CLAY MINERAL PROPERTIES OF MORROW SANDSTONE, LEA COUNTY, NEW MEXICO AND THEIR EFFECT ON RESERVOIR CATION EXCHANGE CAPACITY/WELL COMPLETION

Dr. John W. Neasham
Reservoirs, Inc.
1151-C Brittmore Road
Houston, Texas 77043

ABSTRACT

The composition, relative abundance, and mode of occurrence of silicate clay minerals in 24 Morrow "perm" plugs from a 24-foot zone (12,935-12,959 Ft.) in the Getty No. 1 State "36" Com well, Lea County, New Mexico have been characterized by XRD, scanning electron microscopy, and Qv (CEC/ml.P.V.). The objective of this study has been to define the clay mineralogy of these sands and relate them to reservoir quality.

INTRODUCTION

This report contains the results of mineral, texture, and pore space analysis of Morrow Sandstone conventional core samples taken from the Getty No. 1 State "36" Com well, Lea County, New Mexico. The rock samples consisted of 24 "perm" plug remnants taken at one-foot intervals between depths 12,935-12,959'. The purpose of this study has been to characterize rock properties affecting reservoir quality and log response; specifically, the composition, relative abundance and mode of occurrence of clay crystals occurring within these sandstone samples. In this regard, the following analyses were performed on the submitted samples from the above named well:

- X-ray diffraction of a "bulk" and "less than 20 micron" fraction was performed for each of the twenty-four samples (Table 1). This X-ray diffraction analysis determines the type and amount of the various mineral components within each "bulk" sample, plus the relative percentage of the various silicate clay minerals within the "less than 20 micron" fraction. A "less than 20 micron" fraction rather than a "less than 5 micron" fraction was prepared after it was determined that very coarsely crystalline, diagenetic kaolinite booklets were present within these rock samples. It was considered that a "less than 5 micron" fraction would "miss" a portion of the more coarsely crystalline, diagenetic clay fraction.

- Scanning electron microscopy (SEM) examination of small chips taken from each sample has visually documented the general rock fabric and provided high magnification photomicrographs showing the mineral type, crystal morphology and mode of occurrence of the sandstone's granular and diagenetic (pore-filling) mineral components (Figs. 1-6).

- Qv, expressed as milliequivalents of exchange capacity per milliliter of rock pore volume, was measured on the 24 rock samples submitted for analysis (Table 2). The Qv value was measured using a "membrane potential" apparatus developed by Shell Oil Company.[1] The Qv measurement, made on a small chip taken from each sandstone core sample, provides a measure of the rocks' exchange capacity due to the contained clay minerals when they are in a naturally-occurring (undisturbed) mode of occurrence. In general, Qv provides a quantitative measure of that portion of rock conductivity provided by clay minerals, which affects the resistivity log response.

RESULTS AND INTERPRETATIONS

Analysis of the SEM, XRD, and Qv data generated for these Morrow Formation sandstone samples indicates the presence of three principle Morrow sandstone "facies" within the 24-foot interval analyzed. These facies have been differentiated on the basis of distinct differences in clay content and clay mineralogy, plus general differences in measured cation exchange capacity. The three distinct sandstone facies in this 24-foot interval analyzed are characterized as follows:

1. 12,935-12,937' - The 3 samples at the top of the 24-foot interval analyzed generally consist of quartz-rich sandstones containing approximately 6-8 weight percent silica clay consisting of approximately 50% kaolinite and 50% illite/chlorite clay mineral components (as defined by X-ray diffraction). Scanning electron microscopy for these three samples shows a great abundance of grain-coating (pore wall-coating) intergrown illite and chloritic-type clay crystals containing significant micropore space (Figs. 1&2). The abundance of diagenetic clays plus their pore wall-coating mode of occurrence within these sandstone samples accounts for the very high measured Qv values of 1.0-3.0 MEQ/ml. pore volume.

   (12,938') - This sandstone sample appears to reflect a transition into the next principle sandstone facies. Scanning electron microscopy detects common grain-coating chlorite, but X-ray diffraction shows a marked decrease in the amount of illite/chlorite-type clays and the extreme abundance of kaolinite. Qv data tends to confirm the great abundance of kaolinite over grain-coating illite and chlorite clays in that a relatively low value of 0.2 MEQ/ml. pore volume was measured for this sample. X-ray diffraction data shows approximately 98% of the silicate clay mineral components in this sandstone, which consists of approximately 7 weight percent of the total sample, are composed of kaolinite.

2. 12,939-12,952' - This second principle sandstone facies is generally characterized by sands containing approximately 6-9 weight percent clay which is essentially all diagenetic, vermicular kaolinite. Scanning electron microscopy and X-ray diffraction show small to trace amounts of grain-coating chlorite crystals to also be present. Scanning electron microscopy photomicrographs show the extreme abundance of vermicular kaolinite crystals extensively filling intergranular areas and having a "patchy" distribution throughout the sandstone fabric (Figs. 3&4). Intergranular areas are commonly completely filled with a crystal aggregate of kaolinite crystals consisting of stacked (book-like) crystal platelets. This aggregate of kaolinite crystals probably contains significant micropore space.

   SEM photomicrographs also show these sandstone samples to be extensively cemented with silica cement in the form of quartz overgrowth crystals. X-ray diffraction data, in general, shows the mineral composition of these sands to generally consist of approximately 90-92% quartz, 1-3% feldspar, and 5-9% silicate clays consisting almost entirely of diagenetic kaolinite. Measured Qv values for the sandstone samples in this depth interval show a significantly lower range of values in comparison to the three sandstone samples from 12,935-12,937' above. The Qv values are generally in the 0.5-0.8 MEQ/ml. pore volume range for the samples from 12,939-52'.

   Within this zone there appears to be present a "subzone" of sandstones with appreciably higher amounts of a kaolinite clay. X-ray diffraction data shows the samples from 12,943-12,948' to contain relatively greater amounts of clays ranging in amounts from 6-15 weight percent and consisting of kaolinite. Qv values for these corresponding samples appear to be somewhat lower than the sandstone samples in general, possibly reflecting greater percentages of kaolinite (which has lower cation exchange capacities) and possibly a somewhat greater pore volume.

(12,953') - This sandstone sample appears to reflect the transition from the kaolinite-rich sandstones described above with those sandstone samples described below in the third principle sandstone facies. The sample contains large amounts of kaolinite, but it also shows in both X-ray diffraction and SEM data the presence of increased amounts of diagenetic illite. X-ray diffraction detects a relatively small amount of clay material (5 weight percent), and the measured Qv value is approximately 0.6 MEQ/ml. pore volume.

3. 12,954-12,958' = This lower sandstone facies is in general similar to facies defined above in item 1 in that the samples contain increased amounts of grain-coating illite and chlorite in addition to kaolinite (Figs. 5&6). X-ray diffraction reports increased amounts of silicate clay minerals ranging from 13 to 24 weight percent clays. It should be noted that the sample at 12,956' shows a relatively low amount of clay (4 weight percent), but this appears to be accounted for by the unusually high amount of ankerite cement present within the rock pore system. Qv values for these samples are in general higher than those measured for the kaolinite-rich rocks described above, with values ranging in general from 0.6-1.6 MEQ/ml. pore volume.

SIGNIFICANCE OF Qv

Clay crystals in sandstones can contribute electrical conductivity to a rock which is directly related to cation exchange capacity. This electrical conductivity is parallel and in addition to the conductivity due to pore fluids. This conductivity is primarily due to the fact that clay minerals have the ability to conduct electricity through the large amounts of water loosely bound on the outer surface of the clay platelets, and through their cation exchange capacity. This flow of electricity through a hydrocarbon bearing reservoir rock can complicate log interpretation as resistivity values of clay-bearing sands can be abnormally low compared to the resistivity of the same sands without clay. The conductive path provided by the clays becomes more significant to water saturation calculations as the hydrocarbon saturation increases.

Is is generally accepted that the cation exchange capacity of a rock (CEC equals milliequivalents (MEQ)/100 grams of dry sample) is a function of the clay mineralogy, the amount of clay, and the geometry of the clay crystals and their distribution within the pore space of the specific rock. It is also known that problems can arise in measuring the CEC of a sandstone sample by disaggregating the sample, as CEC has been shown to be dependent on particle size, duration of sample grinding, and method of analysis. In an attempt to get a measure of clay conductivity for a rock sample in a naturally-occurring state, Thomas[1] reported the development of a technique for measuring the amount of CEC within a specific rock sample. This technique measures the value of CEC per unit pore volume (Qv) of a shaly sand from its specific membrane potential. This method utilizes formation rock samples of variable sizes and is completely nondestructive.

Qv values for reservoir-quality sandstones can range from ~0.0 for extremely "clean" sands upward to 2.0-3.0 for extremely shaly and dense (tightly cemented) sands. The Qv for a particular sandstone due to its clay mineral components in part reflects the CEC of its various clay mineral components. Generally accepted values of CEC of clay minerals in milliequivalents per 100 gm. of dry caly are as follows: Kaolinite: 3-10 MEQ/100 gm.; Illite: 10-30 MEQ/100 gm.; Chlorite: 10-30 MEQ/100 gm.; Montmorillonite: 80-100 MEQ/100 gm. These various clay types can combine to give a given rock type a particular CEC, that is, its MEQ/100 gm. Rock conversion of CEC to Qv is expressed by the following empirical equation:

$$Qv = \frac{CEC\ (1-\emptyset)\rho m}{\emptyset \cdot 100}$$

when $\emptyset$ = porosity

ρ m = grain density

The importance of utilizing CEC and Qv data for certain rock types and formations primarily relates to resistivity log calculations of Sw using older empirical formulas (e.g., Archie equation), which do not include exchange capacity, versus more recent formulas (e.g., Waxman-Smits equation) which do. Given similar log/formation parameters, a calculated Archie Sw of 32% would compare with calculated Waxman-Smits Sw of 15% to 28% (Qv ranging from 3.0 to 0.2, respectively).

SIGNIFICANCE OF ANALYTICAL RESULTS TO RESERVOIR QUALITY/EXPOLITATION

Analysis of these 24 Morrow sandstone samples supplied to Reservoirs, Inc. by Getty Oil Company of Midland, Texas leads to the following conclusions and recommendations for exploitation of this sandstone reservoir interval:

1. In general, two sandstone rock types ("facies") are present within this 24-foot interval: (a) a sandstone rock type with abundant grain (pore wall) coating chlorite/illite clay crystals plus significant amounts of kaolinite clays filling intergranular areas. The reservoir intervals represented by this rock type include 12,935-37' and 12,954-58'. Abundant micropore space appears to be present on the sand grain surfaces within the intergrown chlorite and illite clay crystal platelets. This micropore space has the potential to contain immobile water, and this rock type has relatively high Qv values. Although some relatively open intergranular pore space was observed in a few of these samples, in general this sandstone rock type would appear to have a very low permeability in relation to its particular porosity value; (b) the sandstone rock type reflected by those samples from 12,939-12,952' consist of a quartz-rich sandstone containing extensive development of vermicular kaolinite crystals filling the intergranular areas. The quartz sand grains are extensively cemented with silica cement in the form of intergrown quartz overgrowth crystals. The pore system appears to consist of a few scattered, remaining intergranular pores developed between intersecting quartz overgrowth crystals plus a large amount of micropore space developed within the aggregates of kaolinite crystals developed within the intergranular areas. This sandstone rock type has lower Qv values than the sands above and below this interval due to both greater amounts of kaolinite (lower CEC) plus the general absence of grain-coating clay crystal development. It should be noted, however, that small amounts of diagenetic illite and chlorite were also detected in these quartz and kaolinite-rich sands on the scanning electron microscope.
2. Attempts at completion/acidization/stimulation of this sandstone reservoir interval should take into account the great abundance of diagenetic vermicular kaolinite cyrstals. Kaolinite is very stable from a chemical aspect in that it reacts with acid in nearly the same way as quartz. Hence acid treatment has no real affect on kaolinite. Kaolinite can impose production problems, however, due to its loose attachment to sand grain surfaces within the pore system, causing it to potentially behave as a mobil "fines" particle during fluid flow through the pore system. Fluid turbulence within the rock pore system during production, particularly around the wellbore, can cause fines movement to the degree that existing pore throats become "choked off" with kaolinite fines and formation damage can be the result. This migration of fines problem can be dealt with by the use of a clay stabilization agent which helps to "tie down" the individual kaolinite crystals.

3. The use of HCl acid as a completion and/or acidization fluid on this sandstone reservoir interval must take into account the presence of diagenetic, iron-rich chlorite clay crystals in the "upper" and "lower" sandstone facies. Chlorite is soluble in HCl and it has the potential to release free iron which, in turn, can combine with hydroxol ions to form a potentially formation-damaging iron hydroxide precipitate. If the use of HCl is considered necessary in the completion of this reservoir interval, strong iron-chelating agents and oxygen scavengers should be added to minimize development of ferric iron cations due to dissolution of chlorite. It is also recommended that completion fluids brought into contact with the reservoir rock pore system be recovered as soon as possible.

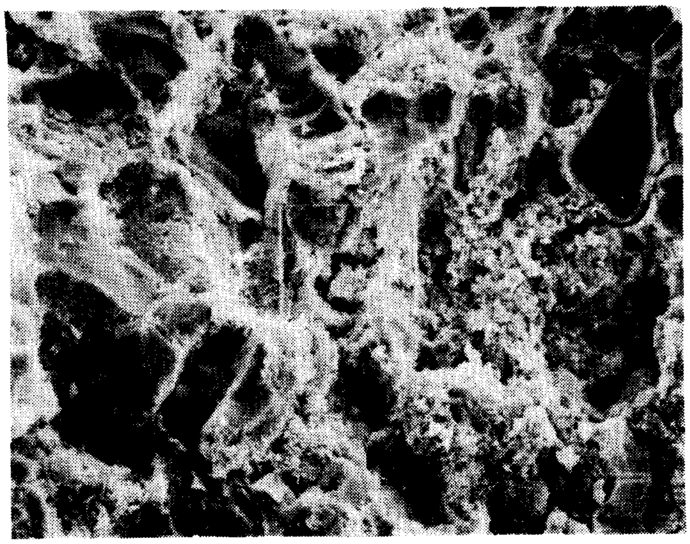

FIGURE 1—SEM PHOTOMICROGRAPH OF SANDSTONE ROCK TYPE CHARACTERIZING UPPER (NO. 1) "FACIES." NOTE SILICA CEMENTED SAND GRAINS CONTAINING ABUNDANT GRAIN-COATING CLAYS (SEE FIG. 2). ALSO NOTE SCATTERED INTERGRANULAR PORES. SAMPLE DEPTH @ 12,937'; 300X.

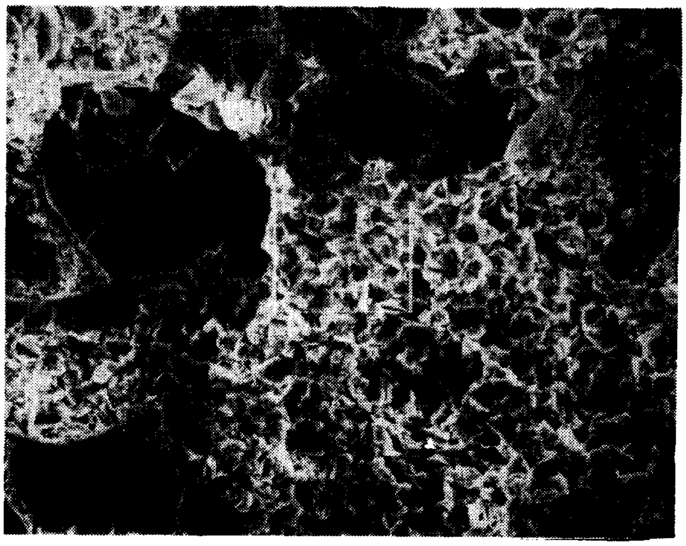

FIGURE 3—SEM PHOTOMICROGRAPH OF SANDSTONE SAMPLE TYPICAL OF MIDDLE (NO. 2) "FACIES." NOTE SILICA CEMENTED QUARTZ GRAINS AND ABUNDANCE OF KAOLINITE CLAY CRYSTALS EXTENSIVELY FILLING INTERGRANULAR AREAS. AREA IN SQUARE SHOWN IN FIGURE 4. SAMPLE DEPTH @ 12,943'; 200X.

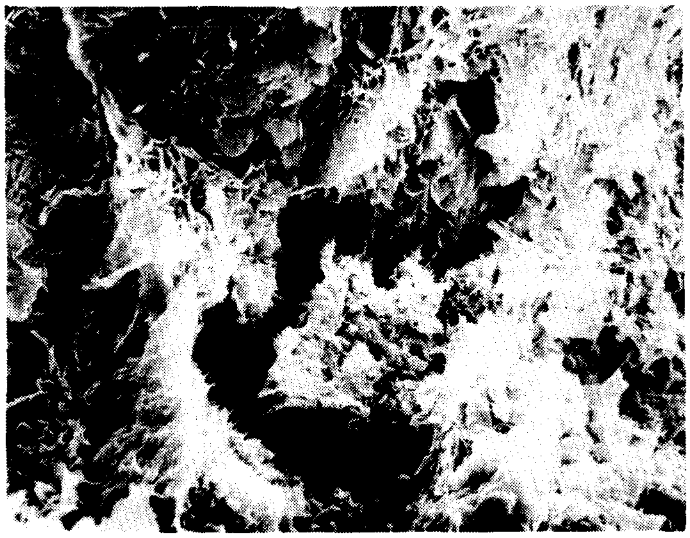

FIGURE 2—VIEW OF AREA WITHIN SQUARE ON FIGURE 1. NOTE GRAIN-COATING, FIBROUS ILLITE AND PLATY CHLORITE CLAY CRYSTALS PLUS REMAINING PORE SPACE. SAMPLE DEPTH @ 12,937'; 1500X.

FIGURE 4—VIEW SHOWING DETAILED CRYSTAL STRUCTURE OF DIAGENETIC KAOLINITE EXTENSIVELY FILLING INTERGRANULAR AREAS. NOTE STACKED ("BOOK-LIKE") CRYSTAL PLATELET MORPHOLOGY AND MICROPORE SPACES BETWEEN CLAY CRYSTALS. SAMPLE DEPTH @ 12,943'; 1000X.

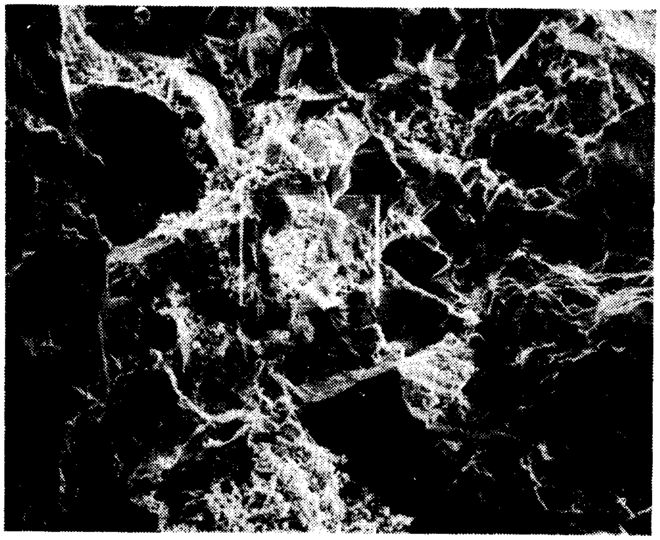

FIGURE 5—SEM PHOTOMICROGRAPH OF SANDSTONE SAMPLE TYPICE OF LOWER (NO. 3) "FACIES." NOTE SILICA CEMENTED QUARTZ GRAINS AND GRAIN-COATING CLAYS. AREA IN CENTRAL PORTION OF SQUARE SHOWN IN FIGURE 6. SAMPLE DEPTH @ 12,955'; 100X.

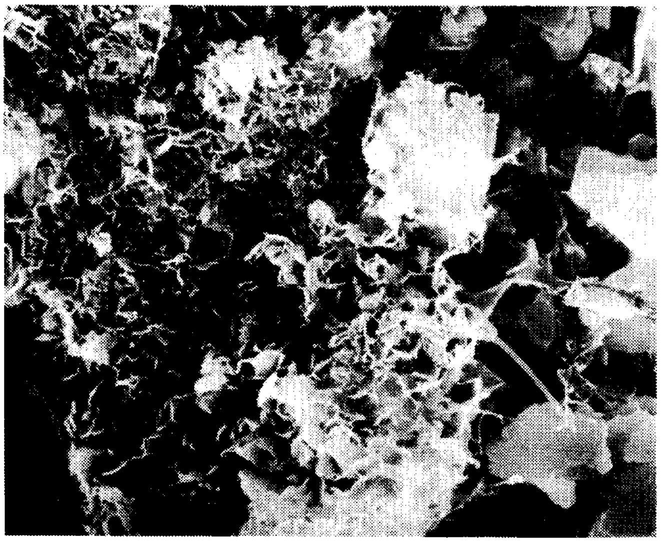

FIGURE 6—VIEW SHOWING DETAILED CRYSTAL STRUCTURE OF GRAIN-COATING/PORE-FILLING FIBROUS ILLITE CLAYS. NOTE ABUNDANCE OF MICROPOROSITY WITHIN CLAY CRYSTALS. SAMPLE DEPTH @ 12,955'; 2500X.

TABLE 1

X-RAY DIFFRACTION DATA FOR CONVENTIONAL CORE SANDSTONE SAMPLES

FROM THE GETTY NO. 1 STATE "36" COM

LEA COUNTY, NEW MEXICO

	Bulk Mineralogy					Clay Mineralogy		
Sample Depth (Ft.)	Quartz	Feldspar	Ankerite	Clays	(Wt. % "Bulk") (<20 microns)	Kaolinite	Illite	Chlorite
12,935'	94			6	(65%)	57	33	10
12,936'	92			8	(58%)	49	35	16
12,937'	93			7	(58%)	55	31	14
12,938'	91	2		7	(52%)	98		2
12,939'	91	4		5	(66%)	94		6
12,940'	90	1		9	(56%)	99		1
12,941'	91	3		6	(54%)	99		1
12,942'	93	1		6	(44%)	99		1
12,943'	88	1		11	(54%)	99		1
12,944'	84	6		10	(64%)	98		2
12,945'	91	1		8	(35%)	98		2
12,946'	92	2		6	(40%)	99		1
12,947'	83	2		15	(25%)	98		2
12,948'	89	1		10	(30%)	98		2
12,949'	88	3	2	7	(59%)	97		3
12,950'	91	2	1	6	(31%)	97		3
12,951'	91	1	2	6	(37%)	99		1
12,952'	91	3		6	(53%)	97		3
12,953'	93	2		5	(46%)	95	4	1
12,954'	81	6		13	(34%)	93		7
12,955'	69	2	5	24	(55%)	86	10	4
12,956'	72	4	20	4	(53%)	100		
12,957'	75	1	4	20	(67%)	92		8
12,958'	85	1	1	13	(66%)	76	12	12

TABLE 2

Qv VALUES FOR CONVENTIONAL CORE SANDSTONE SAMPLES

FROM THE GETTY NO. 1 STATE "36" COM

LEA COUNTY, NEW MEXICO

AS MEASURED BY MEMBRANE POTENTIAL DATA

Sample Depth (Ft.)	Electrometer Reading	Qv (MEQ/ml.PV)
12,935	100.0	~ 3.0
12,936	94.1	~ 2.0
12,937	85.5	1.1
12,938	58.2	0.2
12,939	71.1	0.5
12,940	79.0	0.8
12,941	71.7	0.5
12,942	70.3	0.5
12,943	66.8	0.4
12,944	68.5	0.4
12,945	58.5	0.2
12,946	68.0	0.4
12,947	87.3	1.2
12,948	67.5	0.4
12,949	69.9	0.4
12,950	89.5	1.4
12,951	68.5	0.4
12,952	77.5	0.7
12,953	74.5	0.6
12,954	84.9	1.1
12,955	91.4	1.6
12,956	74.1	0.6
12,957	80.5	0.8
12,958	80.5	0.8

References:

1. Thomas, E.C.: "The Determination of Qv from Membrane Potential Measurements on Shaly Sands", Soc. Pet. Eng. J. 130-136, June, 1976.