are almost completely concealed by alluvium but have been partly explored by drill holes.

Figure 2 is a geologic map of the Rosebud Canyon property, an example of a stratiform deposit in sedimentary rocks. The montmorillonite bed is poorly exposed but it has a thickness of at least 4 ft and possibly as much as 8 ft. The adjacent rocks are clayey siltstone, siltstone and conglomerate. Small amounts of unaltered volcanic ash are present in the siltstones and montmorillonite.

The adsorbent clay bodies of the Ash Meadows district, which furnished a substantial portion of

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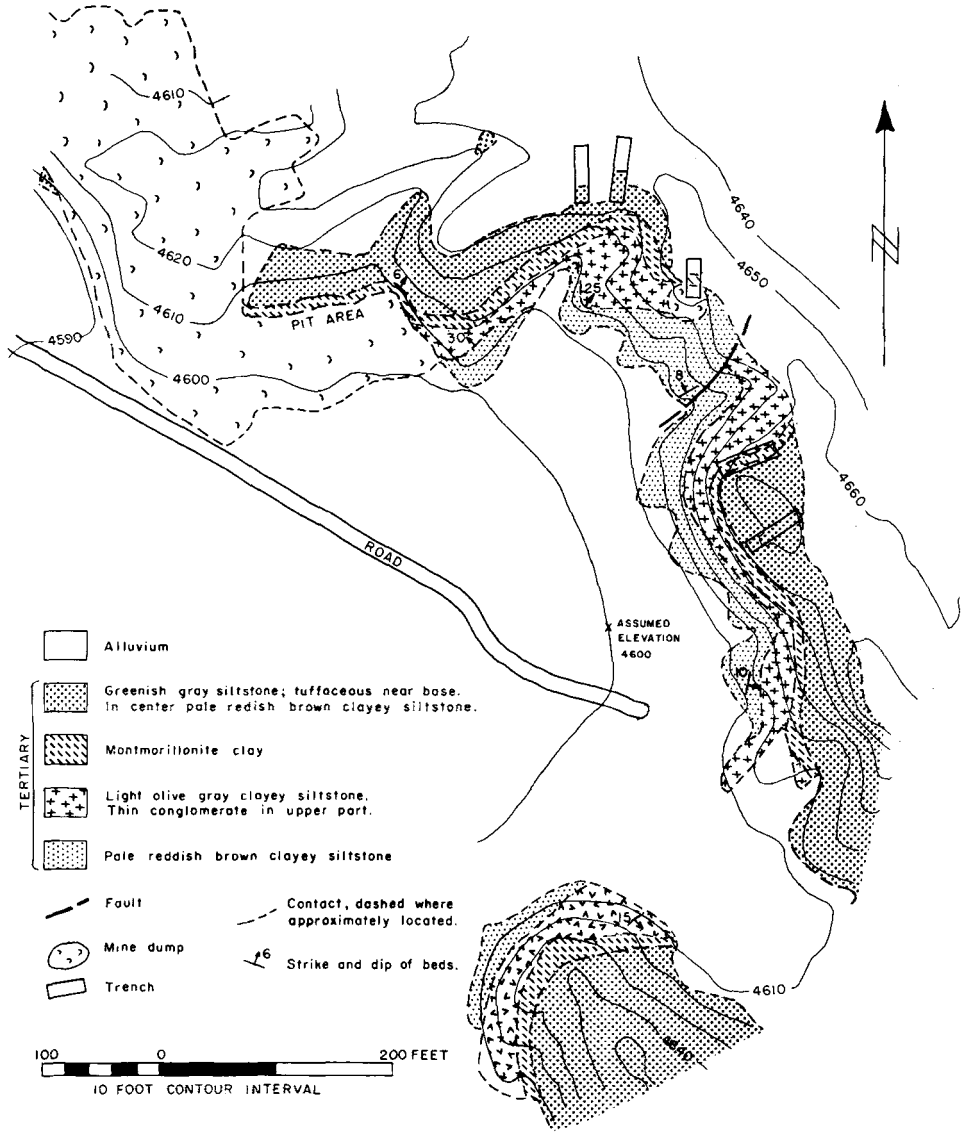


Fig. 2. Geologic map of the Rosebud Canyon montmorillonite deposit, Pershing County, Nevada.

the total montmorillonite production, also are this type of deposit. Most of the tonnage came from two large open pits located on a low terrace that borders the west side of the Ash Meadows valley. The ore bodies in the district are circular in plan and lenticular, reflecting their deposition in shallow playa lakes during Pleistocene time.

2. *Deposits formed by deposition of fine-grained clastics.* These deposits were formed by deposition of mechanically-transported clayey detritus. They are geologically similar in some respects to the deposits formed by alteration of ash falls in lakes. The clastic deposits differ, however, in that they usually are thicker and of greater lateral extent; coarse, detrital quartz and feldspar are much more abundant and volcanic glass is absent. The principal source of the fine-grained clastic material was soil derived from volcanic rocks.

The Rhodes Marsh and Willow Tank deposits were formed by clastic deposition. Montmorillonitic clay beds with the same origin are common in Nevada but most are too impure to be of economic interest.

3. *Deposits formed by hydrothermal alteration.*

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The deposits of this type were formed by the action of heated solutions that were derived, at least in part, from a magmatic source. The deposits differ from those in the other groups in that they were localized by structural features. Fault zones were the controlling structures for most of the clay bodies but contacts of basaltic intrusive bodies also were important in the Beatty deposits.

The clay at the Bristol Silver mine is a fault gouge, but in the other hydrothermal deposits the clay was formed by the alteration of the wall rocks. The hydrothermal deposits are not restricted to glassy volcanic host rocks but they occur in volcanic flows, intrusive rock, and shale in addition to pyroclastic rock.

The clay bodies commonly vary in the amount of impurities present, notably residual quartz and feldspar, and grade into the country rock. The montmorillonite usually replaces both feldspar and glass if both occur in the host rock. There is a wide range in the size, shape, and attitude of these deposits.

Montmorillonite is a common hydrothermal mineral and it is generally believed to have formed in slightly alkaline conditions at a relatively low temperature. It is a typical mineral in the hydrothermal alteration zone that surrounds some epigenetic metallic mineral bodies of the mesothermal and epithermal types and in hot springs areas. Deposits of relatively pure montmorillonite not closely associated with metalliferous rocks or with active thermal areas, such as the deposits described here, probably are common in areas of hydrothermal activity and volcanism, but very few have been described in the literature.

The deposits believed to be of hydrothermal origin are the San Emidio, Section 6, Section 11, Jupiter, Sodaville, Bristol Well, Bristol Silver, Beatty, and New Discovery. The Section 8 and Roswell deposits, which occur in districts where several hydrothermal clay deposits are present, are also probably of hydrothermal derivation.

Figure 3 is a geologic map and cross section of the Jupiter mine, in which a natural adsorbent clay was formed by hydrothermal solutions moving upward along a fault zone. On the hanging wall the montmorillonite has a gradational contact with a diorite porphyry flow. Occasional masses of partly-altered diorite porphyry in the ore body are evidence that this rock was the host for most, and perhaps all, of the clay material. The footwall of the montmorillonite is not exposed. The ore body has been displaced by several high-angle faults.

4. *Deposits formed by ground water alteration.* These deposits are believed to have been formed by the alteration of volcanic rocks by ground waters where geologic or topographic conditions did not permit thorough leaching. Placing the deposits in this group rather than in the hydrothermal group, which they geologically resemble, was based mostly on two factors: their lack of any recognized local structural control; and their tendency to have a blanket-like form that is oriented in the plane of maximum permeability of the host rock.

The host rocks for these deposits are ash-flow tuff, ash-fall tuff, perlite, and vesicular volcanic glass; all the rocks are of rhyolitic composition and probably predominantly glass. Most of these rocks were formed under conditions that precluded their deposition in standing water. The clay often has a gradational contact with the country rock and varies in the amounts of impurities.

According to Keller (1966) volcanic ash on land tends to alter to montmorillonite in the same way that it does in water. Partly stagnant ground water is necessary to prevent the complete leaching of the alkalis and alkaline earths from permeable rocks. Calcium, sodium, and magnesium are released during the hydrolysis of the unstable glass. These ions produce an alkaline environment around the glass particles and aid in the flocculation of silica, thus providing conditions that favor the development of montmorillonite. Other factors, such as host rock and ground water compositions and temperature, would influence the rate of reaction.

In the Nevada Test Site in Nye County, extensive bodies of zeolitized rock, which contain cristobalite and montmorillonite, were formed from unwelded tuffs by mildly alkaline, meteoric waters (Gibbons, Hinrichs, and Botinelly, 1960). The zeolitized beds have irregular upper surfaces and occur immediately above relatively impermeable rocks, such as firmly-welded tuffs, which are rarely altered to zeolites. The authors concluded that the alteration was accomplished in the vadose zone by ground waters whose downward circulation was impeded by the impermeable rocks. A somewhat similar process is postulated for the montmorillonite deposits of this group.

The deposits believed formed by ground water are the Section 2, Mina, Blanco, Pahute Mesa, Sarcobatus Flat, and Castle Mountains. The Blanco, Pahute Mesa, and Sarcobatus Flat deposits are in unwelded ash-flow tuffs; these are sheetlike bodies of *nuée ardente* origin. The Mina deposit is in an ash-fall tuff. A bed of perlite is the host for the Section 2 deposit. The Castle Mountains clay was derived from a frothy volcanic glass that probably solidified in a shallow intrusive body.

The deposits were placed in this group because

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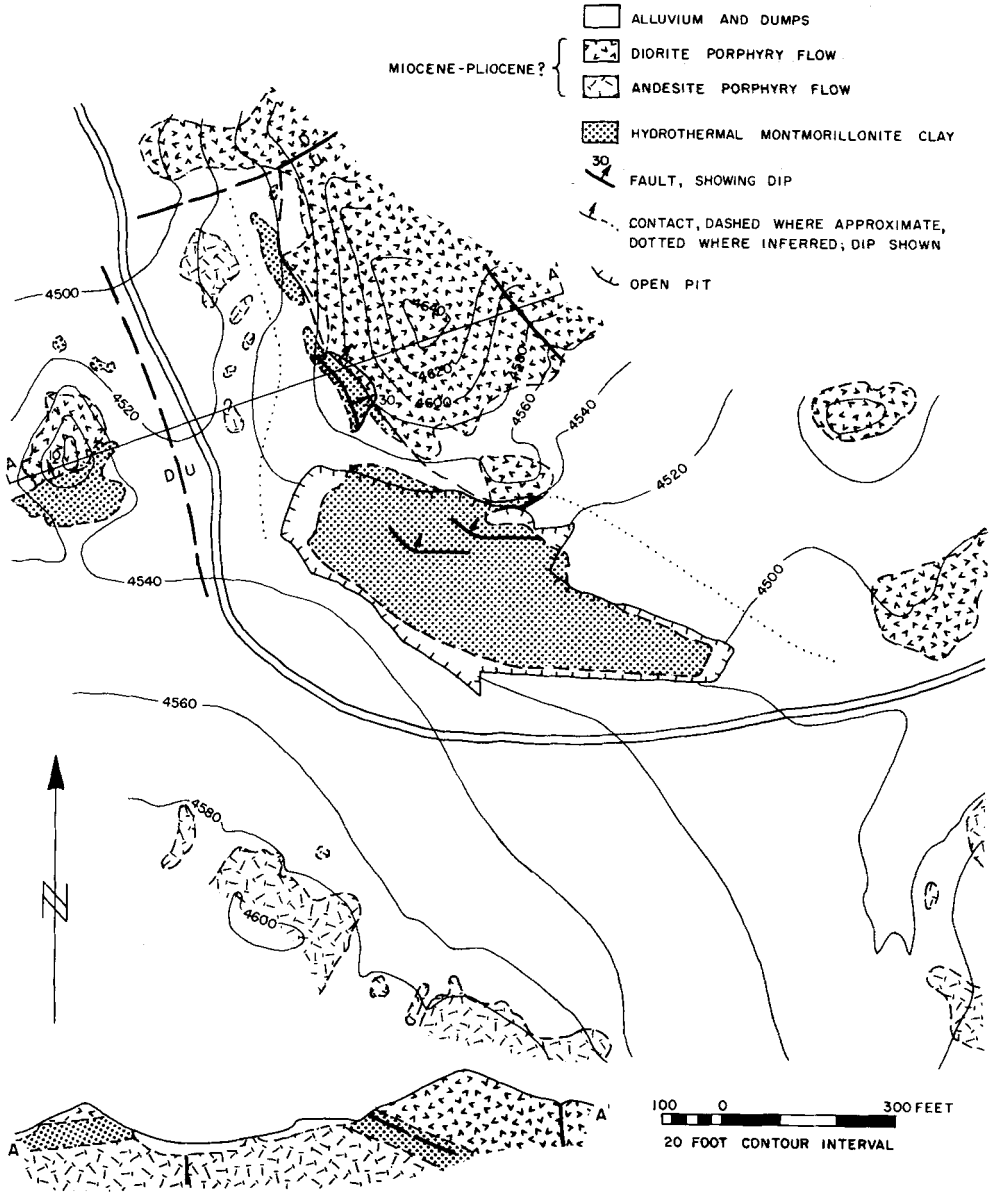


Fig. 3. Geologic map and cross section of the Jupiter montmorillonite deposit, Lyon County, Nevada.

of their form and their lack of recognized structural controls. It is possible that some of these deposits might have been formed by hydrothermal processes, especially the Section 2, Mina, and Castle Mountains deposits.

The Blanco mine of Western Talc Co. is an example of a deposit formed by ground water. The host rock was an unwelded ash-flow tuff of late Miocene or early Pliocene age. A rather homogeneous, montmorillonite-rich unit crops out in an area about 900 by 300 ft and is 20–45 ft thick. Most of the glassy groundmass of the tuff was converted to montmorillonite but some quartz phenocrysts and lithic fragments were not altered.

Age of deposits

Except for those of clastic origin, the age of a clay deposit usually is difficult to determine,

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although the age of the host rock fixes the earliest possible date. Most of the Nevada montmorillonite deposits are either Tertiary or Quaternary in age. At least one-half of the deposits are in rocks regarded as Miocene or Pliocene. This was a time of extensive volcanic activity in the Basin and Range province, during which thick accumulations of both fragmental rocks and flows were formed.

Five clay deposits may be pre-Tertiary in age. One occurs in a fault zone in Cambrian rocks, a second occurs in an igneous body that intrudes Devonian rocks, and a third was formed in shales of Triassic or Jurassic age. These three deposits were formed by hydrothermal processes; thus the clays may be much younger than the host rocks. Two deposits are in sedimentary rocks described as Cretaceous and Cretaceous or Tertiary.

MINERALOGY AND PHYSICAL PROPERTIES OF THE CLAYS

About ninety clay samples were taken from the deposits shown on Fig. 1. In most of the deposits, the typical clay is variable in both mineral composition and physical properties. Therefore, a few samples cannot be used as a basis for the complete evaluation of a deposit. Tests made on the clay samples were:

(a) Mineral composition of clay and non-clay fractions

(b) physical properties: color; texture; slaking rate and type; percentage swelling; plastic viscosity; yield point; gel strength; percentage colloidal material; pH.

Some pertinent physical and mineralogical data from these samples are summarized in Table 1.

Clay minerals

Representative samples from each of the deposits were examined by microscopic and X-ray diffraction methods. The X-ray diffraction technique was used on powder samples of the untreated clay and also on oriented slides of the $-2\,\mu$ fraction at conditions of 52 per cent relative humidity, after expansion with glycerol, and after heating at 550°C for $\frac{1}{2}$ hr. In addition, the $+2\,\mu$ fraction from these samples was subjected to X-ray diffraction analysis. Differential thermal patterns also were made for a few samples.

Members of the montmorillonite group are, by far, the most abundant clay minerals in all of the samples. The spacing of the 060 reflection provides a fairly reliable method for distinguishing between the dioctahedral and trioctahedral varieties of montmorillonite (MacEwan, 1949). The values range from about 1·490 to 1·515 Å for the dioctahedral type and from about 1·515 to 1·535 Å for the trioctahedral type. On this basis, all but five of the Nevada samples are the dioctahedral type; that is, they are either the alumina-rich montmorillonite member, or the iron-rich nontronite member. The low iron content, as indicated by the usual light color of the clay, suggests that almost all of them are aluminum-montmorillonite. The five exceptions with large 060 spacings probably are the trioctahedral mineral, saponite; the identification of saponite was partly confirmed by the Greene-Kelly test as outlined by MacEwan (1961). The five samples are natural adsorbent clay from the Ash Meadows district.

For the untreated powder samples brought to equilibrium at 52 per cent relative humidity, the spacing of the 001 reflection of montmorillonite may give an indication whether the predominant exchangeable cation is sodium or calcium/magnesium (Mielenz, Schieltz, and King, 1955). If sodium is the principal exchangeable ion, the spacing is about 12·4 Å; if calcium and/or magnesium are the principal exchangeable ions, the spacing is about 15·4 Å. Mixtures of these cations give intermediate 001 values. Sodium may be confused with potassium and calcium or magnesium with hydrogen, but potassium and hydrogen are not common in natural clays.

The predominant exchangeable cation could be estimated for 50 samples; about 75 per cent of these had sodium and 25 per cent had calcium and/or magnesium. The average swelling capacity, plastic viscosity, and gel strength of those with sodium was more than two times the averages for those with calcium and/or magnesium.

Other clay minerals identified in the samples are kaolinite, illite, chlorite, and mixed-layer materials. These are listed on Table 1 in order of estimated abundance in a deposit. Kaolinite occurs in one-fifth of the samples but makes up more than a few per cent only in samples from three deposits. Kaolinite is more common in the deposits formed by hydrothermal alteration than in the other types of deposits. Illite was detected in small amounts in one-fifth of the samples. The presence of chlorite was verified in only three samples but some poorly crystalline material may have escaped detection. Mixed-layer clay in minor amounts was found in four samples of clays formed by alteration in lakes and by clastic deposition.

Non-clay materials

The non-clay materials detected in more than trace amounts are quartz, cristobalite, potash feldspar, plagioclase, calcite, gypsum, jarosite, pyrophyllite, clinoptilolite, hydrated iron oxides, and volcanic glass.

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Table 1. Physical and mineralogical data for Nevada montmorillonite samples

Map No. (Fig. 1)	Property name	No. of samples	Range of swell (%)	Colloid content (%)†	Range for 8 per cent clay mixture: Pl. visc.	Range for 8 per cent clay mixture: 10-min gel.	Range of pH‡	−2u clay impurities‡	+2u minerals‡: Qz	Cr	Fe	Ca	Gy
1	Barret Springs	2	370-630	62	4·5–13·0	1·0– 2·0	11·0		L	L		M	
2	Rosebud Canyon	3	270-615	98	4·0–11·5	1·0– 7·0	8·9– 9·8	Ill, Kao, Mix	L	M	L	L	
3	Huntington Ck.	1	600	75	6·5	1·0	8·9		L		M		
4	San Emidio	4	130-555		2·0– 5·0	0 – 9·0	7·4– 9·2		M		L		
5	Section 6	2	485*		7·0– 9·0	3·5– 4·0	9·4– 9·5		L	H	L	L	
6	Section 8	4	185-385		2·0– 4·5	1·0– 1·5	9·0– 9·2		M	M	M	L	L
7	Section 2	3	245-685	86	3·5–11·0	0 –20·0	10·1–10·5		L	H		L	
8	Section 11	1	545		12·0	2·0	8·4		H		L	L	
9	Nixon	4	155-745	71, 75	3·5–17·0	1·0–43·0	9·0–10·5		L	L	M		
10	Trinity	2	170-185		2·0– 2·5	0*	5·5	Kao, Ill	M				M
11	Lahontan	1	70		2·0	0	4·7		H		L		M
12	Jupiter	4	100-145		1·5– 2·0	0*	4·6– 4·9	Kao, Chl	L	M	L		M
13	Broken Hills	2	415-530		2·5– 6·0	0 – 5·0	7·9– 8·2	Kao	M		L		
14	Walker Lake	4	245-600	91	2·5– 8·0	1·0–23·0	8·1*	Chl	L	H	M	L	L
15	Mina	2	355-800	77	4·0– 7·0	1·0–17·0	9·1– 9·2	Kao	L	M	M	L	
16	Sodaville	5	145-855	65	2·0–12·0	0 –90·0	6·7– 7·6	Kao	L		L		
17	Rhodes Marsh	2	285-415		2·5– 3·0	0 – 1·0	11·1	Ill, Mix	L	M	M	H	M
18	Bristol Well	2	170-315		1·5– 2·5	0*	9·2– 9·5	Kao, Ill	M	L	L		
19	Bristol Silver	2	100-130		1·5– 2·0	0*	9·2– 9·7	Kao, Ill	L		L	H	
20	Blanco	4	470-570		8·5– 9·5	1·0*	8·4– 9·8	Chl, Ill	L	H	M		
21	Pahute Mesa	4	315-670	55	3·0– 7·5	0 –10·0	9·0–10·2			M	M	L	
22	Sarcobatus Flat	4	730-1100	49, 76, 80, 87	3·5–14·0	1·5–46·0	9·4–10·4		M		M	L	
23	Beatty	10§	270-755	56, 56, 63	2·0–15·0	0 – 5·0	8·1– 9·7		M	L	M	L	
24	Roswell	1	315		2·5	1·0	8·7		M		M		
25	New Discovery	2	515*		5·0*	1·0*	9·6– 9·9		H		M		
26	K–B	3	385-485		2·5– 5·0	0 – 4·0	8·4–10·2		L		L	L	H
27	Ash Meadows	5	100-215		2·0– 2·5	0 – 1·0	8·9– 9·8	Ill, Mix, Chl	L		L		
28	Willow Tank	2	215*		2·0– 2·5	0*	10·6	Mix	H		L	H	
29	Vanderbilt	3	385-470		3·0– 3·5	0 – 1·0	9·4–10·1		L		L		
30	Castle Mts.	2	155*		2·0*	0*	7·5				L		

Kao = Kaolinite; Ill = Illite; Chl = Chlorite; Mix = Mixed layer; Qz = Quartz; Cr = Cristobalite; Fe = Felspar; Ca = Calcite; Sy = Symposium. L = Low; < 2–3%; M = Medium; < 10–15%; H = High, > 10–15%.

* Several samples had same value.

† Only samples with swelling of 600 per cent or more tested.

‡ Not all samples tested.

§ Hand-sorted sample excluded.

Quartz is present in about 90 per cent of the samples. It is a serious contaminant, perhaps making up one-sixth or more of the rock, in 15 per cent of the samples tested.

Cristobalite occurs in about 40 per cent of the samples tested and probably comprises at least one-third of the material in 15 per cent of the samples tested. Although fine-grained cristobalite is not unusual in montmorillonites, published data do not indicate that it is as abundant as shown in the Nevada samples. It probably is significant that the cristobalite is much more commonly present and is more abundant in clays derived from thick sequences of volcanic rocks than in clays formed from thin ash falls in lakes. Most of the cristobalite apparently is moderately well crystallized, as indicated by a rather sharp 101 peak that ranges from 4·01 to 4·08 Å.

Potash feldspar occurs in about 75 per cent and plagioclase in about 60 per cent of the samples. The feldspars are especially abundant in some samples of partly argillized pyroclastic rock. Calcite is present in about 40 per cent of the samples and gypsum in about 15 per cent.

Physical properties

All the samples were tested for the following: color; texture; slaking rate and type; percentage of swelling in water; and plastic viscosity, yield point, and gel strength of an 8 per cent clay slurry. Detailed study of the plastic viscosity, yield point, and gel strength was made for any sample with above-average plastic viscosity for the 8 per cent clay mixture. The percentage of colloidal material was determined for all samples that swelled 600 per cent or more. The pH of a clay–water mixture was measured for some samples.

Color of the dried, pulverized montmorillonite was judged by comparison with the Rock-Color Chart (Geological Society of America, 1963). White or white with light tints are the most abundant colors, followed by very pale orange (10 YR 8/2), yellowish gray (5Y 7/2, 5Y 8/1), grayish pink (5R 8/2) and pale pink (5RP 8/2). About three-fourths of the samples are of the above-named colors; most of the remainder are shades of yellow, orange, or brown.

The texture of a majority of the clays are fine-grained and compact but some are earthy and friable. In a few instances the tuff host rock has been only partly altered and the material is rather hard.

Approximately 40 per cent of the samples swelled but did not slake when a lump was placed in water. Most of the other samples slaked partly or completely to fines. Of the known adsorbent clays (Jupiter and Ash Meadows), five samples neither slaked or swelled and four slaked to chips. According to Nutting (1943) fuller's earth will not slake or swell but an activable clay will slake to chip-shaped granules.

In the swelling test a volume measure of 3·5 cc was filled with unpacked pulverized clay. The contents were slowly added to a 100 ml graduated cylinder filled with distilled water, using a small spatula and allowing the individual particles to become wet and sink to the bottom. This procedure took as long as 5 min. The total volume of expanded clay at the bottom of the graduated cylinder was read after 24 hr and the percentage of swelling calculated. For example, a sample swelled 200 per cent if the final volume of clay was 10·5 cc. Swelling ranged from 70 to 1800 per cent.The natural adsorbent clays were among the lowest-swelling samples. The highest-swelling material was a hand-sorted, pure montmorillonite from the Beatty district. Two grades of a commercial product made partly from Nevada clays also were tested; Veegum swelled 755 per cent and Veegum T swelled 1000 per cent. Three samples of Wyoming bentonite from different producers swelled 785, 1275 and 1415 per cent.

The plastic viscosity, yield point, and 10-min gel strength were measured with a Fann V-G viscometer (Savins and Roper, 1954), using an 8 per cent clay mixture for all samples. This is a two-speed, rotational-type viscometer which has a rate of shear proportional to the revolutions per minute and a shearing stress proportional to the developed torque shown by a dial reading. The plastic viscosity and yield point were calculated from the torque values at both speeds. The gel strength of the mixture after ten minutes at rest was measured by a manual operation of the viscometer. The value for the plastic viscosity was plotted against the percentage of swelling for the sample and this chart was the basis for determining whether or not a sample was of sufficient interest to be tested at other clay-water ratios.

Figure 4 shows the results of plastic viscosity measurements for 14 samples, including a hand-sorted sample from Beatty, Veegum T, and a commercial Wyoming bentonite. As the plastic viscosity increases, the yield point and the 10-min gel strength also increase although the degree of correlation between the three values is only fair. Figure 5 illustrates the relationship of the yield point and the 10-min gel strength to the clay concentration for three Nevada samples.

Samples from the Blanco and New Discovery mines, where the ore is partially-altered pyroclastic rocks, were fractionated by wet sedimentation technique and the $-2\,\mu$ portion recovered.

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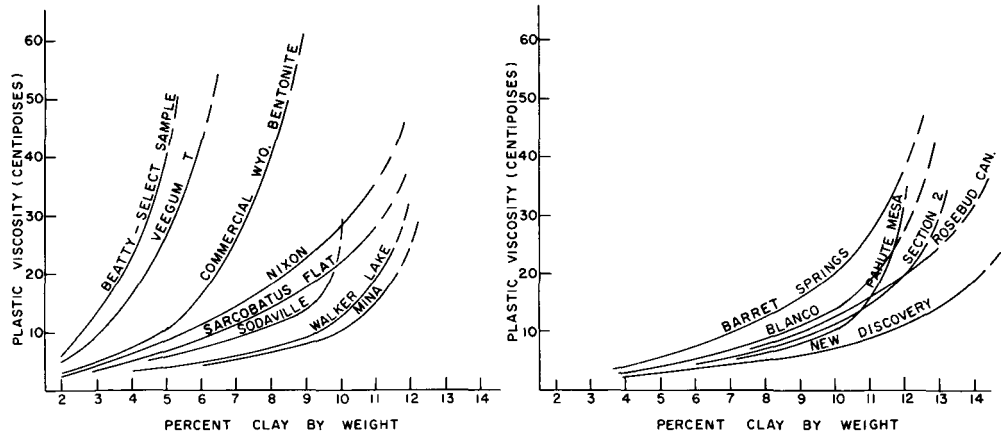


Fig. 4. Variations of plastic viscosity with percentage of montmorillonite in clay–water mixtures for fourteen samples.

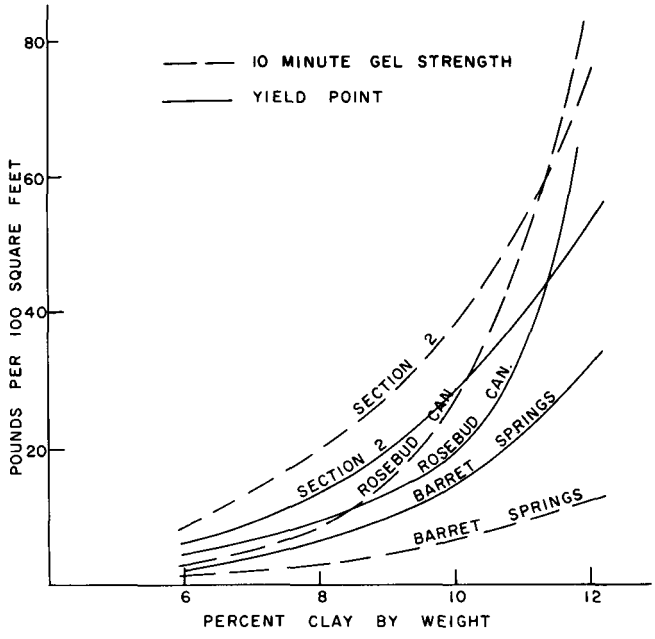


Fig. 5. Variations of yield point and 10-min gel strength with percentage of montmorillonite in clay–water mixtures for three Nevada samples.

The sample from the Blanco deposit was 76 per cent $-2\ \mu$ and the sample from the New Discovery deposit was 42 per cent. Figure 6 shows the variations in plastic viscosity for the original samples and the $-2\ \mu$ fractions.

In the colloidal test 10·0 g of dry, pulverized clay was dispersed in 400 ml of distilled water for 24 hr. The slurry was stirred for 1 hr with an electric mixer, placed in a 500 ml graduated cylinder, brought to 500 ml with more water, thoroughly mixed by inverting the vessel, and allowed to settle. After 24 hr the liquid was decanted down to 50 ml. The residue was dried and weighed; from this weight the percentage of material that had remained suspended in the decanted liquid was calculated. The graduated

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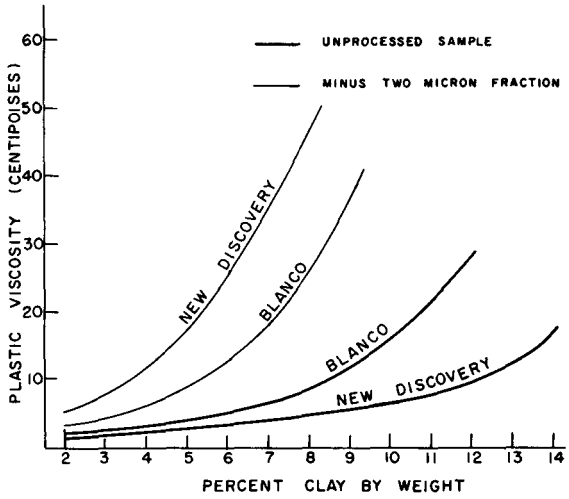


Fig. 6. Variations of plastic viscosity with percentage of solids in clay–water mixtures for unprocessed samples and the -2μ fractions.

cylinder had a maximum particle fall of 263 mm; by Stokes' law the largest particle remaining in the decanted liquid had an equivalent spherical diameter of about $1{\cdot}8\,\mu$. The percentage determined obviously is not strictly the colloidal content since the maximum diameter of a colloidal particle is much less than this. However, it is still a useful test for evaluating swelling montmorillonite. For the 17 samples tested, the percentage of colloid ranged from 49 to 98 per cent. There was only a low correlation between the percentage of swelling and the colloidal content.

The pH of a clay was measured in a mixture of 10·0 g of dry sample and 100 ml of distilled water after 1 hr aging. For the samples tested the values ranged from 4·6 to 11·1, but 80 per cent were between 8·0 and 10·5. According to Lamar (1953) some fuller's earths give an acid reaction in water. Three samples of adsorbent clay from the Jupiter deposit had values of 4·6–4·9 and four from the Ash Meadows district had values of 8·9–9·8.

Generally there is no correlation between the physical properties of the clays and the four genetic types of montmorillonite recognized during this study. Possible exceptions to this are: the high average values for swelling, plastic viscosity, and gel strength of clays formed by ground water; and the high pH of two clays formed by clastic deposition.

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Résumé—L'état de Nevada a fourni un tiers de million de tonnes d'argiles montmorillonites; une grande partie était de l'argile naturelle adsorbante du district d'Ash Meadows. Quatre localités sont actuellement produites: 3 avec montmorillonite gonflant et 1 avec montmorillonite non gonflant.

Des études détaillées de géologie et de laboratoire ont été entreprises dans trente dépôts de montorillonite a l'état de Nevada. Les roches pyroclastiques et autres roches volcaniques, principalement du miocéne et du pliocène en âge, one reçu la plupart de ces dépôts, quie se seraient formés de quatre manières: (1) onze dépôts par altération de la cendre volcanique peu après qu'elle se soit déposée dans les bassins lacustres; (2) deux dépôts par sédimentation de matériaux clastiques à grains fins; (3) onze dépôts par altération hydrothermique d'une variété de types de roches proches des voies structurelles; et (4) six dépôts par filtration et altération partielles de roches volcaniques rhyolitiques hyalines par l'eau de surface.

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Le montmorillonite est le minéral argileux qui prédomine dans tous les dépôts à l'exception de celui d'Ash Meadows, où la saponite est présente. Le sodium est encore plus commun, en tant que cation d'échange, que le calcium et/ou le magnésium. Le kaolin et l'illite sont présents dans un cinquième des échantillon; le chlore ou les matières à couches mixtes sont rares. Le quartz, le cristobalite, le feldspath, le calcite, et le gypse sont des impuretés communes.

Les essais effectués sur les échantillons d'argile comprenaient les essais de couleur, de texture, de réaction de ralentissement, de pourcentage de gonflement dans l'eau, de viscosité plastique, de limite de résistance et de résistance au gel de la boue argile-eau, de la teneur en colloïdes et de pH. Quelques montmorillonites formés par l'altération incomplète de roches pyroclastiques peuvent être séparés à l'état humide donnant une fraction de $-2\,\mu$ légèrement colorée avec une thixotropie et une viscosité supérieures.

Kurzreferat—Nevada hat ein Drittel einer Million Tonnen Montmorillonit Tone produziert, wobei der Grossteil aus natürlichem, adsorbierendem Ton aus dem Ash Meadows Gebiet bestand. Vier Grudstücke, 3 mit quellendem und 1 mit nicht-quellendem Montmorillonit, sind derzeit in Produktion.

Es wurden eingehende, geologische und Laboratoriumsstudien an dreissig Nevada Montmorillonit Lagerstätten durchgeführt. In den meisten Fällen bestand das Muttergestein aus pyroklastischem und anderem vulkanischem Gestein, hauptsächlich mit Ursprung im Miozän und Pliozän. Es wird angenommen, dass sich die Montmorillonitlager auf vier Arten gebildet haben: (1) elf Lager durch Veränderung vulkanischer Asche kurz nach Ablagerung in Binnenseebecken; (2) zwei Lager durch Ablagerung feinkörnigen, klastischen Materials; (3) elf Lager durch hydrothermale Veränderung verschiedener Gesteinsarten in der Nähe von Rinnen im Gefüge; und (4) sechs Lager durch partielle Auslaugung und Veränderung von glasigem, rhyolitischem Vulkangestein durch Grundwasser.

Montmorillonit ist das vorherrschende Tonmineral in all den Lagerstätten mit Ausnahme von Ash Meadows, wo Saponit vorhanden ist. Natrium wird viel häufiger als austauschbares Kation angetroffen als Calcium bzw. Magnesium. Kaolinit und Illit sind in einem Fünftel der Proben zugegen; Chlorit oder Mischschichtmaterial wird selten angetroffen. Quartz, Cristobalit, Feldspate, Calcit und Gips sind häufige Verunreinigungen.

Die Tonproben wurden auf folgende Eigenschaften geprüft: Farbe; Gefüge; Löschreaktion; prozentuale Quellung in Wasser; plastische Viskosität; Fliessgrenze und Gelfestigkeit von Tonwasserschlamm; Kolloidgehalt; pH-Wert. Gewisse durch unvollständige Wandlung pyroklastischen Gesteins gebildete Montmorillonite können nass geschieden werden, so dass sie eine helle Fraktion von weniger als $2\,\mu$ mit hervorragenden Viskositäts- und Thixotropiemerkmalen ergeben.

Резюме—В шт. Невада добыто 1/3 миллиона тонн монтмориллонитовых глин; главная масса их предаставляет природный адсорбент и происходит из района Эш: Медоуз. В настоящее время на трех месторождениях добывается набухающий и на одном- ненабухающий монтмориллонит. Детальными геологическими и лабораторными исследованиями были охвачены тридцать месторождений монтмориллонита. В большинстве из них монтморил лонитовые глины залегают в пирокластических и других вулканических породах, преимущественно миоценовых и плиоценовых.

Различаются четыре пути образования монтмориллонитовых глин: 1. Изменение вулканической золы вскоре после ее осаждения в озерных бассейнах (одиннадцать месторождений); 2. Отложение тонкого глинистого детрита (два месторождения); 3. Гидротермальное изменение различных пород около структурных каналов (одиннадцать месторождений); 4. Изменение под действием грунтовых вод стекловатых риолитовых вулканических пород при ограниченном выносе оснований (шесть месторождений).

Преобладающим глинистым минералом всех месторождений является монтмориллонит; только в Эш Медоуз наблюдается сапонит. Натрий, как обменный катион, более обычен, чем кальций и (или) магний. Одна пятая часть образцов содержит каолинит и иллит; хлорит и смешаннослойные образования наблюдаются редко. К числу обычных примесей относятся кварц, кристобалит, полевые шпаты, кальцит и гипс.

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