Short Papers on Research in 1968

Edited by Doris E. Zeller

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This collection of papers continues the series begun in 1967 as a part of the *Reports of Studies* in the Bulletin. The papers present scientific and economic results of work by members of the State Geological Survey of Kansas and others during the calendar year 1968.

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Computer Applications in Hydrology in Kansas

ABSTRACT

The Kansas District of the Water Resources Division, U.S. Geological Survey, in cooperation with the State Geological Survey of Kansas, has been establishing a data-processing system, including storage and retrieval, for hydrologic data since 1963. The data bank developed contains thousands of well-inventory, water-quality, water-level, and lithologic-log records. Accuracy of data in the bank is assured through a system that begins with coded forms, includes computer programs that check for logic errors, and ends with manual proofing of computer output. Numerous computer programs that manipulate and analyze data from the bank have been written, and these programs have enhanced the interpretive capability of a hydrologist. Methods of examining data that were not practicable before the advent of the computer are now feasible. Use of the computer has encouraged development of new analytical techniques and the adaptation of methods from other scientific fields for the interpretation of hydrologic data. Utilizing a high-speed digital computer, the Kansas District can do specific tasks, achieving higher interpretive quality in less time and at a lower cost than was possible previously.

The Kansas District of the Water Resources Division, U.S. Geological Survey, in cooperation with the State Geological Survey of Kansas, has been developing techniques for handling hydrologic data by means of high-speed digital computers since 1963, in accord with guidelines established by the Water Resources Division, Washington, D.C. (Johnson, 1965; Lang and Irwin, 1965). The techniques of coding, storing, retrieving, and analyzing data are designed to facilitate the manipulation and synthesis of large quantities of basic data from a data bank. These data consist of tens of thousands of data sets (Table 1), a set being, for example, one chemical analysis of water or one well-inventory record. Many programs have been written for use with these data; some programs were developed for the IBM 7040 and GE 625 computers at the Computation Center, The University of Kansas, and are also available for use on the USGS's IBM 360-65 computer in Washington, D.C.

Handling water data manually is a time-consuming, impractical job when large-scale problems are considered, and large-scale problems are becoming more evident as population and industry increase. Many data-handling procedures used in the past, both for reports and in answering requests for information, require a multitude of repetitious operations. The availability of the digital computer makes possible the development of an automatic data-processing system as an obvious solution for increasing the efficiency of handling water data. The computer can do repetitive work efficiently, allowing the hydrologist to pursue solutions to problems for which time formerly was not available.

The development of a successful automatic data-processing system involves two major steps: (1) a method must be perfected for entering the basic records into a computer data bank; and (2) programs must be developed to instruct the computer to select specific data from the bank and rearrange or manipulate the data to obtain the desired print-out.

TABLE 1.—Hydrologic data for Kansas (available, coded on forms, and in computer bank).

Data category	Cards per data set	Estimated total available sets	Coded	Data bank
Water quality	2	20,000*	15,000	15,000
Water level	5 to 500	5,000	1,200	1,100
Well inventory	2	60,000	8,000	8,000
Lithologic log				
Detailed	3 to 20	15,000†	500	500
Abbreviated	1 to 3	....	7,000‡	7,000

* Includes 7,000 from ground-water sources, 5,000 from surface-water sources, and 3,000 from petroleum industry sources.
† Includes 10,000 from USGS-KGS cooperative program and 5,000 from drillers.
‡ Includes logs noted in column 3 plus logs from petroleum industry sources.

The use of a computer allows the hydrologist to examine all available data, thereby reducing costs since chances for error are reduced to a minimum. The actual cost of an average project may not be reduced, but the data are examined more thoroughly in the same length of time. Also, once complete data banks are established

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and retrieval programs developed, requests for information can be answered reliably in a fraction of the time previously required.

One of the first steps in designing an effective system for using the digital computer in hydrology, or for any field requiring large amounts of basic data, is to prepare forms to facilitate coding and keypunching onto cards. Kansas District personnel have worked primarily with methods for coding of ground-water data. Presently, well-inventory, water-quality, water-level, and lithologic-log data are coded as collected. Much of the historical water-quality and water-level data have been coded and punched, but well-inventory and lithologic-log data are complete only for active projects.

The transferring of data from various source documents to coding forms and then to computer cards and tape is the most critical step in the development of a high-quality storage and retrieval system. Data must be accurate, or the most sophisticated computer program can do nothing meaningful. The Kansas District employs a system of data-checking procedures that includes manual proofreading and computer programs that check for errors in logic (Fig. 1). Manual proofreading is a step that cannot be computerized, except in data-handling methods. However, simple logic checks, such as checking for letters in punch-card fields reserved for numbers or examining for illegal codes, are easily programmed for the computer. This type of program for checking data punched on cards not only provides a check on errors in coding and key punching but also lists the data in an easily proofread form. Thus, the data pass through a series of manual and computerized checks until errors are minimal. If data from an active project are involved, a final check is made by the project chief. Normally, this is the first time he sees the data after having delivered the coded forms to the computer applications section.

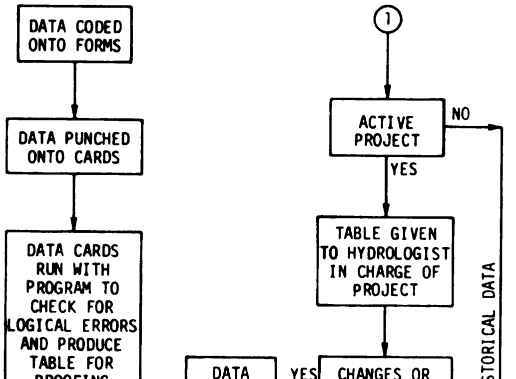

FIGURE 1.—Flow chart of data-handling procedure for computer applications, Kansas District.

The major costs in establishing a data storage-and-retrieval system are in the preparation of the basic data; however, if programs are not available for the type of manipulation required, a significant cost may ensue in writing and testing programs. The writing and development of a simple program may take only a small number of hours to program and require but a few minutes on the computer, but complex and sophisticated programs can require many months to program and many hours of computer time to test. In both cases, the initial objectives for writing the program must be satisfied, *i.e.*, the use of the program must be a money- and time-saving tool and the procedure must be worthwhile.

When the data have been punched correctly on cards and placed in a computer data bank, the data can be manipulated in many ways to reveal facets of the hydrology in a more comprehensive form. Much basic data is presented initially in tables for use in data interpretation and in published reports. Programs for producing tables of well-inventory, water-quality (Morgan, *et al.*, 1966), water-level, and lithologic-log data are designed to present the data in a form that the hydrologist has been accustomed to using. Data also can be sorted in various ways, such as by aquifer or by well depth, so that the tables may be arranged differently for different purposes. Programs for specialized or abbreviated tables usually are written as the need for them arises.

While the various types of tables of basic data are the fundamental methods of presenting data from computer programs, data presented in a diagrammatic format may yield much more information with a minimum of effort by the hydrologist. The several types of diagrammatic output employed include map and graph plots. Maps (Fig. 2), with specific parameters located at their relative positions in two-dimensional space, are commonly used tools in the interpreta-

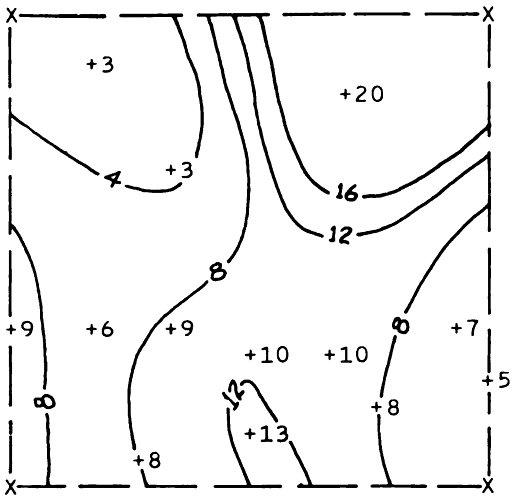

Figure 2.—Map showing saturated thickness (in feet) of Pleistocene aquifer in T 16 S, R 19 W, Rush County, Kansas. (Locations of data points designated by plus sign; corners of township defined by X's. Scale: 1:126720. Solid lines drawn manually.)

tion and illustration of hydrologic phenomena. The programs available for plotting maps (Good, 1964) are designed to adjust the output to any specified map scale, to sort for a parameter within the data set or calculated from the data, and to sort for data from specified aquifers. The hydrologist can request a series of maps with the desired parameters and be assured that the data are located accurately and are represented completely. Such maps are used principally for interpretive purposes; however, the line printer produces maps that are accurate enough for publication.

Program development for graphic output has been concentrated on presentation of water-quality data because of an emphasis on preparation of all available Kansas water-quality data for computer use and the adaptability of these data to graphic representation. The graphic methods (Angino and Morgan, 1966) first programmed were those most commonly used by hydrologists. Two of these programs present a single water analysis on one graph. The Stiff (Stiff, 1951) (Fig. 3) and the Collins (Collins, 1923) diagrams show selected constituents in milliequivalents per liter

A group of water analyses can be represented on quadrilinear and trilinear diagrams (Piper, 1953) that show the relationship of the ions (Fig. 4). These diagrams aid in classification of water types, as well as in pointing out possible mixing of several water types. By use of another program, water can be categorized according to degrees of salinity hazard, denoting suitability for irrigation. The program uses a technique requiring that water conductivity be plotted against the sodium-adsorption ratio (Agriculture Handbook No. 60, 1954). The computer output for all these diagrams includes supplementary tables that identify the analyses used and the aquifer from which the water was obtained.

Methods of analysis or manipulation that are less commonly used because of excessive amounts

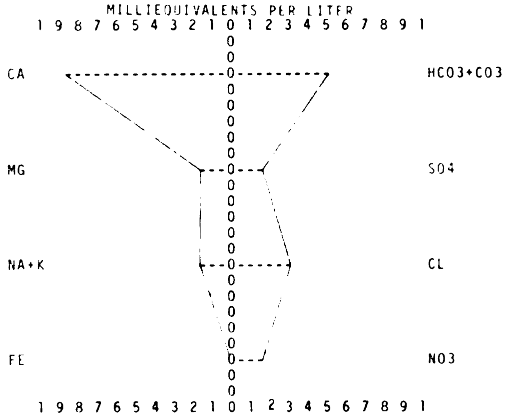

Figure 3.—Stiff diagram of a water analysis from the Pleistocene and Dakota aquifers of Rush County, Kansas. (Scale of diagram is 10 milliequivalents per liter to the left and right of the vertical center zero line. Each dash equals 0.5 meq/l.)

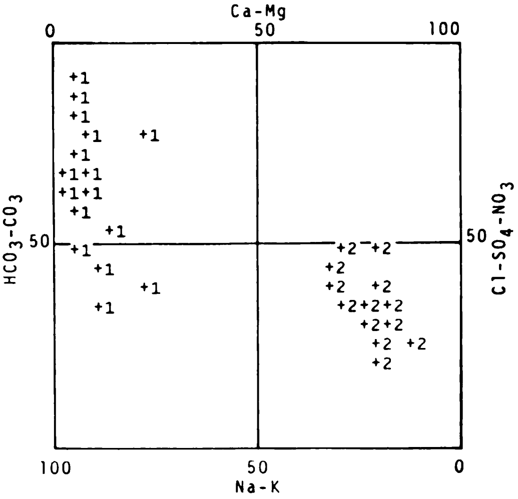

Figure 4.—Quadrilinear Piper diagram of water quality data sorted by aquifer, from Rush County, Kansas. (Pleistocene aquifer designated by numeral 2, Dakota Formation by numeral 1, locations of data points by plus sign. Constituent symbols and grid drawn manually.)

of time involved in manual preparation of the data have been programmed to aid the hydrologist in expanding his interpretive capability. These methods normally involve a great amount of mathematical computation. An example of this type of program is one that calculates a number of additional parameters from basic water-quality data, sorts these data into groups by aquifer, and determines for each aquifer group the maximum, mean, minimum, and sample standard deviation for each parameter. Each chemical constituent is converted to milliequivalents per liter, where possible, and the basic statistics are calculated. Fifty ratios may be calculated for each analysis and the basic statistics determined for the aquifer groups. These ratios are used to determine origin of the water, to indicate mixing or contamination, and to define water types. A group of 100 analyses from 10 aquifers have over 10,000 values determined by the program; in many cases each value involves several computational steps.

A program involving a large amount of computation time is one that calculates drawdown at points within an infinite well field (Fader, 1967). This program uses the permeability, saturated thickness, and storage characteristics of the aquifer, the average pumpage per well, and the number of wells affecting drawdown to produce a table of drawdown values.

Another program was written to manipulate the water-quality data collected periodically at selected stations along a reach of a surface stream. This program will handle up to 50 stations and will calculate 23 parameters for each chemical constituent at each significant station for a given period of time. The results are sorted by station and parameter, placed in order by date, and put in a table format—each station having up to 24 tables. The amount of manual work necessary in the past to handle these data was prohibitive and often the results were inconclusive. Therefore, because time was not available, shortcut methods, such as educated guesses, dictated the resulting interpretation.

Many previously used methods of data manipulation and analysis for which programs are available have been expanded to include new techniques of analysis. This has been made possible by the hydrologist's realization that he now has time available for more thorough interpretation of the voluminous data. Also, new methods of looking at data are being developed and new programs are being written. For example, a program, which is a semilog plot of water-quality data (Fig. 5) designed for both surface- and ground-water data, can sort the data by date of collection, stream discharge or well depth, geologic source of ground water, and constituent value. These sorted data are tabulated along with values for the maximum, mean, minimum, and sample standard deviation. The constituents or parameters are plotted using a $\log_{10}$ scale. This plot emphasizes water groupings and anomalies, as well as the range of concentration of the parameters. Surface-water data also are plotted with respect to time, denoting seasonal changes that affect the water quality. The program as written can sort the data in thousands of possible ways, and the data arrangement and plot scale on the graph can be adjusted to an almost infinite number of combinations. This variety of options allows the user to try many patterns for the most convenient grouping.

Examples of other programs are as follows: one for the examination of water mixtures such as may be found in a study of water contamination, a well pumping from two aquifers, or a well inducing infiltration from a stream; another for estimating water-level fluctuations in a well by using the water levels of an adjacent surface stream; and another for estimating yearly recharge and discharge to a water-table aquifer.

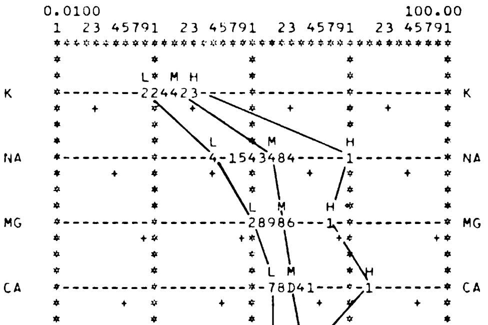

FIGURE 5.—Semilog plot of designated chemical constituents in water from the Ogallala Formation in Kearny County, Kansas. (L=low, M=mean, and H=high constituent values in meq/l. Numbers and letters signify analyses at a position on the dashed line. Milligrams per liter scale given by plus symbols. Solid lines drawn manually.)

Many programs that have been written for various fields of the social and physical sciences also can be applied to hydrologic work. The statistical routines written for medical research by the BIOMED group at the University of California (Los Angeles) (Dixon, 1965) are examples. One routine, the polynomial regression, is being used in evaluating water-quality data.

Samples of time required to run some of the hydrologic programs on the GE 625 computer are shown in Table 2. In all examples, the time used is insignificant with respect to the amount of work accomplished by use of the program.

SUMMARY

Evolution of computer applications in hydrology in Kansas has included design of coding schemes and forms, formulation of a system for checking data, development of computer programs for writing tables of data and plotting a variety of maps and graphs from these data, and adaptation of statistical program packages to these data. The purpose of the development of these applications has been to provide hydrologists with computer facilities for increasing their efficiency, to reduce costs, and to improve their professional capabilities.

TABLE 2.—Time for running various water-data programs through the GE-625 computer.

Programs	Data sets	Output		Computer time, min.
		Tables	Plots	
Data checking				
Well inventory and water quality	176	1	....	1.85
Water level	10	10	....	.20
Tabulation				
Water quality	114	1	....	1.21
Water level	10	10	....	.31
Diagrammatic				
Map plots	176	1	9	1.45
Graph plots				
Stiff diagram	114	....	47	.36
Collins diagram	114	....	41	.42
Piper diagram	114	2	7	.47
Irrigation classification diagram	43	2	2	.32
Semilog diagram	114	19	18	1.44
Other programs				
Ratio determination	114	3	....	1.05
Recharge calculation	325	....	1	.04

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ERNEST E. ANGINO

Far Infrared Absorption Spectra of Plagioclase Feldspars

ABSTRACT

Several well-resolved major and minor bands are present in the far infrared spectra (500-30 cm^{-1}) of the plagioclase feldspars. The major lattice mode vibrations appear to be diagnostic for the respective members of the plagioclase series; shifts of the absorption bands of certain vibrations appear related to the major element composition of the feldspars. A linear plot of the Na_2O content versus wave number indicates a shift of the 190 cm^{-1} albite peak to 215 cm^{-1} in anorthite (*i.e.*, as Na_2O decreases, the absorption shifts to shorter wave lengths). A strong log correlation between the same peak and the $Al/(Al+Si)$ ratio is also indicated. With a decrease in $Al/(Al+Si)$ there is a shift toward longer wave lengths, which is expected from theory. The occurrence of major absorption bands within reasonably narrow wave-length limits helps in characterizing the spectra as a group.

Infrared spectra of plagioclase feldspars have been used for qualitative identification and to study the relation between absorption bands and chemical composition (Milkey, 1960; Thompson and Wadsworth, 1957, and others). These investigations, however, were limited to the intermediate (conventional) infrared region. The far infrared spectra of some of the more common minerals have been presented in only a few papers (Schaefer, *et al.*, 1934; Angino, 1964, 1967; Karr, *et al.*, 1967; Estep, *et al.*, 1968; and Dorsey, 1968). The purpose of this paper is to present the far infrared spectra (70-340 cm^{-1}) of some of the plagioclase feldspars. Owing to incomplete knowledge of the far infrared spectra of such complex inorganic materials as the silicates, a detailed discussion of these spectra is presently impossible. No attempt, therefore, is made to assign any of the absorption bands.

Major plagioclase absorption bands in the far region (70-400 cm^{-1}) can be of four origins: (1) interval vibrations of a polyatomic ion; (2) torsional vibrations of water molecules in the sample, (3) sum and difference modes, and (4) lattice vibration modes. The latter possibility is the most likely origin for some of the major absorption bands observed.

The major absorption bands in this region are probably diagnostic for the specific minerals and it is possible that with further detailed studies shifts in the frequency of certain lattice-mode vibrations may be related to mass and radius differences of cationic substitution (calcium for sodium, etc.) through the plagioclase series. Such effects will surely be complicated in the plagioclases owing to their particular mineralogic phase problems.

The plagioclase specimens studied (Table 1) were obtained from Wards Scientific House. The far infrared spectra were obtained through the

TABLE 1.—Far infrared absorption bands of plagioclase minerals.

Mineral	Location	Absorption bands (cm^{-1})
1 Albite	Bancroft, Ontario	93W,* 116W, 165W, 187M, 252, 300W, 334W, 375W, 400W, 430W, 465W, 475, 500W, 590W
3 Albite (variety cleavelandite)	Keystone, South Dakota	93W, 100S, 115S, 148S, 166W, 187M, 200W, 217W, 266S, 300W, 375S, 400S, 460S, 510W, 528W, 620W
4 Andesine (in monzanite porphyry)	Judith Basin, Montana	89W, 101W, 144M, 170W, 181W, 200M, 244S, 285W, 311M, 320W, 384M, 479W, 540W, 575W, 622M
5 Labradorite	Nain, Labrador	85W, 89W, 95W, 138M, 163W, 182W, 210M, 234S, 290W, 317S, 390S, 470W, 626M
6 Bytownite	Crystal Bay, Minnesota	92W, 130W, 151W, 163W, 214S, 328W, 392M, 470W, 635M
7 Anorthite	Miakejima, Japan	93W, 173W, 217S, 265M, 336M, 376, 395, 465W, 540W

* W=Weak; M=Medium; S=Strong.

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courtesy of Allan Budd and the Lincolnwood Laboratory of Beckman Instruments, Inc. All samples were examined by x-ray diffraction and optical methods to verify their identification. No good oligoclase sample was available. High temperature specimens were not used in the study.

Samples were prepared and run on a Beckman IR-11 spectrophotometer according to the methods described by Angino (1967). The resolution of the IR-11 over the range covered (33-800 cm^{-1}) was better than 5 cm^{-1} and in most cases was between 2 and 3 cm^{-1}. The chemical composition of the samples studied (Table 2) was obtained by atomic absorption spectrometry, using methods modified from those described by Angino and Billings (1967). Sodium and potassium concentrations were determined by standard flame photometric techniques.

TABLE 2.—Chemical composition (percent) of plagioclase samples studied.

	Albite	Labradorite	Bytownite	Anorthite
SiO_2	63.56	54.85	48.83	43.92
Al_2O_3	20.89	28.19	31.96	34.19
Fe_2O_3*	0.17	0.77	0.53	2.30
TiO_2	0.36	0.22	0.43	1.20
CaO	1.75	8.65	14.51	16.35
MgO	0.02	0.03	0.10	1.00
K_2O	0.70	0.48	Nil	Nil
Na_2O	11.47	6.12	2.62	0.53
SrO	0.22	0.02	0.06	0.06
MnO	Nil	0.02	Nil	0.02
NiO	Nil	Nil	Nil	0.04
CaO	0.07	0.07	0.05	0.10
Li_2O	Nil	Nil	Nil	Nil
LOI†	1.18	0.38	0.66	0.05
S	0.02	0.04	T	T
SO_3	0.01	0.01	T	0.02
Total	100.38	99.81	99.75	99.78

* Total Fe.
† LOI=Loss on ignition.
T=Trace.

CONCLUSIONS

Representative spectra are shown in Figure 1. These illustrate the relative intensities of the various absorption bands whose wave number positions are listed in Table 1. The absorption peak at 72 cm^{-1} is due to the high density polyethelene plates used in obtaining the spectra and appears on all the spectra. Peaks present in the range interval 340-800 cm^{-1} have been reported by Milkey (1960), Schaefer, *et al.* (1934), and Thompson and Wadsworth (1957). To the best of my knowledge, no data for the range 70-340 cm^{-1} have been presented in the literature on the plagioclase feldspars.

A linear plot (not shown) of the Na_2O content versus wave number suggests a shift in the 190 cm^{-1} albite peak to 215 cm^{-1} in anorthite (i.e. as Na_2O decreases, the absorption shifts to shorter wave lengths). Another trend for the same peak is indicated by a log plot of Al/(Al+Si) versus wave number. With a decrease in Al/(Al+Si) there is a shift toward longer wave lengths, which is expected from theory (Milkey, 1960). These trends do not include peaks resulting from additive combinations. To speculate at length on the significance and meaning (if any) of these trends would be premature, although it is possible that the Na_2O shift is related to the substitution of the Ca ion for the Na ion in going from the albite to anorthite end of the plagioclase series.

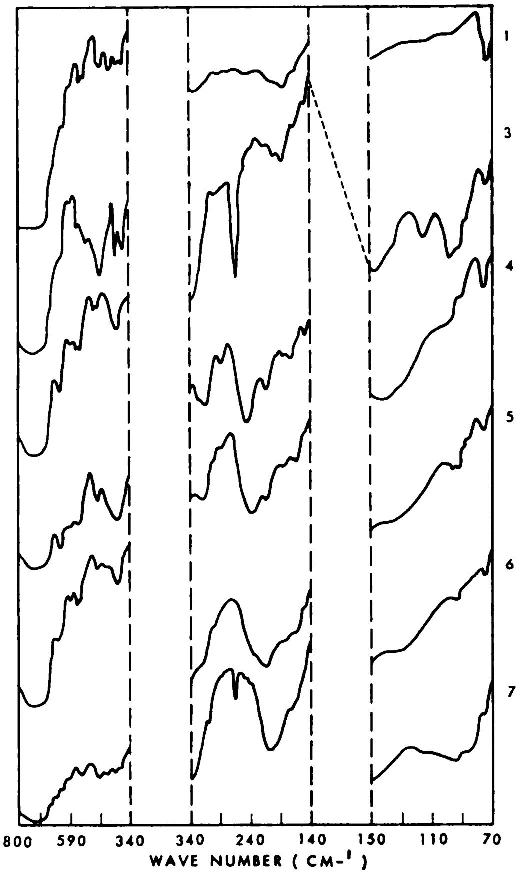

FIGURE 1.—Far infrared spectra of plagioclase feldspars. Identity of the numbered spectra is given in Table 1.

Definite absorption bands for the plagioclase feldspars occur in the far infrared region, and it is possible that these spectra can be related to the chemical composition of each mineral. It is considered likely that the several well resolved major and minor absorption bands present in the far infrared spectra of the plagioclases are diagnostic for each mineral. These spectra obtained as part of another study are presented in the hope that they may stimulate additional studies of the far infrared absorption phenomena of the plagioclase feldspars and thereby extend the usefulness of the infrared method which is becoming commonplace in mineralogical studies.

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MAYNARD P. BAULEKE
ALLISON L. HORNBAKER

Attrition Scrubbing and Flotation Beneficiation of Cheyenne Sandstone (Lower Cretaceous, Kansas)

ABSTRACT

Acidic attrition scrubbing reduced the iron oxide (Fe_2O_3) content of Cheyenne Sandstone to less than 0.040 percent. No significant improvement was obtained by an additional flotation treatment. Sand usage appears limited to foundry sand, abrasive sand, and low-quality glass sand.

The Cheyenne sandstone was sampled on the E. D. Robbins G lease in the E NW NW SW sec. 34, T 30 S, R 16 W, Kiowa County, Kansas (Fig. 1). The exposure is a nearly vertical section of Cheyenne Sandstone on the west bank in the bend of a small stream.

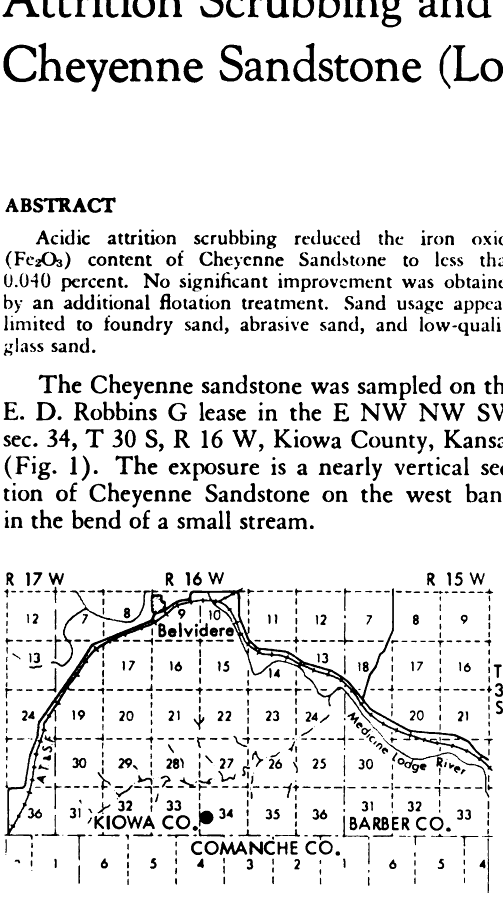

FIGURE 1.—Location of sampling area of the Cheyenne Sandstone.

Channel samples were taken in order to obtain representative samples of the total sandstone section. For convenience in sampling, three channel cuts were taken enechelon up the face of the exposure—one for the lowermost 8 feet of section, the middle 6 feet, and the upper 8 feet, a total of 22 feet.

The sample of Cheyenne sandstone is composed essentially of generally rounded grains of sand. The heavy mineral concentrate consists of discrete grains of iron oxide, ilmenite, and zircon. Limonite associated with the sand grains appears to account for a large part of the total iron and is present in sufficient quantity to give the sand a slightly yellow color. Numerous sand grains contain inclusions of dark minerals. Occasional aggregates of sand grains cemented with limonite are present.

A partial chemical analysis[1] on the "as dug" sample showed an iron oxide (Fe_2O_3) content of 0.092 percent, and an aluminum oxide (Al_2O_3) content of 0.89 percent. Particle size analysis[2] of the sandstone is shown in Table 1.

TABLE 1.—Standard screen particle size analysis.

Screen mesh	Percent weight on screen mesh	Percent weight cumulative
20	0.5	0.5
28	1.0	1.5
35	4.0	5.5
48	21.5	27.0
65	36.0	63.0
100	25.5	88.5
200	11.0	99.5
−200	0.5	......
Total	100.0	

Seven attrition scrubbing tests were done (Table 2). A standard Denver Attrition Scrubber employing double-opposed-pitch propellers was used. Attrition scrubbing cleaned by abrading the sand particles with each other, rubbing away surface layers of iron minerals and clay. The scrubbed sand was deslimed by decantation through a 200-mesh screen.

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[1] All chemical analyses done by the Geochemistry Laboratory, State Geological Survey of Kansas.

[2] All beneficiation tests done by the Denver Equipment Company, Ore Testing Division, Denver, Colorado.

TABLE 2.—Results of attrition scrubbing tests.

Test:	1	2	3	4	5	6	7
Scrubber feed—percent solids	75.7	75.7	74.6	74.6	75.7	75.7	75.7
Reagents*	N	N	OH	OH	H	H	N
Reagent dosage, lbs/ton solids	....	....	0.67	0.67	0.67	0.67	....
Scrubbing stages	1	1	1	1	1	1	2
Scrubbing time, minutes	5	10	5	10	5	10	5:5
Pulp pH	7.6	7.6	11.5	11.5	2.5	2.5	7.6
Sand recovery, percent wgt.	97.0	97.1	96.9	97.0	97.1	97.1	96.9
Slime recovery, percent wgt.	3.0	2.9	3.1	3.0	2.9	2.9	3.1
Assay-sand: percent Fe_2O_3	0.057	0.037	0.045	0.035	0.040	0.029	0.034
percent Al_2O_3	0.15	0.15	0.15	0.15	0.15	0.15	0.13
Approximate costs of chemicals, cents per ton (f.o.b.)	....	....	6.0	6.0	2.0	2.0	....

* N=None; OH=Sodium hydroxide; H=Sulphuric acid.

Four additional tests using both attrition scrubbing and flotation were run:

Test No. 8. After two stages of scrubbing the sand was subjected to flotation using fatty acid collectors in an alkaline circuit to remove iron impurities as a froth product.

Flotation reagents	*lbs/ton sand*
Sodium carbonate	0.40
Aero Promoter 710	0.55
Aero Promoter 765	0.65
Aerofroth 65	0.09

Iron content (Fe_2O_3) of the sand remaining in the cell was 0.028 percent. Total cost[3] of reagents was 21 cents per ton of sand recovered. Recovery was 95 percent.

Test No. 9. Scrubbing procedure was the same as for Test 8. Following scrubbing, the sand was conditioned with petroleum sulphonates in an acid circuit followed by flotation of the iron impurities in an acid circuit.

Flotation reagents	*lbs/ton sand*
Sulfuric acid	0.67
Aero Promoter 801	0.40
Aero Promoter 825	0.40
No. 2 fuel oil	0.05
Aerofroth 65	0.20

Iron content (Fe_2O_3) of the sand remaining in the cell was 0.028 percent. Total cost of reagents was 19 cents per ton of sand recovered. Recovery was 95 percent.

Test No. 10. Scrubbing procedure was the same as Test 8. After scrubbing, the sand was floated away from the suspension by amine type collectors at a neutral pH. Flotation reagents were added in two stage additions to give two sand flotation concentrates and a final tailing.

Flotation reagents	*lbs/ton sand*	
	Stage 1	*Stage 2*
Armac C	0.04	0.03
Methyl isobutyl carbinol	0.10	0.05

Iron content (Fe_2O_3) of sand collected during stage 1 was 0.028 percent, during stage 2, 0.030 percent. Total cost of reagents was 8 cents per ton of sand recovered. Recovery was 77 percent.

Test No. 11. As a last attempt to produce sand with a low iron content, a combination of scrubbing, impurity flotation, and sand flotation was tried. Chemical types and quantities were the same as in tests 8, 9, and 10. After a two-stage flotation of impurities, the sand was given a three-stage flotation to remove pure sand. The first stage of sand flotation gave the lowest iron content sand, 0.021 percent Fe_2O_3. However, the yield was only 26 percent of total sand. Treatment cost was $1.15 per ton of yield, a prohibitive cost for glass sand. The other two flotation stages gave sand with an iron content of 0.027 percent Fe_2O_3.

Enough of the iron content of Cheyenne sandstone is within the sand grain so that it is not possible by low-cost beneficiation methods to routinely produce a glass sand having an Fe_2O_3 content of less than 0.030 percent. Flotation gave no better product than did acid attrition. The extra cost of flotation is not justifiable.

For the area of Cheyenne sandstone sampled it appears that an iron content of 0.040 percent Fe_2O_3 or less could be routinely produced by low cost attrition beneficiation. Such sand could be used as foundry molding sand, sand blasting grit, and as glass sand where a slightly green color is not objectionable.

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[3] Costs listed are only approximations because of current price fluctuations.

MAYNARD P. BAULEKE
JOHN M. HUH

Thermal Expansion of Kansas Volcanic Ash

ABSTRACT

Thermal expansion values of Kansas volcanic ash range from 4.05 to 4.65 $\times$ 10^{-6}/C° (100-650°C), varying with chemical composition. The softening point is above 900°C.

Substitution of volcanic ash for other silicate fluxes in a ceramic body lowers the thermal expansion of the body, often to such an extent that a new glaze has to be prepared to prevent crazing. For a more knowledgeable approach to the use of volcanic ash in bodies and glazes, the thermal expansion of three volcanic ashes were measured: two samples of Pearlette ash of Pleistocene age (MEV-5 from Meade County and JV-6 from Jewell County) and the Calvert ash of Pliocene age (NNV-1 from Norton County). Chemical analyses are given in Table 1.

Thermal expansion test bars were prepared as follows:

1. Press moistened ash into a 2½″ diameter disk, ¼″ thick.
2. Sinter at 1500°F.
3. Cut ¼″ x ¼″ x 2″ bars from the disks.
4. Fire to 2000°F.
5. Grind ends and sides parallel.
6. Measure thermal expansion using a quartz rod dilatometer as described by Bauleke and Edmonds (1968).

Table 1.—Chemical analyses.

	MEV-5, Meade County	JV-6, Jewell County	NNV-1, Norton County
SiO_2	72.40	73.32	76.68
Al_2O_3	11.45	10.76	9.77
Fe_2O_3	1.70	1.66	1.44
TiO_2	0.31	1.36	0.51
CaO	0.76	0.53	1.45
MgO	0.31	0.23	0.27
K_2O Na_2O	8.17	7.57	6.86
L.O.I.	4.90	3.93	3.02

L.O.I.=Loss on ignition.

Thermal expansion curves are shown in Figure 1. From the curves the following observations can be made: (1) Thermal expansion is linear between 100 and 650°C, ranging from 4.05 to 4.65 $\times$ 10^{-6}; (2) above 650° there is an increase in the rate of thermal expansion; (3) the softening point of volcanic ash glass is above 900°C as indicated by the reversal of the expansion curve; and (4) chemical composition controls the thermal expansion, but which oxide is the more important cannot be deduced from these measurements, as there undoubtedly is an interaction. One could say that the thermal expansion decreases with increasing silica content, increases with increasing alumina content, or increases with increasing alkali oxide content.

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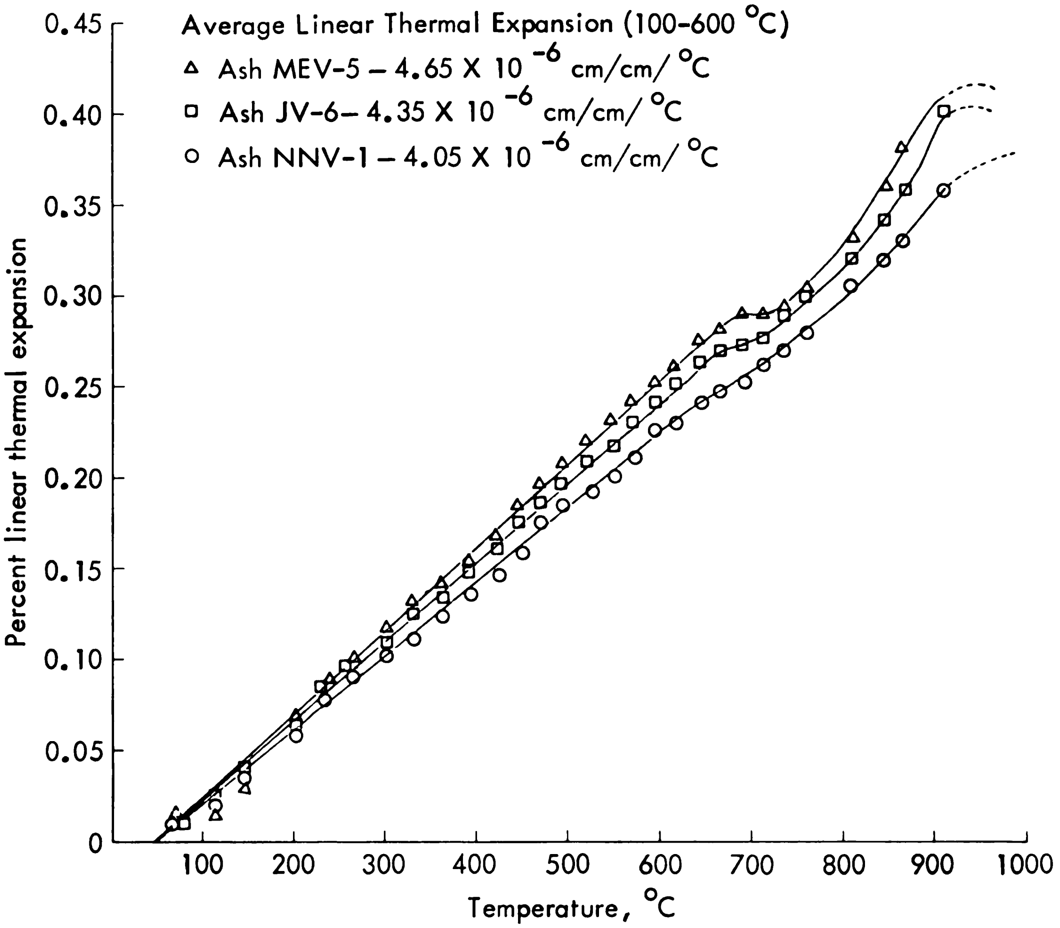

FIGURE 1.—Linear thermal expansion curves for three samples of volcanic ash from Kansas. MEV-5 is from Meade County; JV-6 is from Jewell County; NNV-1 is from Norton County.

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MAYNARD P. BAULEKE
JOHN M. HUH

Absorbent Clay Granules from Kansas Underclays

ABSTRACT

Absorbent clay granules were prepared from Kansas underclays by the addition of a frothing agent to a clay slip, and then drying, crushing, and calcining the product. Absorbent properties were comparable to those of a commercial product.

An absorbent granule differs from an expanded lightweight granule in that the absorbent granule has a minimum of glass formed within the pore structure. A maximum amount of the pore structure should be open to liquid penetration. Absorbent clay granules suitable for absorbing oil, grease, water, etc., were made from kaolinitic Kansas underclays (Fig. 1). The absorbance of these granules is quite similar to that of absorbent clays from Georgia and Florida.

The laboratory method of making low-density absorbent clay granules was as follows:

1. A 50/50 proportion (by weight) of clay and water was blended in a malted milk mixer.
2. Two-tenths of one percent by weight (based on the weight of clay) of Santomerse #1[1] was dissolved in a small amount of water and added to the agitating clay-water mixture.
3. Air was entrapped in the suspension and a stable foam was formed.
4. The foam was poured into a shallow pan and rapidly dried.
5. The dried foam was given a preliminary coarse crushing and rapidly fired to 1500-1800°F.
6. It was crushed to the final required size.

A small pilot plant[2] operation, based on the laboratory procedure, was started in southeastern Kansas, but the work was discontinued after making a study of the competitive material sold in the area. The following are sold as grease absorbent materials:

1. Attapulgite clays from Georgia and Florida.
2. Diatomaceous earth products.

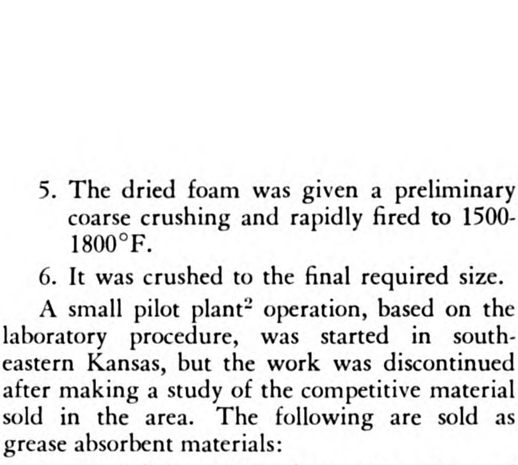

FIGURE 1.—Crushed absorbent clay granules, ×5.

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[1] Santomerse #1 is a 40-percent active alkyl aryl sulfonate manufactured by the Monsanto Chemical Company.

[2] Designed and built by Mr. John H. Denham, Black Diamond Coal Co., Route 1, Weir, Kansas.

3. Expanded vermiculite waste.
4. Absorbent raw clays from Illinois.

Comparison of oil absorption properties of the granules from frothed Kansas underclays and a commercial oil absorbent (Table 1) showed that the ability of Kansas granules to absorb oil was slightly better than that of the commercial product. Kansas granules were rough-textured, equiaxed particles. The economics of full-scale manufacturing appear to be marginal, with only the lower cost of shipping into the market area to offset the additional cost of frothing and drying the clay.

TABLE 1.—Comparative oil absorption tests.*

	Commercial oil absorbent	Absorbent Kansas underclay granules
Weight per cu. ft.	31.97 lbs	27.10 lbs
Specific gravity (determined in kerosene)	2.17	1.93
Oil absorption† (weight of absorbent)	0.417	0.435
Time required for saturation	166 seconds	84 seconds
Kerosene‡ absorption test (−16+40 mesh)	....	20 %

* Tests done by Bruce Williams Laboratories, Joplin, Mo.
† Linseed oil (7.75 lbs/gal) used in absorption test.
‡ Test done in KGS laboratories.

For additional information pertinent to this paper see the following references:

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WILLIAM B. HLADIK
MAYNARD P. BAULEKE

Low-Density Ceramic Bodies from Clay and Expanded Volcanic Ash from Kansas

ABSTRACT

Ceramic bodies with densities ranging from 14.5 to 28.8 lbs/cu. ft. and compressive strengths ranging from 84 to 232 psi were prepared from clay-expanded volcanic ash mixtures. Bodies were not watertight, but they can be used in nonload-bearing construction applications.

An interesting group of low-density clay-expanded volcanic ash bodies have been prepared (Tables 1 and 2). It was necessary to mix the materials in the following steps in order to prevent excessive crushing of the expanded ash and to create the proper cellular structure:

1. Thoroughly dry-mix the clay, bentonite, hydrocal, and aluminum powder.
2. Add water to form a slurry.
3. Add expanded volcanic ash to the slurry, stirring gently.
4. Add sodium hydroxide solution and pour into retaining form.
5. Vibrate the form to fill all parts of the mold.
6. Rapidly dry to prevent loss of the cellular structure.
7. Fire to desired temperature, usually in the range of 1500-1800°F.
8. Shape as required.

The addition of aluminum powder and sodium hydroxide is essential for the creation of good cellular structure. Hydrogen gas is released (Jacobson, 1946) according to the reaction

$$2NaOH+2Al+2H_2O \rightarrow 2NaAlO_2+3H_2.$$

Hydrogen gas forms small cells in the clay bonding matrix around the cellular ash, lowering the bulk density.

TABLE 1.—Batch compositions for Champion and Challenger ball clay and expanded volcanic ash mixtures.

Material	Volume, percent clay/ash 50/50	40/60	30/70	20/80	16/84
C & C ball clay*	82.2‡	77.8	71.5	61.6	56.8
Expanded ash*	10.6	15.1	21.5	31.8	36.7
Wyoming bentonite	2.4	2.3	2.2	1.8	1.6
Hydrocal	4.8	4.8	4.8	4.8	4.9
Aluminum powder	†	†	†	†	†
Water	127	127	127	159	156
1 percent NaOH solution	0.1	0.1	0.1	0.1	0.1

* 0.1 cu. ft. expanded ash=300 gms, 0.1 cu. ft. C & C ball clay =2325 gms.
† 28 gms Al powder per cubic foot of dry material.
‡ Weight percent.

TABLE 2.—Batch compositions for C-27 (Cloud County, Kansas) clay and expanded volcanic ash mixtures (in weight percent).

Material	Volume, percent clay/ash 20/80	18/82	16/84
C-27 clay*	66.8	64.6	62.6
Expanded ash*	26.2	28.5	30.6
Wyoming bentonite	2.2	2.1	2.0
Hydrocal	4.8	4.8	4.8
Aluminum Powder	†	†	†
Water	167	176	182
1 percent NaOH solution	0.1	0.1	0.1

* 0.1 cu. ft. expanded ash=300 gms, 0.1 cu. ft. C-27 clay=3065 gms.
† 28 gms Al powder per cu. ft. of dry material.

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Final shaping of the fired material can be done by any conventional method, cutting, sawing, drilling, chipping, gouging, etc., using ordinary steel tools. The surface can be colored either by the fusion of a glaze or application of an organic finish. Surface texture may be left in the rough condition or smoothed by the application of a filler material or engobe.

There is much variability in the strength versus bulk density relationship (Tables 3 and 4). The material is not capable of carrying a structural load but is capable of being used in any nonload-bearing application requiring a fire-resistant property. An interesting possible use is for sculpturing material. Its light weight is ideal for the creation of designs that need to be hung on a wall or suspended in the air.

TABLE 3.—Physical properties of Champion and Challenger ball clay and expanded volcanic ash mixtures.

	Volume, percent clay/ash				
	50/50	40/60	30/70	20/80	16/84
Percent water absorption	105	135	138	222	207
Crushing strength, psi	113	137	232	107	86
Bulk density, lbs/cu. ft.	28.8	22.6	26.0	15.2	15.9

TABLE 4.—Physical properties of C-27 (Cloud County, Kansas) clay and expanded volcanic ash mixtures.

	Volume, percent clay/ash		
	20/80	18/82	16/84
Percent water absorption	177	200	214
Crushing strength, psi	145	135	184
Bulk density, lbs/cu. ft.	17.4	16.1	14.5

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PEI-LIN TIEN
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Vivianite in Graneros Shale (Upper Cretaceous), Central Kansas

ABSTRACT

An earthy variety of vivianite is found in Cretaceous marine sediments (Graneros Shale) in central Kansas. It occurs as nodular aggregates and encrustations along the surfaces of bedding planes and joints. Vivianite within 2 feet of the outcrop surface is blue, and that beyond 2 feet is white. Associated minerals are jarosite and gypsum. To the authors' knowledge, this is the first reported occurrence of vivianite in Kansas.

Vivianite changes color rapidly from white to blue after collection. Crystallites of the mineral are lath-shaped and range from 2 to 4 μ in length. Differential thermal analysis shows endothermic reactions at 190°, 360°, 470°, and 570°C, and exothermic reactions at 650° and 755°C. The infrared spectrum has wide absorption bands at 3300 and 1000 cm^{-1}, and medium bands at 1620, 800, and 500 cm^{-1}.

Field evidence suggests that iron sulfides and fossil remains in the sediments may contribute to the formation of the vivianite and associated minerals.

Vivianite, $Fe_3(PO_4)_2 \cdot 8H_2O$, was found by one of the authors (Dilts) along a new road cut in the marine Graneros Shale (Upper Cretaceous). The locality is 3 miles south of the town of Wilson, Ellsworth County, Kansas, and is close to one described by Hattin (1965, p. 76, Locality 8). To the authors' knowledge, this is the first reported occurrence of this mineral in the state of Kansas.

The vivianite is concentrated in a zone 9 feet thick, approximately 9 feet below the top of Graneros Shale, in an exposure that is 100 feet long in a north-south direction on both sides of the road (NW sec. 6, T 15 S, R 10 W). Lateral extent of the vivianite zone is not known.

The mineral occurs as 0.5- to 2-cm nodules and encrustations along the surface of bedding planes and joints in the shale. It is blue within 2 feet normal to the surface of the outcrop, and is white beyond 2 feet. Associated minerals are jarosite, gypsum, and, rarely, iron oxides. Molds of invertebrates, impressions of fish scales(?), and plant remains are found in the shale. Montmorillonite, quartz, illite, and kaolinite are major constitutents of the shale.

Fresh vivianite is white, rapidly changing to blue after exposure to air. Because the white material is not stable under laboratory conditions, only blue material was examined. The specific gravity of vivianite was determined by a pycnometric method using distilled water. Five determinations gave a mean specific gravity of 2.56.

The nodules and encrustations of vivianite are aggregates of fine crystallites. The crystallites are lath-shaped and range from 2 to 4 μ in their longest dimension (Fig. 1). Under the petro-

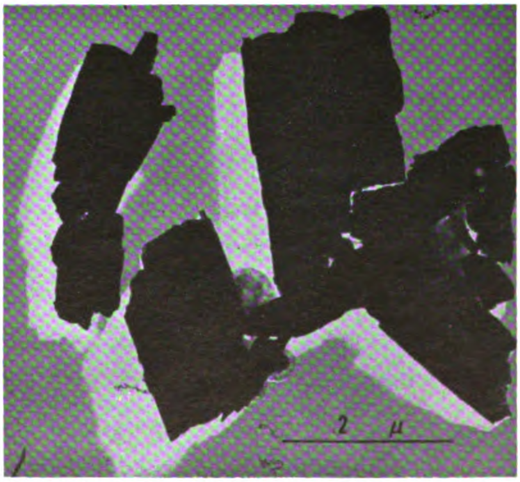

FIGURE 1.—Electron micrograph of vivianite crystallites.

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The infrared spectrum was provided by G. A. McCaskill, of the Kansas State Highway Commission Laboratory. The electron micrograph and the D.T.A. curve were taken by J. M. Huh. The atomic absorption analysis was done by O. K. Galle. E. E. Angino, J. C. Davis, and E. D. Goebel reviewed the manuscript and made helpful suggestions.

graphic microscope in transmitted light, crystallites are light green or colorless and exhibit blue pleochroism.

X-ray diffraction data (Table 1) were obtained at a scanning speed of 0.25° 2θ per minute and chart speed of 0.5-inch per minute. Cu-radiation was used with a diffractometer having a focusing monochromator and proportional counter. The center of the peak at half-height was used for measurement of the reflections.

Vivianite loses weight continuously during heating to 500°C. Less weight is lost between 500°C and 650°C than at 500°C. At 675°C, weight loss reaches a maximum of nearly 24 percent (Fig. 2). At a fixed temperature of 105°C, weight loss is 15.7 percent after the sample has been in the furnace for 28 hours; beyond this time no further weight loss occurs.

The D.T.A. curve (Fig. 3) for vivianite shows endothermic peaks at 190°, 360°, 470°, 570°, and exothermic peaks at 650° and 755°C. Differential thermal data obtained from this study disagree with that available in the literature (Manly, 1950; Pulou, 1955; Lesnyak, Yasinskaya, and Tymchishin, 1961; Anderson, Stringham, and Whelan, 1962; Rao, 1965). Manly (1950) and Kleber, Wilde, and Frenzel (1965) interpreted the first, second, and third endothermic reactions as the loss of five, two, and one waters of crystallization from vivianite. Amplitudes of the endothermic peaks are roughly proportional to water loss (Manly, 1950, p. 112). Information obtained from D.T.A. and weight loss in this study does not demonstrate clearly such relationships. It is likely that loss of water continues after the first strong endothermic reaction occurs. At the same time, oxidation of ferrous iron takes place until completed at 650° to 700°C. The exothermic reaction at 755°C suggests that a phase change is taking place.

The infrared absorption spectrum (Fig. 4) for vivianite has wide bands at 3300 and 1000 cm^{-1}, and medium bands at 1620, 800, and 550 cm^{-1}. The spectrum was obtained with a Perkin-Elmer 521 grating spectrophotometer. A disc containing a mixture of 0.2 gm of KBr and 1 mg of powdered sample was used to obtain the spectrum. It was found that the spectrum for the vivianite from Kansas is similar to that reported by Anderson, Stringham, and Whelan (1962, p. 1307), Omori and Seki (1960, p. 401), and Omori (1961, p. 128; 1964) in the range 550 to 4000 cm^{-1}. No reference was found in the literature for the spectrum between 300 and 550 cm^{-1}.

A quantitative analysis for major constituents was made on the vivianite sample, and a semi-quantitative spectrographic analysis was made for minor constituents (Table 2). Total iron was determined by atomic absorption (Galle, 1968).

The chemical elements necessary for the formation of vivianite and associated minerals are available locally. Iron sulfides (pyrite and marcasite) in the shale decomposed by weathering have formed acidic solutions. These solu-

TABLE 1.—X-ray powder data for vivianite.

Kansas sample		ASTM*		Kansas sample		ASTM*		Kansas sample		ASTM*	
dÅ	I†	dÅ	I†	dÅ	I†	dÅ	I†	dÅ	I†	dÅ	I†
7.97	44	8.00	27	2.533	13			1.781	3	1.78	13
6.758	100	6.80	100	2.528	10	2.52	33	1.768	3		
4.925	44	4.91	40	2.433	15	2.42	40	1.673	9	1.67	40
4.563	7	4.50	13	2.318	9	2.31	27	1.653	6		
4.347	6	4.32	4	2.288	6			1.601	6		
4.073	15	4.09	13	2.229	10	2.23	20	1.591	7	1.59	23
3.858	13	3.84	40	2.188	9	2.19	20	1.585	9		
3.636	6	3.65	5	2.074	10	2.07	23	1.554	6	1.55	7
3.347	4	3.33	3	2.011	4	2.01	8	1.525	6	1.52	11
3.203	22	3.20	53	1.974	6	1.96	8	1.503	4		
2.976	30	2.97	67	1.937	4			1.489	6	1.49	12
2.768	7			1.928	7	1.92	33	1.468	3	1.47	7
2.724	22	2.71	67	1.900	6	1.89	20	1.410	3		
2.698	15			1.887	6			1.331	3		
2.641	13	2.64	8	1.819	3	1.82	11	1.236	3		
2.589	4			1.797	3						

* ASTM X-ray Powder Data File, Inorganic Sets 1-5, p. 558, 3-0070.
† Observed.

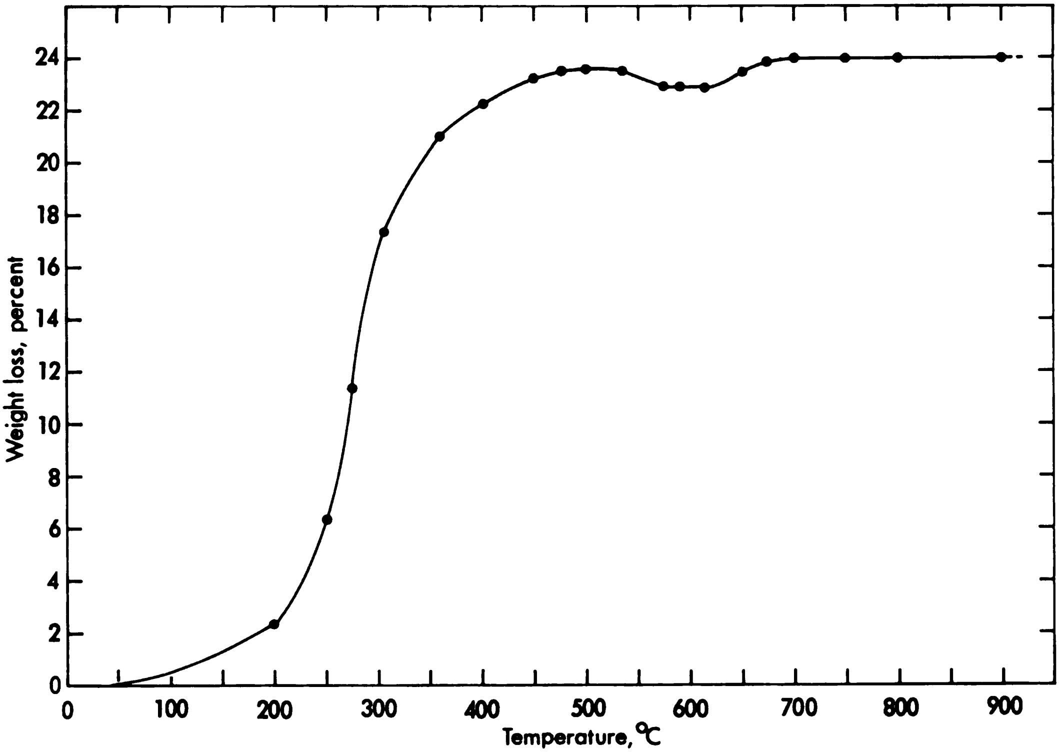

FIGURE 2.—Weight-loss curve for vivianite upon heating.

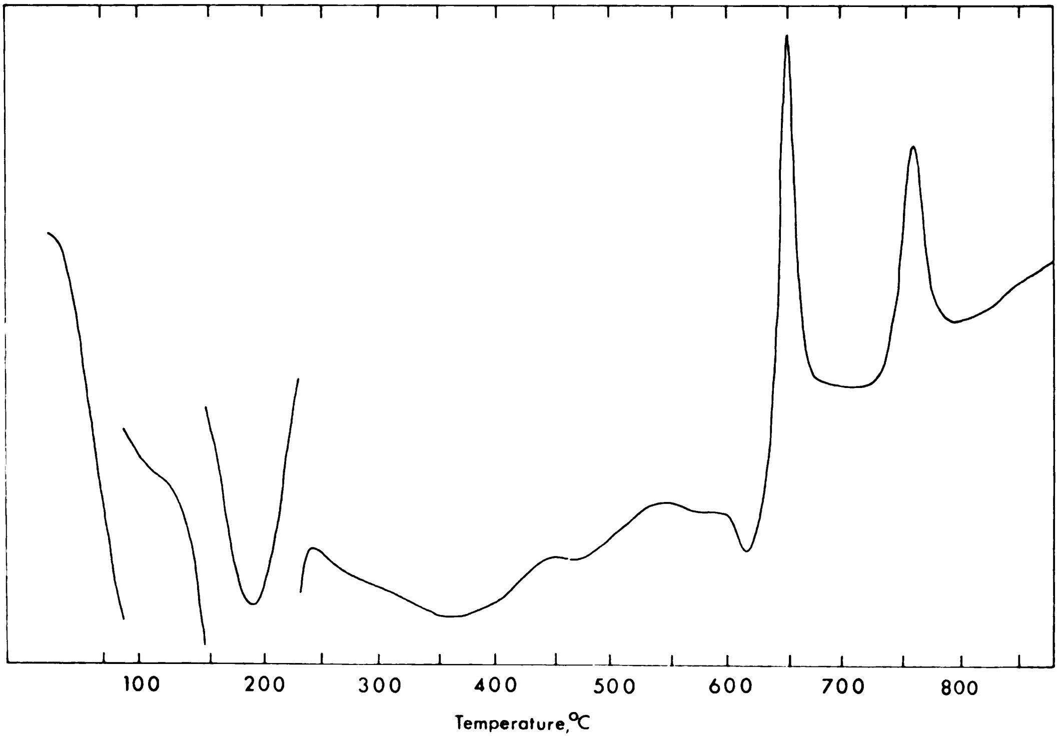

FIGURE 3.—D.T.A. curve for vivianite. Rate of heating 10°/min.; mixture of calcined kaolinite and alumina as reference.

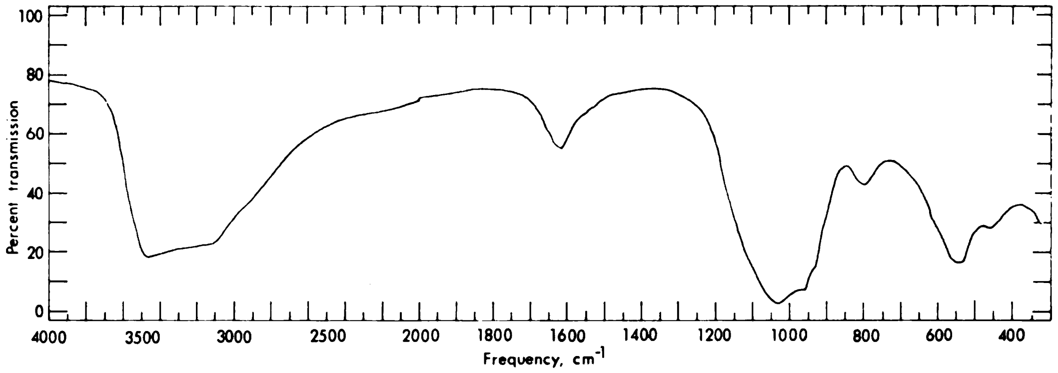

FIGURE 4.—Infrared absorption spectrum for vivianite.

tions have migrated along bedding planes and joints and reacted with fossil remains and clay minerals to form vivianite and associated jarosite and gypsum.

TABLE 2.—Chemical analysis of sample of vivianite from Kansas.

Major constitutents	Oxides, percent		Oxides, recalculated to 100 percent		Oxides, calculated for $Fe_3(PO_4)_2 \cdot 8H_2O$
P_2O_5	28.37		29.07		28.31
FeO	40.51		41.51		42.96
H_2O^-	15.76	28.71	16.15	29.42	28.73
H_2O^+	12.95		13.27		
	97.59		100.00		100.00

Minor cations, percent

Al*	0.1	Mn	0.01
Si	0.5	Na†	0.1
Ca	0.01	K	0.1
Mg	0.1		

HCl insoluble residue 1.28 percent

* Spectrographic.
† Flame.

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FRED E. MILLER

Linear Programming of Osage County Resources: A Preliminary Report

ABSTRACT

The goal of optimal utilization of a region's mineral resources has been widely discussed and has been approached from several points of view. Heretofore, no known application of linear programming to this problem is in existence. This study is an attempt to devise such a model.

Osage County, rich in unexploited mineral reserves, was chosen as an ideal basis for a closed-region linear programming model. The model contains 43 activities which are operated subject to 18 constraints. Optimal solutions can be determined analytically for any desirable objective that is data-possible, such as maximizing the corporate profits within the County.

One of the most important elements of the economic process is the conversion of resources from one form to another. The task of determining which products should be produced with a given set of mineral resources can be quite formidable when one is searching for the "best" solution. For instance, a region producing only five products and using any or all of five raw materials finds that there is a minimum of 25 decision alternatives available to it, assuming that it will produce only one of the products. Should it be decided to produce more than one product in this region, the number of decision alternatives could conceivably become very large. Under certain assumptions, primarily linearity, such problems can be solved by the method of linear programming. A suitable definition of linear programming for our purposes is the maximization or minimization of a linear objective function subject to linear constraints. An example will assist in clarifying the terminology.

Assume that the economic development commission of a region knows that the personal income (P.I.) realized from various activities is \$2.00 per ton for coal mined, \$100.00 per million kilowatt-hours power produced, and \$5.00 per ton of Portland cement produced, these being the only feasible activities of this region. The objective is to maximize personal income and thus a mathematical statement of the objective function is:

$$\text{P.I.} = \$2A + \$100B + \$5C$$

where A, B, and C are the units of coal, electric power, and Portland cement, respectively.

This function as it stands will of course be maximized by producing an infinite number of units of each, but since the raw materials labor, coal, clay, and limestone are limited, there must be some finite solution that satisfies the constraints imposed upon the resources, such that no other solution gives a greater value for the objective function.

Let us examine what is meant by constraints. Each of the activities above competes with the others for the available raw materials coal and labor. The substitutability of these resources in the activities is one of the salient features of linear programming, since it provides us with alternative uses concerning which we must make our decisions. Thus we must make judicious use of our resources by applying them where they will return the greatest personal income.

An additional constraint common to all linear programming problems is that the variables themselves must not be negative. This constraint should appear to be neither arbitrary nor confining since it is difficult to conceive of, say, negative coal.

Finally we should understand the meaning of linearity as it applies to the linear programming problem. We assume that the relationships existing among all of the variables in our problem are linear. It has already been pointed out that the objective function is linear; we must also set up the constraints on the problem as a linear system. This will become evident as the model begins to develop.

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OSAGE COUNTY RESOURCES

Very large reserves of water, coal, clay and shale, limestone, sand and gravel, and sandstone are known to exist in Osage County, as well as probable reserves of marble, yellow ocher, and salt. These eleven commodities with the addition of labor and six intermediate commodities form a model constrained by 18 limited resources in the operation of 43 activities thought to be suitable uses for these resources.

Resources

1.	Labor	(man-hrs)
2.	Water	(gallons)
3.	Coal	(tons)
4.	Clay/shale	(tons)
5.	Sand/gravel	(tons)
6.	Sandstone	(tons)
7.	Marble	(tons)
8.	Yellow ocher	(tons)
9.	Salt	(tons)
10.	Limestone	(tons)
11.	Electric power	(kw-hrs)
12.	Hydrated lime	(tons)
13.	Portland cement	(tons)
14.	Coal ash	(tons)
15.	550 btu gas	(cubic ft)
16.	Alumina	(tons)
17.	HCl	(tons)
18.	Coke	(tons)

Activities[1]

1. Electric power—produced as intermediate (kw-hrs) (1,2,3,11,14)
2. Hydrated lime—produced as intermediate (tons) (1,2,10,11,12,14)
3. Portland cement—produced as intermediate (tons) (1,2,3,4,6,10,11,13,14)
4. Coal—finished product (tons) (1,2,3)
5. Clay/shale—finished product (tons) (1,2,4)
6. Sand/gravel—finished product (tons) (1,2,5)
7. Sandstone—finished product (tons) (1,2,6)
8. Marble—finished product (tons) (1,2,7)
9. Yellow ocher—finished product (tons) (1,2,8)
10. Salt—finished product (tons) (1,2,9)
11. Limestone—finished product (tons) (1,2,10)
12. Coke—finished product (tons) (1,2,3,11,12,15,18)
13. Electric power—finished product (kw-hrs) (1,2,3,14)
14. Hydrated lime—finished product (tons) (1,2,3,10,11,14)
15. Portland cement—finished product (tons) (1,2,3,4,6,10,11,14)
16. Alumina—finished product (tons) (1,2,3,11,17)
17. Alumina—produced as intermediate (tons) (1,2,3,11,16,17)
18. Cinder blocks—finished product (tons) (1,2,11,13,14)
19. Foam concrete—finished product (tons) (1,2,5,11,13)
20. Rock wool—finished product (lbs) (1,2,4,5,10,11,18)
21. Pottery—finished product (tons) (1,2,3,4,11,14)
22. High-grade tile—finished product (tons) (1,2,3,4,11,14)
23. Kiln furniture—finished product (tons) (1,2,3,4,11,14)
24. Terra cotta—finished product (tons) (1,2,3,4,11,14)
25. Fire brick and block—finished product (tons) (1,2,3,4,11,14)
26. Fire-clay mortar—finished product (tons) (1,2,3,4,11,12,14)
27. High-alumina brick—finished product (tons) (1,2,3,4,11,14,16)
28. Glass refractories—finished product (tons) (1,2,3,4,11,14)
29. Zinc retorts/condensers—finished product (tons) (1,2,3,4,11,14)
30. Common brick—finished product (tons) (1,2,3,4,11,14)
31. Face brick—finished product (tons) (1,2,3,4,11,14)
32. Paving brick—finished product (tons) (1,2,3,4,11,14)
33. Drain tile—finished product (tons) (1,2,3,4,11,14)
34. Sewer pipe—finished product (tons) (1,2,3,4,11,14)
35. Terrazzo—finished product (tons) (1,2,5,6,7,10,11)
36. Mineral filler—finished product (tons) (1,2,3,4,11,14)
37. Limestone paving blocks—finished product (tons) (1,2,10,11)
38. Refractory stone—finished product (tons) (1,2,3,10,11,14)
39. Flagging/curbing—finished product (tons) (1,2,10,11)
40. Sandstone paving blocks—finished product (tons) (1,2,6,11)
41. Monumental stone—finished product (tons) (1,2,7,11)

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[1] The numbers in parentheses indicate the resources used in the activities as numbered earlier.

42. Ornamental stone—finished product (tons) (1,2,7,11)
43. Hydrochloric acid—produced as intermediate (tons) (1,2,3,9,11,14,17)

Immediately evident is that all resources and activities are measured in physical units and thus our model is dependent only on current technology in the industries and not on inflatable values.

THE OSAGE COUNTY MODEL

Let $X_1, \ldots, X_{43}$ represent the operating levels of the activities described above and add $X_{44}, \ldots, X_{61}$ to represent disposal activities of the limited resources that do not become fully utilized.[2] Let $R_1, \ldots, R_{61}$ represent the amount of personal income (or tax revenue, corporate profit, etc.) resulting from the operation of $X_1, \ldots, X_{61}$ at the level of one unit.[3] We now can write our objective function:

$$\text{Objective} = R_1X_1 + \ldots + R_{61}X_{61}$$

The goal is now to maximize this function subject to constraints as shown:

$$\begin{array}{ccc} a_{11}X_1 + \ldots + & a_{1,61}X_{61} & = C_1 \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ a_{18,1}X_1 + \ldots + & a_{18,61}X_{61} & = C_{18} \end{array}$$

$C_1, \ldots, C_{18}$ represent the negatives of the limitations on each of the resources and are expressed in terms of man-hours, tons, etc., per year.[4] Physically, the limitations are the maximum availability of these resources annually. The primary limitations here are capital investment and the availability of markets for the products. Thus the limitations must be forecast or estimated by such methods as are available.

The matrix a_{ij} represents the production coefficients which are of three types:

a. Input coefficient—a_{11} is an example of an input coefficient and specifically represents the man hours of labor required to produce one ton of coal. All input coefficients, by convention, are negative and thus the reason for $C_1, \ldots, C_{18}$ being negative.
b. Output coefficient—$a_{14,1}$ is an example of an output coefficient, representing the tons of coal ash produced per kilowatt-hour of electric power produced from coal. Again by convention, all output coefficients are positive.
c. Zero coefficient—$a_{4,1}$ is an example of a zero coefficient representing the tons of clay required in the production of electric power—obviously zero.

An awareness of the assumptions and drawbacks of a linear programming formulation must be maintained if its results are to be meaningful and valid.

Discussed above is the assumption of linearity. The primary factors included in linearity are the absence of fixed costs and the neglect of efficiency or inefficiency due to size. However, within a limited range of production, the errors involved are slight.

Transportation effects have been eliminated in one of two ways—either the commodity is used entirely within the region or it is marketed to outsiders f.o.b. mine or factory. Obviously the market must be forecasted correctly for our model to produce meaningful results.

The usefulness of this linear programming model has been touched on earlier with respect to optimizing the use of limited mineral resources. With a simple change of the coefficients in the objective function it is possible to maximize personal income, tax revenue, corporate profits, gross revenue, or any other desirable function that is data-feasible. The production coefficient matrix is not affected by changing the objective function, thus the model is quite versatile. Other manipulations can be made by varying the limiting constraints to reflect market considerations or capital investment limitations.

It is hoped that eventually a similar model will be constructed for the entire State of Kansas, resulting in the development of the relatively untouched resources of Kansas by private industry.

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[2] The addition of $X_{44}, \ldots, X_{61}$ (called slack variables) is necessary to provide an equality condition in each of the 18 constraints on the model.

[3] Obviously $R_{44}, \ldots, R_{61}$ are all zero since a disposal activity adds nothing to the region.

[4] The reason for $C_1, \ldots, C_{18}$ being negative is purely computational and not of real importance to the study. It should also be noted that the restraint on each intermediate commodity is zero since the amount produced is equal to the amount consumed.

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Reference Section for Lincoln Limestone Member, Greenhorn Limestone (Upper Cretaceous), Lincoln County, Kansas

ABSTRACT

The lowest part of the Greenhorn Limestone received a geographic name more than a quarter of a century before the remaining part of the unit was formally subdivided. First referred to as the "Lincoln Marble" (Logan, 1897), the unit was later renamed "Lincoln Limestone Member" by Rubey and Bass (1925). Because no type section for the Lincoln Limestone Member was designated by early workers, the author has designated as a reference section the exposure in SE SE sec. 31, T 12 S, R 10 W, Lincoln County, Kansas. The stratigraphic section is described and illustrated.

The Lincoln Limestone Member (Cenomanian) of the Greenhorn Limestone (Upper Cretaceous) is the oldest formally named member of the formation. Originally known as the "Lincoln Marble" (Logan, 1897), the member has been known in more recent years as the "Lincoln Limestone Member" (Rubey and Bass, 1925, p. 27). The Member is recognized across the entire outcrop of central and western Kansas and enjoys formal status also in New Mexico and Colorado. The Member extends also into Cimarron County, Oklahoma, where it is poorly exposed in an outlier of the Colorado Group near the former town of Mineral (Kauffman, Powell, Hattin, manuscript). Logan did not designate a type section for the Lincoln and he failed to indicate whether the name is derived from the city of Lincoln or from Lincoln County. The base of the member is poorly exposed on the east side of Kansas Highway 14 about 1 mile north of Lincoln, but I know of no completely exposed section in the vicinity of that city. Parts of the Member are well exposed in cuts on Highway 14 in northern Lincoln County and also north of Sylvan Grove, Lincoln County, on Kansas Highway 18. Partial sections of the Lincoln are exposed at a number of additional localities in Lincoln County, in road cuts and gullies, and I have measured a complete, but poorly exposed, section on Interstate Highway 70 in S½ sec. 36, T 13 S, R 7 W, Lincoln County. However, the only complete, extensively exposed, fresh exposure in Lincoln County known to me is in a road cut on an east-west county road, approximately 1.5 miles east of the Wilson Dam and located in SE SE sec. 31, T 12 S, R 10 W and in NE NE sec. 6, T 13 S, R 10 W. The cut was made when road improvements were undertaken during construction of Wilson Dam. The cut is approximately 100 yards long and the faces are relatively steep. It is likely that the Lincoln will remain well exposed here for many years, and probable that the cut will be regraded from time to time because of the heavy flow of reservoir-bound traffic. Because of the general desirability of having a reference section for any stratigraphic unit, and especially one where the unit is well exposed, of characteristic lithologic development, and of typical thickness, I am designating the exposure on the north side of this cut as the reference section for the Lincoln Limestone Member of the Greenhorn Limestone. Description of this section is presented herein because this material will not be included in a forthcoming publication on the Greenhorn Limestone (Hattin, in preparation).

In the Kansas outcrop the Lincoln Limestone Member ranges in thickness from 16.2 feet (western Kearny County) to 32.4 feet (southeastern Mitchell County), averaging 23.1 feet for eleven measurements including two that are composites. At the reference section the thick-

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ness is 24.1 feet. Through much of central Kansas the base of the Member lies at a widespread disconformity (Hattin, 1968) that separates mostly noncalcareous or only weakly calcareous shales in the upper part of the Graneros Shale from basal Greenhorn skeletal limestones that are overlain by shaly chalk or chalky shale and other carbonate rocks. In westernmost Kansas and in the northern part of central Kansas the contact is gradational and, in a section that grades upward from noncalcareous shales to calcareous strata, is placed at the base of the first bed or zone of abundant lenses of skeletal limestones, or bed of chalky limestone, above which the section consists predominantly of shaly chalk and skeletal limestone. The upper contact is located at the top of the uppermost bed, group of beds, or zone of abundant lenses of skeletal limestones above which the section is largely devoid of such rock. In most of central Kansas this contact lies from 0.91 to 11.68 feet below a prominent, widespread marker bed that contains the *Sciponoceras gracile* assemblage of invertebrate fossils and that characteristically shatters readily upon weathering. In general, the interval increases in thickness from northeast to southwest. In the southwestern part of the central Kansas outcrop and along the Arkansas River (in Kearny and Hamilton counties) the contact is located much lower in the section, owing to the lateral gradation of the upper part of the Lincoln into a predominantly shaly chalk section having characteristics typical of the Hartland Shale Member.

As thus defined the Lincoln Limestone Member consists principally of shaly chalk through which are scattered abundant lenses and mostly irregular thin beds of calcite-cemented skeletal limestones, including rare calcilutites, calcarenites, and calcirudites, as well as numerous seams of bentonite and a few thin, commonly discontinuous, beds of chalky limestone. In the northern part of central Kansas the lower part of the Lincoln contains some calcareous shale and chalky shale, especially in Mitchell, Cloud, and Washington counties. Molds of ammonites, especially including species of *Calycoceras, Dunveganoceras?, Borissiakoceras,* and *Stomohamites,* have been collected at many Lincoln localities, but the most abundant and characteristic fossil is an early form (*fide* E. G. Kauffman) of *Inoceramus pictus* J. de C. Sowerby. *Ostrea beloiti* Logan and *Exogyra columbella* Meek occur locally in the basal part of the member. An undescribed species of *Exogyra* is abundant in the lower part of the Lincoln at most central Kansas localities, and this species occurs in the middle and/or upper parts of the Member in Hodgeman, Ford, and Kearny counties.

At the newly designated reference section lithologic and stratigraphic character of the Lincoln is typical for the Member as developed in Lincoln County, as well as for nearby counties to the south and west (i.e., Russell, Ellsworth, and Ellis counties), with the exception that the lowermost few feet contains some calcareous and chalky shale. North and northeast of Lincoln County, such rocks are common in the lower part of the Lincoln. The upper and lower contacts are typical of sections exposed in or directly adjacent to Lincoln County. Although the reference section contains few ammonites, the rest of the fauna is typical of the Lincoln of central Kansas. The reference section is illustrated in Figure 1 and described in detail below.

In the description colors are based on the National Research Council Color Chart (Goddard, 1948) and code designations are given only for those names having more than one color or that are not actually included in the chart. Skeletal limestones are wholly cemented by sparry calcite unless otherwise noted. Although many units are measured to the nearest hundredth of a foot, the thickness totals are rounded to the nearest one-tenth foot.

Greenhorn Limestone

HARTLAND SHALE MEMBER

		Thickness, Feet
42.	Chalky limestone, relatively hard, shatters upon exposure, burrow-mottled. This is the lowest widespread chalky limestone marker bed in the Greenhorn of Kansas	0.6
41.	Shaly chalk, olive-gray (5Y 4/1) to dark olive-gray (5Y 3/1), thinly laminated, calcareous, silty, speckled, weathers chippy; 0.02-foot thick lensing layer of foraminiferal and *Inoceramus*-fragment skeletal limestone, grayish-orange, hard, brittle, petroliferous, lies 0.52 foot above base; 0.15-foot thick bed of soft, crumbly, burrow-mottled chalk lies 0.55 foot below top	3.5
40.	Bentonite, yellowish-gray (5Y 8/1), much stained by limonite, sparsely speckled by minute dark-colored mineral grains, very slightly silty	0.21
39.	Shaly chalk, dark olive-gray (5Y 3/1), thinly laminated, calcareous, silty, speckled, weathers chippy; bentonite, yellowish-gray (5Y 8/1), 0.01-foot thick, lies 0.32 foot above base. FOSSILS: *Inoceramus* fragments, fish scales	0.89
	Thickness of measured part of Hartland Shale Member	5.2

LINCOLN LIMESTONE MEMBER

38.	Shaly chalk and skeletal limestone; shaly chalk as in unit 39; skeletal limestone, light olive-gray (5Y 6/1) to very pale orange, hard	

Thickness, Feet

to very hard, mostly brittle, mainly foraminiferal, harder lenses also contain *Inoceramus* fragments and sparse fish scales and bones, lenses very small in lower 0.5 foot, larger and more abundant in upper 0.15 foot. FOSSILS: ***Inoceramus pictus, Inoceramus*** fragments, fish scales and bones 0.71

37\. Bentonite, very pale orange to nearly white, locally olive-gray (5Y 4/1), much stained by limonite 0.25

36\. Shaly chalk, olive-gray (5Y 3/2), as in unit 39, with much powdery gypsum along joints and bedding fractures; unit contains moderately abundant very thin to extremely thin lenses of hard, brittle, skeletal limestone, light olive-gray (5Y 5/2) to pale grayish-orange (10YR 8/4), mainly foraminiferal, some with *Inoceramus* fragments. FOSSILS: ***Inoceramus pictus, Inoceramus*** fragments 1.25

35\. Shaly chalk and skeletal limestone; shaly chalk dark olive-gray (5Y 3/1), as in unit 39, weathers flaky, many fine-grained crystals of selenite along joints and bedding fractures; skeletal limestone, light olive-gray (5Y 6/1, 5Y 5/2), dark yellowish-brown, or pale grayish-orange (10YR 8/4), somewhat chalky to wholly spar-cemented, ranges from very thin streaks consisting mainly of foraminifera to small irregular lenses consisting mainly of foraminifera and/or *Inoceramus* prisms and fragments; large lens 0.35 foot above base is 0.24-foot thick and 1.5 feet wide and consists of very hard *Inoceramus*-prism limestone that contains abundant bone fragments and scattered *Inoceramus* fragments; many limestone lenses have burrow and fecal casts on soles, largest lens is load casted; most of limestone has petroliferous odor. FOSSILS: ***Inoceramus pictus, Inoceramus*** fragments, fish scales and bones, coprolites 3.6

34\. Chalky limestone, medium olive-gray (5Y 4/2), very fine-grained, in part crystalline, soft, somewhat crumbly, weakly resistant; FOSSILS: ***Inoceramus pictus, Inoceramus*** fragments 0.16

33\. Bentonite, light olive-gray (5Y 5/2), silty, biotitic, stained by limonite 0.03

32\. Shaly chalk, dark olive-gray (5Y 2/2, 5Y 3/1), as in unit 39, contains widely scattered very thin, small, mostly irregular lenses of hard, brittle, petroliferous skeletal limestone that is grayish-orange to pale grayish-orange (10YR 8/4) and consists chiefly of *Inoceramus* prisms. FOSSILS: ***Inoceramus pictus, Inoceramus*** fragments, fish bones 2.6

31\. Bentonite, pinkish-gray to very light-gray, very slightly silty, very sparsely speckled by minute dark-colored mineral grains, much stained by limonite, locally wedges out beneath lens of soft, very fine-grained, granular chalk that is very light-gray 0.06

30\. Shaly chalk, dark olive-gray (5Y 3/1), as in unit 39, only slightly calcareous silty 0.12

29\. Bentonite, very pale orange, very slightly silty, very sparsely speckled by minute dark-colored mineral grains, contains small sele-

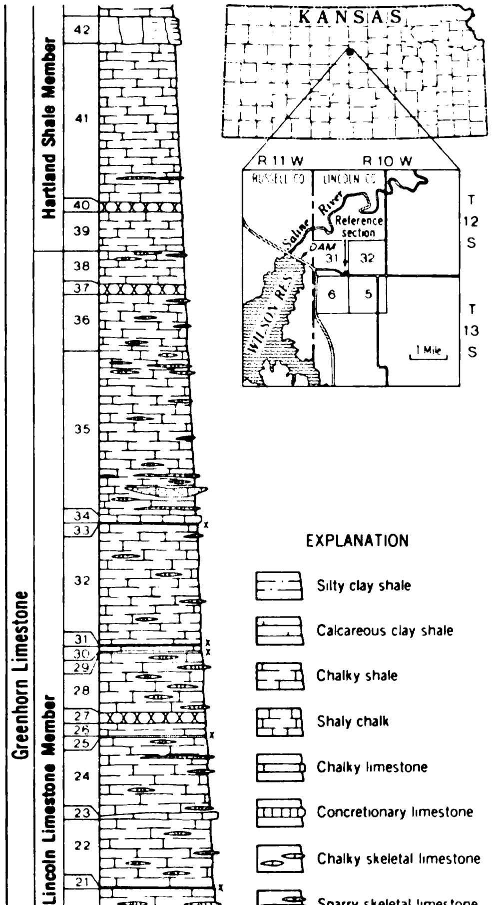

FIGURE 1.—Graphic representation of reference section of the Lincoln Limestone Member of the Greenhorn Limestone.

		Thickness, Feet
	nite crystals in parts that are much stained by limonite	0.05
28.	Shaly chalk and skeletal limestone; shaly chalk, dark olive-gray (5Y 3/1) as in unit 39, much powdery gypsum along bedding fractures of partly weathered rock; skeletal limestone, pale grayish-orange, hard, brittle, as numerous very thin and mostly very small lenses, consists of foraminiferal and/or *Inoceramus* prisms and fragments; lenses most abundant in lower 0.9 foot. FOSSILS: *Inoceramus pictus, Inoceramus* fragments, fish scales and bones	1.3
27.	Bentonite, nearly white, slightly silty, very sparsely speckled by minute dark-colored mineral grains, stained by limonite and jarosite	0.23
26.	Shaly chalk, dark olive-gray (5Y 3/1), thinly laminated, speckled, slightly calcareous silty, with much fine granular gypsum along bedding fractures. FOSSILS: *Inoceramus pictus, Inoceramus* fragments, fish scales and bones	0.27
25.	Bentonite, nearly white, sparsely speckled by minute dark-colored mineral grains, much stained by limonite, many slender selenite crystals in limonitic part	0.04
24.	Shaly chalk and skeletal limestone; shaly chalk, olive-black, as in unit 26, with much powdery gypsum along bedding fractures; skeletal limestone, consisting largely of shell fragments, pale grayish-orange, very thin beds and irregular very thin lenses, petroliferous odor; unit also contains very thin, small even lenses of pale yellowish-brown calcisiltite; all limestone is hard, brittle. FOSSILS: *Inoceramus pictus, Inoceramus* fragments, coprolites	1.65
23.	Chalky limestone, discontinuous bed, olive-gray (5Y 3/2), very fine-grained, gritty, speckled, contains very thin lenses of olive-gray (5Y 4/1) foraminiferal limestone and local, irregular-shaped, flattened nodules of marcasite	0.0-0.17
22.	Shaly chalk, dark olive-gray (5Y 3/1) to olive-black, as in unit 39, contains scattered fragments of *Inoceramus* and very thin lenses of skeletal limestone consisting of imbricated *Inoceramus* fragments and very thin lenses of pale yellowish-brown bone-fragment-bearing *Inoceramus*-prism limestone that contains sparse foraminifers	1.5
21.	Bentonite, nearly white, very slightly silty, limonite stained, contains sparse, minute, dark-colored mineral grains	0.02
20.	Shaly chalk, dark olive-gray (5Y 3/1), as in unit 39, contains scattered very thin, small lenses of partially spar-cemented olive-gray (5Y 4/1), chalky limestone and pale grayish-orange skeletal limestone consisting of *Inoceramus* prisms and fragments and fish bone fragments. FOSSILS: *Inoceramus pictus, Inoceramus* fragments, fish scales and bones	1.65
19.	Bentonite, yellowish-gray (5Y 7/2), silty, biotitic, much stained by limonite	0.25
18.	Shaly chalk, dark olive-gray (5Y 3/1), as in unit 39, slightly calcareous, silty. FOSSILS: *Inoceramus pictus, Inoceramus* fragments, fish scales	1.70
17.	Bentonite, discontinuous bed, nearly white, silty, sparse minute dark-colored mineral grains and selenite crystals, much stained by limonite	0.0-0.35
16.	Chalky limestone, medium-gray, medium dark-gray, and light olive-gray (5Y 6/1), very fine-grained, speckled, tough, weakly resistant, gritty	0.24
15.	Shaly chalk, chalky limestone, and skeletal limestone, dark olive-gray (5Y 3/1), very slightly calcareous, silty, with abundant *Inoceramus* both whole and as fragments; skeletal limestone, pale grayish-orange to very pale orange, abundant lenses in upper half of unit consisting of *Inoceramus* prisms and fragments with fish bone fragments in some lenses; lower half of unit contains some skeletal limestone lenses and many very thin lensing beds and small lenses of relatively hard, olive-gray (5Y 4/1) to light olive-gray (5Y 5/2) chalky limestone that contains *Inoceramus* shell fragments and fish bones. FOSSILS: *Inoceramus pictus, Inoceramus* fragments, fish bones and scales	1.75
14.	Skeletal limestone, olive-gray (5Y 4/1), hard, brittle, resistant, thin to very thin irregularly bedded, composed chiefly of *Inoceramus* prisms with locally abundant fish bones, all spar cemented, unit thins laterally where it is split by shaly chalk partings. FOSSILS: *Inoceramus pictus, Inoceramus* fragments, ammonite mold fragment, fish scales and bones	0.65-0.7
13.	Bentonitic shaly chalk, olive-black, calcareous, silty	0.05
12.	Bentonite, light bluish-gray, slightly silty, biotitic, jarosite- and limonite-stained	0.15
11.	Skeletal limestone, olive-gray (5Y 4/1), thin to very thin irregularly bedded, with very thin shaly chalk partings, consisting mainly of *Inoceramus* prisms with some *Inoceramus* fragments, fish bones, coprolites, small white fecal? pellets, clay galls, and clay-gall molds, and bentonite pebbles. FOSSILS: *Inoceramus pictus,* mold fragment of large acanthoceratid ammonite, sharks' teeth, fish bones and scales, coprolites	0.2
10.	Chalky shale, olive-black, thinly laminated, speckled, weathers flaky, with much finely crystalline selenite on bedding fractures; basal 0.12 foot contains very thin lensing beds of skeletal limestone consisting mostly of *Inoceramus* prisms and small bone fragments	0.75
9.	Calcareous sand, olive-gray (5Y 4/1) weathering grayish-orange to dark yellowish-orange, unconsolidated, consisting of foraminifera and *Inoceramus* prisms	0.18
8.	Shaly chalk and chalky shale, olive-black, thinly laminated, calcareous, silty, speckled, weathers flaky, with much finely crystalline gypsum along bedding fractures	0.15
7.	Skeletal limestone, olive-gray (5Y 4/1), thin- to very thin-bedded, upper part thinly laminated to gently cross laminated, lower part consists of one or two irregular, lensing beds that are separated from upper part by 0.04	

Thickness, Feet

foot of olive-black shaly chalk. FOSSILS: Fish scales and bone fragments, coprolites .. 0.25

6. Chalky shale and calcareous shale, dark olive-gray, thinly laminated, slightly speckled, weathers flaky, with very thin even lenses of pale yellowish-brown skeletal limestone consisting of foraminifers and *Inoceramus* prisms lying 0.6 foot below top 0.9
5. Limestone, discontinuous, very light olive-gray (5Y 7/1), weathers to nearly white spheroidal masses, very fine-grained, crystalline, breaks blocky, apparently a concretion. FOSSILS: *Borissiakoceras*? sp. 0.0-0.35
4. Bentonite, bluish-gray weathering yellowish-gray (5Y 8/1), slightly silty, limonite- and jarosite-stained along joints, especially in upper part 0.25
3. Skeletal limestone, olive-gray (5Y 4/1) weathers pale yellowish-brown, one bed that locally splits into three beds, irregularly jointed, hard, brittle, consists chiefly of *Inoceramus* prisms and shell fragments and fish scales and bone fragments, sparsely glauconitic, basal part consists of oyster biostrome. FOSSILS: *Ostrea beloiti*, *Inoceramus* sp., *Inoceramus* fragments, fish scales and bones 0.23-0.28

Total thickness of Lincoln Limestone Member 24.06

GRANEROS SHALE

2. Shale, dark olive-gray (5Y 3/1), thinly laminated, weathers flaky, weakly calcareous to non-calcareous, moderately silty, very small selenite crystals throughout; unit contains very thin lens of dark yellowish-brown (10YR 4/2) skeletal limestone lying 0.45 foot below top consisting of *Inoceramus* and *Ostrea* fragments. FOSSILS: *Ostrea beloiti*, *Inoceramus* fragments 1.0
1. Bentonite, very light olive-gray (5Y 7/1) to pale greenish-yellow, biotitic, stained with jarosite and limonite, tastes of melanterite; this unit is the bentonite marker bed ("X" bentonite of authors) that lies near the top of the Graneros Shale throughout most of central Kansas 1.2

Measured thickness of Graneros Shale 2.2

Total thickness of measured section 31.5

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