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OKLAHOMA GEOLOGY NOTES

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Cover Picture[1]

INTRUSION BRECCIA, WICHITA MOUNTAINS

This photograph shows a sharply contrasted intrusion breccia in a quarry at Cold Springs in the Wichita Mountains, SW¼ sec. 21, T. 4 N., R. 17 W., Kiowa County, southwestern Oklahoma. Here, light-colored aplite has intruded dark microdiorite with minimal assimilation, giving the center of the rock an appearance of boulders set in place by mortar. Elsewhere in the quarry, assimilative effects have evidently been extensive, with the rock grading compositionally from tonalite to adamellite.

This rock has been quarried here by the so-called Cold Springs Granite Co. The site is the ninth stop of a February 28 and 29 field trip studying the plutonic igneous rocks of the Wichita Mountains, held in conjunction with the South-Central Section meeting of The Geological Society of America in Houston.

The photograph and description are taken from the field-trip guidebook, *Plutonic Igneous Geology of the Wichita Magmatic Province, Oklahoma,* by Benjamin N. Powell, Rice University, and Joseph F. Fischer, The University of Texas at Arlington, with contributions by David W. Phelps, Rice University, and Martin A. Pruatt, Shell Development Co. The book was published by the Oklahoma Geological Survey in cooperation with GSA and can be ordered from the Survey for $5.00 a copy by writing to the address on the front cover.

(Photograph by Joseph F. Fischer)

[1]See page 43 for information about bicentennial cover on *Oklahoma Geology Notes.*

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Oklahoma Geology Notes is published bimonthly by the Oklahoma Geological Survey. It contains short technical articles, mineral-industry and petroleum news and statistics, an annual bibliography of Oklahoma geology, reviews, and announcements of general pertinence to Oklahoma geology. Single copies, seventy-five cents; yearly subscription, $3.00. All subscription orders should be sent to the address on the front cover.

Short articles on aspects of Oklahoma geology are welcome from contributors. A set of guidelines will be forwarded on request.

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Generation of Explicit Parameters for a Quantitative Geomorphic Study of the Mill Creek Drainage Basin

P. Jan Cannon[1]

Abstract—A quantitative geomorphic investigaton of the Mill Creek drainage basin, south-central Oklahoma, resulted in the formulation of consistent definitions for several terms and parameters. The stream segments of the entire Mill Creek drainage net were numbered, using the Strahler stream-ordering system. The net contains 8,799 first-order streams, 1,987 second-order streams, 451 third-order streams, 90 fourth-order streams, 18 fifth-order streams, 3 sixth-order streams, and 1 seventh-order stream. A reliable method for determining the main channel of a drainage basin was then devised (using the Strahler system as a starting point); it consists of calculating the cumulative length of the highest order stream segment plus the longest of the connecting segments of the next-lower order at the junction where the higher order segment begins, and continuing down through the first order.

In order to determine if this definition of a main channel produces a representative main channelway, the Mill Creek drainage basin was partitioned into 62 component basins that constitute approximately 84 percent of the total area of Mill Creek. The main channel was determined for each basin. In 56 of the 62 component basins, the main channel was found to correspond to the longest channelway in the basin. In 5 of the 6 remaining basins, the difference between the length of the longest channelway and the length of the main channel was less than 5 percent.

A drainage-basin hierarchy was devised in order to provide an absolute ranking for component basins of a major basin. The hierarchy proposed herein provides for a division of a major basin (the largest basin under investigation) into component basins (basins that empty into the main channel of the major basin) and subbasins (basins that do not empty into the main channel of the major basin), which are further divided into superior or inferior component basins (depending on whether the component basin's drainage divide is, superior, or is not, inferior, a part of the major basin's drainage divide) or superior and inferior subbasins (determined by whether or not the subbasin's drainage divide is, superior, or is not, inferior, a part of a component basin's drainage divide).

Three suggestions were offered for explicit divisors to be used in calculating elongation ratios: the length of the main channel, the basin chord, and the cumulative total of mean stream lengths for a basin. These same three values plus a fourth, the diameter of a circle having the same area as the basin, were suggested for calculating relief ratios. One of the explicitly generated divisors, the cumulative total of mean stream lengths, offers promise as a value that can closely relate the elongation and relief ratios to the entire drainage net of a basin.

Use of strictly defined divisors in calculating elongation ratios and relief ratios and precise definitions of terms such as main channel, major basin, component basin, and subbasin will help remove ambiguities from drainage-basin analyses and provide a standard for communication among investigators.

INTRODUCTION

The Mill Creek drainage basin encompasses an area of 249.9 square kilometres (96 mi^2) in the eastern Arbuckle Mountains, south-central

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Oklahoma (table 1). A detailed quantitative geomorphic investigation of the Mill Creek drainage basin was undertaken to provide a basis for the evaluation of various types of remote-sensing data (Cannon, 1973a). The investigation indicated that there was a need for more explicit parameters in certain aspects of quantitative geomorphology and that there existed no relative drainage-basin hierarchy to aid in communicating the results of geomorphic studies to other investigators.

The purpose of this report is to propose a possible drainage-basin hierarchy and to present some ideas on the selection and definition of the main channel, elongation ratios, and relief ratios. These strictly defined terms and parameters provide guidelines that should be considered whenever quantitative geomorphic data are being collected for use in drainage-basin analyses. The techniques of automatic data processing require rigorous definitions of data sources if they are to be utilized to their greatest potential. The collection of explicitly defined data may be considerably more time consuming than the collection of general data. However, this extra amount of time can be counteracted, possibly, by the speed of automatic data processing. If the results of such processing are better suited for practical applications, the amount of time involved can be of minor importance.

The Mill Creek region is subhumid, receiving approximately 89.0 centimetres of precipitation annually. The topography consists of low, rolling hills; broad, grass-covered divides; and tree-lined creeks. The total relief of the entire drainage basin is 210.0 metres.

A drainage net was made of the Mill Creek basin on a base of 1:24,000-scale topographic maps. Unfortunately, this drainage net is too large to be reduced and presented with this paper. Field work and aerial photographs aided in establishing an accurate network of channels. Field observations indicated that the length of a first-order stream was dependent upon the intensity of a particular rain shower; the heavier the shower, the closer to the drainage divide sheet flow would collect in sufficient quantities to start channel flow (sheet flow, as used here, means overland flow; see Horton, 1945, p. 284). The headward portions of first-order streams in the basin are gentle swales that extend from the drainage divide to a definite channel. First-order streams in the drainage net were extended to points near the drainage divide, where, under moderate rain-shower conditions, sheet flow would begin to collect as definite channel flow. Extending channelways to the drainage divide in areas of low relief, like the Mill Creek region, does not provide a realistic presentation of the processes that are operative within the basin. Sheet flow is a major process along drainage divides, and its extent away from the divides can be considerable.

It is pertinent to point out that the length of a first-order stream is not explicit, and it will vary depending on ground conditions prior to a particular rain shower as well as on the intensity of rainfall. The effects of the variability of the length of first-order stream segments will be minimized in the calculations discussed later in this report. The major importance of the first-order stream segments is that the junction at which any two run to-

TABLE 1.—QUANTITATIVE DATA FOR MILL CREEK DRAINAGE BASIN

Area	249.9 km^2
Relief	210.0 m
Total length of all stream segments	2,285,847.5 m
Length of main channel	64,712.2 m
Length of basin chord	42,368.6 m
Cumulative total of mean stream lengths	49,440.6 m
Drainage density	9.15 km/km^2

Elongation Ratios	Relief Ratios
E1 - - -0.276	R1- - -0.0032
E2 - - - .421	R2 - - - .0049
E3 - - - .361	R3 - - - .0042
	R4 - - - .0118

STREAM ORDER	NUMBER OF STREAMS	TOTAL STREAM LENGTH (METRES)	MEAN STREAM LENGTHS (METRES)
1	8,799	1,378,353.7	156.7
2	1,987	451,158.5	227.1
3	451	227,134.1	503.6
4	90	124,615.9	1,384.6
5	18	37,207.3	2,067.1
6	3	33,414.6	11,138.2
7	1	33,963.4	33,963.4

gether explicitly defines the starting point of a second-order stream segment. From the beginning of the second-order stream segment through the higher order stream segments, the length of each segment is explicitly defined by using the stream-ordering system suggested by A. N. Strahler (1957, p. 914).

The stream segments of the entire Mill Creek drainage net were numbered, using the Strahler system (table 1). The drainage net contains 8,799 first-order stream segments. The combined length of these first-order streams (1,378.4 km) represents over 60 percent of the total length of all stream segments in the drainage basin. The highest order for a stream segment in the Mill Creek basin is the seventh.

MAIN CHANNEL

It is necessary, in performing certain quantitative geomorphic analyses of drainage nets, to delineate a specific main channel. The runoff from a drainage basin leaves that basin via a single channel, and this exit from the drainage basin is the mouth of the main channel of the basin. The only usable guideline that had been suggested in the literature to determine, unquestionably, the course of the main channel from the mouth to the head is the identification of the longest channelway from the mouth to the drainage divide (Hack, 1957, p. 47). Horton (1945, p. 281-282) provided a systematic approach to the problem, based in part on stream angles, but his definition of main channel is complex and unusable.

The major problem with using the longest channelway as the main channel is that locating it in a drainage net can be something like trying to find a path through a maze. It can require measuring the lengths of large numbers of stream segments all the way to the drainage divide and selectively comparing their lengths. However, an explicitly defined main channel can be systematically determined from the mouth to the head in any drainage basin by utilizing the Strahler ordering system. Therefore, the main channel of a drainage basin as defined in this paper consists of the cumulative length of the highest order stream segment plus the longest of the connecting segments of the next-lower order at the junction where the higher order segment begins, and continuing down through the first order. This means that the main channel in the Mill Creek drainage basin consists of the cumulative length of the seventh-order segment, plus the length of the longest of the sixth-order segments that branch off from where the seventh-order segment begins, plus the length of the longest fifth-order segment that branches off from where the previously mentioned sixth-order segment begins, plus the lengths of the succeeding similarly determined next-lower stream segments down through the first-order segment.

This is an explicitly defined channel, but is it a realistic main channel? What are its shortcomings? In a hypothetical homogeneous basin, having an even distribution of the length and number of stream segments, this channel would be the best representation of a main channel, and it would also be the longest channelway in the basin. However, in nature, drainage basins are not entirely homogeneous, and the perturbations inflicted by the inhomogeneities produce a great range of probabilities. Therefore, it seems possible that there could exist in nature a situation in which a main channel, as determined by this method, would be extremely unrepresentative by being too short. This situation would occur in a basin where a small portion of the basin exhibited an anomalously high drainage density. Anomalously high drainage density of a portion of a basin occurs only where there is a strong structural or lithological influence to cause it (Miller, 1961, p. 97). In such a situation, any type of drainage-basin analysis would be spurious because of the uniqueness of the basin.

In order to test this definition of a main channel in nature, the Mill Creek drainage basin was partitioned into 62 selected component basins, which constitute approximately 84 percent of the total area of Mill Creek. The main channel was determined for each basin by the stated method. In 56 of the 62 component basins, the main channel determined by this method corresponded to the longest channelway in the basin. The remaining six basins, which had main channels that were shorter than their longest channelway, are small component basins. In 5 of these 6 basins, the difference between the length of the longest channelway and the length of the main channel as defined is less than 5 percent, and it is important to note that the difference is usually in the length of a first- or second-order segment. The other basin's longest channelway is 20 percent longer than the main channel. This basin, Stereo Creek, exhibits extreme drainage anomalies, owing to the nature of the bedrock and local structure (Cannon, 1973b, p. 21-22), that would make it difficult to analyze with any standard procedure.

This author feels that an unrepresentative main channel is not likely to result by applying this definition, although it does not necessarily provide a method of locating the longest channelway in a drainage basin. The chances of obtaining a spurious main channel by this method are lessened because of the requirement for using the sum of the length of the highest order stream segment plus the longest length of subsequent lower order segments. This acts as a safeguard and ensures that the choice of a main channel is representative.

The validity of the outlined method for indicating a main channel is partially supported by data from previous quantitative studies. This supporting information is related to findings that mean lengths of stream segments of each order increase with the order of the stream segment (Horton, 1945, p. 286-291; Morisawa, 1962, p. 1029-1030) and drainage area increases with stream order (Horton, 1945, p. 293-294; Schumm, 1956, p. 606; Morisawa, 1962, p. 1030-1032). The validity is also supported by the quantitative data for Mill Creek, listed in table 1, which show an increase in mean length of stream segments with an increase in stream-segment order.

Figure 1 is a drainage net of Cardinal Creek, a component basin of Mill Creek. The main channel as determined by the definition presented herein is indicated on the net; it is apparent that this is also the longest channelway. One distinct advantage of this definition is that the main channel can be determined from the mouth to any point within the basin without going all the way to the drainage divide. A possible objection to this method of ascertaining the main channel is the requirement of making a comparative measurement of two stream segments at the junction where the next-higher order segment of the main channel begins. However, in the 62 component basins of Mill Creek, the choice of the longer of the 2 segments under consideration at each junction was obvious and did not necessitate measurement. A second objection might be the necessity of ordering the entire drainage net by the Strahler system. Usually in a drainage-basin analysis, this is done anyway; and for basins like Cardinal Creek, the drainage net can be ordered by the Strahler system faster than a few of its stream segments can be measured.

It is essential that all investigators who study the same drainage basin be able to identify accurately the same main channel. The method presented here will ensure an accurate identification.

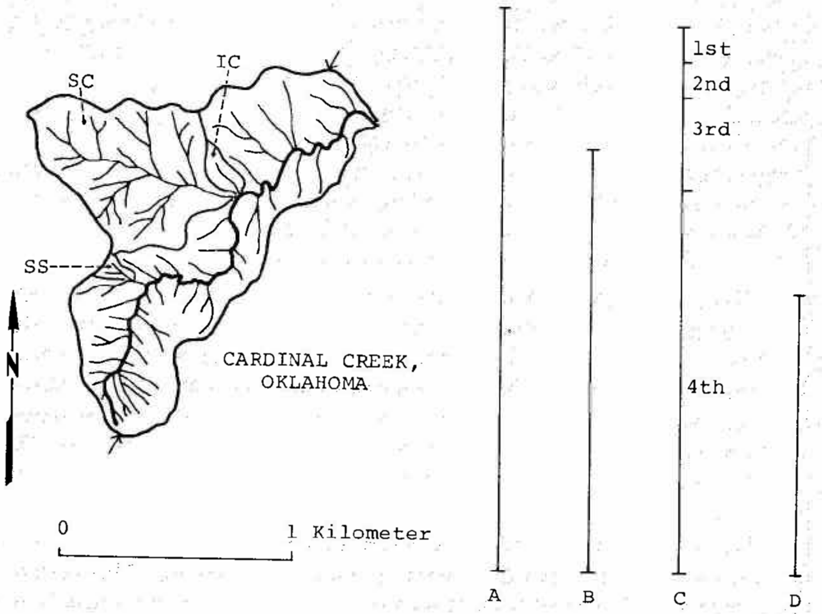

Figure 1. Drainage net of Cardinal Creek, a component basin of Mill Creek. The heavy line in the drainage net is the main channel of the Cardinal Creek basin, as defined in text. Under the hierarchy presented in this paper, *SC* indicates a superior component basin, *IC* an inferior component basin, and *SS* a superior subbasin (see table 2). The four vertical lines represent the values used in the computation of elongation and relief ratios for Cardinal Creek. The lines are drawn to scale with the drainage basin: *A* represents the length of the main channel, *B* represents the basin chord (arrows on perimeter of basin indicate where the basin chord was measured), *C* represents the cumulative total of mean stream lengths, and *D* represents the diameter of a circle having the same area as Cardinal Creek.

DRAINAGE-BASIN HIERARCHY

Every drainage basin greater than first order is composed of lesser basins, and within basins the size of Mill Creek, geologic conditions can vary a great deal (Cannon, 1973a, p. 506; Morisawa, 1962, p. 1035; Hack, 1957, p. 50). Therefore, a drainage-basin hierarchy is needed to provide a method for partitioning a basin such that it can be analyzed by component parts as well as by the whole. The hierarchy should be explicit, so that basins can be ranked automatically; the only arbitrary choice should be the selection of the basin to be analyzed. At present, no systematic method for subdividing a basin exists. Therefore, a drainage-basin hierarchy is proposed herein as an aid to the communication of information collected or generated in an analysis and as a step toward the eventual application of automatic analytical techniques.

There are two obvious basin types within a sizable drainage basin like Cardinal Creek (fig. 1), basins that empty directly into the main channel of the basin under consideration and basins that empty into a tributary rather than the main channel. The former are termed component basins of the major basin; the latter are termed subbasins of the major basin. Figure 1 shows a component basin and a subbasin of Cardinal Creek.

In a major basin the size of Mill Creek or Cardinal Creek, it is evident that the component basins can be further divided into two types that are significantly different in terms of their contributions to the drainage net of the major basin and to the discharge of the main channel of the major basin. One type is the component basin whose drainage divide forms a part of the major basin's drainage divide, and the other type is the component basin nestled within the major basin whose drainage divide does not constitute, in any part, a part of the major basin's drainage divide. The first type is termed a superior component basin, and the second type is termed an inferior component basin.

Of the 62 component basins in Mill Creek selected for study, 22 (35.5 percent) were inferior component basins, but they constituted only 9 percent of the total area of Mill Creek. Also, the 16 percent of the area of Mill Creek that was not included in the 62 component basins selected was entirely composed of small inferior component basins. In other words, the superior component basins represent 75 percent of the Mill Creek area, versus 25 percent for the inferior component basins. The minor importance of the

TABLE 2.—DRAINAGE-BASIN HIERARCHY

BASIN TYPE	DESCRIPTION
Major basin	The largest basin under investigation
Component basin	Any basin that empties into the main channel of the major basin
Superior component basin	A component basin whose drainage divide constitutes, in any part, a part of the major basin's drainage divide
Inferior component basin	A component basin whose drainage divide is not a part of the major basin's drainage divide
Subbasin	A basin that does not empty into the main channel of the major basin under consideration
Superior subbasin	A subbasin whose drainage divide constitutes, in any part, a part of a component basin's drainage divide
Inferior subbasin	A subbasin whose drainage divide is not a part of a component basin's drainage divide

inferior component basins is obvious in the drainage net of Cardinal Creek shown in figure 1.

The subbasins can also be ranked as superior or inferior with this system. Table 2 outlines the complete drainage-basin hierarchy. The importance that the main channel plays should be noted. This hierarchy provides a rank for the numerous lower order basins that empty into the main channel; they now can and should be treated separately from the superior component basins in some types of drainage-basin analyses, and the system not only provides for ranking basins in any situation, it also sets up a procedure whereby the meaning of the rank can be accurately communicated among investigators. To denote Cardinal Creek as a superior component basin of Mill Creek conveys a simple but accurate relation of Cardinal Creek to Mill Creek. The ranking can be extended in the opposite direction with Mill Creek. A definite relationship is conveyed by indicating that Mill Creek is a superior component basin of the Washita River drainage basin and a subbasin of the Red River drainage basin.

ELONGATION RATIO

Measurements were made of the Mill Creek drainage net to obtain values for area, perimeter, length and number of stream segments, and length of the main channel. These values were obtained for the entire Mill Creek drainage basin and, separately, for the 62 component basins partitioned by the drainage-basin hierarchy. This was done in order to determine the possible existence of any quantifiable reciprocal relationships (values of the component basins that indicate similar values for the same parameter of the major basin, or the reverse situation) between the component basins and the major basin. The 40 superior component basins and 22 inferior component basins provide a representative sample of the component parts of the major basin. Since these component basins make up 84 percent of the area of Mill Creek, any reciprocal relationships should have become apparent. Values for the total relief of each basin were taken from 1:24,000-scale topographic base maps.

A useful quantitative expression calculated from these values was the elongation ratio. The elongation ratio is an expression of the geometry of a basin, and it may be related to the stream's adjustment to structure and to the geologic history of the basin (Cannon, 1973b, p. 80; Davis, 1909, p. 343). The elongation of a drainage basin is related to the manner in which the water that falls within a basin is distributed. The distribution determines how the potential energy of the water will be released. Consider two basins that have equal area, relief, and stream density but dissimilar shapes. One is circular, and the other is elongate. The drainage net of the circular basin is more complex, and although it contains the same length of channelway and number of stream segments, it is a higher order basin. The elongate basin will be a lower order basin, having higher bifurcation ratios between the lowest order stream segments (Strahler, 1964, p. 4-45). The elongate basin is the more simple flume. Therefore, the energy available for downcutting and headward erosion would be greater along a longer portion of the main channel of the elongate basin than along the main channel of the more circular basin.

The elongation ratio is determined by dividing the diameter of a circle having the same area as the basin being studied by the longest dimension of the basin parallel to the principal drainage line (Schumm, 1956, p. 612). The divisor used in this ratio, the longest dimension of the basin parallel to the principal drainage line, has led to some confusion (Strahler, 1964, p. 4-66; Lustig, 1965, p. F15; Ongley, 1968, p. 85) and has been variously interpreted by investigators as the length between the two most distant points on the basin perimeter (Strahler, 1957, p. 918), the length of some undefined principal channel (Lustig, 1965, p. F14), or the length of the valley of some vague main channel (Proctor, 1969, p. 28). The divisor set forth in the original definition of the elongation ratio is not explicit, and it is difficult, if not impossible, for two investigators to determine the same value for the divisor in the same basin. In order to solve some of these shortcomings, I looked for better ways to express this parameter and experimented with three explicit values as substitutes for the longest dimension of the basin parallel to the principal drainage line in determining elongation ratios. The three explicit values are the length of the main channel as defined in this paper, the basin chord, and the cumulative total of mean stream lengths for a basin.

Use of the length of the main channel as the divisor in the elongation ratio has shortcomings; in some instances the main channel seems to be too long in relation to the geometry of a basin. A low-relief basin with a main channel that meanders provides a spurious elongation ratio that indicates, erroneously, that the basin is elongate.

The second value substituted for the divisor in the elongation ratio was the straight-line length between the two most distant points on the basin perimeter. This distance is termed the basin chord and is indicated on the drainage net of Cardinal Creek (fig. 1) with two small arrows. The basin chord seems to give a good representation of the elongation of some drainage basins; however, if the basin is curved or crescent shaped, it gives a poor elongation value by being too short and indicating, incorrectly, that the basin is nonelongate. A major personal objection to the basin chord is that it has no relationship to the streams within the basin, and although it is explicit, it is sometimes difficult to locate.

The third value used as a divisor was the cumulative total of mean stream lengths for a basin. This value is obtained by summing the mean lengths of the stream segments for each order. The cumulative total of mean stream lengths is related to all the stream segments within a basin and produces an elongation ratio that can be almost precisely duplicated by other workers. The only possible discrepancy is in the lengths of the first-order segments, but the effects of this are lessened by using the mean length of all the first-order segments in a basin. This divisor produces a representative, mean main channel that reduces the effects of odd-shaped basins and unusual lengths of main channels.

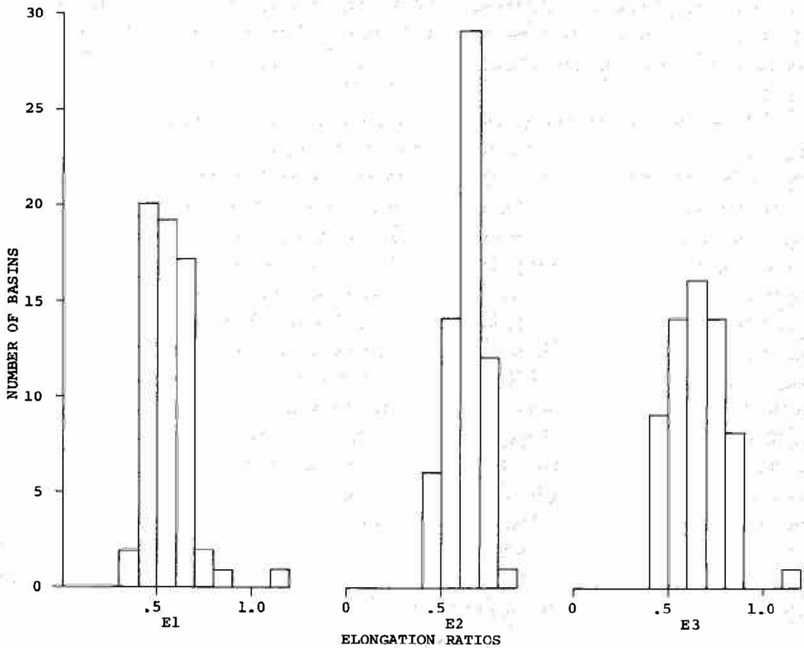

Figure 2. Histograms of 3 different elongation ratios calculated for the 62 component basins of Mill Creek. *E1* represents the elongation ratios calculated using the length of the main channel as the divisor, *E2* represents the ratios calculated using the basin chord, and *E3* represents the ratios calculated using the cumulative total of mean stream lengths (statistical data for each histogram are shown in table 3).

Elongation ratios were calculated for Mill Creek and, separately, for each of the 62 component basins of Mill Creek, using each of the 3 divisors. For purposes of comparing the 3 elongation ratios, histograms (fig. 2) were constructed of the values of the elongation ratios of the 62 component basins. Also, in order to get an idea of grouping and range, the arithmetic mean, mean deviation, and standard deviation were calculated for each set of elongation ratios for the 62 component basins. These values are listed in table 3. The elongation ratio calculated with the main channel length (E1) had the greatest range of values and the lowest mean. Elongation ratio E1 has the lowest mean of the 3 ratios, because in the 62 component basins, the main channel length was longer than the basin chord in 56 basins and longer than the cumulative total of mean stream lengths in 52 basins. The elongation ratio calculated with the basin-chord length (E2) moderated the extremes of all the elongation ratios by having the smallest range of values, as indicated by its low values for the mean deviation and standard deviation. The third elongation ratio (E3), derived by using the cumulative total of mean stream lengths, provides a symmetrical grouping of values having the

TABLE 3.—STATISTICAL DATA FOR 3 ELONGATION RATIOS CALCULATED FOR 62 COMPONENT BASINS OF MILL CREEK BASIN

RATIO	MEAN	MEAN DEVIATION	STANDARD DEVIATION
E1	0.557	0.090	0.164
E2	.632	.074	.095
E3	.657	.113	.138

largest mean. This shows that, on the average, elongation ratio E3 indicates a basin that is slightly less elongate than would be indicated by the other two types of elongation ratios, E1 and E2. Although elongation ratio E3 provides the highest values for the mean and mean deviation for the 62 component basins, the standard deviation indicates that the variance in this set of values is between the variances of elongation ratios E1 and E2. The values derived from the different types of elongation ratios for the 62 component basins do not differ greatly, and the use of any of the 3 should yield similar results. However, the important thing is that by specifying use of any one of them ambiguity in the calculation of elongation ratios can be minimized.

The three types of elongation ratios calculated for the Mill Creek drainage basin are listed in table 1. There appears to be no reciprocal relationship between the values of the elongation ratios of the component basins and those of the major basin. This may be a factor of the size and heterogeneity of the Mill Creek drainage basin.

RELIEF RATIO

Another important quantitative expression that was investigated in this study was the relief ratio, which provides a rough expression of the topographic relief throughout a basin. This expression can possibly provide a relative indication of the potential intensity of the fluvial processes occurring within drainage basins of similar size and environment. The relief ratio of a drainage basin is defined by S. A. Schumm (1956, p. 612) as "the ratio between the total relief of a basin (elevation differences of lowest and highest points of a basin) and the longest dimension of the basin parallel to the principal drainage line." This definition has been subject to the same problem of misinterpretation as the elongation ratio, because the parameter used for length in calculating the relief ratio has not been precisely defined.

In order to find a more explicit length parameter for determining the relief ratio, 4 different relief ratios were calculated for each of the 62 component basins and for the Mill Creek drainage basin, using 4 precisely defined values for length. The three values considered first were the values used to calculate the elongation ratios: the length of the main channel, the basin chord, and the cumulative total of mean stream lengths for a basin. The fourth value considered was the diameter of a circle having the same area as the basin. All four of these parameters for Cardinal Creek are diagrammed in figure 1 for purposes of comparison.

Calculations using the lengths of the main channel as the divisor provide a relief ratio (R1) that might represent the value Schumm was after when he defined the divisor to be the length of "the principal drainage line" (Schumm, 1956, p. 612). This value would certainly indicate a relationship between the relief and the length from the mouth, along a principal drainage line, to the drainage divide. The relief ratio (R2), calculated using the basin chord, provides a value that might represent a regional slope, but various peculiarities of basin shapes, as indicated in the discussion on elongation ratios, could make this value unrealistic. The cumulative total of mean stream lengths produces a relief ratio (R3) whose value is not as greatly influenced by abnormal main-channel lengths and odd basin shapes as are the values of the other relief ratios. Also, the use of the cumulative total of mean stream lengths gives a value that closely relates relief to the entire drainage net of a basin. The fourth relief ratio (R4) uses a length parameter that is directly related to the area of a basin and gives a relief ratio that expresses the relationship between relief and area. However, this expression is unrelated to the hydrogeologic regimen of a drainage basin and may be completely unrepresentative of the original concept for the relief ratio.

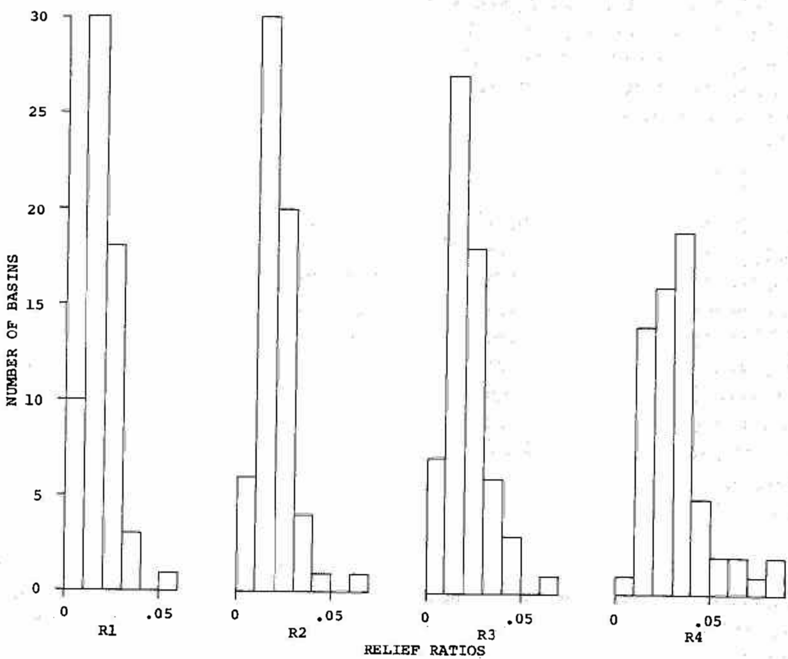

Figure 3. Histograms of the 4 different relief ratios calculated for the 62 component basins of Mill Creek. Ratios were calculated using the following divisors: *R1*, the length of the main channel; *R2*, the basin chord; *R3*, the cumulative total of mean stream lengths; and *R4*, the diameter of a circle having the same area as the basin (statistical data for each histogram are shown in table 4).

In order to obtain a comparison of the values for the 4 relief ratios, histograms were constructed to show the values obtained for the 62 component basins of Mill Creek (fig. 3). The arithmetic mean, the mean deviation, and the standard deviation were also calculated for each type of relief ratio, and they are listed in table 4. The values for the first 3 types of relief ratios (R1, R2, and R3) are so similar and the variances so small that, for most situations, any of the 3 could be used with similar results. However, as previously indicated, it is this author's opinion that the relief ratio calculated with the cumulative total of mean stream lengths (R3) is closely related to the entire drainage basin and best reflects the hydrogeologic regimen of the drainage basin under consideration. The relief ratios calculated with the diameter of a circle having the same area as the basin (R4) have the highest arithmetic mean and the largest values for the mean deviation and standard deviation. The histogram and calculated values of this relief ratio (R4) depart so significantly from the histograms and values of the other three types of relief ratios that they are considered unrepresentative.

TABLE 4.—STATISTICAL DATA FOR 4 RELIEF RATIOS CALCULATED FOR 62 COMPONENT BASINS OF MILL CREEK BASIN

RATIO	MEAN	MEAN DEVIATION	STANDARD DEVIATION
R1	0.0176	0.0066	0.0093
R2	.0199	.0067	.0099
R3	.0210	.0081	.0113
R4	.0323	.0119	.0164

The four types of relief ratios were calculated for Mill Creek, and their values are listed in table 1. As was the case with the elongation ratios, there appears to be no reciprocal relationship between the values of the relief ratios of the component basins and those of the major basin. It is important to note that in the values of all ratios, the influence of the local geology was reflected similarly in both the superior and the inferior component basins. The means and ranges of each relief ratio and elongation ratio were calculated separately for the 40 superior component basins and for the 22 inferior component basins. Since the differences in the values were insignificant, the values were presented collectively for the 62 component basins.

CONCLUSIONS

This investigation has produced several suggestions that offer geomorphologists the means to increase the precision and applicability of certain geomorphic terms and quantitative parameters. Explicitly defining the main channel of a basin, using the Strahler ordering system, is a solid step toward removing the ambiguity from drainage-basin analyses and toward the application of various automatic-data-processing techniques to quantitative geomorphology. I believe that the main channel as defined in this paper can be readily determined in a basin and that it is a representative main channelway. It is essential to the validity of quantitative geomorphology that investigators be able to identify the same main channel in a particular drainage basin, accurately and independently, and consistently measure the identical parameter in different basins.

The drainage-basin hierarchy introduced in this paper is flexible enough to be applied to any drainage basin. The division of a basin into component basins and subbasins will greatly improve the communication of values and ideas between geomorphologists and potamologists. This ranking will allow a systematic approach whenever a complete drainage-basin analysis is attempted, and the analysis of a part of a drainage basin will certainly be easier, more meaningful, and more useful with the application of this hierarchy. Although the values investigated in this report do not show any apparent reciprocal relationships between a major basin and its component basins, it is anticipated that future investigations into other drainage-basin parameters will produce some obvious reciprocal relationships.

The ambiguity that has existed in elongation and relief ratios can now be eliminated. Three options have been presented for divisors that can be used to obtain the elongation ratio, and four possible divisors were outlined for use in the relief ratio. The choice of which of the divisors to use should be up to the particular investigator, but the investigator should state clearly which parameter is used, because when the same parameter is used in the calculation of both the elongation and relief ratios for a basin, the two ratios are related to each other.

This is not to say that all of the divisors are recommended equally. The distribution of water within a basin is influenced by the length of the stream segments and the shape of the basin. In a similar manner, the movement of water through a basin is influenced by the length of the stream segments and the relief of the basin. If the elongation and relief ratios are intended to be more than just physical descriptions, they must be related to the stream segments within a basin. Since the values for the ratios are considered to be representative of the whole basin, the more stream segments they are related to, the better the representation. It appears, therefore, that of the various divisors presented here for the elongation and relief ratios, the cumulative total of mean stream lengths for each order would best relate the ratios to the complete stream system within a drainage basin.

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ERDA Announces Publication Changes

The Energy Research and Development Administration (ERDA) prepares a monthly abstract journal, *ERDA Research Abstracts (ERA),* which became available to the public with the January 1976 issue. Publication of *ERA* began in March 1975 as an in-house service, and distribution was limited to ERDA's staff and its contractors. *ERA* abstracts and indexes ERDA-originated, energy-related scientific and technical reports, patents, journal articles, conference papers, theses, books, and monographs. Subject, author, issuing-organization, and report-number indexes are included with each monthly issue and will be cumulated and issued annually.

ERDA will cease publication of its nuclear abstract journal, *Nuclear Science Abstracts (NSA),* as of volume 33, number 12, which will be dated June 30, 1976. ERDA-originated nuclear-related abstracts will be included in *ERA,* and the International Atomic Energy Agency plans to expand the scope of its publication, *Atomindex,* to include all nuclear-related abstracts. Therefore, ERDA believes that *NSA* no longer serves a useful function.

Subscriptions to *ERA* will be sold by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402. One-year subscription prices are as follows: *ERA* and an annual index will be $119 (domestic), $148.75 (foreign); index only, $30.50 (domestic), $38.15 (foreign); individual copies, $7.10 (domestic), $8.90 (foreign). *Atomindex* is available from UNIPUB, P.O. Box 433, Murray Hill Station, New York, New York 10016, at a subscription rate of $150 per year, including cumulated indexes, or $110 per year for the 24 regular issues without cumulated indexes.

AAPG Reprints Papers on Organic Reefs

The 3d volume of reissues of papers on carbonate rocks and the 15th work in its Reprint Series, *Carbonate Rocks III: Organic Reefs,* has been released by The American Association of Petroleum Geologists.

The 11 reprints included are presented in the order of their appearance in the *AAPG Bulletin,* ranging from Twenhofel's classic 1950 paper on "Coral and Other Organic Reefs in Geologic Column" to C. J. R. Braithwaite's 17-page discussion of "Reefs: Just a Problem of Semantics?," first published in 1973. Some of the intervening papers are specific descriptions; others are conceptual. Bob F. Perkins, The University of Texas at Arlington, states in his preface to the volume that the AAPG in its 59 years has published over 2,200 pages on reefs in more than 90 major papers and 95 abstracts. He relates this preponderance of reef literature to the importance of reefs to the petroleum geologist.

Reefs, however, ecologic or stratigraphic, bioherms or morphologic, petroleum traps or not, are of interest to non-petroleum geologists also. Thus AAPG Reprint Series No. 15 offers a great deal of information on the origin, relationships, and structure of reefs, and on their geochemical, petrographic, and petrologic composition as well as their roles in the accumulation of oil.

Carbonate Rocks III: Organic Reefs can be ordered from The American Association of Petroleum Geologists, P.O. Box 979, Tulsa, Oklahoma 74101. The price is $4.00 to AAPG or SEPM members and $5.00 to nonmembers.

Oklahoma Water Reports Available from USGS

The following open-file reports on ground water in Oklahoma and Kansas river basins have been issued by the U.S. Geological Survey:

Ground Water in the Verdigris River Basin, Kansas and Oklahoma, by S. W. Fader and R. B. Morton, 26 p., 4 pls., 2 figs., 1 table (USGS Open-File Report 75-365).

Ground Water in the Grand (Neosho) River Basin, Kansas and Oklahoma, by R. B. Morton and S. W. Fader, 35 p., 4 pls., 4 figs., 1 table (USGS Open-File Report 75-366).

Ground Water in the Middle Arkansas River Basin, Kansas and Oklahoma, by S. W. Fader and R. B. Morton, 44 p., 4 pls., 7 figs., 1 table (USGS Open-File Report 75-367).

These three reports have been labeled as nonreproducible, but they are available for inspection at USGS libraries and public-inquiry offices throughout the United States, including the National Center at Reston, Virginia, the Denver Federal Center, and the Water Resources Division offices in Lawrence, Kansas, and in Oklahoma City. In addition, a copy is on file with the Oklahoma Geological Survey.

U.S. Board on Geographic Names Decisions

The U.S. Board on Geographic Names recently approved five Oklahoma place names, and they were published in the July through September 1975 issue of *Decisions on Geographic Names in the United States* (Decision List 7503).

Cushing Lake (variant: Cushing Reservoir) has been adopted to identify a reservoir that is 2.1 kilometres (1.3 miles) long, on Big Creek 2.7 kilometres (1.7 miles) east-southeast of Ripley, Payne County, Oklahoma; secs. 27, 28, 33, and 34, T. 18 N., R. 4 E., Indian Meridian (36°00′45″ N., 96°52′30″ W., at dam).

Keefton (variant: Keefeton) has been adopted for a community that is 17.7 kilometres (11 miles) south of Muskogee, Muskogee County, Oklahoma; sec. 24, T. 13 N., R. 18 E., Indian Meridian (35°35′30″ N., 95°20′45″ W.).

Last Chance (variant: Morse) has been adopted to identify a community 1.6 kilometres (1 mile) east of Morse, Okfuskee County, Oklahoma; secs. 4, 5, 8, and 9, T. 12 N., R. 10 E., Indian Meridian (35°32′11″ N., 96°15′52″ W.).

Morse has been adopted for a community 3.1 kilometres (1.9 miles) east-northeast of Okemah Lake, Okfuskee County, Oklahoma; secs. 5, 6, 7, and 8, T. 12 N., R. 10 E., Indian Meridian (35°32′11″ N., 96°16′55″ W.).

Salt Creek has been adopted for a stream 19 kilometres (11.8 miles) long that heads at 36°12′15″ N., 96°50′30″ W., flows southeast to the Cimarron River 2.7 kilometres (1.7 miles) south-southwest of Yale, Payne and Pawnee Counties, Oklahoma; sec. 25, T. 19 N., R. 5 E., Indian Meridian (36°05′38″ N., 96°43′17″ W.).

Uranium Bibliography Released by USGS

Selected Bibliography Pertaining to Uranium Occurrence in Eastern New Mexico and West Texas and Nearby Parts of Colorado, Oklahoma, and Kansas, compiled by Warren I. Finch, James C. Wright, and Michael W. Sullivan, was released recently for public distribution.

The bibliography is described as "nearly complete through 1972," and it contains some later entries as well. It includes nearly 500 selected references to uranium and to the stratigraphy, structure, and ground-water geology of the uranium-bearing formations in the area covered. A geographic and subject index accompanies the bibliography.

The 98-page publication was prepared at the Lakewood, Colorado, regional office of the USGS and was released through the National Technical Information Service (NTIS) as PB 241 629. It is available from NTIS, Springfield, Virginia 22161.

A copy of the bibliography has been reposited in The University of Oklahoma Geology and Geophysics Library.

The Mineral Industry of Oklahoma in 1975[1] (Preliminary)

Robert H. Arndt[2]

The value of minerals produced in Oklahoma in 1975 reached $2.3 billion, the highest level in history, a growth of 8.7 percent above that of 1974, according to the Bureau of Mines, U.S. Department of the Interior (table 1). The record was supported by a 9.8-percent increase in the value of fuels to $2,218 million, which constituted 96.04 percent of the State's mineral value. The value of produced metals and nonmetals declined. Output of all minerals except coal, high-purity helium, natural gas, and salt declined. Lead, zinc, copper, and silver production ceased.

Crude-oil production experienced its sixth consecutive year of decline, dropping 9.2 percent below that of 1974 despite intensive drilling. Increased drilling for natural gas boosted production 5.9 percent over that of 1974 and reversed a 2-year downward trend in production. Producers substantially increased dedicated intrastate reserves of natural gas. Increases of 1.9 percent in production and 16.3 percent in value of coal over those of 1974 accompanied an increase in the number of active coal mines from 17 to 28 during 1975. Kerr-McGee Corp. installed an underground system to degasify coal beds in its Choctaw mine. The U.S. Geological Survey granted funds to the Oklahoma Geological Survey for a program of coal analysis.

Decreases in production of sand, gravel, cement, clays, and gypsum reflected curtailment of highway and other construction. Commercial Brick Corp. installed a fully automated system for manufacturing brick at Wewoka. Installed kiln modifications increased production capacity by 200 tons of lime per day at St. Clair Lime Co. Amoco Production Co. and Houston Chemical Co. started construction of a plant to extract iodine from formation brines in Woodward County.

Eagle-Picher Industries, Inc. closed its copper mine in Jackson County. A permit to engage in zinc mining in Ottawa County was issued to one company. National Zinc Co. of Oklahoma started construction of an electrolytic zinc plant at Bartlesville.

Mining companies undertook the organization of the Oklahoma Mining Institute, an industry association. The State Legislature passed bills that will permit women to work in coal mines, that resulted in appointment rather than election of the State's Chief Mine Inspector in the future, that favored control of surface mining by states, and that retained a depletion allowance of 22 percent for oil producers. A Federal District Court Commission favored the Osage Indian Tribe in a suit with the U.S. Army Corps of Engineers over the Birch Creek Reservoir site.

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[1]Prepared December 19, 1975, in the State Liaison Program Office-Oklahoma, U.S. Bureau of Mines, through a cooperative agreement between the USBM and the Oklahoma Geological Survey that calls for collecting information on all minerals except fuels.

[2]Liaison Officer-Oklahoma, U.S. Bureau of Mines, Oklahoma City.

TABLE 1.—MINERAL PRODUCTION IN OKLAHOMA[1]

MINERAL	1974 QUANTITY	1974 VALUE (THOUSANDS)	1975 (PRELIMINARY) QUANTITY	1975 (PRELIMINARY) VALUE (THOUSANDS)
Clays (thousand short tons)	1,289	$ 2,105	968	$ 1,644
Coal (bituminous) (thousand short tons)	2,356	24,759	2,400	28,800
Gypsum (thousand short tons)	1,225	5,622	966	4,382
Helium				
High-purity (million cubic feet)	169	5,915	220	7,700
Crude (million cubic feet)	134	1,608	131	1,965
Natural gas (million cubic feet)	1,638,942	458,904	1,735,934	531,196
Natural-gas liquids:				
LP gases (thousand 42-gallon barrels)	31,231	166,461	29,953	196,250
Natural gasoline and cycle products (thousand 42-gallon barrels)	12,581	84,638	11,121	85,010
Petroleum (thousand 42-gallon barrels)	177,785	1,277,076	161,394	1,367,007
Sand and gravel (thousand short tons)	8,708	13,772	7,751	11,626
Stone (thousand short tons)	22,228	36,599	19,087	35,406
Value of items that cannot be disclosed: cement, copper, feldspar, lead (1974), lime, pumice, salt, silver, tripoli, and zinc (1974)	XX	45,231	XX	38,297
Total	XX	$2,122,690	XX	$2,309,283

XX Not applicable.

[1]Production as measured by mine shipments, sales, or marketable production (including consumption by producers).

USGS Report Analyzes Mineral Needs for Energy Goals

A report just placed on open file by the U.S. Geological Survey, *Non-Fuel Minerals and Materials Needed by the Energy Industry—A Preliminary Report,* focuses on a wide variety of materials that must be available to the energy industry if our national goal of self-sufficiency in energy production within the next few decades is to be met. John P. Albers and Walter J. Bawiec, authors of the report, present estimates of the basic materials needed over the next 15 years or so by 5 major energy industries—fossil fuels (coal, oil, gas, and oil shale), geothermal, hydroelectric, nuclear, and solar, as well as electric-power-transmission facilities.

Minimum estimates for some of the basic materials needed by the primary energy industries are listed below.

Commodity	Short tons	Commodity	Short tons
Aluminum	15,300,000	Lead	26,800
Antimony	1,180	Magnesia	532,000
Asbestos	139,000	Manganese	1,930,000
Barite	25,700,000	Mica	4,920
Bentonite	11,200,000	Molybdenum	87,200
Boron	45	Nickel	289,000
Cadmium	89	Niobium	44
Chromium	279,000	Silicon	3,860
Cobalt	6,770	Silver	418
Concrete	335,000,000	Tin	1,090
Copper	3,760,000	Titanium	5,220
Fiberglass/Plastic	2,000,000	Tungsten	38,100
Glass	7,960,000	Vanadium	173
Iron	187,000,000	Zinc	3,530

The problem is that many of these materials are already in short supply, domestically. V. E. McKelvey, director of the USGS, states that in 1974 the United States was more than 90-percent dependent on imports of primary materials for 7 commodities (manganese, cobalt, chromium, titanium, niobium, strontium, and sheet mica); 75- to 90-percent dependent for 8 commodities (aluminum, platinum, tin, tantalum, bismuth, fluorine, asbestos, and mercury); and 50- to 75-percent dependent for 8 commodities (zinc, gold, silver, tungsten, nickel, cadmium, selenium, and potassium). In other words, unless domestic exploration is strongly encouraged, our nation's goal of expanded domestic production of energy will lead to increased dependency on other countries for our mineral needs.

Non-Fuel Minerals and Materials Needed by the Energy Industry—A Preliminary Report is part of a larger report (that will be broader in scope and will relate materials supply to demand), which is expected to be published within the next several months. The preliminary report is available for inspection at a number of USGS libraries and public-inquiry offices throughout the United States; the repository closest to Oklahoma is the Public Inquiries Office, Room 1C45, Federal Building, 1100 Commerce Street, Dallas, Texas.

AIPG Becomes APGS

By a recent vote of its membership, the American Institute of Professional Geologists (AIPG) became the Association of Professional Geological Scientists (APGS) and an affiliate of the American Geological Institute (AGI). This change had been in the mill for 3 years and was the result of a concerted push by a number of geological scientists for a single, unified organization to speak to matters relating to the professional (as distinct from the scientific) practice of the geological sciences. The Committee for Planning a Unified Professional Organization, or the PUPO Committee, as it has been more commonly known, was sparked back in 1973, when R. Dana Russell was president of AGI. Successive AGI presidents James E. Wilson and Frank B. Conselman helped work out particulars of the new organization with representatives of AIPG, The American Association of Petroleum Geologists, the Association of Engineering Geologists, and the Society of Exploration Geophysicists. (Throughout this period, the Oklahoma Geological Survey's own Charles J. Mankin participated in the discussions as a representative of the Association of American State Geologists.)

President John D. Haun is enthusiastic about APGS's growth potential, as he reports in the association's January newsletter. In reviewing national and state activities, he looks forward to revitalized efforts in monitoring federal and state legislation as it pertains to the practice of the geological sciences and to the public good. Other programs will be carried out by the following committees: public affairs, geology in the environment, and professional employment standards. President Haun restated the association's position on state laws requiring registration of geologists: that APGS neither favors nor discourages such laws but maintains files on existing and proposed laws as a source of information to interested inquirers.

Hailing a "new era of cooperation among geologists, geophysicists, and other geoscientists," John Haun raises this rallying standard: "Now that our first priority of unification of the professional objectives of geological scientists has been achieved, our next priority is to increase membership. We hope that all Certified Petroleum Geologists and Registered Professional Geologists will choose to become members. . . . We speak for *all* geological scientists. . . . Urge your friends to join, now!"

New Theses Added to OU Geology Library

The following M.S. theses have been added to The University of Oklahoma Geology and Geophysics Library:

Archeomagnetic Study of Anasazi-Related Sediments of Chaco Canyon, New Mexico, by Ronald F. Nichols.

Palynology of the Middle and Upper Seminole Coals (Pennsylvanian) of Tulsa County, Oklahoma, by Daniel L. Pearson.

Surface Analysis, "Cherokee" Group (Pennsylvanian), Northern Kingfisher County, Oklahoma, by Clifford W. Zeliff.

OKLAHOMA ABSTRACTS

AAPG Regional Meeting, Mid-Continent Section
Wichita, Kansas, October 1-3, 1975

The following abstracts are reprinted from the Mid-Continent Regional Meeting Program of The American Association of Petroleum Geologists. Page numbers appear in brackets below each abstract. Permission of the authors and of Gary Howell, AAPG managing editor, to reproduce the abstracts is gratefully acknowledged.

Geology of the Permian Blaine Formation and Associated Strata in Southwest Oklahoma

KENNETH S. JOHNSON, Oklahoma Geological Survey, The University of Oklahoma, Norman, Oklahoma

Outcropping rocks in the Hollis basin of southwest Oklahoma include a 700-foot-thick sequence of red beds and evaporites in (ascending order) the San Angelo, Flowerpot, Blaine, and Dog Creek Formations. Each of the formations is typically 100-250 feet thick, and the three upper units can be subdivided by persistent evaporite marker beds. The formations extend at least 300 miles along the outcrop from north Texas, through western Oklahoma and into southern Kansas.

The Hollis basin is on the northeast shelf of the Permian basin and is bounded by the Red River-Matador arch on the south and the Wichita uplift on the north. As seawater transgressed the Permian basin from the southwest, it was partly evaporated and was successively concentrated with respect to carbonates, sulfates, and chlorides. Thus, a complete cycle of evaporite deposition in the region includes (ascending) dolomite, gypsum/anhydrite, salt (halite), red-brown shale, and gray shale. Individual beds in each cycle are typically 3-20 feet thick. The main part of the evaporite sequence contains 14 complete or partial cycles. [8]

Depositional Environments of Cherokee Reservoir Sands, Kincaid Oil Field, Southeastern Kansas.

RICHARD VAN DYKE, University of Kansas, Lawrence, Kansas

The Kincaid Oil Field, located in southeastern Anderson County, Kansas, produces oil from a Middle Pennsylvanian (Cherokee) sandstone. This

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OKLAHOMA ABSTRACTS is intended to present abstracts of recent unpublished papers relating to the geology of Oklahoma and adjacent areas of interest. The editors are therefore interested in obtaining abstracts of formally presented or approved documents, such as dissertations, theses, and papers presented at professional meetings, that have not yet been published.

sandstone is interpreted to be the Skinner Sandstone, which in eastern Kansas most commonly occurs as an elongate "shoestring" sand intercalated with Cherokee shales. In the Kincaid Field, the Skinner Sandstone forms a north-south trending combination stratigraphic-structural trap.

The sandstone is of fluvial channel origin with associated channel and overbank facies. It has a sharp basal contact with conglomerate or sandstone overlying either shale or coal. The sand grades from a medium to fine-grained sandstone upward into interbedded siltstones and shales. Cross sections of the sand show a convex downward shape, which is characteristic of a fluvial channel sand, as is the fining upward vertical sequence.

Sedimentologically, the sandstone can be classified as a litharenite with approximately 70% quartz, 20% metamorphic rock fragments, and 10% accessory minerals.

Paleogeographically, this sand body was deposited on the Cherokee platform, which formed a shelf-like extension of the Arkoma Basin. During Cherokee time this shelf area (eastern Kansas and northeastern Oklahoma) fluctuated from nonmarine to marine, causing the sediments to be deposited in a cyclic nature, producing "shoestring" sandstones and thick shales throughout the Cherokee interval. [12]

Stimulating Recovery from Heavy Oil Resources, Mid-Continent Area

LARMAN J. HEATH, Bartlesville Energy Research Center, Bartlesville, Oklahoma

The Bartlesville (Okla.) Energy Research Center, ERDA, is developing petroleum-recovery techniques for the many shallow, low-productive, heavy-oil sand deposits in southeastern Kansas, southwestern Missouri, and northeastern Oklahoma. In 1971, the Research Center began a field experiment in Labette County, Kansas, using a recovery method that combines chemical explosive fracturing to create communication between wells with solvent injection to improve the mobility of the oil.

This paper points out the general boundaries of heavy oil deposits and describes the areal extent and general characteristics of the reservoir in Labette County. Laboratory experiments, to determine optimum field operating conditions, are briefly described.

The fracturing, production, and injection techniques used in the field experiment are described, and the production results given. Final conclusions on the technical success of the field experiment await efforts to recover the solvent left in the formation after solvent injection ends. [17]

Heavy Oil in Western Missouri—Update

JACK WELLS, Missouri Geological Survey, Rolla, Missouri

The energy crisis of the early 70's and the resulting increased price for new and stripper oil have revived interest in the potential of heavy oil-tar sand deposits of Missouri, Kansas and Oklahoma as a petroleum resource. Recent drilling in Missouri permits a review and update of the geology of these deposits.

In parts of western Missouri, southeastern Kansas and northeastern Oklahoma, sandstones of the Middle Pennsylvanian Cherokee Group are impregnated with heavy oil. These deposits, commonly referred to as tar sands or asphaltic sandstones, occur at the surface or near the surface in Missouri to depths in excess of 500 feet.

Estimates of the amount of oil in place in the Tri-state area range from 1 to 75 billion barrels. Based on available data, the Missouri Geological Survey currently estimates that 8 billion barrels of heavy oil in place may exist in the Missouri portion of this area.

Current drilling by industry points out the need for geologic study in determining the nature and geometry of these oil-bearing sand bodies. A program undertaking a coordinated study of the surface and subsurface occurrences of heavy oil and tar sand by the Geological Surveys of Missouri, Kansas and Oklahoma has been partially funded. Initial work will be carried out in the outcrop area by the Missouri Geological Survey, Department of Natural Resources. [18]

Engineering and Geological Challenges in Heavy Oil Recovery

G. PAUL WILLHITE, University of Kansas, Lawrence, Kansas

Heavy oil resources in the four state region adjacent to the common boundaries, of Kansas, Missouri, Oklahoma and Arkansas represent a potential crude oil supply for the Mid-Continent region. Development of this resource was generally uneconomic prior to the Arab embargo, but price increases for domestic oil offer new possibilities. Typical deposits in Southeastern Kansas are reviewed to characterize the size of the resource and to identify geological parameters which are needed for evaluation of potential oil recovery. Oil recovery processes which may become economically attractive are described. Field tests of these processes are discussed with emphasis on the effect of geologic properties on the selection, design and operation of the improved oil recovery process in the field. [19]

A Subsurface Presentation and Producing Characteristics of the Lower Morrow Sandstone in Southern Ellis County, Oklahoma

DONALD A. BLOUSTINE, Oklahoma City, Oklahoma

The Lower Morrow formation of Southern Ellis County, Oklahoma, consists of a thick sequence of lenticular sands and shale deposited in a cyclic transgressive-regressive sequence of events. Recent significant discoveries in the Lower Morrow and attractive economic incentives have made Southern Ellis County one of the most active drilling areas in the Anadarko Basin.

Increased drilling activity in the study area has supplied the necessary control, displaying excellent reservoir characteristics, which led to the development of the West Vici Field, Northeast Peek Field, and the extension of the Higgins Field.

The possibilities of stratigraphic entrapment due to the lenticular nature of the Lower Morrow sand formation coupled with excellent producing characteristics of already established gas fields, make Southern Ellis County a highly potential area for future gas reserves in the Anadarko Basin. [20]

The Current Dibble to Mustang Area Hunton Play, McClain, Grady, and Canadian Counties, Oklahoma

JOHN ALLEN TAYLOR, Independent Petroleum Geologist, Oklahoma City, Oklahoma

We expect to demonstrate the regional geology that has led to entrapment along an extensive narrow band by combination of fracture and intergranular porosity in an inter-relation that has led to commercial concentrations at certain locales.

The economics of this activity will be an inherent part of the presentation. A series of colored slides will demonstrate the regional geology, both structure and stratigraphic, plus the geology of the local collections of commercial hydrocarbons. [20]

Sedimentary Cycles and Depositional Environments in Virgilian (Pennsylvanian) Rocks in the Anadarko Basin

BAILEY RASCOE, JR., Phillips Petroleum Co., Bartlesville, Oklahoma

The deposition of the regionally widespread Heebner Shale in earliest Virgilian (Late Pennsylvanian) time marked a brief episode in the Anadarko basin when sedimentation was virtually at a standstill. Upon resumption of sedimentation clastics were deposited in the Anadarko basin in the form of delta-shaped submarine fans which range up to 1000 ft. (305 m) in thickness. The Ouachita foldbelt is believed to be the source of most of the clastic material. Many of the fans contain one or more sands, one of which—the "Laverty-Hoover" sandstone—is gas productive in the Laverne district of Harper and Beaver Counties, Oklahoma. Each of these fans is overlain by an extensive shelf-carbonate unit which grades into a narrow, porous, greatly thickened, shelf-edge carbonate bank located on the outer margin of the fan. In Virgilian time more than a dozen of these cycles—each consisting of a shelf-carbonate unit, a shelf-edge carbonate bank, and a submarine fan—prograded westward into the Anadarko basin.

To account for this style of cyclic sedimentation, a depositional model is proposed in which (1) the Anadarko basin subsided at a constant rate, (2) the supply of clastic sediments provided by the Ouachita foldbelt was not sufficient to fill the Anadarko basin within a limited time, and (3) periodic lowering of base level through eustatic sea-level changes enabled clastic material to move from time to time across the carbonate shelf and into the Anadarko basin. [21]

Developments in South Central Oklahoma

L. S. MORRISON, Westheimer-Neustadt Corporation, Ardmore, Oklahoma

Significant discoveries in South Central Oklahoma have been found in overturned and thrusted beds along the Wichita Mountain front in Comanche County and in the Arbuckle Mountains in Murray County. Pay zones range from Woodford in the Westheimer-Neustadt's #1 Dillberg, Sec. 5-T3N-R10W, to Bromide in the Exxon Beaver Gas Unit #1, Sec. 5-T2N-R9W, and Basal Oil Creek in the Mapco's #1 Howell, Sec. 14-T1S-R1E. A stratigraphic trap proved to be productive from the 2nd Tuley sand in the Creslenn Oil Company's #1 Ruppe, Sec. 9-T1N-R1E, in August of 1974, and since then 17 wells have been drilled on 40-acre spacing. The Sycamore play continued to expand in Stephens County at Sholem Alechem and in the Ardmore basin the deep Goddard sand play grew with the completion of the first offset to the Burmah Oil Company's #1 City of Ardmore, Sec. 4-T4S-R1E, with a stabilized potential of 16 million feet of gas per day. In Coal County the Wapanucka lime is of growing importance as a gas reservoir. [24]

Report—Oklahoma and Texas Panhandles

JERRY M. SHELBY, Amarillo Oil Company, Amarillo, Texas

This proven hydrocarbon producing area of the Mid-Continent continues to be explored and developed by over a hundred different operators. In 1974 more than 600 completions were reported and activity continues high well into this year with Beaver and Hemphill Counties being the most active.

There have been two particularly interesting wildcat discoveries in the area, the Shreily field of Roberts County and the Wheeler-Pan field of Wheeler County, Shreily presently has eleven wells producing gas from a Morrowan chert conglomerate stratigraphic trap and Wheeler-Pan presently has two wells producing from the Siluro-Devonian Hunton in a structural trap which has stratigraphic complexities.

Discoveries like Shreily (Morrow) and Wheeler-Pan (Hunton) fields and the continued development well success in other fields promise to keep this area active for many years to come. [25]

Trends and Origins of Ordovician Sandstones, Northern Arkansas

RAYMOND W. SUHM, Texas A & I University, Kingsville, Texas

Surface and subsurface stratigraphic studies of the Calico Rock and Newton Sandstones of the Everton Formation and the St. Peter Sandstone of northern Arkansas show them to be lobate sands up to 200 feet thick.

High porosities and permeabilities as well as equivalency with the productive Simpson Group in Oklahoma suggest potential reservoirs. Stratigraphic trends are established from isopach maps prepared from this study.

Depositional environments and geologic histories are derived from the areal geometry, thickness, and fabric of the sandstones and from a study of subjacent and superjacent rock units. The data suggest the sands accumulated in a barrier island-shelf sea complex. The sands were partially reworked and modified by marine processes in transgressing seas. [29]

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The following abstracts are reprinted from the *Abstracts with Programs* of The Geological Society of America, v. 7, no. 7. Page numbers are given in brackets below each abstract. Permission of the authors and of Mrs. Jo Fogelberg, managing editor of GSA, to reproduce these abstracts is gratefully acknowledged.

Early Late Silurian Biofacies in South-Central Oklahoma as Determined by Point Counting

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The Fitzhugh Member, Clarita Formation (Wenlockian), is largely organo-detrital, grain-supported limestone ranging from biosparite to biomicrite. Terrigenous detritus is generally low, and no reefs are present. Thin-section point counts show pelmatozoan plates are the dominant organic element, constituting up to 25% of the rock volume. Ostracodes are next in abundance and, combined with trilobites, may exceed the pelmatozoan volume. Brachiopods and bryozoans are a small part of the fossil debris; corals are rare. No algal heads or mounds were observed. A varied microfauna is present but only rarely shows in the count. Three major lithofacies are recognized: (1) organo-detrital sparite averaging less than 1% insoluble detritus; (2) organo-detrital micrite averaging about 5% detritus; (3) mud-supported marlstone averaging about 18% detritus. Distinctive biofacies are associated with these lithofacies: (1) Pelmatozoans contribute about 25% volumetrically to the sparites, the combined ostracode-trilobite volume being 19%; bryozoan-brachiopod debris comprises 7%. (2) Ostracode-trilobite material (14%) surpasses the pelmatozoan plates (11%) in the micrite facies; gastropods and cephalopods (7%) replace the bryozoans-brachiopods (3%) as a major rock element. (3) Ostracodes (16%) are dominant in the marlstone lithofacies (matrix 67%), with trilobites contributing 3%; all other fossils contribute less than 1%. These biofacies changes are associated with a transition from the clean, washed sands of the sparites toward an increasingly clay-silt-rich environment. Depth of water may have been the ultimate condition controlling these changes, but probably the major factors affecting the faunas were bottom conditions and accompanying turbidity, which under extreme conditions, almost eliminated the sessile benthos. [974-975]

Seismicity and Glacial Rebound in the Central Stable Region

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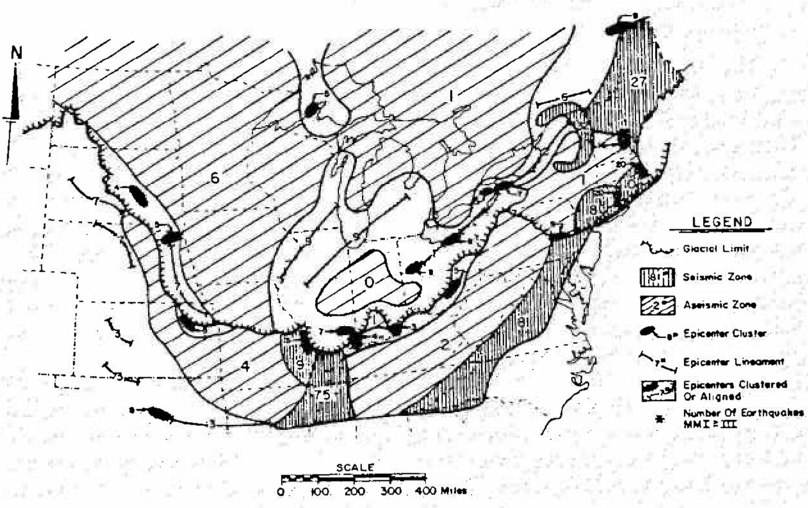
A seismotectonic model for the Central Stable Region must consider the effect of glacial rebound as well as other tectonic factors (intra-plate movements, mantle plumes, and residual stress release). A causative relationship between seismicity and glacial loading is implied by the coincidence of the glacial margins and clusters of earthquake epicenters. We propose that this coincidence stems from stress release at the glacial margins due to the isostatic difference between areas still loaded by drift, a peripheral area within the glacial forebulge, and the unglaciated area. This pattern results in relatively earthquake-free areas beneath the drift, a ring of epicenters at the glacial terminus, an aseismic ring within the forebulge, and another epicentral ring at the outer edge of the glacial forebulge. The concentric ring pattern is overprinted by tectonic effects in areas of known or suspected faulting such as New Madrid and the St. Lawrence-Erie-Ontario lineament.

The figure below shows the distribution of earthquake epicenters in the glaciated region of the central and northeastern United States intended to support our conclusions. Other than the Mississippi Embayment and the Appalachian belt, there are numerous small clusters of epicenters that have the following interesting characteristics:



DISTRIBUTION OF EARTHQUAKES, CENTRAL STABLE REGION AND NORTHEASTERN U.S.

1. Many of the epicenters are situated along the glacial margins. This is true for those at Manhattan, Kansas, St. Louis, southwestern Indiana, Louisville, Kentucky, and south central Ohio. Furthermore, the Ap-

palachian trend abruptly stops at the glacial limit (in southeastern Pennsylvania) and thence follows the glacial limit along the northeastern U.S. coast.

2. There is a noticeable absence of seismicity beyond the glacial limit in a 200-mile wide marginal zone (with the exception of the Mississippi Embayment) corresponding to the area of "glacial forebulge." Beyond this 200-mile wide zone there is a reoccurrence of seismicity, as in western Nebraska, western Kansas, central Oklahoma, northern Arkansas, and the Appalachian trend.

3. There is a noticeable absence of seismicity within areas of thick drift. Because drift is 2.5 times the density of ice, a 150- to 400-foot thickness of drift would isostatically affect the crust as much as a 450- to 1000-foot thickness of ice. Thus, the crust is still isostatically unrelieved, especially along the glacial margins, where drift thickness is a maximum and ice-thickness was a minimum. A forebulge beyond the glacial limit might, therefore, still be unrelieved in the opposite sense. These isostatic conditions are supported by geodetic and gravity measurements, and by the dating of submerged terrestrial fossils.

4. There is a major lack of correspondence of many epicenters with mapped faults. This aspect emphasizes the need to consider other than tectonic forces.

5. The New Madrid area typifies the interaction of glacial as well as tectonic forces. Fault plane solutions of earthquakes in the upper Mississippi Embayment indicate two compressional stress fields; one east-west and the other north-south. The north-south field, we hypothesize was caused by glacial movement while the other is tectonic.

6. Not associated with glacial tectonics, is a trend along a line which passes through the St. Lawrence Valley, Cleveland, and northwestern Ohio, and perhaps continues to the Wabash Valley and the New Madrid area. This trend parallels the Appalachian trend.

We propose that future seismicity could be expected in the Central Stable Region in clusters aligned along the glacial limit resulting from unrelieved compressional stresses caused by glacial loading, residual drift loading, and forebulge. The significance of glacio-tectonic forces added to the present tectonic framework of the Central Stable Region provides a mechanism to explain many earthquakes which appear to be unassociated with known faults or structures. In addition, a glacial explanation restricts the occurrence of previously unexplained earthquakes to the glacial margins. [1129-1130]

Texture of Arkansas Novaculite Indicates Thermally-Induced Metamorphism

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Arkansas novaculite in the Hot Springs-Little Rock area exhibits the texture, in scan electron micrographs, of a thermally metamorphosed rock ostensibly from cryptocrystalline chert. The stratigraphic formation, named Arkansas Novaculite, grades monotonically from a metamorphic rock in central Arkansas to typical cryptocrystalline chert at Atoka, Oklahoma, 160 air-miles west. The Bigfork chert behaves similarly. It appears desirable to restrict the term "novaculite" to a petrologic name for a thermally metamorphosed chert which shows polygonal, triple-point texture; Arkansas Novaculite is the type occurrence.

Very coarse texture, quartz crystals 60 μ m in diameter, is developed within 100 yards of Mesozoic intrusives, e.g., at Magnet Cove. Coarse texture, crystals 10-20 μ m in diameter, is wide-spread at Hot Springs and Little Rock quarries. Fine texture (metamorphic) which ranges down to 1 to 2 μ m, occurs in the western part of Trap Mountain, 7 air-miles southwest of Hot Springs. Similar texture occurs in the Broken Bow, McCurtain County, Oklahoma region. Incipient-metamorphic texture appears in the Potato Hills region, Okla., but at Atoka, Arkansas "novaculite" is cryptocrystalline chert.

Thermal metamorphism from vulcanism yields novaculite. In Ouachita locales of intense structural deformation coarse-textured novaculite is developed. Whether deformation alone generates adequate heat to produce novaculite is uncertain.

Novaculite may be a geologic clue to a hidden intrusion, a thermal ore deposit (as the vanadium in Arkansas), or a source of geothermal energy. [1141]

Non-Glacial Varves in the Arkansas Novaculite (Devonian-Early Mississippian), Arkansas and Oklahoma

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Non-glacial varves in the Arkansas Novaculite are of two types, here termed terrigenous and calcareous. Terrigenous varves, 2 to 10 mm thick, show cyclically alternating laminations of cryptocrystalline quartz enriched in terrigenous debris and microcrystalline quartz containing little terrigenous detritus. Calcareous varves, 1 to 2 mm thick, are defined by alternating carbonate-rich and carbonate-poor layers.

The bulk of the silica was carried into the Ouachita Basin by ocean surface currents from areas of volcanism and upwelling to the south and west. The terrigenous varves also include terrigenous detritus carried by aeolian and aqueous currents from a shallow-marine to subaerial northern shelf. Calcareous varves include aeolian terrigenous quartz and transported and diagenetic carbonate grains.

Terrigenous varves formed in areas of sedimentological overlap between southerly clay-carrying aqueous currents and northerly silica-bearing currents. The stratigraphic intervals showing terrigenous varves represent times when the surface water layers in the Ouachita Basin were circulating and when water was exchanged freely with seas to the south and west. The calcareous subdivisions apparently formed under more restricted conditions when intrabasinal circulation was sluggish, less water entered from adjacent seas, and extensive supratidal and evaporitic flats developed on adjacent shelves.

Varve counts suggest that the lower member of the Arkansas Novaculite, 120 m thick at Caddo Gap, was deposited in about 100,000 years. The possibility of significant unconformities within the Novaculite, especially at the top of the lower member, must be considered. [1178]

Geochemical Anomalies, Uranium Potential of South-Central Oklahoma

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Hydrogeochemical anomalies were used to delineate areas of potential uranium mineralization in south-central and southwestern Oklahoma. Many of the anomalies were localized along or near the axes of major oil-producing structural trends which displayed bleaching of Permian red beds. This bleaching was caused by vertically migrating hydrocarbons which reduced the ferric iron to the more soluble ferrous state, resulting in its removal by ground waters. The alteration was restricted to the sandstone intervals of the overlying formations, and over one leaking reservoir altered sandstones were found to a depth of 2,500 feet.

Structural, stratigraphic and petrographic studies were conducted in areas where geochemical anomalies were found associated with red bed alteration. At Cement, Oklahoma reduction of sulfates and uraniferous solutions by migrating hydrocarbons resulted in the precipitation of uranium and calcium carbonate. The uranium mineralization was associated with a zone characterized by diagenetic carbonate (normal carbon and oxygen isotopes), indicating that the uranium was transported into the ore zone by ground waters moving upward along the flanks of the structure.

Radioactivity was also indicated by gamma ray-neutron logs in the Permian Rush Springs Formation and Hennessey Shale at Cement and in the Duncan Sandstone at Cox City, Oklahoma. At Cox City the subsurface anomalies were located along a fault which had been a major conduit for migrating hydrocarbons.

Geochemical anomalies and surface alteration near other oil-producing structures in southern Oklahoma (Chickasha, Velma-Cruce, Eola and Healdton) suggest potential targets for future exploration. [1219]

Carboniferous Deep-Sea Fan Facies of Arkansas and Oklahoma

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The Carboniferous flysch facies in the Ouachita Mountains of Arkansas and Oklahoma consists of over 20,000 feet of turbidites and related sediments. The section in Oklahoma is mainly shaly flysch, but Morris recently described several sections in Arkansas which contain thicker-bedded and coarser-grained rocks than those encountered in Oklahoma. More recently Graham, et al, suggested that the Ouachita flysch originated as a submarine fan system, similar to the Bengal fan.

The writers recently studied exposures of Stanley, Jackfork, Johns Valley, and Atoka strata in Arkansas and Oklahoma in an attempt to classify these strata according to the submarine fan-channel model of Mutti and Ricci-Lucchi.

Sequences in which sandstones thin upward and thicken upward, indicative of channel and fan-lobe, respectively, are common in all units studied. Sequences in which sands thicken upward and then reverse themselves to continue thinning upward are thought to represent lobes which are gradually abandoned.

Examples which best fit the submarine fan-channel model occur in the Jackfork. The section in Big Rock Quarry at North Little Rock consists of at least eleven distinct channel-fill sequences. Along Route I-30 between Arkadelphia and Malvern five distinct channel-fill sequences can be seen. Deposits at both of these localities are interpreted as inner fan, with the former being most proximal. Midfan deposits are present farther west in the vicinity of DeGray dam, and outer fan deposits occur in eastern Oklahoma. The submarine canyon which fed this deep-sea fan complex was located to the east near Memphis. [1298-1299]

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The Southern Oklahoma Aulacogen

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The southern Oklahoma Aulacogen, as defined by the Russian geologist Shatski, parallels Precambrian trends and extends 450 Km into the mid-continent from its junction with the Ouachita foldbelt in southeastern Oklahoma. The history of the Aulacogen includes 3 stages: a rifting stage from latest Precambrian through Middle Cambrian time; a subsiding stage from Late Cambrian through Early Devonian time; and a deforming stage from Late Devonian to Early Permian time. The rifting stage was dominated by mafic intrusions and extrusions followed by silicic igneous activity. The mafic intrusions formed as lopoliths of layered gabbros, anorthosites and troctolites along the axis of the aulacogen including the present day Wichita Mountains and Marietta Basin. Seismic data suggests, and

gravity models are consistent with, an anomalous zone beneath this intrusion extending down to the upper mantle. Seismic data also indicates that the upper mantle is anomalous beneath the aulacogen. Cambrian faulting suggests the early aulacogen was a graben with uplifted flanks. During the subsidence stage the aulacogen accumulated 5 to 10 times more shallow water sediment than adjacent areas. The deformational stage was dominated by large vertical displacements which formed the Anadarko, Marietta, and Ardmore basins, and the Wichita, Criner and Arbuckle uplifts. Left-slip displacements are indicated by offset facies boundaries as well as fold axes which trend at an acute angle to the faults. Deformation within the aulacogen may be genetically related to a collision which formed the Ouachita Mountains and deformed the continental margin of Early Paleozoic time.

[1332]

Oklahoma State University

Depositional Trends and Environments of "Cherokee" Sandstones, East-Central Payne County, Oklahoma

ARTHUR MICHAEL ASTARITA, Oklahoma State University, M.S. thesis, 1975

Scope and Method of Study: Subsurface data served as the means of determining the geometry of each of five "Cherokee" sandstones and served as the basis for estimating sandstone trends and depositional environments. Geometry was determined primarily from eight correlation sections and an isopach map of each sandstone. The latter portrays the thickness of the section from the overlying marker to the base of the sandstone. A log map was prepared of each sandstone in an area with significant changes in sandstone development. Influence of sediment distribution by paleotopography and/or paleostructure was determined from study of isopach maps of lower and upper "Cherokee" strata.

Findings and Conclusions: The "Cherokee" Sandstones represent regressive phases which interrupted the overall transgression by the Pennsylvanian (Desmoinesian) Cherokee sea. Major developments of "Cherokee" sandstones are thought to represent deposition in major and minor distributary channels of southward to eastward prograding deltaic complexes. Poorly developed sandstones within the "Cherokee" sequence may be associated with related local environments such as distributory-mouth bars, offshore bars, and interdistributary bays. Local depositional trends of the Red Fork, Lower Skinner, and Prue sandstones are generally north-south, whereas the Bartlesville and Upper Skinner sandstones have dominant east-southeast trends. Distribution of lower

"Cherokee" sediments, particularly the Bartlesville Sandstone, was influenced by paleostructure and paleotopography. Upper "Cherokee" distribution was probably influenced to some extent by continued structural movement and differential compaction.

Log maps are thought to be better for defining sandstone trends and edges than conventional isopach maps.

Geochemistry and Mineralogy of the Permian Red Beds and Related Copper Deposits, Payne, Pawnee, and Noble Counties, Oklahoma

RICHARD RALPH HEINE, Oklahoma State University, M.S. thesis, 1975

Scope and Method of Study: Geochemical stream sediment and bed rock maps including all or parts of T19, 20, 21, 22N, R3, 4, 5E, were prepared to assist in locating copper mineralization. All samples were analyzed for their copper content. Lead, zinc, and silver concentrations were determined for selected samples. Statistical methods were used to determine the spatial distribution of copper mineralization and the influence of structural configurations on the localization of copper. The lithofacies of host rock were investigated using field methods.

Findings and Conclusions: The host rock for the copper mineralization is of Early Permian age. The minerals occur in deltaic, interdeltaic-deltaic, and shallow marine facies. The mineralization is dominantly chalcocite nodules, replacement of carbonaceous wood and pyrite. Factor analysis shows that copper concentration increases in a northerly direction. The copper in bed rock seems to coincide with known sub-surface structural features in the study area. No direct relationship between distribution of the clay minerals and copper concentration was observed. The alteration of illite and chlorite to kaolinite in sandstone and shale is interpreted as weathering effects.

The Surficial Geology of the Guthrie North Quadrangle, Logan County, Oklahoma

GARY DEAN MEYER, Oklahoma State University, M.S. thesis, 1975

Scope and Method of Study: The surficial deposits in the Guthrie North Quadrangle were mapped by airphoto interpretation and field work. To aid in the correlation of the alluvial deposits, longitudinal profiles of terraces and floodplains were constructed. Cross sections were prepared to show the vertical relationships of the surficial deposits. Both the geologic units and the soils in the study area were evaluated environmentally. Interpretations of the geologic units can be used in conjunction with the surficial geologic map of the Guthrie North Quadrangle. Environmental maps of a twelve-square-mile area immediately to the north of Guthrie, Oklahoma, were prepared, based largely on environmental interpretations of the soils.

Findings and Conclusions: The Pliocene Ogallala Formation may have overlain this area but subsequently has been eroded away except for a few lag gravels. Five alluvial deposits are present; in descending order they are the Paradise Terrace Alluvium, the Summit View Terrace Alluvium, the Perkins Terrace Alluvium, the Lawrie Terrace Alluvium, and the floodplain alluvium. The eolian deposits in the study area are comprised of dune sands of two ages and of loess. Colluvium is present on almost all of the hillsides, being thickest at the bases of slopes where it commonly interfingers with the alluvium.

The properties of the geologic units and the soils in the twelve-square-mile study area to the north of Guthrie indicate that about half of this area is ideal for urbanization. The two most serious potential engineering problems in the area north of Guthrie are flooding and local areas where soils are of high shrink-swell potential.

Local Depositional Trends of "Cherokee" Sandstones, Payne County, Oklahoma

RAYMOND DALE SHIPLEY, Oklahoma State University, M.S. thesis, 1975

Scope and Method of Study: Determination of the geometry of the five sandstone units in the "Cherokee" Group of north-central Oklahoma from subsurface data served as the basis for estimation of depositional environments and interpretation of sandstone trends. Geometry was determined primarily from seven correlation sections and isopach maps of net sandstone prepared for each sandstone in the study. Log maps were also prepared for each sandstone to compare techniques for mapping sandstone trends in the subsurface. Control of sediment distribution by paleotopography and/or paleostructure was determined from study of isopach maps of the lower and upper parts of the "Cherokee" interval.

Findings and Conclusions: The five sandstone units contained within the "Cherokee" Group in the study area represent regressive phases which interrupted an overall transgression by the Middle Pennsylvanian (Desmoinesian) Cherokee sea. These sandstones are thought to have been deposited in deltaic environments, classified as major and minor deltaic distributary channels and delta-fringe. The latter includes a variety of local environments such as distributary-mouth bars and barrier-bars. The trends of the Red Fork, Lower Skinner, and Upper Skinner Sandstones in the area are generally north-south; however, the Bartlesville and Prue Sandstones have dominant northeasterly trends. Paleotopography primarily controlled the trend of Bartlesville Sandstone in the east-central part of the area. Paleostructure, characterized by differential compaction, structural movement, or a combination of both, influenced the distribution of upper "Cherokee" sediments.

The use of the log map is thought to improve the accuracy of determining sandstone trends and estimating sandstone edges. It represents a more useful exploration tool for delineating subtle sandstone trends than conventional isopach maps.

Hydrogeochemistry of the Washita River Alluvium in Caddo and Grady Counties, Oklahoma

LYLE RAMSAY SILKA, Oklahoma State University, M.S. thesis, 1975

Scope and Method of Study: The hydrogeochemistry of ground water has become an important consideration in the study of the water environment. Because over one-fourth of the water consumed in the United States is derived from ground water, it is hoped that the present study will facilitate understanding of the processes which affect water quality. The Great Plains Small Watershed Research Project area of the Agricultural Research Service, U.S.D.A., located in Caddo and Grady Counties, Oklahoma, was used as study area for this investigation. The chemical, mineral, and hydrogeologic parameters were measured in 49 wells. Factor maps and factor analysis were used to infer which processes are controlling the ground-water chemistry. Using infrared and color ektachrome aerial photography, a land-use map was constructed to represent possible relationships between land use and ground-water quality. Analysis of variance was used to investigate the effects of agricultural fertilization on the occurrence of N, P, and K in the ground water. Stability relations for the clays and calcite and gypsum were investigated using phase equilibria diagrams.

Findings and Conclusions: Results of the study revealed that the major processes affecting the hydrogeochemistry are bedrock sources of ions (Ca^{++}, Mg^{++}, SO_4^{--}, Na^+, CL^-, K^+, Cu^{++}, Pb^{++}, and Zn^{++}), carbonate equilibria (Ca^{++}, Mg^{++}, Mn^{++}, H^+, CO_2, and HCO_3^-), redox equilibria (Fe^{++}, Mn^{++}, and Zn^{++}), clay-water equilibria (various cations, Si, H^+), metal complexes (Cu^{++}-PO_4^{---}, Cu^{++}-CO_3^{--}, Cd^{++}–NO_2^-, and Cd^{++}–NO_3^-), permeability (K^+, Cd^{++}, Mg^{++}, Si, NO_3^-, and Cl^-) and agricultural practices (N, PO_4^{---} and K^+).

THE UNIVERSITY OF OKLAHOMA

Quantitative Geophysical Study of the Cleveland Sand Reservoir (Pennsylvanian) in Eastern Part of Logan County, Oklahoma

DIMITRIOS KOUSPARIS, The University of Oklahoma, M.S. thesis, 1975

A subsurface study was made of the Cleveland sand (Pennsylvanian) in the south half of T. 17 N., R. 1 E., in Logan County, Oklahoma, by the use of electrical and induction logs. The study involved the determination of a number of electrical parameters and enabled recognition of facies variations

within the Cleveland sand. Identification of possible fracture and/or fault systems in the Cleveland sand will enable selection of areas most favorable for a future water flood project.

Nannofossils of the Ozan Formation (Cretaceous), McCurtain County, Oklahoma

ANTHONY EDWARD KRANCER, The University of Oklahoma, M.S. thesis, 1975

A stratigraphic and micropaleontologic study, concentrating on nannofossils, was made of the Ozan Formation of Upper Cretaceous (Gulfian Series) in southeastern McCurtain County, Oklahoma, from a previously described section 2½ miles east of the town of Tom (Morgan, 1967).

Samples of the Ozan Formation were obtained from locations in Oklahoma and Arkansas for laboratory analysis. Standard laboratory procedures were used in the preparation of calcareous microfossils from the sediments. No attempts were made to extract the carbonaceous forms, as these had been previously studied by Morgan (1967).

A wide variety of fossils were encountered in the study. Invertebrates occur abundantly and include representatives of Pelecypoda and Cephalopoda in these sections of the Ozan Formation. Also found abundantly throughout the Ozan Formation are representatives of Foraminifera, Ostracoda, spores, pollen, dinoflagellates, acritarchs, and nannofossils. Scanning Electron Microscope and Light Microscope studies revealed 31 genera and 49 species of nannofossils. Seventeen genera of microforaminifera were distinguished and were examined in a manner similar to that used for the nannofossils.

Analysis of the fossil assemblages shows that the Ozan Formation is a transgressive marine unit. Spores and pollen indicate a tropical climate, marine invertebrate filter feeders indicate quiet water conditions, and the microforaminifera indicate a depositional depth of less than 600 feet.

A correlation with the nannofossil zonations determined from Deep Sea Drilling Project cores indicates that the Ozan Formation was deposited during the *Broinsonia parca* zone of the early Campanian Stage.

The Structure of the Eastern Part of the Mill Creek Syncline

ROBERT FRANKLIN LUKE, The University of Oklahoma, M.S. thesis, 1975

The Arbuckle Mountains are basically characterized by a large amount of vertical uplift, but recently several people have proposed that there may be a component of strike-slip present in the Arbuckle Mountains. The purpose of this study is to compare and contrast the deformational structures of the Arbuckle with experimental models of wrench faults. The area of study is between the Reagan fault and Sulphur fault. Method of study will be construction of a structure map by examining aerial photos and then field checking the map.

Carbonate Petrology and Lithostratigraphy of the Lecompton Member (Pawhuska Formation), Jennings-Shamrock Area, Oklahoma

SUZANNE BARRERE MISTRETTA, The University of Oklahoma, M.S. thesis, 1975

The Lecompton member of the Pawhuska formation (upper Pennsylvanian, Virgilian series) is examined along a north to south traverse from the Jennings, Oklahoma area (T. 20 N., R. 7 E., southern Pawnee County) where the Lecompton is entirely limestone, to the Shamrock, Oklahoma area (T. 17 N., R. 7 E., western Creek County) where it is dolomite. In this study area, the Lecompton ranges in thickness from 0.5 to 15.5 feet, with one local thickening to 45 feet.

The Lecompton member is informally divided into three sequences. The basal beds (sequence A) of the Lecompton are characteristically thick bedded carbonates separated by very thin bedded to thin bedded shales. Intrasparites dominate the lower portion of sequence A rocks and interfinger laterally with biomicrites and biosparites in the upper portion. Pelmatozoans and fusulinids are the chief faunal types. The intrasparites pinch out completely in the southern section of the study area.

The carbonates of sequence B can be described as thin to medium, wavy bedded biomicrites with laminated to thin bedded shale interbeds. However, where these carbonates are dolomitized limestones or dolomites, they are, in places, thick bedded. The bioclasts are primarily pelmatozoans and bryozoans.

The carbonates of sequence C are described as thin to medium bedded fusulinid biosparites and fusulinid biomicrites. Where this sequence is dolomitized limestone or dolomite, it is, in places, thick bedded.

Deposition of the Lecompton member occurred in the intertidal to subtidal environments on a shallow shelf. The basal beds mark the transgression of the sea from the north. The large cross-beds exhibited by some of the intrasparites represent tidal channels cutting the shelf. There seems to have been less current strength in the upper portion of sequence A carbonates, perhaps due to baffling or deepening of water.

A low intertidal environment is represented by the carbonates of sequence B. The wavy thin beds may be indicative of rippling and deposition was periodically halted by influx of fine terrigenous clastics.

Sequence C marks the farthest advancement southward of the marine environment. It may also represent the beginning of the sea's retreat.

Early diagenetic introduction of a ground water mixture of fresh water and sea water first produced the inversion of aragonitic or high magnesium calcite mud to low magnesium calcite micrite, the neomorphism of micrite to microspar and/or pseudospar, and the cementation of grain supported rocks with sparry calcite. This mixed solution then dolomitized part of the Lecompton member. This early diagenetic solution may have been introduced vertically by regressions of the sea shortly after the beginning of sequence B deposition and at the end of sequence C deposition. However, this fresh-water mixing may also have been introduced from the continental south.

The meteoric water-sea water mixture model for diagenetic changes is supported by several lines of evidence: (1) the geochemical data presented, (2) the crystal size and crystal form of the dolomite, and (3) the lack of mudcracks, algal mats, evaporites, or restricted fauna supporting a hypersaline, high magnesium dolomitizing solution.

A Vertical Intensity Magnetic Survey of the Western Part of the Arbuckle Mountains

PATRICK JOSEPH RYAN, The University of Oklahoma, M.S. thesis, 1976

The purpose of this investigation is to study the applicability of the vertical intensity magnetic survey in obtaining tectonic information in the Arbuckle Mountain area. The area of investigation is located primarily in the Arbuckle anticline, which is an intensely folded and faulted structural complex in Murray and Carter Counties, Oklahoma. In order to evaluate the applicability of the method, a series of detailed magnetic profiles will be made across the Arbuckle Mountains. The profiles will be surveyed so as to cross major tectonic features and traverse major magnetic anomalies as they become apparent during the survey. To help interpret the magnetic data, numerical model studies will be conducted for selected profiles. The numerical models will be calculated using a modified version of the computer program of Talwani and Heirtzer (1964).

Subsurface Analysis, "Cherokee" Group, Southern Garfield and Northern Kingfisher Counties, Oklahoma

CLIFFORD W. ZELIFF III, The University of Oklahoma, M.S. thesis, 1975

The area under investigation is on the northeast flank of the Anadarko basin in northern Kingfisher and southern Garfield Counties, Oklahoma. The area includes T. 17 N., Rs. 7-9 W., T. 18 N., Rs 4-8 W., T. 20 N., Rs. 5-6 W. (fig. 1).

The study will focus on: (1) occurrence and distribution of Pennsylvanian "Cherokee" sands in the area; (2) possible relationships between the pre-Pennsylvanian erosional surface and sand distribution; (3) depositional history and environments of the units deposited during the interval investigated; and (4) significance of trapping mechanisms, both structural and stratigraphic, for commercial accumulations of hydrocarbons in these sands.

ONG Buys Interest in Alabama Coal

Oklahoma Natural Gas Co., through its subsidiary ONG Exploration Inc., has purchased a 43.75-percent interest in Dixie Coal Co. This small strip-mining company operates in northwestern Alabama, and its assets include leases with recoverable reserves that have been estimated at over 1 million tons of high-grade bituminous coal, strip-mining equipment, and a number of unevaluated leases.

Reading & Bates Oil and Gas Co., Tulsa, also bought a 43.75-percent interest; the remaining 12.5 percent is owned by Ebanoro Holdings Ltd., Dallas. The total purchase price for the company was $1.5 million; ONG's share cost about $700,000.

USGS Updates Coal Estimates

The latest estimates of U.S. coal resources show a 23-percent increase over former evaluations, according to a recently issued report by Paul Averitt, geologist with the U.S. Geological Survey's Branch of Coal Resources. Averitt estimates that 3,968 billion tons of coal remained in the ground as of January 1, 1975; 1,731 billion tons is known and identified from detailed geologic mapping and exploration, and the remaining 2,237 billion tons is believed to be present in unmapped and unexplored areas.

Although only about 5 percent of the coal resources is believed to be recoverable under present conditions and present methods of mining, coal constitutes 69 percent of the recoverable resources of fossil fuel. Its mining and transportation make it the second-largest mineral industry in the country, and its cumulative production totals 42.3 billion tons, half of which has been mined since 1933.

Averitt's report, published as USGS Bulletin 1412, contains tables showing the total resources by states and by rank of coal, distribution of resources, relation of resources of coal to resources of other fossil fuels, and world resources by continents. Two index maps of coal fields of the conterminous states and Alaska are included.

Coal Resources of the United States, January 1, 1974, can be ordered from the USGS Branch of Distribution, 1200 South Eads Street, Arlington, Virginia 22202. The price is $1.60, prepaid.

Editors Dare to Visit Chocolate Town, U.S.A.

At considerable risk to their waistlines, members of the Oklahoma Geological Survey editorial staff trekked to Hershey, Pennsylvania, alias Chocolate Town, U.S.A., for the ninth annual meeting of the Association of Earth Science Editors. Bill Rose, OGS editor, Rosemary Croy, associate editor, and Elizabeth Ham, assistant editor, attended the November 16-19 conference.

Technical sessions on in-house composition, marketing, computer-assisted manuscript processing, and indexing were featured, along with concurrent workshops on editorial selection and redacting. The marketing session, entitled "How to Get Rid of Your Turkey," emphasized that it is easy to market a valuable product and differentiated between marketing and selling by explaining that the former involves encouraging a company (or even a government agency) to produce what the buyer wants, while the latter concentrates on getting the prospective buyer to want what the company has already produced. The in-house composition session resulted in admonitions from several AESE members against hasty decisions to purchase printing systems and, especially, against buying the state of the art—letting a company sell its most advanced equipment before the bugs have been worked out.

One of the highlights of the editorial meeting was provided when Pete Wilshusen, Pennsylvania Geological Survey, who served as local-arrangements chairman for the meeting, organized a field trip to the Cornwall Furnace. One of the earliest ironmaking facilities in our country, the furnace played an important role in the Revolutionary War and is now administered by the Pennsylvania Historical and Museum Commission.

New officers introduced at the Hershey meeting were Patricia Wood Dickerson, editor, Bell & Murphy & Associates, Houston, president; A. F. Spilhaus, Jr., executive director of the American Geophysical Union, vice-president and president-elect; and Michael Latremouille, Bedford Institute of Oceanography, Dartmouth, Nova Scotia, director-at-large. Rosemary Croy is chairman of the nominating committee this year, and Bill Rose has accepted membership on the program committee, which will be responsible for next year's meeting, October 17-19, in Albuquerque.

The *Notes* Go Red, White, and Blue

The 1976 edition of *Oklahoma Geology Notes* sports a bright red, white, and blue cover in honor of the bicentennial. Our thanks to Survey cartographer Sondra Underwood, who continues to demonstrate that a good eye for line, color, and detail comes in handy for more than fine map making. She designed the covers of volumes 33 through 35, so our appreciation and public acknowledgment is long overdue.

Sondra, please accept our sincere gratitude.

—*The Editors*

1976 Oil-Industry Directory Available for U.S.A.

Over 23,000 personnel and their titles, from officers and directors to key operating personnel, are listed in the *1976 USA Oil Industry Directory.* Prepared by the publishers of the *Oil and Gas Journal,* the directory is billed as "an indispensable reference book for anyone who needs instant, accurate information about the companies [it contains listings for every major integrated oil company in the United States plus major independents, pipeline companies, and drilling and marketing firms]—and the people who run them. . . ." Government agencies involved in the oil industry are listed, and their addresses, plus the names and titles of a number of individuals who work for them, are also contained in the directory.

Orders for the publication should be sent to The Petroleum Publishing Company, P.O. Box 1260, Tulsa, Oklahoma 74101. The directory sells for $45 per copy, plus postage (if payment accompanies the order, the publisher will pay the surface postage), and it contains a guarantee for a complete refund if returned within 10 days after receipt.

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