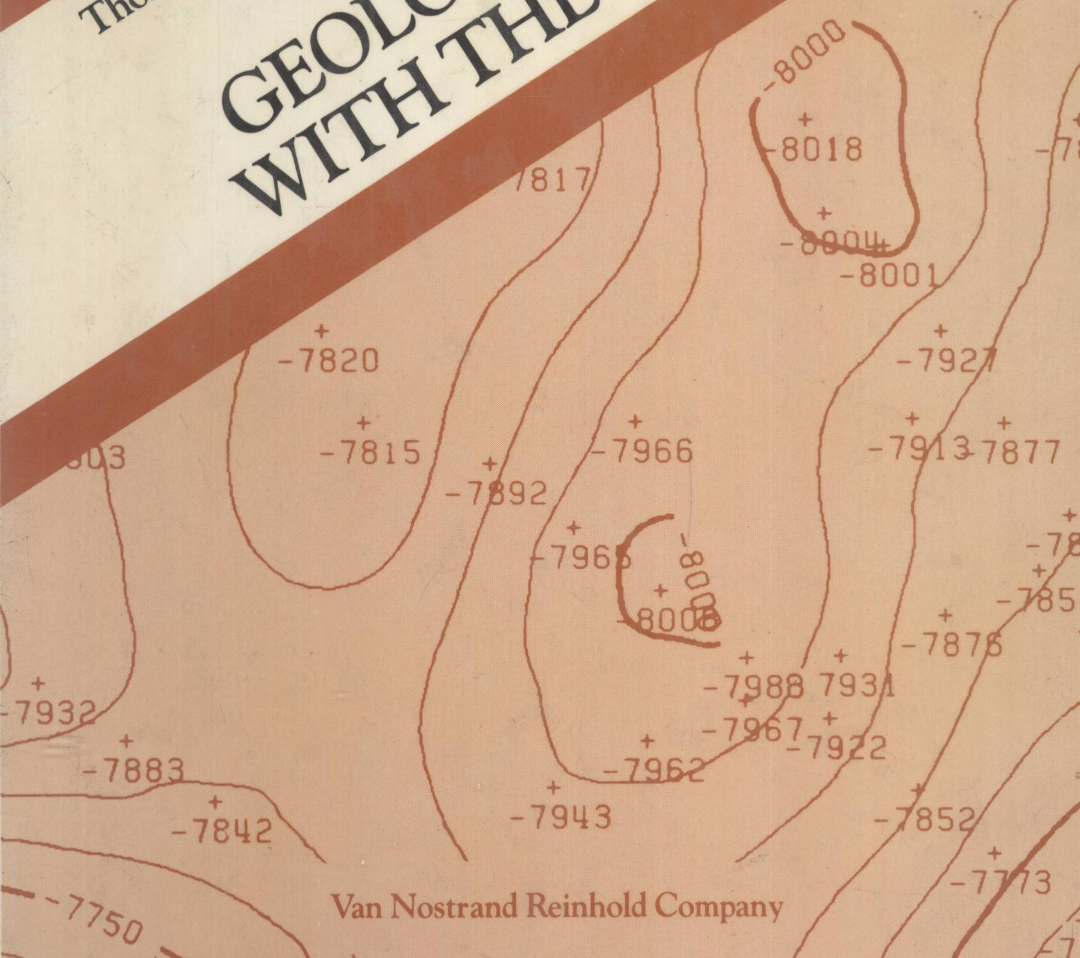
COMPUTER METHODS
IN THE GEOSCIENCES

Thomas A. Jones / David E. Hamilton / Carlton R. Johnson

CONTOURING GEOLOGIC SURFACES WITH THE COMPUTER



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Contouring Geologic Surfaces with the Computer

COMPUTER METHODS IN THE GEOSCIENCES

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Series Editor's Foreword

Graphics are the end product of any analysis, whether as a listing or multicolored computer CRT display, and are the aspect of any project that probably receives the least attention from the analyst. Graphics, of course, are important because of the influence on the interpretation depending on the presentation. Although graphics take many forms, contouring two-dimensional surfaces is one of the most important and widely used techniques used by geologists and other earth scientists. It is in this manner that three-dimensional aspects can be represented in two-dimensional space. Combine with the computer the various methods of contouring and the representation of results by this form, and you have a powerful tool to analyze data.

The development and implementation of software generally has been dependent on the development of hardware. Because of the small but powerful microcomputer and many software packages developed both in academia and industry, mapping software is now available. Consequently, there is a need for guidance in the use of different mapping methods. *Contouring Geologic Surfaces with the Computer* provides the background desirable for those interested in spatial analysis, including information on the data, methods, applications, and interpretation—all of a practical nature.

As the authors note, the book is not meant to be a user's manual but a supplement to acquaint the reader with the subject. Method coverage is inclusive: introduction, concepts, data, gridding, displays, and applications. Geological coverage concentrates on mapping structural surfaces and thickness intervals. The authors justify their contribution by outlining the advantages of the use of computers for mapping: (1) for manipulating large quantities of data; (2) for speed; (3) for manipulating maps; (4) for updating; (5) for objectivity and consistency; and (6) for incorporating geologic interpretations.

Contouring Geologic Surfaces with the Computer fulfills the objectives of the series well. It is written by geologists for geologists, the topic is of considerable interest, and little is available in one place on the subject. The value of this contribution lies in its practicality—the authors routinely use what they present here—and that use supplements and enforces the geologist's experience. Again, as noted by the authors, "Geological interpretation and the computer cannot be treated separately, but must be closely interwoven." They demonstrate this symbiotic relationship well.

The book can be used by students and practitioners alike. It may be a primary source of information for some, a text and supplement, and a reference for others. It is appropriate for regular course instruction, short courses, or self-study. With the fast moving developments of the field, this book is "must" reading for all those interested and involved in computer applications to solving geological problems.

D. F. MERRIAM

Preface

Computers started becoming generally available to earth scientists during the early 1960s. Since then, the use of computers has expanded manyfold, both in academia and in industry. Indeed, attendees at recent national geological conventions cannot fail to have noticed the many vendors exhibiting computing equipment and programs. The generation of contour maps is a major application of such products. Paralleling the development of the computer, contour-mapping packages have grown from primitive programs to complex integrated systems.

We continue to observe many situations in which the computer and mapping program are used as a "black box." Data are passed to the machine without special instructions, and the resulting maps are accepted without question, even though the maps ignore (or even violate) geologic knowledge or interpretation. Modern sophisticated programs have the capability to incorporate geologic information, and geologists are negligent if that information is not used.

In this book, we stress that two types of information are available for the typical mapping project. The first type consists of the well-known data points. However, the second type of information — often ignored or not recognized as such — consists of geologic knowledge, principles, and interpretation. Maps that are constructed without taking this important information into account could be in error.

The purpose of this book is to introduce tools or methods that allow a geologist to use a mapping program so that it incorporates geological interpretation during contour mapping. Many geological variables are mapped, but applications that involve structural or stratigraphic surfaces continue to dominate. In this book we therefore concentrate on methods for mapping structural surfaces and thickness of intervals between such surfaces.

Application of these methods can prevent such unreasonable results as structure maps containing contours where the surface is known to be missing due to truncation or nondeposition, faults with inconsistent throw, faults treated as folds, or thickness maps with unrealistic, wandering zero contours. These methods also can aid in calculating reserves or correcting mis-ties in geophysical surveys.

The methods we present are just that—general methods to be applied with the program the geologist has available. The program need not be specially tailored because most modern mapping systems can be used without reprogramming. Each of these methods is essentially a series of steps using program options that allow introduction and modeling of geologic interpretation.

Our techniques are not tied to a specific program; they are generic. They are not discussed in terms of specific program parameters, but in terms of general capabilities. Neither are the methods limited in terms of style of operation; they are applicable for interactive processing or batch-submitted jobs, for micros or mainframes.

Our intended reader is a geologist with access to a modern mapping program and enough experience to be able to enter data and obtain simple maps. Such a person can immediately use the methods discussed here. This book is not a replacement for the program user's manual, but is meant to be a supplement.

The book essentially consists of three parts. The first part covers introductory and review material, data entry, and simple contour mapping. The second part is concerned with special data considerations, faulting, and mapping sets of structural-stratigraphic horizons. The third part discusses miscellaneous applications and extensions of the previous concepts, including trends and bias, volumetrics, and construction of paleocontour maps. Appendixes describe required program capabilities and present a set of example data.

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This book is based on research at Exxon Production Research Company during the past 15 years, although Exxon does not endorse or sponsor the book. We thank Exxon for permission to publish this material; special thanks are due to Al Rogers and George Thomas for extra effort on our behalf. Exxon also furnished drafting services.

Bill Byrd, Jim Downing, Steve Hunt, Chuck Iglehart, Kevin McCarthy, Kermit Graf, and Robert Palmquist read all or part of the manuscript and made many helpful suggestions.

We also thank our many colleagues, past and present, who contributed to our knowledge of computer mapping, either through development of Exxon's mapping program or by discovering processing techniques. Among many others, these include Bill Byrd, Henry Dumay, Doug Fenton, Ian Grierson, Dan Hayba, Ron Herdman, Mona Hobby, Neal Jordan, Joe Klingshirn, Mark McElroy, Danny Phillips, Brian Proett, Bill Ryman, and Bob Wilbur.

We also thank Toby Turner, Bill Tippit, and Doug Palkowsky for providing encouragement, aid, and support.

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Contents

CHAPTER 1

Computers, Contouring, and Geologic Interpretation

INTRODUCTION TO COMPUTER MAPPING

Geologists routinely perform three-dimensional analyses to understand and describe spatial relationships, but the typical mode of display—maps and cross sections—is two-dimensional. Contour maps are useful for this analysis, and as soon as the computer became available to the geologic community in the 1960s, interest arose in generating such maps by computers. The early programs were primitive, but they showed that the computer could be a valuable mapping tool.

Rapid improvements in storage capacity and computational speed enabled these primitive programs to grow into sophisticated mapping systems. At present, many contour-mapping programs, with different levels of capability, are available for many machines, from mainframes to microcomputers. This abundance of programs would not exist unless substantial advantages were associated with computer mapping.

Advantages of Computers for Mapping

Geologists have determined computers to be valuable mapping tools because modern programs offer important capabilities.

Manipulate large quantities of data. Modern technology allows measurements on many variables to be collected quickly, providing numerous data points. It is difficult to handle so much information, and the ability to store and manipulate large amounts of information is an important aspect of computer mapping.

Speed. The computer can contour data more rapidly than can a geologist, especially when a series of maps must be constructed. Creating several maps with the computer requires little more effort than creating one, whereas the geologist might require an equal additional amount of time to draw each map.

Manipulate maps. It may be necessary to manipulate old maps to create new ones. For example, one structure map may be subtracted from another to create a map of thickness of the intervening interval. This process requires tedious cross-contouring by hand, but the computer can operate quickly on two surfaces to create a third.

Updates with little effort. Easy updates are an important advantage; if additional data are obtained after a map is created, an update requires that the steps done previously be repeated. With the computer, virtually no effort is required, but manual updating can require as much time as did the original map. Even if only a few points are added, computer processing has an advantage. A geologist with an existing map typically modifies it locally to accommodate the new data. As time goes on, patching new points into the old interpretation can degrade both the appearance and the geological reality of the map. However, independent analysis of the combined old and new points could lead to a new interpretation and major revision.

Objective, consistent maps. Studies comparing computer- and hand-drawn maps indicate that well-designed programs draw maps that are reproducible, consistent, and objective. Dahlberg (1972, 1975) gave subsets of data points from known areas to experienced geologists. The points were contoured both manually and by computer, and the maps were then compared to the known geology. The geologists differed in accuracy, and the computer was at an intermediate position. Dahlberg determined that the computer-generated maps were basically an average of the various geologists' interpretations; he concluded that computer mapping is objective. Modern programs allow the user great flexibility in controlling the appearance of the map.

Incorporate geologic interpretation. Stratigraphic relationships (e.g., truncation) in a region may be incorporated through generation and mapping of subcrop lines. Procedures described in this book allow the incorporation of geologic interpretations into objective computer-drawn maps.

A potential disadvantage of computer mapping is the data-hungry nature of the computer. Best maps are obtained if many data points are available. Further, unreasonable extrapolations in areas of poor data control are possible. However, even with small data sets or if the advantages listed above do not apply, when data are in digital form it is usually worthwhile to create maps with the computer, if only to give a quick look at the data.

Studies Appropriate for Computer Mapping

Not all projects are appropriate for computer usage, and some may profitably be done by hand. However, projects with the following characteristics are recommended for computer processing.

Large data sets. Projects involving large data sets, with several thousand points, can only be done efficiently with the computer. This mapping can range from geophysical surveys in frontier areas to regional studies in densely drilled areas.

Computer-accessible data. If the information is already in a computer database, the project is a good candidate for the computer. Much time in mapping projects is taken up with data gathering and handling. With the information in an accessible form, the geologist can concentrate on mapping.

Updates. Experienced computer users know that data gathering, organization, and input can require a large effort. Similarly, putting together program instructions can be time consuming. In fact, it is not unusual for a first-time study to take longer when it is done by computer than when it is done by hand. However, subsequent computer work with additional data may be finished more quickly than with manual methods. If program instructions are saved, later repeats with added or updated information can be done more rapidly than the original study. Similarly, minor modifications to the original process rarely add substantial time to completion. In short, an appropriate project for the computer is one in which updates are expected.

Need to test multiple hypotheses. Another aspect of repeated mapping occurs when multiple hypotheses are tested. For instance, faulting may be known to exist in a region, but it may be possible to interpret the faults in many ways. When mapping is done by hand, time constraints typically force selection of the one interpretation that seems most likely, and the map is drawn accordingly. When the computer is used, the basic dataset remains the same, but the program instructions change from situation to situation. Testing four hypotheses with the computer may take no longer than testing one by hand.

Need for analysis by other programs. Extensive manipulation or analysis may be done on mapping results, usually by using other programs to analyze the computer's representation of the maps. For example, special programs using computer maps speed the difficult task of mine planning and scheduling. Estimation of petroleum reserves, reservoir simulation, and statistical analysis are other uses of mapping results.

INCORPORATING GEOLOGIC INTERPRETATION

In the previous section, we pointed out the objective nature of computer maps as well as the ability to test multiple hypotheses. These features are not contradictory, as geologic interpretation can be introduced by various methods. In fact, the main theme throughout this book is the inclusion of geologic interpretation into structural and stratigraphic mapping.

Both geologists and computer scientists tend to ignore interpretation in computer mapping, possibly because it is difficult to quantify. Anyone who expects a computer-mapping program to operate effectively when only measured data is supplied will be disappointed. When this happens, the geologist usually believes that computer mapping is not useful, when in reality the lack of a strong and well-integrated geologic interpretation is responsible for a set of incorrect maps. If the geologist does not operate the program, it is his or her responsibility to provide interpretation to the mapmaker and to understand the mapping process. Geologic interpretation and the computer cannot be treated separately, but must be closely integrated.

Types of Projects

A wide variety of projects, ranging from simple to complex, are often handled by the computer. A simple project involves one or more surfaces that do not intersect one another. Complex projects involve several surfaces, some of which intersect one another. The computer-mapping procedures used for simple and complex projects are different. However, modern complete mapping systems available today have capabilities to handle both types.

Simple single-surface projects assume no other horizons exist, as shown by the cross section in Figure 1.1A. This is clearly an unlikely assumption, as such an isolated surface is rare. Mapping the data directly is usually all that is required. However, special processing might be required to incorporate such interpretation as trends or faults into the map. This type of project includes mapping such geologic attributes as geochemical content, rock density, porosity, magnetic field strength, and many others.

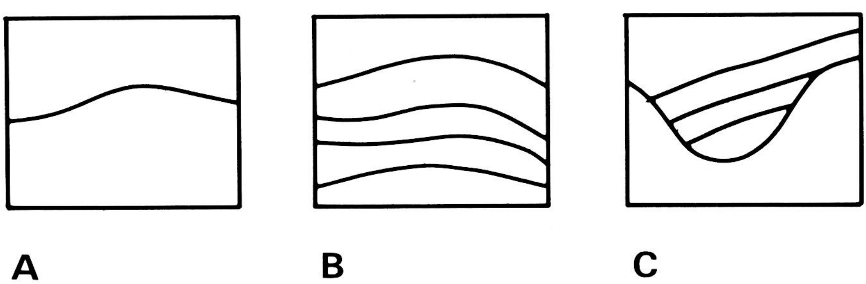

Figure 1.1 Cross section diagramatically showing the major types of surface mapping projects. *(A)* Simple single-surface: one independent surface. *(B)* Simple multiple-surface: several conformable or nonintersecting surfaces. *(C)* Complex multiple-surface: several surfaces involving baselap or truncation.