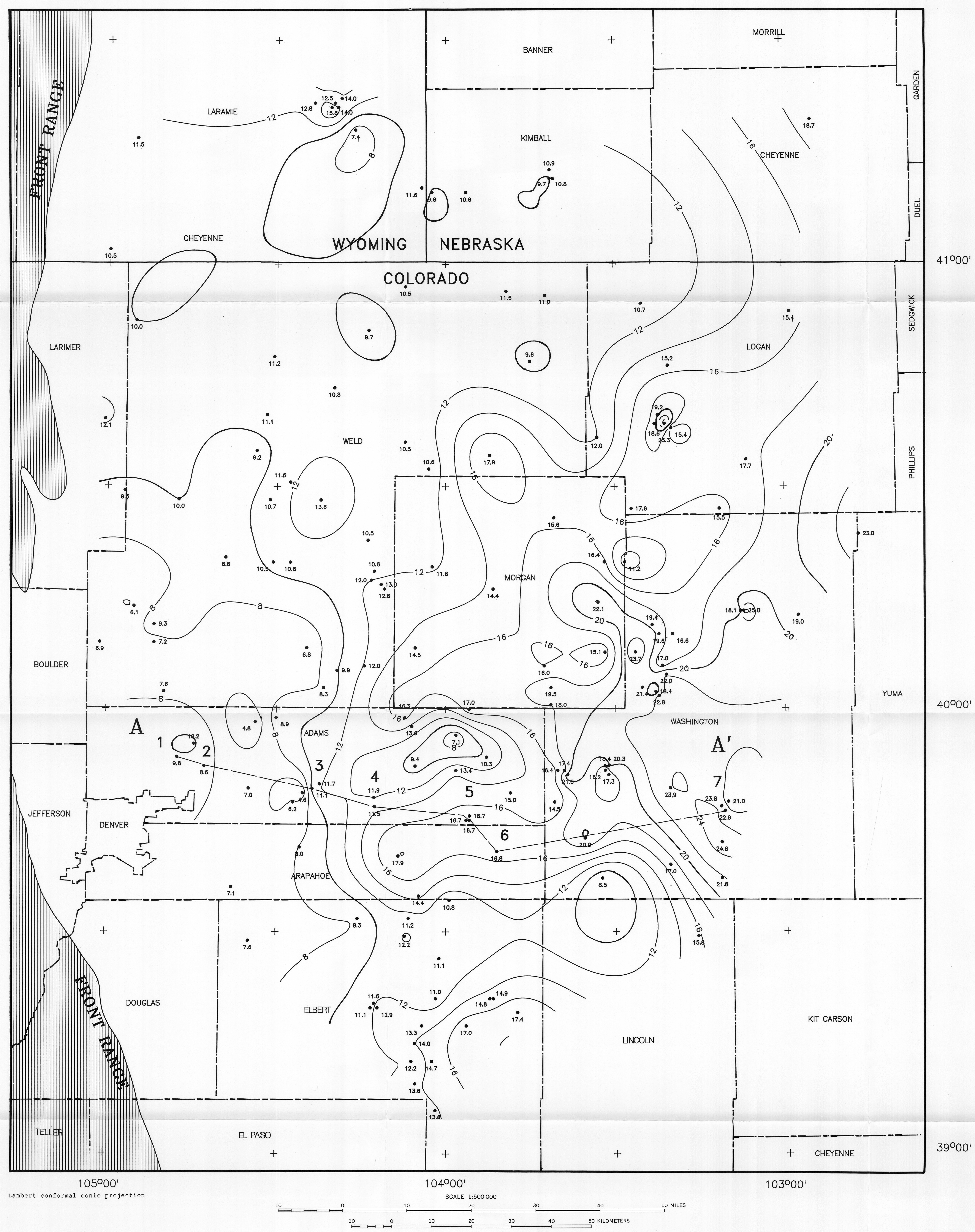
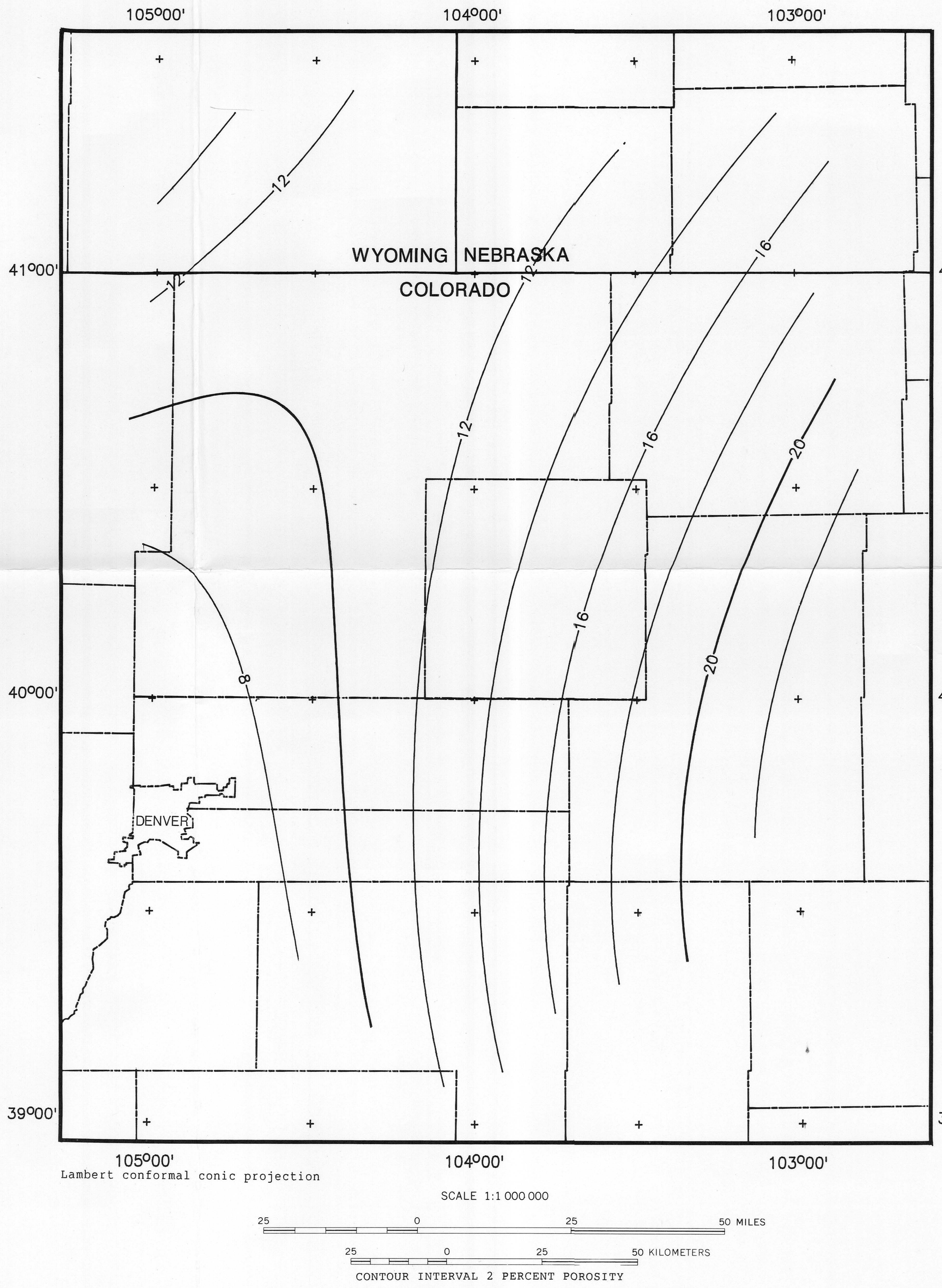
DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

MISCELLANEOUS FIELD STUDIES
MAP MF-1982




MEDIAN-POROSITY CONTOUR MAP




MEDIAN-POROSITY TREND CONTOUR MAP

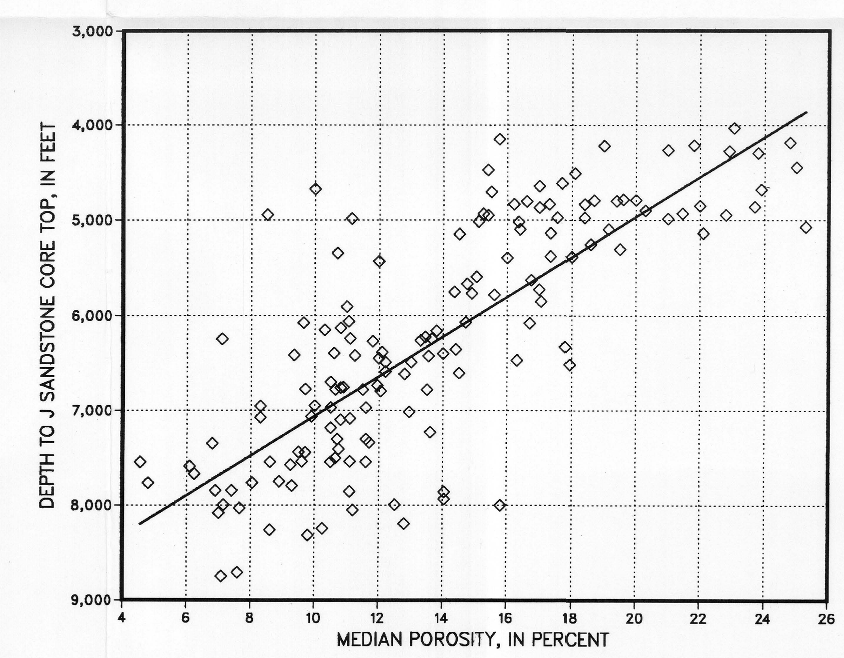



Figure 1.--Linear regression of median porosity against sample depth for the J sandstone.

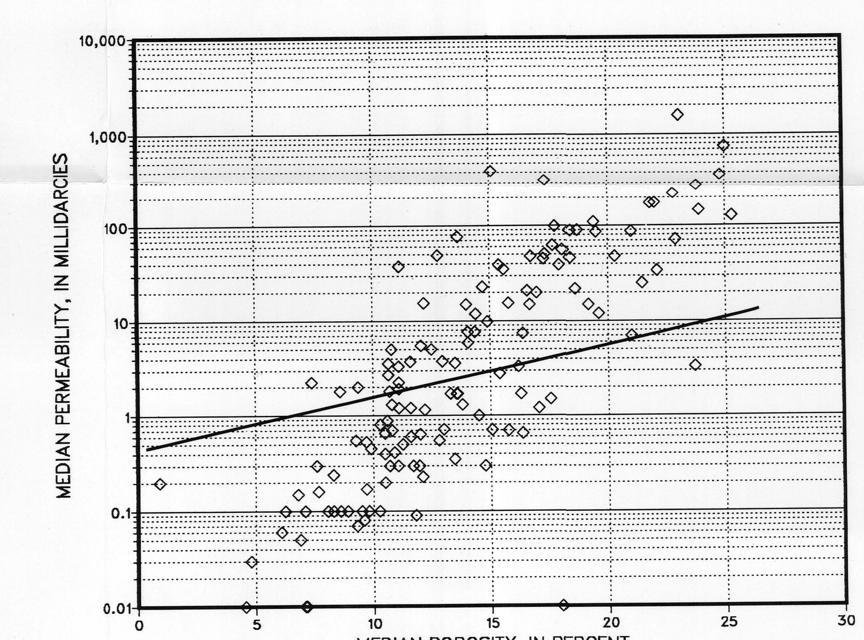



Figure 2.--Linear regression of median permeability against median porosity for the J sandstone.

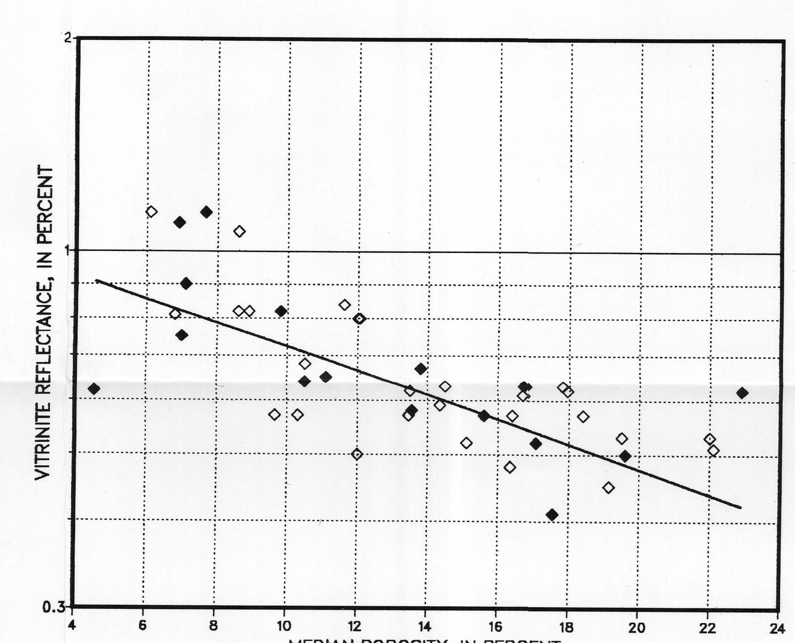
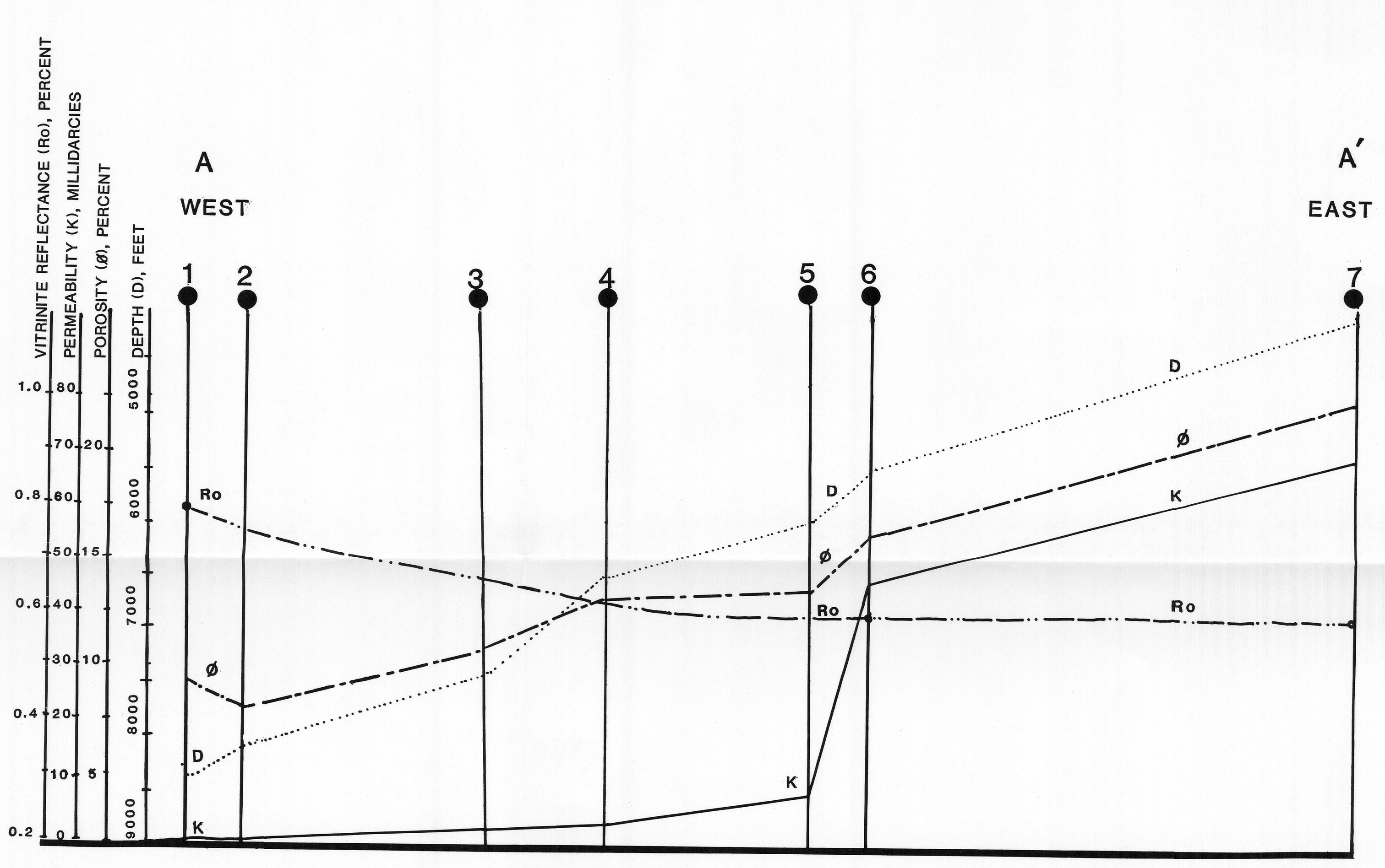



Figure 3.--Linear regression of median porosity against vitrinite reflectance ($R_o$) for the J sandstone. Open diamonds represent measured $R_o$ values from which core porosity values were available, while closed diamonds represent values extrapolated from the vitrinite isoreflectance map (Higley, Pawlewicz, and Gautier, 1985) and the porosity contour map and compared to sample depth.




Cross section A-A′ illustrates the relationships among depth (D, in feet), porosity (Ø, in percent), permeability (K, in millidarcies), and thermal maturity ($R_o$, in percent) of the J sandstone in the Denver basin.

## EXPLANATION

● 18.7 BOREHOLE--Showing median core porosity, in percent. Numbered wells are shown in cross section A-A′

—12— LINE OF EQUAL MEDIAN POROSITY--Contour interval 2 percent porosity

—12— LINE OF EQUAL MEDIAN-POROSITY TREND--Contour interval 2 percent porosity

## INTRODUCTION

The Lower Cretaceous J sandstone of the Dakota Group is present in the Denver basin in eastern Colorado, southeastern Wyoming, and southwestern Nebraska. Deposited during a regression of the Cretaceous epicontinental sea, this informally named unit is composed primarily of sandstone and shale of deltaic and nearshore-marine origin. The J sandstone can be divided into an upper transgressive sand, a middle marginal-marine and deltaic facies, and a lower prodelta sequence (Clark, 1978). The depth from the surface to the top of the J sandstone increases from about 4,000 ft on the gently-dipping eastern flank of the basin to more than 8,000 ft at the basin axis near the steeply-dipping western flank.

Porosity data compiled in this study were determined from J sandstone cores from 134 widely spaced boreholes. Porosity in areas of poor core coverage was determined from neutron density logs from an additional 20 boreholes (corrected to core average grain density). Median, rather than average, porosity was used in order to minimize the statistical effect of anomalously high and low porosity values. Thirty-five oil companies and independent operators supplied core porosity data. Core porosities were determined by means of helium porosimetry, primarily by Core Laboratories of Denver, Colo.

## METHOD OF ANALYSIS

The sampled cores vary as to the tested interval and thickness of J sandstone, but cores mainly represent sandstones of the middle marginal-marine and deltaic facies. Prodelta sandstones were sampled in a few wells when middle unit sandstone porosities were not available, and porosities of those samples are also included in the data set. Core was submitted to Core Laboratories for analysis over a 25 year period, although data analyzed from 1975 to present were used where available. Cores were sampled in one-foot increments, from intervals ranging in thickness from 8 to more than 60 ft, and averaging about 30 ft.

Plots of median porosity and of third-order median porosity trends were constructed using the Dynamic Graphics, Inc., Interactive Surface Modeling[1] (ISM) computer mapping package. Trend analysis utilizes polynomial equations to determine the slope of a plane that is the "best fit" of the data. The degree of polynomial chosen in the trend analysis depends upon which map features are to be delineated. For example, a first-order trend, requiring a first-order polynomial equation, only shows broad regional trends while successively higher order surfaces fit the data more closely, showing more local effects. For a detailed explanation of trend-surface analysis refer to Davis (1986).

A third-order trend surface was chosen for J Sandstone porosity because it shows regional porosity effects and large-scale local effects, such as areas of high porosity where delta systems enter the basin. Higher order trends can be used to identify successively smaller local features; however, effects of noise and computational errors may also be introduced.

Cross section A-A′ illustrates changes in permeability, porosity, and degree of thermal maturation (as indicated by vitrinite reflectance) with depth across the basin. The relationships among these variables is also indicated on figures 1-3. The least-squares linear regression of the two correlated variables on each figure is the regression line. This line is the "best fit" of the data.

## DISCUSSION

Porosity trends in the Denver basin are interpreted as follows:

1. The deepest parts of the basin are about along a line joining Denver, Colo., and Cheyenne, Wyo. In general, the lowest porosity and permeability and the highest vitrinite reflectance values are found here.

2. Porosity decreases markedly from east to west as burial depth increases in the basin, ranging from a high of 25 percent porosity at 5,000 ft depth to 5 percent at 7,800 ft. The relationship between porosity and depth (fig. 1) is approximately linear, and the correlation coefficient is -0.92. This relationship accounts for the approximate north-south alignment of porosity contours.

3. A region of high porosity extends from the southeast to the northwest and covers most of the southeastern quarter of the contour map. This region corresponds in size and location to a large northwesterly-prograding delta system interpreted by Haun (1963). The delta system contains high-porosity and high-permeability distributary-channel sandstones. This area is visible on the porosity trend map. The high-porosity area results in trend contours that are convex towards the basin center. Haun also identified a small delta system which enters the basin from the southwest, but existing data points are insufficient to delineate this system.

4. Porosity increases approximately linearly with an exponential increase in permeability, (cross section A-A′ and fig. 2). The correlation coefficient of porosity to permeability is 0.5. The low correlation coefficient is due largely to the highly variable permeability values of the core samples; values may range from below the detection limit to hundreds of millidarcies for samples from within a small vertical or horizontal distance of one another.

5. Porosity decreases linearly with an exponential increase in $R_o$ (vitrinite reflectance) (fig. 3). The correlation coefficient of porosity to vitrinite reflectance is 0.67. The porosity-$R_o$ relationship is primarily a function of a third variable, burial depth (and associated temperature effects), which strongly affects the magnitude of both porosity and vitrinite reflectance.

6. Indicated on cross section A-A′ are general relationships among vitrinite reflectance, porosity, permeability, and depth across the basin. Both major trends and local effects are indicated on the cross section; for example, compared to porosity and permeability for the cross section as a whole, porosity and permeability appear anomalously low for corehole number 5. Local depositional effects are indicated by the lower porosity and permeability of nonchannel sandstones of corehole number 5 than of the channel sandstones of corehole number 6.

7. Numerous porosity anomalies on the map, as evidenced by small, closed contour patterns ("bulls-eyes"), result from the core sampling and analysis methods, the highly variable porosities and permeabilities in cores, and the computer mapping method used. The mapping technique involves strict mathematical calculation of contours with a nearest-neighbor type of gridding algorithm.

## ACKNOWLEDGMENTS

Kathrine B. Krystinik, of the U.S. Geological Survey, assisted with statistical and computer applications; Mark Pawlewicz, of the U.S. Geological Survey, provided vitrinite reflectance analyses; Roy Gallop of Core Laboratories, Denver, Colo., forwarded the core-analysis data for approximately 120 wells; many oil companies generously released core data. The assistance of these individuals and companies is gratefully acknowledged.

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[1] Any use of trade names is for descriptive purposes and does not imply endorsement by the U.S. Geological Survey.

# MEDIAN-POROSITY CONTOUR MAPS OF THE J SANDSTONE, DAKOTA GROUP, IN THE DENVER BASIN, COLORADO, NEBRASKA, AND WYOMING

By

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