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THE EFFECTIVENESS OF TWO AND THREE DIMENSIONAL ISARITHMIC SURFACES IN COMMUNICATING MAGNITUDE, GRADIENT, AND PATTERN INFORMATION.

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THE EFFECTIVENESS OF TWO AND THREE DIMENSIONAL ISARITHMIC SURFACES IN COMMUNICATING MAGNITUDE, GRADIENT, AND PATTERN INFORMATION

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THE EFFECTIVENESS OF TWO AND THREE DIMENSIONAL
ISARITHMIC SURFACES IN COMMUNICATING MAGNITUDE,
GRADIENT, AND PATTERN INFORMATION

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CHAPTER I

INTRODUCTION

There are four basic languages by which people communicate and express ideas, observations, concepts, and accumulated knowledge with one another: words, numbers, music, and graphics (Ackerman, 1957, 109). Guilford (1959, 469-479) identified as many as 120 aspects of intelligence and concluded that they could be grouped into four basic types; figural, symbolic, semantic, and social. Balchin (1976, 33), in referring to Guilford's groups, suggested that these four types encompassed the four basic modes of communication used by humans; however, as Balchin contended even though man has the innate potential to develop these skills, they can only come to full realization with education. Writing ability has as its educated counterpart, literacy; audio ability, articulacy; numeric ability, numeracy; and visual spatial expression, graphicacy. Graphicacy encompasses a wide spectrum of visually oriented fields including cartography, computer graphics, photography, graphic arts, and geography (Balchin, 1976, 33-34). Even though man has effective verbal and written language, graphic language[1] is unique in its ability to present data in a highly condensed visual

[1]The term language refers to any mode of communication. Robinson and Petchenik (1967) offer strong philosophical arguments that maps and language, as systems, are "essentially incompatible". The phrase 'maps as graphic language' is intended to mean only a mode of pictorial communication. A philosophical discussion of maps and language can be found in Robinson and Petchenik's Nature of Maps.

format which enables many viewers to comprehend more effectively the expressed idea (Davis, 1911; Balchin and Coleman, 1966; Brooks, 1970).

Graphic portrayal is accepted by the scientific community as an effective communication mode because visual representation tends to produce a clarifying effect which allows the individual to comprehend complicated phenomena which cannot be successfully communicated by the three other communication modes (Reichenbach, 1958, 101; McCleary, 1972). Boas (1964) suggested that "scientists often resort to pictures to illustrate a point which cannot be made in words"; how often does one turn to a sketch, graph, picture, or map to help clarify a confusing idea or concept? The time tested adage that "a picture is worth a thousand words" conveys the idea that maps, as one form of a graphic, help man communicate spatial information more effectively than other forms of communication.

There is no doubt that cartography, as Monmonier (1977, 9) stated, is the "study of mapping methods and map communication"; therefore, it becomes essential to begin to investigate more scientifically the efficiency of maps from an information communication viewpoint (Robinson and Petchenik, 1975, 1976). Even as basic as this concept may be, research into the communication aspects between the map and map reader has not been a major research concern until recent decades (Robinson and Petchenik, 1976, 23). The relationship between mapping technique and the perception of cartographic information within a communication framework is the focus of this research. If, according to Balchin (1976), visual spatial expression has as its educated counterpart, graphicacy, then consideration of the map as a cartographic communication system is warranted.

Problem Statement

Does the addition of depth by the use of a three dimensional isarithmic mapping technique to a graphic surface significantly increase the recognition and perception of magnitude, gradient, and pattern information displayed on the mapped surface? This question represents the problem that is the focus of this research.

Cartographic variables which affect the transfer and processing of information such as the graphic dimension of the map, complexity of map surface, map reader viewing angle, and map reading ability of the viewer were controlled in the experimental design. Consequently, the influence of such variables on information transfer from two and three dimensional maps were assessed. As such, the appropriateness of certain principles of information theory and processing and visual perception to map interpretation are assessed in an attempt to place map perception concepts on a sounder theoretical base.

Robinson and Petchenik (1976), in their preface to Nature of Maps, discussed the growing need for cartographers to address themselves to the communication effectiveness of the maps they create. As they pointed out ". . . until recently the way in which a map accomplishes what its maker intends, and how it relates to other forms of knowing and communication, have not been subjects for study, least of all by cartographers" (Robinson and Petchenik, 1976, viii). They further suggested that research in map communication has two objectives:

> ". . . to gain specific understanding that will lead to improvements in practial information transmission, and to solutions, of limited problems. In cartography this includes the psychophysical investigations of scaling symbols and the comparision of the communicative effectiveness of various types of maps. The second objective of research is to acquire understanding of a more general and fundamental nature that can be used to augment or construct comprehensive theory. Such research includes the study of communication by means of maps (sometimes called metacartography), and often seems of little or no immediate practical applicability. On the other hand, research done for the first purpose, practical application, often contributes little to the progress of theory development" (Robinson and Petchenik, 1976, ix).

This research contributes to both areas of concern, practial applications of various types of maps in transferring information, and augmentation to the body of theory concerning a further understanding of the interrelatedness of communication and psychological principles involved in the cartographic process.

Maps As Graphic Communication Systems

The map[2], a specific form of a picture[3], represents the most effective graphic format of recording and communicating locational information between intelligent human beings (Davis, 1911, 33; Ackerman,

[2]The term map has been defined by many cartographers and geographers. Perhaps the most universally cited, but traditional, is the definition by the cartographer Erwin Raisz:

> "A map is a selective, symbolized, and generalized picture of some spatial distribution of large areas, usually the earth's surface, as seen from above at a much reduced scale" (Raisz, 1938, 1-2; Raisz, 1962, 32).

The contemporary definition, which in no way violates the definition by Raisz, is stated in The Multilingual Dictionary of Technical Terms in Cartography (1973, 1) as follows:

> "The art, science and technology of making maps together with their study as scientific documents and works of art. In this context maps may be regarded as including all types of maps, plans, charts, and sections, three-dimensional models and globes representing the Earth or any celestial body at any scale."

Robinson, Sale, and Morrison (1978, 3) aptly point out that this definition encompassed elements which indicated that cartography was but one subdivision of the communication skill, graphicacy. Furthermore, Robinson and Petchenik (1976, 16) defined the map in a more generalized term as ". . . a graphic representation of the milieu." This included topographic, cadastral, thematic, and even cognitive maps. The term map in this dissertation refers to the general category of thematic maps.

[3]The term picture denotes a variety of graphic formats; pictures may be a photograph, painting, line drawing, graph, or any image which portrays objects at various levels of abstraction (Arnheim, 1969, 137-138; Kennedy, 1974, 29). A map is one form of a pictorial graphic which functions as an iconic representation of reality with its features recorded in symbolic, not literal form (Churchman, 1957, 158; Heath, 1958, 22-25; Boas, 1964; Board, 1967, 671-725; Blaut and Stea, 1971, 387-393).

1957, 109; Miller, 1964, 13-19; Keats, 1972, 169). It not only communicates recorded spatial phenomena, but represents a permanent visual display which enables viewers to convert data into usable information. The map, therefore, represents an organized and efficient attempt to communicate spatial concepts (Board, 1973, 228) and the explanation of geographic phenomena (Ackerman, 1957, 108; Harvey, 1969, 9-22).

Three interrelated concepts are intrinsic to every map; a map is a visual communication system (Dornbach, 1967), comprehension of mapped data involves the process of visual perception (Kolacny, 1969), and data transformed to information, are dependent upon the map reader's perception and cognition of the mapped data (Kolacny, 1969). If the map is to be used more effectively as a graphic communication system, then greater understanding of the cartographic process is needed as it relates to visual perception and information processing.

Cartographic Surfaces

There is no doubt that advances in the field of cartography have resulted in the refinement and development of new techniques (Devine, 1972, 82-88; Morrison, 1974a, 5-14; Robinson, 1979). A review of cartographic literature revealed that the state of the science has progressed from the mapping of absolute space, as was reflective in exploration, cadastral, and topographic maps, to one concerned with mapping relative space, mental images, and statistical surfaces (Abler, Adams, and Gould, 1971, 54-90; Gould and White, 1974;

Downs and Stea, 1973, 1977). A review of current geographic texts and journals substantiates this trend toward mapping conceptual and abstract forms of data.

One of the most common formats used to represent these conceptual and abstract data sets is the mapping of quantitative geographic values as represented by a statistical surface. Very often the nature of the mapped data will be an intangible or abstract notion such as amount, value, or index (Muehrcke, 1972, 7) which is subsequently displayed thematically. Jenks (1973, 27) defined the thematic map in the following manner:

> "A thematic map is a small scale, highly generalized, special purpose map used by an author to communicate information about a geographic distribution. Each thematic map is a simplified model of some aspect of the real world as it is perceived and interpreted by the cartographer designer. It is also clear that many thematic maps are highly intuitive in character since the map model represents an 'unseen' or intangible phenomena."

Just as mappable data has become more abstract and technical, so has the method of graphic portrayal; two such methods include isarithmic and three dimensional perspective maps.

Isarithmic Maps[4]

One functional purpose of isarithmic mapping is symbolization of the relationships among continuous numeric values of the distribution

[4]The cartographic literature contains numerous terms used to depict quantitative areal distributions with the use of lines connecting points of equal value. Terms which have been used

(Hsu and Robinson, 1970, 4). The quantitative distribution is represented as a volume, and to comprehend visually any volume, it is necessary to perceive the shape of the outside area enclosing that volume (Robinson and Sale, 1969; Robinson, Sale, and Morrison, 1978). Viewer attention is focused upon various surface shapes which result from variation in the data; these variations result in surface forms such as hills, rises, passes and troughs (Hsu and Robinson, 1970, 4).

It is important to emphasize that isarithmic mapping does not present a direct pictorial representation of surface form, the pictorial quality is passive. The viewer must visualize forms on the surface as characterized by the shape, arrangement, and spacing of the isolines. Therefore, the visual effectiveness of the isarithmic map is in part affected by the training and experience of the map reader in discerning those characteristic shapes and patterns of the isarithms (Hsu and Robinson, 1970, 4-5).

interchangeably include isopleth, isoline, isobase, and isometric line. Discussion of these various terms can be found in Wright (1944, 653-654), Raisz (1948, 246-250), Blumnstock (1953, 289-304), Robinson (1961, 53-55), Warntz (1967, 8-10), Robinson and Sale (1969, 141-170), Monkhouse (1971, 39-43), and Robinson, Sale, and Morrison, (1978, 217-258). Isarithmic mapping, a more generic term, is used in this dissertation. "An isarithm" is defined as simply as the trace made by the intersection of a horizontal Z - level plane with any three dimensional surface" (Robinson, Sale, and Morrison, 1978, 225). Isarithms showing quantities that cannot actually exit at points are isopleths.

The isarithmic technique depicts a volume distribution conceptually rather than pictorially, therefore, it is not uncommon to find that three dimensional perspective diagrams are often used to supplement isarithmic maps (Hsu and Robinson, 1970, 5) thus suggesting the value of the technique in clarifying spatial concepts. The perspective map is used because it provides the map reader with a direct, pictorial format through the use of depth perception obtained with the addition of the third dimension (height) to the graphic.

Perspective Maps[5]

Schou (1962), in discussing block diagrams, emphasized that many spatial phenomena are three dimensional in nature.

[5]The three dimensional surface diagram is a perspective map which provides two linear dimensions, one each in the X and Y direction plus a third dimension, Z, which represents the magnitude of the distribution at given locational coordinates. A review of this method can be found in Maps and Diagrams: Their Compilation and Construction (Monkhouse and Wilkinson, 1971, 87-90). Block diagrams have been the primary use of this technique. Block diagrams are perspective maps of elevation, primarily used for depicting landforms. A review of this method can be found in The Construction and Drawing of Block Diagrams (Schou, 1962), and Elements of Cartography (Robinson, Sale, and Morrison, 1978, 234-242). An understanding of the construction method will provide a conceptual foundation for the mapping of numeric data with the perspective map. Although the term block diagram is generally associated with landform representation, it has been used recently to include the representation of quantitative data (Jenks, 1963, 15-26; Jenks and Brown, 1966, 857-864; Jenks and Caspall, 1967; Jenks and Crawford, 1967; Jenks and Steinke, 1971; Muehrcke, 1972, Peucker, 1972; Robinson and Sale, 1969; Robinson, Sale, and Morrison, 1978). Whenever social, cultural, or statistical data is represented in this format, the term used most readily is surface. The term perspective map in this dissertation refers to the mapping of such surfaces.

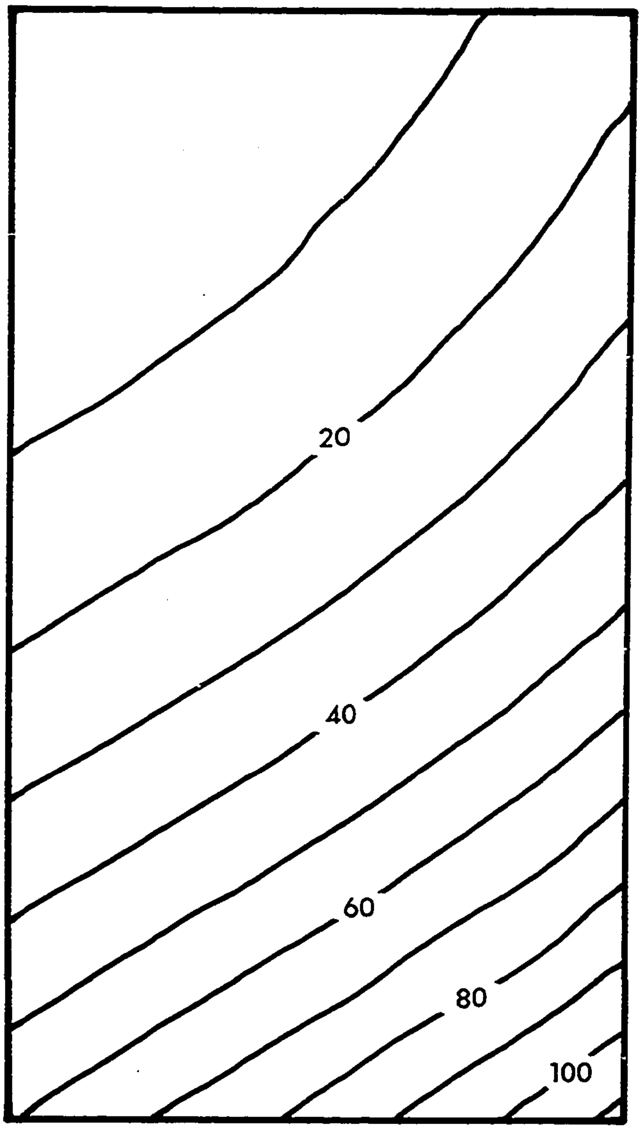
Although Schou was specifically referring to landform representation, quantitative mapping also possesses this three dimensional nature, a magnitude (Z) located at specific planimetric geographic coordinates (X, Y). Whereas a two dimensional representation of magnitude data, as in the case of the isarithmic map, is difficult to perceive, a three dimensional perspective map presents a directly observable pictorial format to the viewer. Schou (1962) further contended that since the perspective map provided this directly observable format to the viewer it has become a valuable instructional aid. Adams (1969, 45) supported this viewpoint by stating that maps, especially thematic maps, are two dimensional records of three dimensional data; data may be represented either in a two dimensional form (isarithmic) which must be interpreted or in a form (three dimensional perspective) which allows direct perception of the data.

The increasing adoption rate of these two methods can partially be attributed to advances in computer hardware and software technology. Historically, construction of these maps, especially the perspective map, was prohibitive, both in terms of time and money (Jenks and Brown, 1966), but computer technology has now made the use of these maps an economic, viable system for mapping quantitative data (Figure 1).

Although each map in Figure 1 displays the same data, the information transferred to the reader probably varies because the

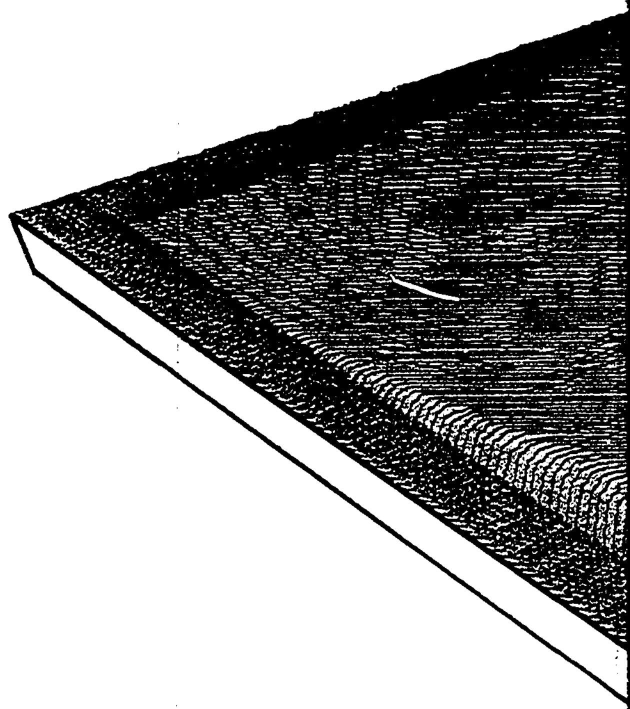
Figure 1

5th Degree Polynomial Su



Contour Interval=10

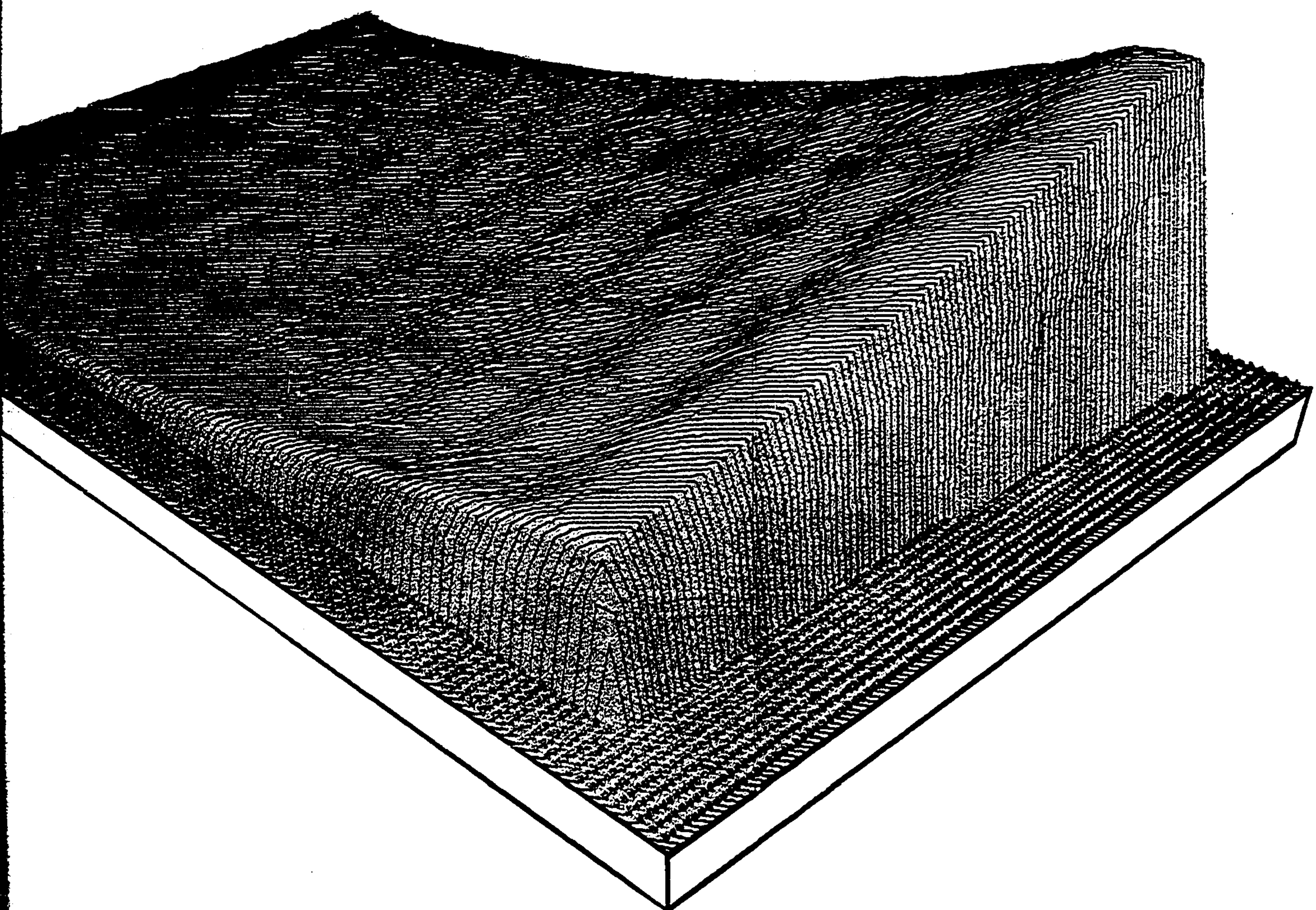
Two Dimensional Surface



11

Figure 1

Degree Polynomial Surface



Perspective Surface

physical structure of the visual stimuli of each map is different. Because the physical stimulus is different, the perception of information will vary with the graphic format.

The basic consideration then becomes, which graphic format, two or three dimensional, more effectively transmits spatial information (magnitude, gradient, pattern) to specific groups of map readers? If the current cartographic paradigm is accepted that a map is a functional tool of our society (Koeman, 1971) which helps readers learn something they did not know before (Dale, 1954, 539), then it must be determined what affect graphic dimension has upon the perception of spatial information if the cartographic process is to be truly considered as an informative communication system.

Structure of Analysis

Chapter I, introduction and background, is followed by Chapter II which examines the nature of the cartographic process as an information system, the nature of cartographic information, and specific types of information contained on two and three dimensional isarithmic surfaces. Chapter III presents the research hypotheses and rationale while Chapter IV details the experimental methodology used to determine the communication effectiveness. Chapter V provides an interpretation of results, and Chapter IV provdes a summary of results and future research considerations.

CHAPTER II

INFORMATION AND THE CARTOGRAPHIC PROCESS

Map Design and Communication

The purpose of the cartographic process is to communicate spatial information to the map reader effectively and accurately (Saunders, 1958). Although this goal seems relatively simple, many decisions are required of the cartographer. Assuming that the cartographer has perceived the milieu accurately, decisions must be made regarding the appropriate mapping technique, generalization of data, selection of symbols and design of the map. These and other components in the cartographic process are extremely critical if the map reader is to grasp the intended information. The entire cartographic process becomes effective only when the individual components of the map are properly arranged (Miller and Voskuil, 1964; Kingsbury, 1966).

Since the cartographer is not the intended map reader, a map should be designed to maximize information transfer to the map reader. This can be accomplished through various map designs. If the information effectiveness of various map designs can be determined, then cartographers can make the proper decisions regarding graphic communication. Map design involves many questions, but:

> ". . . the basic problem in all map design is to logically select and effectively combine a set of graphic symbols in order to display spatially distributed data in the most efficient, easily perceived manner"[1] (Delucia, 1972, 14-18).

The essence of the current cartographic paradigm is that the map must be designed to meet the needs of the map reader (Kolacny, 1968, 1969; Morrison, 1974a, 1974b; Robinson and Petchenik, 1976; Monmonier, 1977) or as Saunders (1958) contends, a map must be designed according to the informational purpose for which it is intended.

Static Display and Design

A common misconception is that maps are static displays of data, that data are unsystematically selected from a milieu and presented for general viewing. This paradigm held the position that the map should display every possible bit of data and let the map reader extract what was relevant to his needs. This notion was nurtured by the cartographer's subjective approach to map design and presentation, plus a lack of commitment to research into map design and user needs (Dornbach, 1967, 72).

[1]Although Delucia's definition relates directly to graphic symbols, the term map design also includes the process of selecting the display dimension, viewing angle, typology, line weight, color and so on.

Map design traditionally concentrated upon the cartographer's decision to select data and to determine an acceptable display style. The results were maps based upon creative efforts, or as a display mode for visual effectiveness (Dornbach, 1967, 55). In either case, however, the approach was subjective, for objective criteria were seldom used to make decisions. Of course, map construction cannot be totally objective, and every map will possess some degree of subjectivity since the map is created by a cartographer who bases his decisions upon his perception of the mappable milieu (Wright, 1942). However, the important fact is that when subjectivity dominates map design bias is introduced (Board, 1967, 675-680).

Even if a cartographer presented data in the most effective design, the reader could misinterpret the information represented by mapped symbols (Muehrcke, 1974b; 1978). Reader misinterpretation typically occurs because of a lack of scientific investigation into the needs of the map reader (Morrison, 1973, 1974b). If the map is to be an effective information system, then the needs of the map reader must be included into the design of the map[2] (Astley, 1969; Kolacny,

[2]A classic example of effective map design based upon user needs was accomplished by John Sherman in the mid 1950's. Sherman designed and produced maps which could be used by blind persons. Using materials with different surface textures, Sherman created a map which blind individuals could identify streets, sidewalks, paths, and buildings. His pioneering work in the design of this map system represents one of the early works in which map design was based totally upon user needs. A detailed discussion of his methodology can be found in "Maps The Blind Can See" (Sherman, 1955). Likewise, Sorrell's (1974, 82-90) "Map Design--With the Young in Mind" represents a current attempt to create and evaluate maps designed for young children.

1968, 1969; Gerlach, 1971; Wood, 1968, 1972; Morrison, 1973, 1974a, 1974b; Sorrell, 1974; Robinson and Petchenik, 1975, 1976; Robinson, 1977; Muehrcke, 1978).

Maps as Information Display Systems

One of the strongest statements advocating a change in the cartographic paradigm was by Arthur Robinson in 1966. In the forward to the second edition of The Look of Maps Robinson (1966, xi-xii) stressed that the cartographic process should represent an information display system with map design based upon user requirements. Furthermore, this task could only be accomplished if the cartographer applied basic principles of human visual perception (Robinson, 1966, 19; 1977). Other cartographers have supported this viewpoint more recently:

> "For any graphic produced for a certain situation or for a particular viewer, the major problem in design is to determine principles, materials, and techniques that can best provide the human eye-brain combination with the stimulation it needs to visually receive the informational content. If use of color, symbol design, and other methods of portrayal can be substantially validated through psychological and physiological studies, then cartographic design may be lifted from the realm of subjective creative expression, and placed in the field of functional design where experimental evidence concerning the behavior of man, the users of maps and charts, will support the display design applications of cartographers" (Dornbach, 1972, 68).

Since the mid 1960's, cartographers have been increasingly concerned with design, symbolism, and techniques and their effect upon cartographic communication (Wright, 1967; Dornbach, 1967; Castner and

Robinson, 1969; Castner and McGrath, 1971; Dent, 1971, 1972a, 1972b, 1973, 1975; Crawford, 1971, 1973; Delucia, 1972; Cox, 1973, 1976; Flannery, 1956, 1971; Cuff, 1972, 1973a, 1973b; Meihoefer, 1973; Phillips and Delucia, 1975; Muehrcke, 1976,; Dobson, 1977; Monmonier, 1974, 1977a, 1978; Robinson, 1977).

In an earlier work Dornbach (1967) stated that a map was ". . . physically designed by the cartographer but functionally designed for the map readers." He believed that map design could be categorized into three groups: 1) design as creative effect, 2) design for visual effectiveness, and 3) design for information presentation. He concluded that only those maps designed to convey specific spatial information to specific groups of map readers could be considered as effective communication systems.

Design Based Upon Psychological Principles

Map design for information maximization must consider psychological concepts, especially perception and vision (Dornbach, 1967, 62-64). While a trend towards incorporating psychological and psychophysical concepts into the design process is evident, most studies have analyzed only the psychophysical aspects of perception and symbolization (Flannery, 1956, 1971; Williams, 1956, 1958; Ekman and Junge, 1961; Ekman and Lindman, 1961; McCleary, 1970; Jenks, 1973; Dobson, 1977). To expand the scope of psychological investigation in cartography the cartographer must identify those "user needs" and design the map to convey a specific sub-set of information to that particular group.[3]

Cartographic Communication Process

Cartographic production consists of the following transformations: data are collected from the real world (the milieu), data are transformed into a representation of reality (the map), and information is obtained through the process of map reading (Heath and Sherman, 1958; Robinson, 1966, 1972; Tobler, 1968, 3-4; Olson, 1971, 108; Morrison, 1973, 1974a, 1974b, 1977; Robinson and Petchenik, 1975, 1976; Monmonier, 1977a). Koeman (1971, 171) concisely summarized the process as ". . . how do I say what to whom."

If the cartographic communication is defined as the process of transmitting cartographic information to a map reader (Kolacny, 1968, 1969, 1971, 66), its effectiveness can be conceived of as a ratio of the accuracy of information in the raw data to that which is obtained by the reader from the map. Ideally, the ratio should be 1:1 (Muehrcke, 1972, 12; Monmonier, 1977a). Transmitted information (I) is a function of not only the physical stimuli (X) but also individual perception (Y) of each viewer plus noise (Z)[4]:

$$I = f\ (X,Y,Z) \qquad (2.1)$$

[3]Dornbach (1967) applied his conceptual model to the design of aeronautical charts, however, his methodology can be applied to any cartographic format, especially thematic maps.

[4]Monmonier (1977b, 11-14) provided an excellent summary of the various noise elements which enter into the cartographic process and hinder communication. The following types are identified: author, design, reproduction, perception, vigilance, and interpretation.

If variables X and Y are considered into the design of the map and Z reduced to a minimum by design filters (Monmonier, 1977a), then the map can be considered an efficient communciation system.

Map information is transmitted in an iconic format through three basic physical components: lines, points, and symbols, or combinations of the three (Churchman and Ackoff, 1957; Board, 1967, 671-725; Robinson and Sale, 1969, 94-101; Monkhouse and Wilkinson, 1971, 83; Morrrison, 1974b, 115-127). A map, an accumulation of physical stimuli, transmits diverse information depending on the combination of physical components on the map. For example, an isarithmic map becomes more generalized as the isoline interval increases. Also, the map reader could perceive the components differently, this too could result in varying amounts of perceived information.

Cartographic Communication Modeling

If communication is to occur, the cartographic process must include the creation and the interpretation of maps (Astley, 1969; Kolacny, 1969, 47-49; Sheppard and Adams, 1971; Wood, 1972, 123). Kolacny (1968, 1969), has defined cartographic communciation as this process. According to Morrison (1974b, 116) the conceputal models of Board (1967), Kolacny (1969), and Ratajski (1973) represent the state of the act in depicting the cartographic process as a communication system.[5] Three characteristics are common to each model: 1) the system includes both the cartographer and map percipient,[6] 2) the map represents a channel of communication between them, and 3) the cartographer must convey his perception of reality (from the milieu) successfully to the map viewer. Kolacny and Ratajski's models form the basis for this research. A schematic diagram of each is shown in Figure 2.

Kolacny's Communication Model

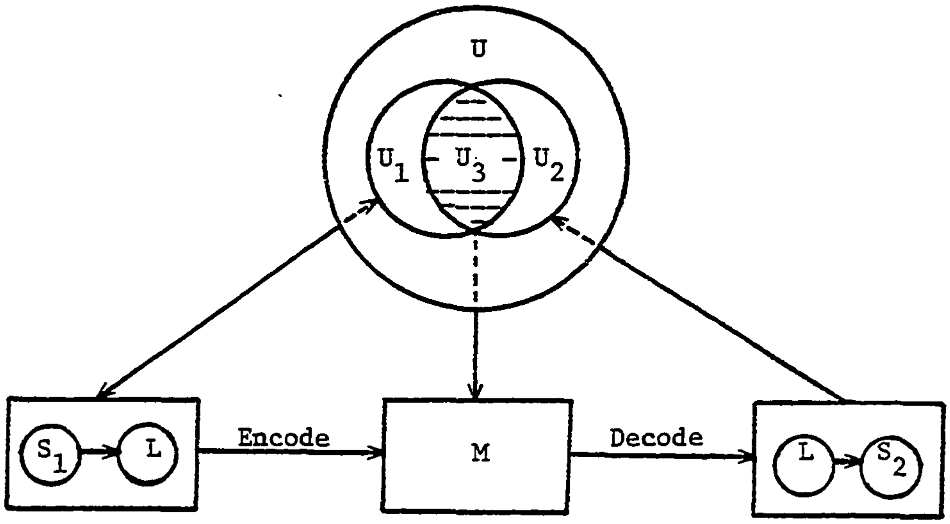
Kolacny (1968, 1969, 1971) was the first cartographer to call attention to the communication aspect of the cartographic process and

[5]The most concise and current examination of this topic is presented by Robinson and Petchenik in Chapter 2, entitled "The Map as a Communication System," in The Nature of Maps. As Monmonier (1977b, 246) has indicated in the review of this major new work . . . "this book might well be the most important work published in cartography this century. . . Had this collection of essays appeared in 1956, modern cartography would be more vigorous and relevant to map use than it now is. . .".

[6]Robinson and Petchenik (1976) have introduced several new terms to the field of cartography. The terms map reader and map user are now limited terms which offer no indication that the viewer has added to his spatial knowledge. They (Robinson and Petchenik) stated that these terms ". . . suggest operations similar to that of using a dictionary to find out simply how to spell or pronounce a word, which adds little if anything to one's understanding of the meaning of the word and therefore of the language to which it belongs." The term map percipient has been introduced to the discipline as a more meaningful term referring to those who view a map and increase their spatial knowledge. "The (map) percipient, one who obtains information about the milieu by looking at a map is coordinate with the cartographer, one who attempts to communicate spatial information about the milieu by making a map" (Robinson and Petchenik, 1976, 20).

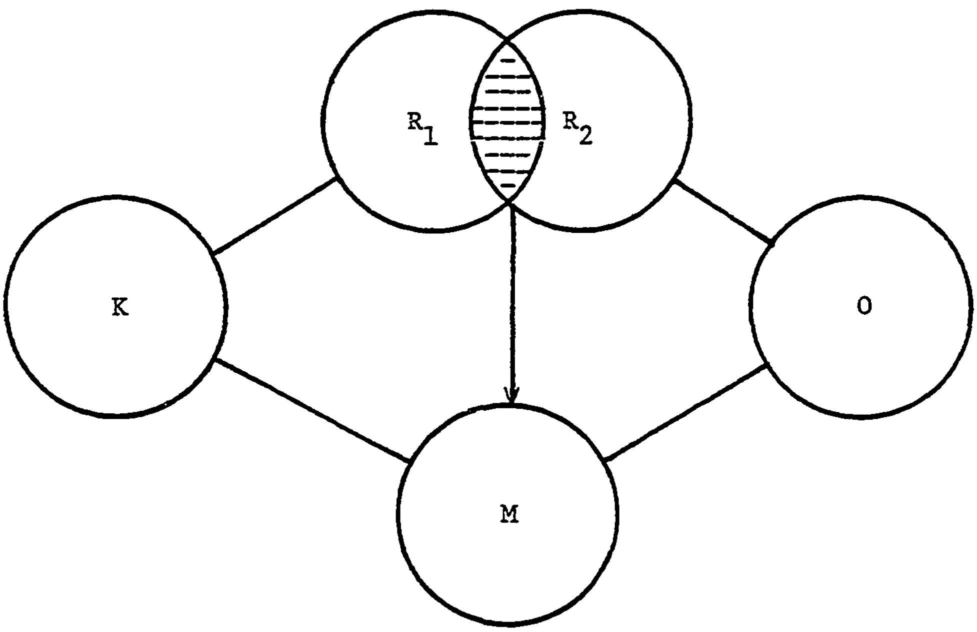
Figure 2

Communication Models of the Cartographic Process



Kolacny's Communication Model

Source: After Kolacny (1969, 48-49).



Ratajski's Communication Model

Source: After Ratajski (1973, 218-219).

develop a conceptual model. Components of the model (Figure 2)[7] include the milieu (U), the cartographer's perception of reality (U_1) from the milieu, transformation of the perceived data to a conceptual two dimensional model (S_1), expression of components of the conceptual model through the selection of map symbols (L), the map (M) as the iconic representation, perception of the mapped data by the viewer (S_2), and the viewer's perception of reality (U_2). The shaded area (U_3) represents that portion of reality which has been successfully conveyed to the map reader.

During this process input data (encoding by the cartographer) are transformed to information at the end state (decoding by the map reader). The ideal situation is for circles U_1 (perceived reality by the cartographer) and U_2 (perceived reality by the map percipient after viewing the map) to be congruent, for then the map viewer has perceived exactly what the cartographer intended. The cartographer's task is to maximize the overlap through functional design.

Ratajski's Communication Model

Ratajski's (1973, 219) model (Figure 2)[8], like Kolacny's, is concerned with the interface between perceived reality (R_1), the

[7] Figure 2 represents a generalized version of Kolacny's model with only the major components identified. A discussion of the model in its entirety is presented by Kolacny (1969, 47-49) in the article entitled "Cartographic Information - A Fundamental Concept and Term in Modern Cartography".

[8] Figure 2 represents a generalized version of Ratajski's model. A description of his model is presented in "The Research Structure of Theoretical Cartography" (Ratajski, 1973, 217-227).

cartographer (K), the map (M), the map viewer (O), and (R_2) the perceived reality by the map viewer. Although the two models are essentially alike, Ratajski placed additional emphasis on the transfer of cartographic information. He referred to this conceptualization of cartographic communication as 'cartology':

> ". . . a science that studies the expression and transformation of chorological information by means of a map. The map functioning as a source of transformed information enables the reader to become acquainted with reality" (Ratajski, 1973, 220).

The methodology of 'cartology' focused upon the functioning of cartographic transmission and the relationships to theories of map form and content (Ratajski, 1973, 222-224). He contended that a major component to the understanding of cartographic transmission was through the inclusion of perception theory and its relationship to graphic display and perceived information by the map percipient:

> ". . . this latter theory (perceiving cartographic information) covers such aspects as the relationship of the level and conceptual range of map content and form with the extent of intellect and memory of the map user; the ability to reconstruct a mental picture of reality; and the psychological and physiological process of perceiving" (Ratajski, 1973, 222).

Both Kolacny's and Ratajski's models provide a conceptual framework for an understanding of the cartographic communication process. Implicit in both models is the idea that a series of transformations take place in the entire process. An understanding of the various transformations provides insight to an understanding of the nature of various types of cartographic information.

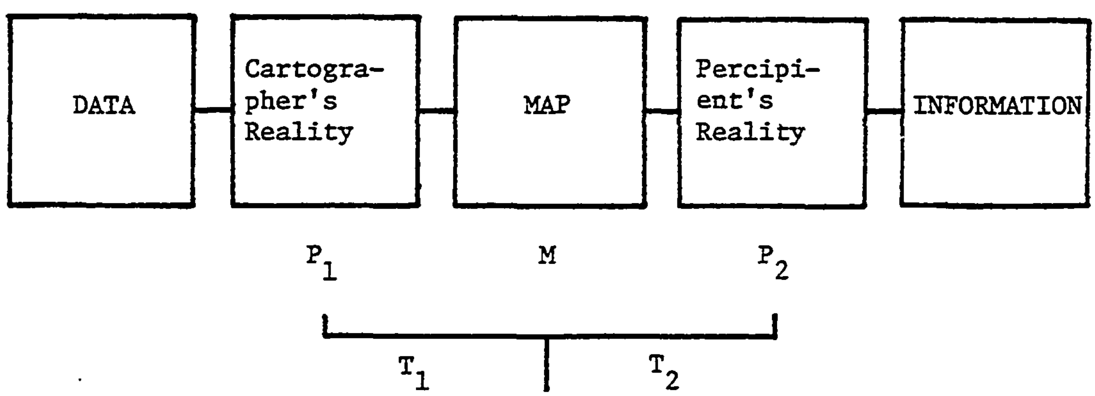
The Nature of Cartographic Information

For years, the term cartographic information has been the source of some confusion. Only within the last two decades have there been attempts to clarify the concept. A common misconception has been that 'data' and 'information' are synonymous. Much of the misuse of the term has been due to a lack of understanding of the physical and mental transformations which take place in the cartographic process.

Morrison's (1973, 1974b) model (Figure 3) illustrates the data to information transformation which occurs in the cartographic process. P_1 represents a subset of physical data as it is perceived by the cartographer; T_1, the composite physical transformation of perceived raw data to a set of points, lines, and area symbols by the process of generalization and compilation of the map (M); and T_2, the map viewer's mental transformation of map components. During

Figure 3

Morrison's Cartographic Model



Source: After Morrison (1973, 1974b).

this process from input of raw data to the perception of information, the 'viewer' becomes a 'percipient' only if he has perceived data to a specific level of information, that is, he now knows something regarding the distribution that he did not know before.

Morrison was not alone in his conceptualization of the transformation from data to information. Muehrcke (1972, 3-4) suggested that ". . . a measure of communication efficiency of the cartographic system is related to the amount of transmitted information, which is simply a measure of the correlation between input and output information". This concept parallels the principle of congruent circles (perfect correlation of the cartographer's and map percipient's reality) offered by Kolacny's and Ratajski's models. The concept of transformation from data to information seems relatively simple, but in reality, it represents a complex series of physical and cognitive processes.

Both Morrison's and Muehrcke's models provide a working structure for interpretation of Kolacny's and Ratajski's models. The cartographer's transformation involves the encoding of data as perceived from the real world. The viewer's transformation involves the perception of data to information through the process of decoding symbols from the map. The map, therefore, represents the cartographer's subset of real world phenomena and represents a set of physical elements of information to be conveyed. To the map viewer, however, the map represents data or potential information. The process of decoding involves the processes of perception and cognition of the visual stimuli. It is logical, therefore, to assume that alteration of the physical stimuli, the dimension of the map, will effect the viewer's perception of intended information.

Both Morrison's and Muehrcke's models emphasized the duality of the cartographic process, the cartographer's representation of reality and the map viewer's perception of that reality. Likewise, they emphasized the dichotomy between data and information, what the cartographer senses as information the reader may interpret only as data. Muehrcke (1973a, 1973b, 1974a, 1974b) supported this position that information was contained in the various symbols presented on the map, but unless these symbols are perceived as the representation of reality, misinformation can be presented to the viewer. Morrison (1974b, 127) contended that the cartographer's reality and viewer's reality will never constitute a one to one relationship because the transformations which take place were dual in nature, i.e., a physical transformation (encoding) and a mental transformation (decoding). A one to one relationship could conceivably occur if the cartographer and map reader were the same individual (Morrison, 1974b).

While the nature of the cartographic process has been examined as it relates to information, before proceeding further a definite understanding of information must be obtained.

Information Theory

Information, as defined by communication engineers, is knowledge obtained from a signal or character as conveyed from a transmitter to a receiver. This definition is not radically different from cartographic information. Information engineers, however, have developed precise mathematical measures for information content. Cartographers defined information as the end result of a mental process (perception and cognition) which permits the viewer to know something he did not know before. The map, as a communication system, has as its objective the transmission of spatial knowledge to the map reader. Moles (1964, 11) and others (Board, 1967; Muehrcke, 1969; Salichtchev, 1970; Jolliffe, 1974; Robinson and Petchenik, 1975, 1976; Monmonier, 1977a) see the cartographic process as a particular expression of information theory.[9]

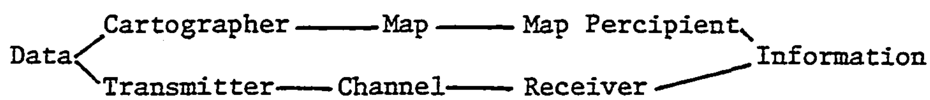
All communication systems have three basic components: a transmitter, a channel over which the message travels, and a receiver (Moles, 1966; Johnson and Klare, 1969). The cartographic analog is

[9]The most recent examination of this topic is provided by Robinson and Petchenik (1976) in Chapter 2 entitled "The Maps as A Communication system" in The Nature of Maps and by Monmonier (1977a) in Chapter 2 entitled "Cartographic Communication" in Maps, Distortion and Meaning.

shown in Figure 4.

Figure 4

Map/Communication System Analog



In theoretical terms, the objective of a communication system is the reproduction of the message as exactly as possible from one point to another (Shannon and Weaver, 1949, 3). As has been discussed, this is also the cartographer's task. But, how do we assess if the receiver has perceived the intended message?

Engineers use a quantitative model to measure the amount of information contained in a transmitted message. The amount of information in the system is measured in 'bits', a binary measure of the uncertainty as to what message, among many possible messages, a transmitter will actually produce (Pierce, 1961, 203). Moles (1966, 24) provided a more generalized definition: ". . . the quantity of information transmitted by a message is the binary logarithm of the number of choices necessary to define the message without ambiguity." Redundancy, another important measure in communication theory, is that which is superfluous in the message; however, redundancy furnishes a guarantee against error in transmission because it permits the receptor to reconstruct the message even if some of its elements are missing. The redundancy measure is often expressed as a percentage and is used as a measure of the efficiency for a system. The higher the percentage, the lower the efficiency of a language in transmitting the message. Likewise, if the redundancy measure decreases, efficiency will be high. If, however, the redundancy measure is extremely low the receiver may not be able to decode all the information and overload may occur. It must be noted, however, that the engineer's concepts of information and redundancy relate to the quantity of information as Shannon and Weaver (1949, 3) indicated:

> "Frequently the messages have meaning (Weaver's underscore); that is they refer to or are correlated according to some system with certain physical or conceptual entities. These sematic aspects of communication are irrelevant to the engineering problem."

Two messages, one with no meaning, could therefore, have the same quantitative value, but have completely different meanings.

Another concept, noise, can act as a deterent to efficiency. Communication engineers defined noise as any undesirable signal in the transmission of a message through a channel (Pierce, 1961). Just as redundancy reduces map content, so noise inhibits potential information to the map percipient. Monmonier (1977a, 11-14) indicated that cartographic noise stems from many sources; design, reproduction, perceptual, vigilance, and interpretation. Although the noise variable cannot be totally eliminated, it can be reduced through the use of filters. The graphic format selected by the cartographer represents a filter, a design filter, which will influence the amount and type of information conveyed to the reader. Design is but one filter which the cartographer has at his disposal:

> ". . . the most common control that is employed to maximize the probability of communicating the desired message is cartographic design. The effectiveness of the judicious use of design to evoke the cartographer's message is a topic of considerable importance in cartographic research" (Dobson, 1977, 44).

Attempts have been made to incorporate the general mathematical methodology of information theory to cartographic surfaces. Sukhov (1970, 41-47) arrived at a value for the information content of an atlas map, while Balasubramanyan (1971, 177-181) similarly calculated a value for topographic maps. More recently, Pipkin (1977) has examined information conveyed by choropleth maps using information theory. Robinson and Petchenik (1976, 40-42) indicated, however, that attempts to mathematically determine information content of a map and arrive at a generalized model for cartography have had only limited success, for when applied to maps no consideration was given to positional attributes of the data. A blank area on a map contains no information from a purely mathematical sense, but it does possess information based on its relative position to other features on the map. Therefore, while information theory provides a mathematical methodology for measuring information, its utility in evaluating cartographic information is questionable. In discussing the two bodies of theory Robinson and Petchenik (1976, 42) aptly stated:

> "What is needed, however, is not simply the direct application of cartography to the

> mathematical--statistical techniques of another field, but the development of techniques, perhaps through adaption, to the unique conditions of cartography."

The applicability of information theory to cartography is, then, more conceptual than operational.

Several cartographers have used information theory concepts to analyze the information content of maps. Astley (1969), for example, concluded that user's needs for road map information was limited, and that certain physical symbols, such as contours, and cultural features, such as churches, monuments, and railways were redundant. Sheppard and Adams (1971, 105-114) similarly found physical data such as hill shading and contours a hinderance on road maps. In both cases the physical data acted as noise which hindered the transfer of information to the viewer.

One topic which has not been extensively investigated is the effect of graphic dimension, as a design factor, upon the perception of cartographic information by map readers. Controlling graphic format, map reading ability, and surface noise provides a testable experimental situation in which the effects of graphic format upon the perception of various types of cartographic information can be determined.

Cartographic Information

The nature of cartographic information has been examined in terms of the cartographic process itself and its relation to information theory. But what actually constitutes cartographic information?

As Morrison (1973, 1974b) suggested, information is a result of the mental process of perception on the part of the map reader. This viewpoint is not unique among cartographers.

Wood (1972, 129-130) suggested that each segment of a map which the viewer focused upon represented essentially three types or levels of cartographic information; physical, legend, and interpretive. Physical information includes essentially the form characteristics of the map components. For example, the two dimensional isarithmic map (Figure 1) contains a series of black lines, X dimension in width, and Y dimension in length. Additionally, the map is rect-angle in shape and contains a series of spaced isolines. Legend information for this figure contains a printed statement about the interval between isolines and thus provides an explanation of the line symbols used on the map. The final category, interpretive, represents the highest level of information which is based on the spatial structure of map elements and the reality it represents. For example, a viewer perceiving the relationship and arrangement of the isolines in Figure 1 concludes that the surface increases from the upper left corner to the lower right corner. Within this third level of information a great variance in subsequent knowledge can and does occur based upon the viewer's cognitive abilities (Muehrcke, 1974b) and experiences with the particular format.

Category one, physical information, does not require any prior knowledge by the map reader, rather it requires only observation and assessment of physical properties of the map. Legend data, however, requires some data transformation by the reader because the viewer must recognize the symbols which the cartographer has selected and be able to relate such symbols to a particular concept or value. To Robinson and Petchenik (1976, 20), this process is analogous to using a dictionary, and they called it 'map reading'.

Interpretive information, however, represents a meaningful base for knowledge. The physical stimulus of the map provides informational clues which stimulate the viewer's perceptual and cognitive processes. The result is a new subset of spatial knowledge based on interpretation of the map symbols. The interpretive level of cartographic information is the goal of every cartographer, but no two individuals will perceive the same level of interpretive information or meaning due to variations in the mental process and intellectual capabilities of the map viewer (Wood, 1972; Muehrcke, 1974b; Robinson and Petchenik, 1976).

Information, as it has been defined, must convey to the viewer something that he did not already know. For example, if one does not recognize the trend of the surface in Figure 1 as increasing from upper left to lower right, then no new knowledge has been imparted. If the cartographer wished to emphasize the concept of trend then the graphic format would need to be altered. The two dimensional format of the isarithmic surface may not facilitate the transfer of trend information. However, the perspective map of the same data in Figure 1 map provide a graphic format which allows the trend information to be communicated to the reader effectively (Figure 1 - perspective map).

Thematic Map Information

The objective of thematic mapping is to display a specific subset of reality (a theme) to a specific group of map viewers, as opposed, for example, to a topographic map which displays a multitude of physical and cultural data. Viewer attention is focused on one specific topic with a thematic map, and, theoretically, information about that topic is maximized. If information is not maximized then a different graphic format or type of map might be needed to convey all the intended information. On the other hand, the possibility exists that the physical stimuli was presented properly, but the viewer decoded the data improperly.

It must also be noted that every visual element on a map cannot be "unique" to each viewer, or infomation overload occurs and the salient information may go unrecognized. Consequently, a map must contain some repetition of organization in its stimuli, i.e., redundancy (Balasubramanyan, 1971). Redundancy, as Peucker (1972, 3) suggested, ". . . is the compliment of information, it links information to the framework of knowledge." Furthermore, ". . . those elements of a map which inform about the variation of the object (the earth's surface) relate to information; those elements which account for the visual effect of the map relate to redundancy."

It must be concluded that thematic information is composed of both unique and redundant elements, the unique elements provide the basis for information, while the redundant elements reinforce that information into knowledge and subsequent meaning.

Information Content of Isarithmic Maps

Two Dimensional Surface

Physical data on two dimensional maps consists of line width, length, color, and spacing of the isolines. Legend data consists of an alpha numeric statement informing the viewer about the isoline interval. Interpretative content includes data relating to the concepts of magnitude, gradient, and pattern that are based on the location, arrangement, and intensity of the isolines.

Physical and legend data are necessary for at least a minimal understanding of the map; however, the interpretive level represents the most meaningful information. Physical and legend data are often redundant and do not present unique information. For example, reference isolines, either numbered or bolder line weight, are redundant elements for they provide no new data to the viewer if the interval is provided in the legend.

At the interpretive level, the spacing and arrangement of the isolines provide a definite clue to the viewer concerning magnitude, gradient, and pattern information.[10] Magnitude information refers to

[10]The terms magnitude, slope, and pattern were operationally defined by the author for testing purposes in the experimental design.

range and extent of numeric values in the distribution. Interpretation of the spacing and associated values of the isolines provides slope information. Pattern conveys information about spatial arrangement of values and is transmitted by the arrangement and spacing of the isolines. It should be noted that the degree or level of interpretive information is based on the cognitive abilities of the viewer to decode and process the data.

Perspective Surface

A perspective map portrays approximately the same data as the two dimensional map, although the graphic format is different. Information, especially interpretive, is presented in a perspective, pictorial form rather than through the use of planimetric arrangement of isolines.

Physical and legend data[11] are presented in basically the same manner as the two dimensional surface; however, presentation of interpretive data is significantly different. The interpretive data are the same, surface magnitude, gradient, and pattern; however, the perspective map provides a pictorial representation of these concepts. With the addition of depth and height clues perspective maps provide a pictorial display of interpretive data. The direct pictorial representation of spatial concepts would appear to make a reasonably good alternative to the planimetric representation.

[11]Rather than an isoline interval being given, a vertical scale is provided to give the map viewer a reference scale to assess the high and low values of the surface. The scale is relative to each numeric distribution presented.

The perspective map possesses several unique characteristics which the two dimensional format does not.

1) The pictorial representation of height of a surface is unique to the perspective map. The addition of the third dimension, exaggeration, is the ratio of vertical to horizontal scale. As is the case with any type of distortion it can enhance or distort potential information.

2) Perspective maps are constructed in such a manner that vertical and horizontal scale changes depending upon the point[12] perspective (Schou, 1962; White, 1968; Monkhouse and Wilkinson, 1971). Additionally, proportionate shortening of lines (foreshortening) in the direction of depth occurs so that an illusion of projection or extension in space is obtained.

3) Data can be hidden by the selection of a viewing angle in a perspective map.

Perspective maps have always been used by cartographers, but on a limited basis. Recently, however, their use has increased due, in part, to advances in both computer software and hardware technology, and also the increased realization that different maps should be used in the information process.

Since perspective maps add a dimension to the graphic, this addition would appear to enhance the transfer of interpretive information the the map viewer; however, very little attention has been

[12]A one point perspective map contains one vanishing point on the horizon, while a two point perspective contains two vanishing points on the horizon. A detailed discussion of these two perspectives can be found in Axel Schou's The Construction and Drawing of Block Diagrams, 1962, and Gwen White's Perspective, 1968. Three dimensional maps in this dissertation are constructed as two point perspectives.

given to this topic as it relates to the actual perception of interpretive information (Brandes, 1976). Before considering a research design which can be used to test the relative effectiveness of two and three dimensional maps, theories of visual and form perception must be considered. These theories provide a basis for understanding how the actual process of reading a map will influence the amount of information transferred. The map reading process involves decoding numerous 'bits' of data through the physical process of vision while cognitive processes render meaning to that data. The cartographic process, as an information system, must consider both processes if cartographic design is to enhance information.

The Perceptual Process

Information and Aesthetics

A map is a specific form of a picture, a symbolic representation of reality, or visual analogue which can assume various levels of abstraction (Gombrich, 1961, 120; Arnheim, 1969, 137, 1976, 5-10). A photograph for example, is a representation of a real object, a 'picture' of it. A caricature, also a form of a picture, is a drawing in which distortion conveys the intended message. In a cartographic sense, the orthophotomap,[13] is analogous to the photograph (Thrower and

[13]Thrower and Jensen (1967, 139) provide a current discussion of this relatively new type of photomap. . . "An orthophotomap is a vertical photograph or mosaic which displays images of objects in true planimetric (horizontal) position. . . when an orthophoto is printed in register with controlled map elements the composite becomes an orthophotomap."

Jensen, 1976) while the cartogram,[14] like caricatures, uses distortion to stimulate the visual and cognitive processes (Harris and McDowell, 1955).

A picture at any level of abstraction has two purposes, to provide information and an aesthetic experience (Kennedy, 1974, 14-18). Of these two the function of the map is primarily the transmission of information. This does not mean that artistic considerations are not important, but map aesthetics are important primarily because they enhance the transmission of information (Harrison, 1958, Arnheim, 1976; Monmonier, 1977a).

Information contained in pictures is a function of the light striking the picture. As light strikes an object from various angles it creates illumination contrasts and a resulting pattern of optical arrays. In a map the optic array posseses a structure of elements depicting features of the environment and is sensed by the eye (Kennedy, 1974, 14-27). In part, the structure of elements consist of line symbols forming contours, angles, and texture (Bourne and Ekstrand, 1973; Kennedy, 1974; Gibson, 1950, 1954, 1960, 1966, 1971). The arrangement of these elements provide informational clues, specifically, form information. For example, two different texture patterns can meet

[14] Monmonier (1977a) provides an overview of the cartogram technique, both contiguous and non-contiguous areas in Maps, Distortion and Meaning. Specific information on cartograms can also be found in Raisz (1934), Tobler (1963), Dent (1972, 1975), and Olson (1976).

to form a line; the line is then interpreted as a boundary which supplies specific information and meaning to the viewer.

In the psychological literature no studies have been completed directly relating perceptual phenomena to the perception of information contained on two and three dimensional isarithmic maps. One exception has been a work by Arnheim (1976) in which he examined the perception of maps as forms of visual analogues of reality. In no instances, however, has there been any attempt to relate perceptual processes to different graphic forms of presentation.

In considering the perceptual aspects of maps, Arnheim (1976) discussed several important associations. First, that visual shapes are sensitive to orientation. Specifically, shapes turned 90 to 180 degrees do not remain the same and the subsequent change in figural character may not be recognized by the viewer. Since viewing angle is controlled in the construction of perspective maps, an orthogonal view may hide or change the surface form to the extent that the reader does not perceive the intended message.

Arnheim also related the importance of the figure-ground phenomenon to maps and the value of depth by overlay. For example, contour lines tend to "stand-out" from their background, especially when typology is applied. Thus lettering appears to be on a frontal plane from the background. Perspective maps, because of the addition of the third dimension, provide even better clues to depth. The pictorial quality is enhanced by the depth clues thus providing a more realistic analogy of reality. Additionally, the perspective map possesses a noticeable surface texture, which, in itself, provides an additional clue to enable the viewer to more effectively decode figures and shapes from a picture.

Arnheim (1976, 9) also related the important process of cartographic generalization to form simplicity in the process of extracting map information. He suggested ". . . that simplified images are what remain in memory. . . and a map containing a maximum of details makes it impossible to group the essential elements." The complexity of isolines on an isarithmic map may provide a too complex line structure for the reader to decode information,an overload situation. The perspective map, although complex in its line structure, provides texture and depth clues which should provide a more simplified visual image to the reader to remember and subsequently extract information.

In the past two decades some attempt has been made to compare maps to a verbal language, all have met with mixed success (Blaut, 1954; Dacey, 1970; Bertin, 1970). Some research into the relative effectiveness of words and pictures in transmitting information has been undertaken. George (1967, 49) stated:

> "Perhaps the most important aspect of the use of maps lies in its more direct appeal to the eye. The use of words is secondary rather than primary, and the two can be clearly used together, and when this is done, we can place the interpretation of 'scientific theory' on the results."

Because of the direct pictorial appeal of pictures to the visual senses, the map may be more effective than written communication. Some evidence exists to support the theory that more information is perceived and recalled from pictures than words (Dallett and Wilcox, 1968; Haber, 1969, 1979; Haber and Hershenson, 1973). Paivio believed that the recall of pictures from memory was better than words because pictures were stored and recalled in either verbal form or image format (Paivio and Rodgers, 1968, 138).

It was stated earlier that a two dimensional isarithmic map is a conceptual representation of surface form and geographic concepts and requires several additional cognitive steps on behalf of the viewer to process the line symbols to information. The viewer must perceive the relationship of the isolines, encode these into appropriate figural shape, and then decode that shape before information can be realized. For example, an area on a two dimensional isarithmic map containing equally spaced concentric isolines is a conceptual form representation of a hill. The viewer must mentally transform those lines into the mental image of the hill before any further processing of the data can occur. This is not the case with the perspective map.

Perspective maps would appear to allow for more efficient data transmission because of their direct pictorial format. The perspective map, more like a picture of reality than the two dimensional map, can be stored and recalled as a direct visual mental image. Perspective maps, through the addition of height by the third dimension, represents the hill by its associated shape, a cone like figure rising above a datum. Adams (1969, 45) offered this statement regarding the direct pictorial appeal of the perspective map over the two dimensional isarithmic map:

> "Maps are two-dimensional records of the three dimensional features of the landscape and relief may be represented either in a code that must be interpreted or in a form which allows direct perception of depth. Layer colouring and contouring are examples of the former method and reference must be made to a key or to figures to establish the meaning of each colour or line. Direct perception of shape is given by hill shading, or by oblique or perspective block diagrams."

Although his example was directed to landform elevations the concept can be applied to any three dimensional spatial phenomena. It is therefore a reasonable assumption that because of the high visual appeal, perspective maps do transfer information more efficiently than two dimensional isarithmic maps. Before testing this hypothesis the physical process between the map viewer and map reading must be examined.

Eye Fixations, Map Reading, and Information

Eye Fixations

In viewing any graphic the eye focuses upon segments of the visual stimuli, the image is collected by the retena, and then it travels via the optic nerve to the brain where it is transformed into knowledge by cognitive processes. Research indicates that the eye fixates upon specific visual elements in the optic field and then quickly jumps to other fields of high visual interest. When a graphic is initially viewed, little or no information is perceived by the viewer. The process of perception begins as the eye fixates upon specific visual fields of elements. Eye fixations then jump from one highly stimulating visual field to another. As the eye shifts or re-focuses back to one or more of these visual fields indications are that these fields of stimuli are potential sources of information (Yarbus, 1967; Macworth and Morandi, 1967; Zusne, 1970; Norton and Stark, 1971). Attempts to relate map interpretation to this process include Jenk's (1973) research using eye fixations and movements in the determination and identification of spatial patterns and regions; Bartz (1970) using the search task for type legibility; and Dobson's (1977) work evaluating eye movement as it related to the general map reading process.

Attneave (1954, 184) related the fixation process in visual perception to information theory by suggesting that information was contained along lines and at points on the lines where direction changed. He concluded that more information was concentrated at points where lines changed direction most abruptly. The location of this change represented unique visual points in the stimuli (high information) whereas those points along a line which changed gradually represented a form of visual redundancy (low or no information). Two and three dimensional maps contain both unique and redundant visual elements, the unique elements providing information, the redundant elements reinforcing the information. In two dimensional isarithmic maps Z values at point locations (spot evaluations on contour maps) represent potential magnitude information. Likewise, the map contains numerous isolines, redundant line structure, but this structure, plus height data, can provide potential information regarding magnitude, gradient, and trend information.

The same information is contained on the perspective map but it is represented in a more direct pictorial format. It possesses a depth-height dimension that has direct visual appeal to the eye because it is a more representative analogue of reality. Features such as peaks, hills, and depressions are more readily discernable by the viewer than the same features represented conceptually on the two dimensional surface. With the two dimensional map the viewer must convert a series of concentric isolines to form the shape of a hill, whereas the viewer needs only to directly sense the "form" of the hill as it already exists on the perspective map.

Summary

The contemporary paradigm in cartography is that the cartographic process represents an efficient communication system which transmits spatial information to map readers. This paradigm has its conceptual foundation in information theory and principles of form perception. Graphic format, as a design filter, helps to increase the communication efficiency of a map.

Two dimensional isarithmic maps presents conceptually interpretive level information pertaining to magnitude, gradient, and pattern by the value, arrangement, and direction of the isolines. Perspective maps, however, present interpretive information in a direct pictorial fashion through the addition of depth to the surface.

Research in form perception suggests that the addition of depth to a graphic improves its communication attributes. As such, the perspective map should enhance the transmission of magnitude, gradient, and pattern information more than a planimetric, two dimensional isarithmic surface.

CHAPTER III

RESEARCH HYPOTHESES

The previous chapter focused upon the nature of the cartographic process, communication, and the relationship of cartographic information to perceptual phenomena and information theory. The research hypotheses examined in this chapter address the communication aspects of two and three dimensional surfaces based upon principles of visual perception and concepts of information theory.

Cartographic research among the topics of perspective mapping, perception, and information transfer is almost non-existent. A recent review on the state of perceptual research in cartography by Brandes (1976) revealed that the focus of studies has primarily centered on the perceptual process as related to quantitative point and area symbols. As he stated ". . . little work has been undertaken with regards to studies of non quantitative symbols, in particular, line and area symbols " (Brandes, 1976, 172-176).

Although individual topics have been examined (Dornbach, 1967, Muehrcke, 1969; Monmonier, 1977) no investigation has considered the relationship of graphic dimension as a design filter and its effect on the perception of various types of interpretive information.

The majority of cartographic research containing three dimensional mapping has been conducted by the American cartographer, George Jenks.[1]

This research applies an experimental design to information transfer from two and three dimensional maps in a search for the determination of the effectiveness of each graphic format in displaying magnitude, gradient, and pattern information to map percipients. As Hanby and Shaw (1969, IV) have suggested:

> "The historical development of cartography demonstrates that, even up to the present time, cartographic design has been largely intuitive and subjective, based on tradition and convention. Subsequent evaluation has usually been made by the map-makers and not the map-users. If techniques of cartographic data display are to keep pace with the advances in data handling and storage, (and these involve an increasing range of kinds or quality, as well as increased quantities of information), objective methods of evaluation must be devised.
>
> Very little previous research into objective testing of cartographic displays has been done-no methodology has been established. But clearly some of the psychologist's basic concepts and hypotheses concerning visual communication and perception, and his concern with measuring people's reactions and performance should form the foundations of such methodology."

[1]His work included a methodology for producing perspective drawings (Jenks and Brown, 1966), the use of perspective maps in the representation of selected topographic situations (Jenks and Steinke, 1971), determination of viewing angles for representation of cultural and topographic features (Jenks and Crawford, 1967), and considerations of vertical to horizontal exaggeration (Jenks and Caspall, 1967).

Before the research hypotheses are presented the rationale is provided for the dependent variable of communication efficiency. Additionally, the independent variables which influence the transmission of cartographic information, map reading ability, surface complexity, and viewing orientation are examined.

Dependent Variables

Communication efficiency of a map is a function of how accurately and quickly the intended message is transferred to the map reader. As such, measurement of transfer efficiency became the response time and accuracy achieved by each map reader based upon completion of a perceptual task pertaining to magnitude, gradient, and pattern information. As a subject's index score for a task approached 0.0, the map became more efficient in transferring the intended information. Likewise, as the score increased, the map became less efficient in transferring information.[2] Separate analyses of response time and task accuracy were also conducted. As such, several main effect hypotheses and interaction effects were examined and assessed simultaneously for accuracy, response time, and efficiency.

Magnitude, gradient, and pattern data were selected as information types because in any spatial distribution they possess high

[2]The efficiency index is mathematically presented in Chapter IV.

informational content for the map reader. Specifically, the location of the minimum and maximum values and range represent important information concerning the distribution of the phenomena being mapped. Furthermore, changes in the numeric distribution over a linear distance provides valuable gradient information pertaining to the rate of change in values over a spatial distance. Pattern information, the specific arrangement of surface characteristics, and specifically, trend information, provide information pertaining to the overall spatial relationship between individual values of the distribution. All three types of information are valuable to the viewer to gain knowledge concerning the spatial structure of the distribution, and that is, one basic function of any map.

Additionally, all data must be represented on a map by either point, line, or area (volume) symbolization. Magnitude data were coded on the stimulus map by point symbols, gradient data by line symbols, and pattern by area symbols (primarily texture). As stated earlier, perceptual research in cartography has primarily focused upon types of point symbols and types of area patterns. Only recently have any cartographers examined the legibility of relief and isarithmic maps (Philips, Delucia, and Skelton, 1975; Taylor, 1975).

Factors Influencing the Perception of Information

Map Reading Experience

While it is generally accepted that perception of information from maps is influenced by the experience of the map reader (Kolacny, 1969; Olson, 1975; Wood, 1972),the effects of map reading ability and graphic format upon the perception of cartographic information have not been considered. If reading ability of potential users can be assessed by the cartographer then this information can help determine the most effective graphic format in presenting thematic information to that specific group of readers. Map reading experience, as one measure of map reader attributes was controlled in the experimental design by testing two groups of map readers, those who have been introduced only to basic map interpretation techniques and those who have had extensive map interpretation experience.[3]

Surface Complexity

No two cartographic surfaces have identical surface structure or complexity. Surface complexity, as measured by the variation in Z values of the distribution being mapped, has been investigated by several cartographers, however, no agreed upon measure of this surface characteristic exists (Olsen, 1972; Muehrcke, 1973a, 1973b; Monmonier, 1974). Furthermore, in previous work no attempt has been made to evaluate the relationship between complexity, perception of cartographic information, and the dimensionality of the graphic format. Are three dimensional maps more effective in transferring information

[3]Chapter IV details the criteria and composition of the two groups used in the experimental design.

from less complex surfaces than for more complex surfaces? How does map reading experience influence this relationship? Information theory and form perception principles suggest a positive relationship between complexity of a surface and the occurrence of information overload. This, however, has never been tested. As with the variable of map reading experience the effect of surface complexity was controlled in the experimental design.[4]

Viewing Angle

The third relationship considered was that between viewing angle and the perception of cartographic information. Although two and three dimensional maps can be drawn at any viewing angle, two dimensional isarithmic maps are usually drawn with the cardinal direction North oriented "up". This is due to cartographic convention and because the user can quickly obtain directional information. While the reader generally expects to view the isarithmic map with North oriented towards the top of the map, this is not the situation with perspective maps.

Perspective maps are drawn at many different angles because transmission of information is influenced by the viewing angle. Part of a surface can be hidden from the viewer if the proper angle is not selected. The effect of viewing angle upon the perception

[4]The methodology in generating the various surfaces for two and three dimensional maps is explained in Chapter V.

of cartographic information was controlled in the experimental design by selecting two different viewing angles for both the two dimensional isarithmic maps and three dimensional perspective maps under different conditions of surface complexity.[5]

Main Effect Research Hypotheses

Graphic Dimension

The overall research hypothesis tested was that three dimensional maps transfer magnitude, gradient, and pattern information more efficiently than two dimensional isarithmic maps. Furthermore, it was hypothesized that response times would be faster and that greater accuracy would be achieved with perspective maps. The testable research hypothses for time, accuracy, and efficiency were:

$$\bar{X}_{T,3D} < \bar{X}_{T,2D} \qquad (3.1)$$

$$\bar{X}_{A,3D} > \bar{X}_{A,2D} \qquad (3.2)$$

$$\bar{X}_{E,3D} < \bar{X}_{E,2D} \qquad (3.3)$$

where $\bar{X}$ = mean — T = response time

2D - two dimensional maps — A = accuracy score

3D = three dimensional maps — E = efficiency score

[5]The selection of specific angles is described in Chapter IV.

Map Reading Experience

Hypothesis: Experienced map readers perceive magnitude, gradient, and pattern information more efficiently than those readers with less experience. Additionally, more experienced readers will have faster response times and be more accurate in their responses than the less experienced group of readers. The testable research hypotheses were:

$$\bar{X}_{T,G2} < \bar{X}_{T,G1} \quad (3.4)$$

$$\bar{X}_{A,G2} > \bar{X}_{A,G1} \quad (3.5)$$

$$\bar{X}_{E,G2} < \bar{X}_{E,G1} \quad (3.6)$$

where $\bar{X}$ = mean
T = response time
G1 = inexperienced readers
A = accuracy score
G2 = experienced readers
E = efficiency score

Surface Complexity

Hypothesis: Magnitude, gradient, and pattern information are transferred less efficiently as the map surface becomes more complex in its structure. Additionally, response time should increase with complexity while accuracy should decrease with complexity. The testable hypotheses for time, accuracy, and efficiency were:

$$\bar{X}_{T,C10} \neq \bar{X}_{T,C15} \neq \bar{X}_{T,C20} \quad (3.7)$$

$$\bar{X}_{A,C10} \neq \bar{X}_{A,C15} \neq \bar{X}_{A,C20} \quad (3.8)$$

$$\bar{X}_{E,C10} \neq \bar{X}_{E,C15} \neq \bar{X}_{E,C20} \quad (3.9)$$

where $\bar{X}$ = mean
C10 = least complex surface
T = response time
C15 = more complex surface
A = accuracy score
C20 = most complex surface
E = efficiency score

Map Reading Viewing Angle

Hypothesis: A relationship should exist between viewing angle and magnitude, gradient, and pattern information which is transmitted to map readers. The specific effect, that is, whether the 45 degree view is more effective than the 315 degree view is not known. Furthermore, it is unknown whether either view will affect response time or accuracy. Therefore, the testable hypotheses were:

$$\bar{X}_{T,V45} \neq \bar{X}_{T,V315} \qquad (3.10)$$

$$\bar{X}_{A,V45} \neq \bar{X}_{A,V315} \qquad (3.11)$$

$$\bar{X}_{E,V45} \neq \bar{X}_{E,V315} \qquad (3.12)$$

where $\bar{X}$ = mean; T = response time

V45 = 45 degree viewing angle; A = accuracy score

V315 = 315 degree viewing angle; E = efficiency score

Analytical Procedure

These hypotheses were tested in a factorial analysis of variance design thereby assessing the main effects of the four independent variables. These four main effect hypotheses were tested under the assumption that each independent variable (graphic dimension, reading ability, surface complexity, and viewing angle) separately influenced the dependent variables (time, accuracy, and efficiency) of magnitude, gradient, and pattern information. Kerlinger (1975) indicated that this seldom occurs. The combined influence of the variables can be determined by assessing the interaction effects of the four independent variables upon the dependent variable (Williams, 1968; Kerlinger, 1975). For example, the interaction between graphic dimension and map reading experience allows the researcher to examine differential effects of these two variables. Although hypotheses statements can be generated for each interaction, it is customary in a factorial design to discuss only those statistically significant interaction effects. The main effects and combinations of two-way, three-way, and four-way interactions are presented in Table I.[6]

The basis for the research hypotheses are now examined within the conceptual framework of the principles of visual perception and information theory. Specifically, the independent variables of graphic dimension, map reading experience, surface complexity, and viewing angle are examined as to their specific relation to the perception of magnitude, gradient, and pattern information.

Magnitude Information

As previously defined, magnitude information pertains to the range and extent of values in a distribution. Magnitude data, such as minimum and maximum values, are represented as point locations on two dimensional isarithmic maps. The viewer must be presented with isolines and interval values if these points are to be identified.

[6]The criterion set for rejection of each of the main effect null hypotheses and interaction hypotheses was $p = .01$.

Table I

Main Effects and Interaction Combinations of Independent Variables

Variable		Levels of Variable
Main Effects		
Graphic Dimension	(D)	2 (G1, G2)
Map Reading Experience	(G)	2 (2D, 3D)
Surface Complexity	(C)	3 (C10, C15, C20)
Viewing Angle	(V)	2 (V45, V315)
Two Way Interactions		
Experience x Dimension	(GxD)	(2 x 2)
Experience x Complexity	(GxC)	(2 x 3)
Experience x View	(GxV)	(2 x 2)
Dimension x Complexity	(DxC)	(2 x 3)
Dimension x View	(DxV)	(2 x 2)
Complexity x View	(CxV)	(3 x 2)
Three Way Interactions		
Experience x Complexity x View	(GxCxV)	(2 x 3 x 2)
Experience x Dimension x View	(GxDxV)	(2 x 2 x 3)
Experience x Dimension x Complexity	(GxDxC)	(2 x 2 x 3)
Dimension x Complexity x View	(DxCxV)	(2 x 3 x 3)
Four Way Interactions		
Dimension x Complexity x View x Experience	(DxCxVxG)	(2 x 2 x 3 x 2)

Source: Author

The typical means of portrayal is by reference isolines and point identification of selected values on the surface. Likewise, an alphanumeric legend statement is provided concerning the isoline interval (Figure 1). Reference contours on black and white maps are normally wider than other isolines. Additionally, these lines have assigned numeric values to indicate a specific value for the isoline in order to attract the viewer's attention. These reference contours represent redundant elements in the visual array. They are repeated at regular intervals to provide the viewer lines of reference for further interpretation of the remaining isolines and points on the map.

Spot values are symbolically represented on the map with an associated numeric value and point symbol[7], for example, $.^{100}$. The point symbol identifies a very specific two dimensional location with an associated three dimensional value. The point symbol is a unique element in the surrounding visual array of isolines, and as such, it attracts the viewer to an important point of potential information. The reader will have difficulty in locating specific point locations and interpreting their values if a symbol is not used. It is important to have these reference points otherwise the viewer must interpolate all point values from surrounding isolines.

[7]Standard cartographic point symbols used for spot elevation are . or an x.

Magnitude data, such as minimum, maximum, and range, are represented in the (Z) or vertical dimension on a perspective map. The maximum value of a distribution is at the apex along a continuum of increasing values on the surface. While eye fixations and movements scan at various locations along a line, eventually they focus on the peak of specific hills. The eye probably scans several "peaks" and re-focuses upon the "highest peak" when searching for the highest value represented by the surface. The eye fixates at points of interest, points where an abrupt change is noted in the angle of the isoline (due to an abrupt change in a data value of the spatial distribution). This abrupt change, usually at high informational points such as the minimum and maximum, cause a new form to appear on the surface from surrounding features. A form that is dissimilar to the surrounding visual field stimulates the eye to immediately fixate at that location. Peucker (1972, 23-24) describes this process:

> "If a person looks at a map representing topographic or thematic surface, he does not sample the surface randomly, that is, let his eyes jump over the map to find indications of the surface's 'height' at random points, neither does he scan the map in equidistant steps, but rather he searches along the steepest slopes for local maxima or minimal, very similar to the hillclimbing technique in statistics and numerical analysis. In other words, he most probably looks for hills and valleys to get an idea of the surface-structure".

The viewer directly perceives the unique, sharp change in the curvature of the isoline as a subsequent source of potential information.

A cognitive association with the unique feature on the surface and known concepts also occurs as the viewer observes the perspective surface. The picture of the peak is recalled as either an image or symbolically through the association with the term "peak". The same process would occur when searching for any unique value on the surface whether it be the maximum, minimum, or other specific value.

The effect of map reading ability on the perception of magnitude information is not totally known. Based upon existing theories of form perception, it is reasonable to assume that magnitude information is more effectively transferred by three dimensional maps due to its direct pictorial quality regardless of the viewer's prior map reading experience. Likewise, as a surface becomes more complex in its visual structure, the transmission efficiency of both maps in conveying magnitude information probably decreases because a complex surface contains more visual noise elements than a less complex surface. The increase in noise produces visual distraction in the search process for intended information. Information theory suggests whenever the information system contains excessive noise, the intended message will not be accurately communicated, and in some cases, not at all.

The effects of viewing angle upon the perception of magnitude information on two dimensional isarithmic maps is probably minimal since these maps possess no height dimension. Perspective maps, however, do possess a height dimension and the selection of the angle can either enhance or hinder potential information depending on the magnitude and location of values in the mapped distribution. If a particular point is higher than surrounding values the surface form becomes a peak which is higher than adjacent peaks. This peak may block or cause a shadow on a smaller values directly behind it. The same peak may be viewed from other angles which allow a clear view of both surface forms.

As with the variables of reading ability and surface complexity, very little research has been conducted on the effect of viewing angle and its influence on the perception of information (Jenks and Crawford, 1967). The effect of this variable was controlled and assessed in the experimental design by selection of two orthogonal viewing angles for all map surfaces in both two and three dimensions.[8]

Gradient Information

Several types of gradient information can be perceived from isarithmic maps, but perhaps the most important of these is the identification of points of sudden change in surface gradient. The location of maximum change in slope is determined by the magnitude of one data value to another over a specific linear distance. On a two dimensional map this location is represented by the arrangement and spacing of the isolines. Widely spaced isolines represent a area of gradual slope between two points, while tightly packed,

[8]Selection of the specific viewing angles is presented in Chapter IV.

concentrated isolines between two points are representative of an area with steep slope.

Determination of the steepest slope on a two dimensional isarithmic map requires the viewer to scan the entire surface and focus upon those visual fields where the optical elements of isolines are tightly packed. The viewer then re-focuses upon the one visual field which is perceived to contain the greatest number of tightly packed isolines between two points, location of steepest slope on the surface.

This process can be related to Gestalt theory of form perception. Specifically, it is related to the principle of form continuity, that is, a set of visual elements determines the direction of the next element. While scanning the map the viewer must be aware of the spacing, direction, and associated values of the isolines. When the continuity of these elements changes abruptly, there is a resulting roughness and relief to the surface. The map reader must then decode that data to slope information. The reader may even generate a mental image of a hill which represents a figure showing the perceived slope.

Gradient information on a perspective map is shown by changes in the vertical dimension of the surface. Features can be directly recognized as hills, valleys and troughs because the map provides the viewer a directly observable, pictorial form on the surface of the map. Perceptual principles which account for the recognition of gradient information include figure-ground (a figure will stand out from its surrounding background) plus Gestalt continuity and proximity (Wood, 1968).

Koffka (1935) stated that principles of Gestalt continuity and proximity indicated that a set of elements will determine the direction of the next element and groups of elements are formed that are spatially close to one another. The perspective map is constructed with a series of closely spaced parallel lines with values of a continuous distribution being expressed as a specific direction and curvature of a line. The structure of these lines result in specific forms, such as hills and peaks. The figure-ground relationship is important because the gradient of a surface feature is directly observable in a pictorial format and will stand out from other surface features. The figure of a surface feature will be visually recognizable from the background of the surrounding datum, for example, a peak from surrounding hills.

Sudden and abrupt changes in gradient are readily discernable from the perspective surface. A change in the numeric values of a distribution are represented by a change in isoline angle and height. As the search process is performed any change in isoline angle is visually noticeable to the viewer, especially if the change is aburpt. Since the surface is constructed by a series of parallel lines, any vertical change in a series of these lines will be also recognizable by the viewer.

The effect of map reading experience upon the perception of gradient information is not known. Based upon the theories of form perception it is probably that perspective maps transfer gradient information more efficiently than two dimensional isarithmic maps regardless of the map reader's experience. This is due to pictorial characteristics of the perspective map. As the map becomes more complex the ability of the reader to identify specific points of gradient probably decreases. More visual stimuli are presented to the viewer which probably causes a situation of information overload and with complex surfaces differences in gradient from point to point may be minimal and thus difficult to compare and assess.

Again, the effects of viewing angle on the perception of gradient information on two dimensional maps is probably minimal, but on a perspective map a specific slope which possesses high informational content may be blocked because of the viewing angle.

Pattern Information

Pattern is the specific arrangement of texture on a mapped surface. Pattern information on a map is subject to a high level of individual interpretation thus the map reader cannot focus on specific points for this information but must scan various optic fields and recognize regularities in the relationship between isolines. Several types of pattern information are presented on the surface including the arrangement of high and low points and the trend of these values.

Trend information includes the overall direction which the values in the distribution assume.

When viewing a two dimensional map the reader must scan and locate areas of repeated, regularly spaced isolines plus recognize the direction of these isolines. This process is based upon the Gestalt principles of form similarity and continuity of the visual stimuli. The isolines are similar in their spacing and are repeated (continued) in a given direction. This provides the information clue to pattern recognition. The pattern information represented on the two dimensional surface is presented conceptually to the reader. The reader must process the arrangement and direction of the isolines to obtain a mental image of a range of peaks extending in a given direction.

Pattern information is inherent in the arrangement and direction of values in the numeric distribution. Values of the distribution on perspective maps are expressed in the vertical dimension. As identical values are plotted in this dimension, like figures will appear on the surface of the map. For example, repetition of exact high values from the distribution results in a series of peaks all the same height above the datum plane. As an individual peak is visually sensed, so will a string of peaks be perceived as a range. The viewer has combined several like visual fields into a unified but unique whole. Additionally, the direction of the range is sensed, and ultimately, trend information is perceived. Unlike the two dimensional map, the perspective map displays information in a pictorial format directly on a mapped surface. A peak, for example, is represented as the shape of a peak on the surface.

The influence of map reading experience upon the perception of pattern information is not known. Theory suggests that map readers with prior experience will perform better than less experienced map readers. Furthermore, as the surface becomes more complex efficiency probably decreases because of the visual noise factor.

As with the other types of information, the selected viewing angle can either block potential information or it can enhance it on perspective maps. Again, if data values forming a series of peaks are viewed "head on" the trend of the range might be obscure. If viewed from the side the clue to trend information might be enhanced.

Four main effect research hypotheses were presented at the beginning of this chapter regarding the influence of graphic dimension, map reading experience, surface complexity, and viewing angle upon the perception of magnitude, gradient, and pattern information. Furthermore, a series of two, three, and four-way interactions were presented which allowed the combined effects of the four independent variables to be assessed upon the dependent variable of communication efficiency. The experimental design used to test these hypotheses and interactions is presented in the next chapter.

CHAPTER IV

EXPERIMENTAL DESIGN

The theoretical considerations of information theory, form perception, and cartographic information were examined in Chapter II. Furthermore, several testable research hypotheses were presented in Chapter III concerning the influence of graphic dimension, map reading experience, surface complexity, and viewing angle upon the perception of cartographic information. This chapter describes the experimental design including subject population and characteristics, compilation of stimulus maps, development of the measurement instrument, testing procedure, and method of analysis.

Subject Characteristics

It has been hypothesized that prior map reading experience has an influence upon the efficiency in which a map reader perceives information from a map. Although this variable is thought to be important, there are no known attributes of map readers, such as educational or geographical training, that influence map perception (Robinson, 1977, 164). The criteria used in the study to differentiate experienced map readers from non-experienced map readers was completion of college level course work involving map interpretation.

The rationale for using completed course work to operationalize map reading ability was based on the assumption that increased experience in interpretation of maps and aerial photos produced a more proficient map reader. These groups only represented an attempt to categorize readers into two gross levels of map reading ability. Again, it must be emphasized that map reading ability has not been universally defined and classified and represents a separate research topic in itself (Robinson, 1977).

The less experienced group of map readers consisted of 39 students enrolled in Introduction of Physical Geography, Fall quarter, 1976, at the University of California, Berkeley. Potential subjects were requested to volunteer for the experiment with no preestablished reward for their participation, thus eliminating the potential effect of reward influencing task performance.[1] Subjects were tested in the last three weeks of a ten week term after classroom and lab introduction to topographic map interpretation. All students were also introduced to air photo interpretation techniques using stereographic pairs during the lab experience. Thus each student had at least a minimal level of training in the interpretation of features

[1] A pilot study was conducted in 1975 at the University of Oklahoma in which subjects were required to participate as a course requirement. Several subjects were observed performing the experimental task as quickly as possible with little or no regard for accuracy. The decision was made not to require or reward any subject based upon this reaction in the pilot study.

on both two dimensional isarithmic maps and three dimensional models. Although all subjects were enrolled in the same geography course, they were diverse in attributes such as age, sex, and declared major.[2]

The more experienced group of map readers was composed of 39 students enrolled in Map and Air Photo Interpretation, Fall term, 1976 at Sonoma State University, Rohnert Park, California. All potential subjects were requested to voluntarily participate in the experiment with no reward. Subjects were tested during the last two weeks of a fifteen week semester. Students enrolled in this course received two hours of lecture and six hours of lab experience in map and air photo interpretation per week. The Sonoma group had more contact hours and experience in both map interpretation and stereoscopic air photo interpretation than the Berkeley group. The Sonoma group, however, was not as diversified in their declared major as the Berkeley group.[3]

The total experimental population consisted of 78 subjects, 39 each in the two map reading groups. It was necessary to use

[2]Specific composition by percent major for the group was: Business Administration, 17.9%; Geography, 15.3%; Natural Resources, 15.3%; Architecture (including landscape architecture), 10.2%; unclassified and continuing, 10.2%; Economics, 7.6%; Engineering, 7.6%; Political Science, 5.1%; Math, Anthropology, Marine Biology and Environmental Studies, 2.5% each.

[3]Composition included: Geography, 72.0%; Geology, 10.2%; Environmental Studies and Special Majors, 5.1% each; English, Psychology, and Political Science, 2.5% each.

students from two institutions due to the criteria established for map reading experience. An air photo class of sufficient size did not exist at the Berkeley campus, therefore the Sonoma class was used. As such, map reading experience, as an independent variable had two levels, less experienced readers (G1) and more experienced map readers (G2).

Stimulus Maps

Compilation of the stimulus maps consisted of four major components: 1) structuring the spatial research area, 2) generation of the numeric data distribution, 3) location of the isarithmic control points, and 4) physical construction of the maps.

A theoretical aerial unit was generated to avoid any subject contamination due to prior knowledge of a known geographic area. For example, if the state of California was used as a stimulus map a test subject might conclude that the location of a maximum value for a given distribution occurred at the location of Los Angeles or San Francisco without looking at the map.

The shape of the aerial unit was a 24 by 40 inch rectangle subdivided into 10 rows and 6 columns resulting in 60 square cells, 4 inches on a side. A centroid was established for each cell which resulted in 60 equally spaced control points for the research area.[4]

[4]The selection of this aerial unit, number and location of control points was based on extensive experimentation. Data values were randomly generated for 20, 50, 500, and 1000 control points. Both the random data values and control point coordinates proved to be unsatisfactory due to the surface either being too generalized or too

The use of centroids as control points is acceptable when the values are to be evenly distributed over the geographic area:

> "When the distribution is uniform over an area of regular shape, the control point may be chosen as the center. If the distribution within the unit area is known to be uneven, the control point is shifted toward the concentration. Center of area may be considered as the balance point of an area having an even distribution of values without an uneveness of the distribution taken into account. The center of gravity takes into account any variation of the distribution" (Robinson, Sale, Morrison, 1978, 225).

The aerial unit, including location of the control points by matrix row and column designation, is provided in Figure 5.

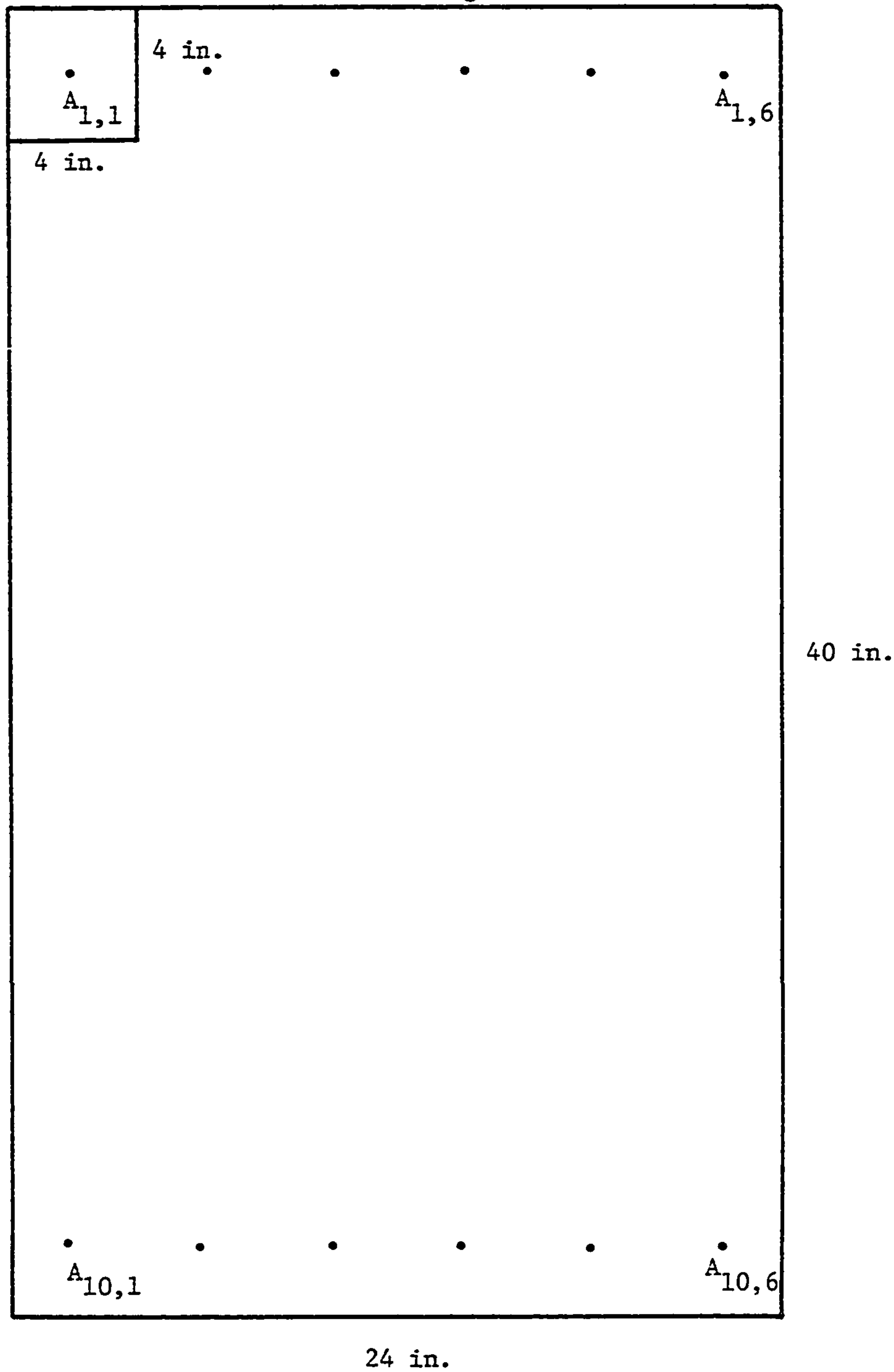
Sixty data values were used to generate the surface configurations from which subjects were asked to identify magnitude, gradient, and pattern information. Sixty values were produced using a 5th degree polynomial model of the form[5]:

detailed. The random values and locations (for 500 and 1000) produced a great deal of visual noise, so much, in fact, that no discernable pattern or trend to the surface could be discerned. Likewise, magnitude and gradient information was difficult to assess. Data values and locations produced for 20 and 50 values simplified the distribution producing little or no information to the reader. Based upon these findings, it was concluded that 60 equally spaced control points and values would be used.

[5]Other methods of data generation were attempted but proved to be unsatisfactory. Random values were generated that produced a surface in which minimum and maximum values could be identified, but slope and trend information was very difficult to discern. The 5th degree polynomial surface did allow for recognition of minimum and maximum values, various gradients on the surface, and trend information.

Figure 5

Research Area Configuration



$$\begin{aligned} Y = A + B_1M = B_2N = B_3M^2 = B_4MN \quad & (4.1) \\ + B_5N^2 + B_6M^3 + B_7M^2N = B_8MN^2 & \\ + B_9N^3 + B_{10}M^4 = B_{11}M^3N + B_{12}M^2N^2 & \\ + B_{13}MN^3 + B_{14}N^4 = B_{15}M^5 & \\ + B_{16}M^4N + B_{17}M^3N^2 + B_{18}MN^3 & \\ + B_{19}MN^4 + B_{20}N^5 \quad \text{(Yeates, 1974, 149)} & \end{aligned}$$

A square root transformation of the 60 values was performed to smooth the surface. The transformed values were then assigned to the 60 control points within the theoretical research area--value one to $A_{1,1}$, two to $A_{1,2}$. . . 60th value to $A_{10,6}$ (Figure 5). The resulting two and three dimensional 5th degree polynomial surfaces are presented in Figure 1.

Surface Complexity

The surfaces display in Figure 1 are relatively simple in their visual line structure. Neither surface displays numerous hills, peaks, valleys, or troughs. As stated earlier, no two maps are alike in their visual structure, and therefore represent varying degrees of complexity. The initial surfaces had to be modified so the influence of surface complexity upon the perception of cartographic information could be assessed.

Surface complexity, as just one form of visual noise, has not been commonly defined or measured by the cartographic community (Monmonier, 1977). Surface complexity of the stimulus maps was operationalized by adding a predetermined number of values to the numbers generated by the polynomial model. Depending upon the magnitude and number of values, the resulting figures inherent in the two dimensional line structure and shapes of the three dimensional map provided a basis for visual complexity. The least complex surface contained 10 values, the more complex 15, and the most complex 20 noise values.

Three sets of random values and control point locations were generated using the IBM scientific subroutine RANDU.[6] One thousand, two digit random numbers, ranging from 0 to 99, were generated for each of the three surfaces. Each set was printed in matrix format with each row digit representing the control point location and the column digit representing the value which was added to the transformed square root 5th degree polynomal value. A portion of the actual matrix for the least complex surface is shown in Figure 6. Location $A_{1,1}$ represented the 8th control point ($A_{2,2}$ in Figure 5) to which a value of 8 units was added to the value generated by the 5th degree equation. Likewise, $A_{2,1}$ represented the 15th control point ($A_{9,2}$ in Figure 5) to which a value of 50 (from $A_{1,2}$ below) was added.

Figure 6

RANDU Surface Complexity Matrix

<u>8</u>	50	27	11	. . . .	$A_{1,25}$
<u>15</u>	. . . .				$A_{2,25}$
29	. . . .				$A_{3,25}$
.	. . . .				
$A_{40,1}$.	. . . .				$A_{40,25}$

[6]RANDU is an IBM scientific subroutine which generates random numbers (International Business Machine, 1977, 77).

Three separate matrices of random numbers were generated for the three surfaces. Ten pairs of numbers were selected from the first matrix to form the least complex surface, 15 from the second matrix for the more complex, and 20 from the third matrix for the most complex surface.[7] This resulted in three unique surfaces, each of different complexity, to which questions could be asked of the subjects pertaining to magnitude, gradient, and pattern information.

One further modification was made to each surface. It was desirable for experimental purposes to keep the maximum value on each surface a constant range from the second largest value on each of the three surfaces. This was achieved by summing the range between the maximum and second largest value on each of the three surfaces. This sum (15 units) was then added to the second largest value on each surface to arrive at the new maximum.

Creating stimulus maps using the concept of visual noise as an expression of surface complexity allowed the influence of this variable upon the perception of cartographic information to be tested and assessed. As such, the independent variable of surface complexity had three levels, a 10 complexity (C10), a 15 (C15), and (C20) surface complexity. Two dimensional maps in the three surface

[7] RANDU is actuated by the parameter IX, any 9 digit or less odd interger. The least complex surface (C10) was actuated with IX= 35533, the more complex (C15) with IX=77777, and the most complex surface (C20) with IX=17711. A description and listing of RANDU can be found in IBM scienfitic subroutine programmer's manual (IBM, 1970, 77).

complexities are presented in Figure 7, 8, and 9. The corresponding perspective maps are presented in Figure 10, 11, and 12.

Graphic Dimension and Viewing Angle

All stimulus maps were compiled using computer mapping routines.[8] Two dimensional maps were generated by using the computer program CONTUR.[9] The two dimensional maps were drawn with an equal isoline interval of 10 units. This interval provided sufficient detail for each subject to respond to perceptual tasks pertaining to magnitude, gradient, and pattern information. Reference isolines were emphasized (thicker line weight) every 20th isoline value. Additionally, a legend statement "Contour = 10" appeared on each map. Typology concerning title, scale, and geographic direction was eliminated in an effort to minimize any potential source of visual distraction. This legend information was not needed to complete the perceptual tasks.

Three dimensional perspective maps were compiled using the computer program SYMVU.[10] The program provided the cartographer the

[8] All mapping routines were executed on an IBM 370/158 computing system and drawn with a CALCOMP drum plotter.

[9] CONTUR is a program "to draw contour maps from data given in the form of geographical matrices" (Tobler, 1973, 89). A description and listing of CONTUR is presented in Tobler's, Selected Computer Programs (1973, 89-109.)

[10] SYMVU is a program which generates three dimensional line drawing displays of data. A detailed description of the program is presented in the SYMVU Manual (Harvard Laboratory for Computer Graphics and Spatial Analysis, 1971).

Figure 7

Two Dimensional Surface - C10 Complexity

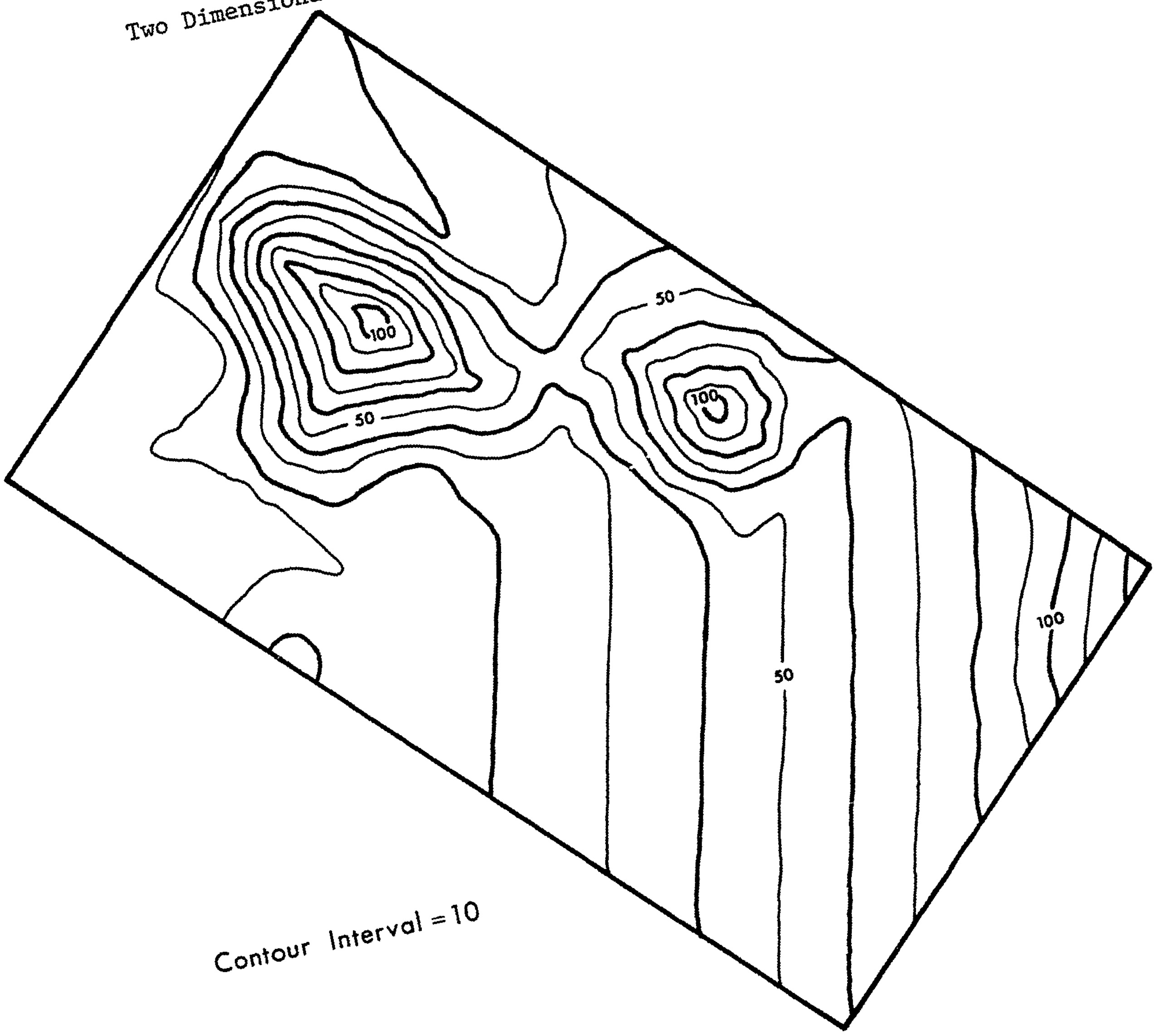


Figure 8

Two Dimensional Surface - C15 Complexity

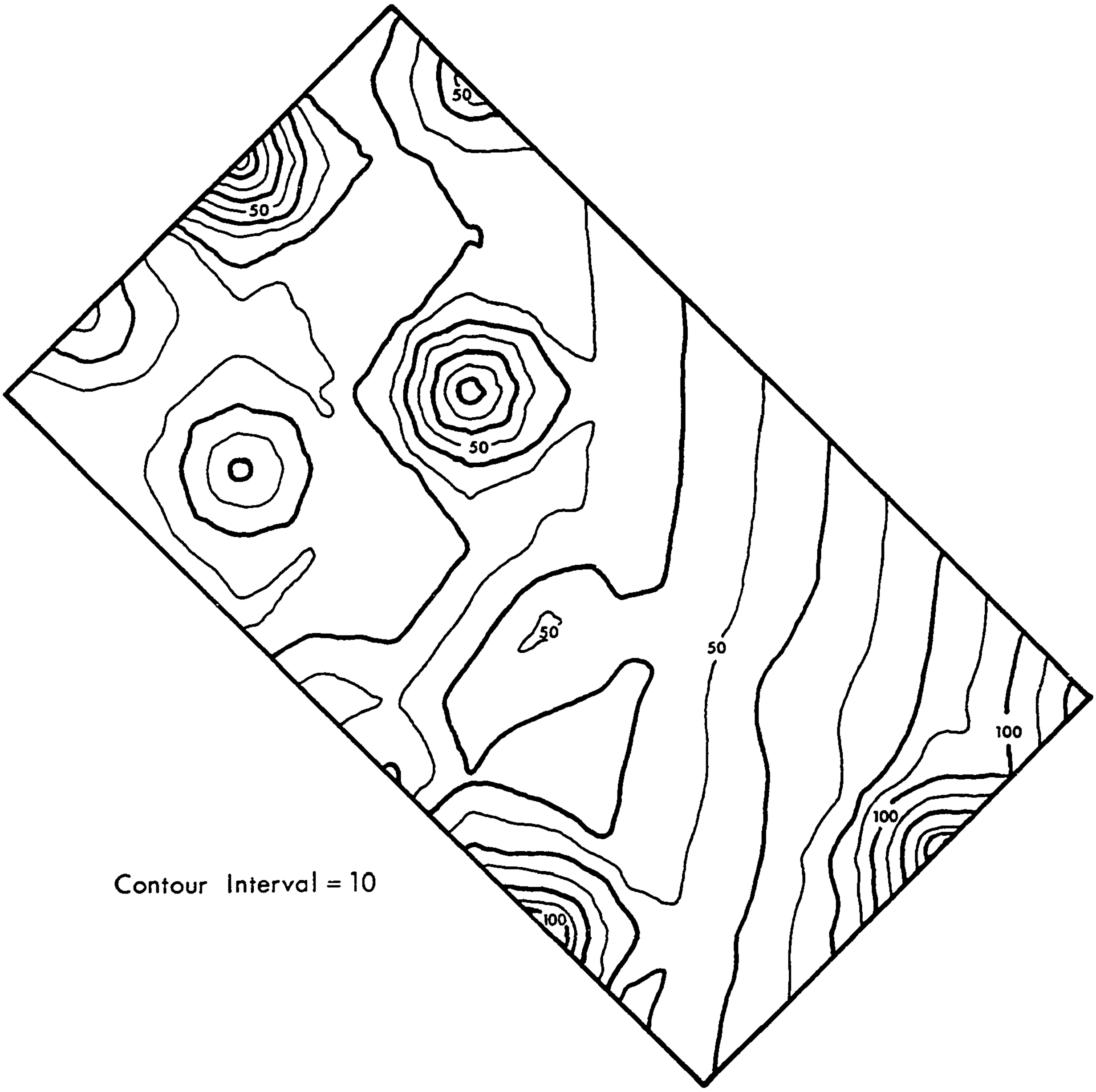
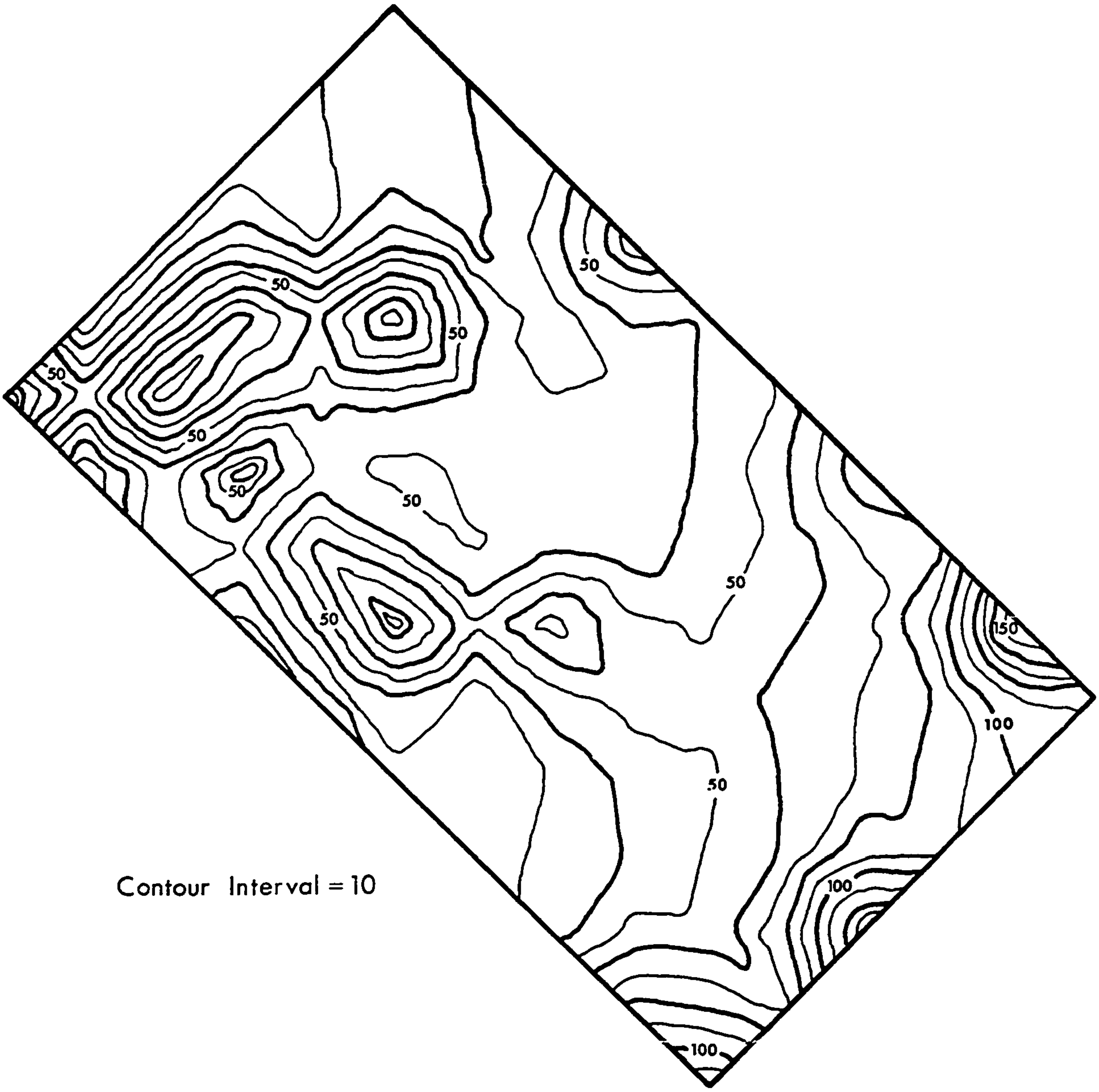


Figure 9

Two Dimensional Surface - C20 Complexity



Contour Interval = 10

Figure 10

Perspective Surface - C10 Complexity

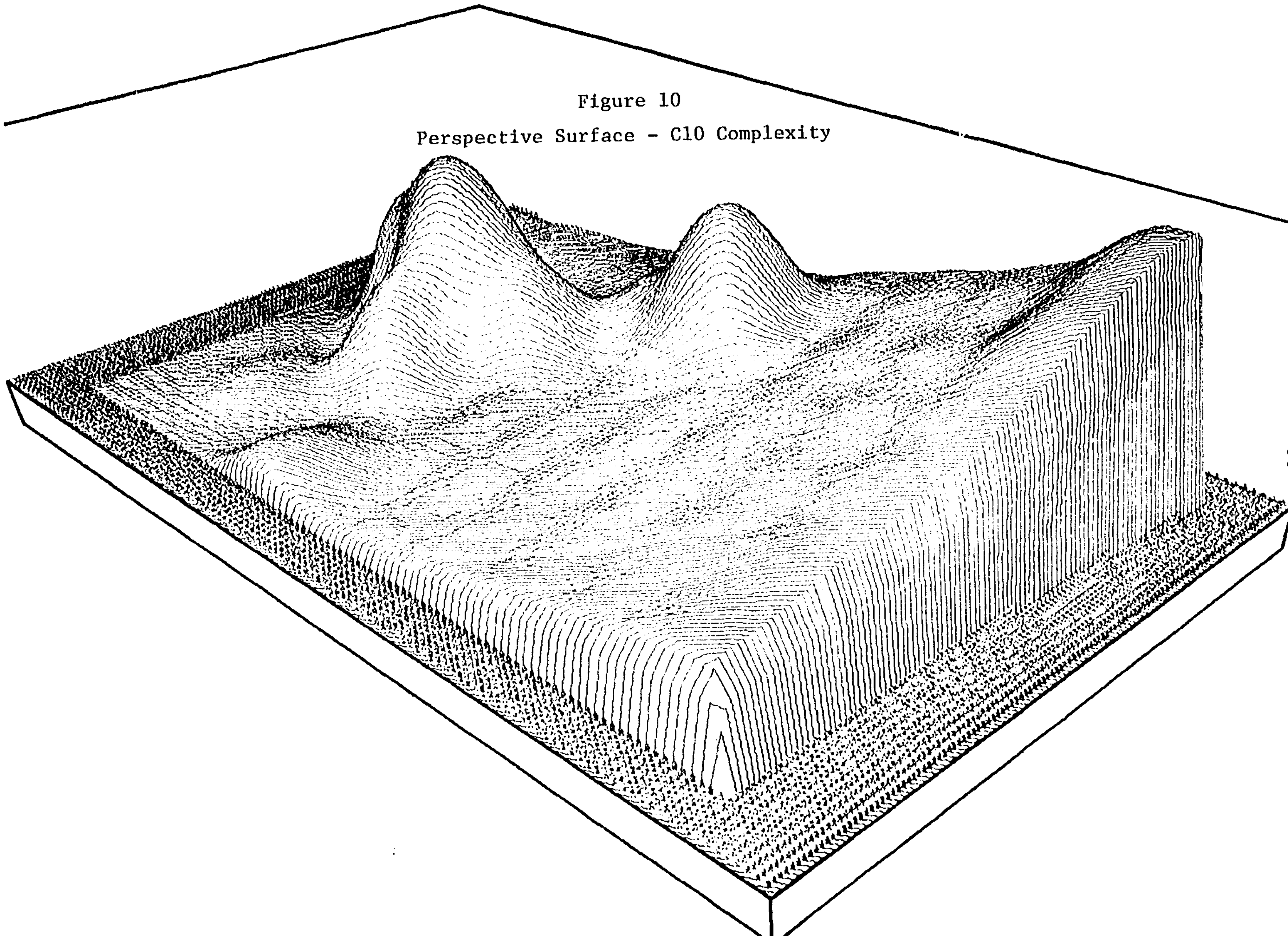


Figure 11

Perspective Surface - C15 Complexity

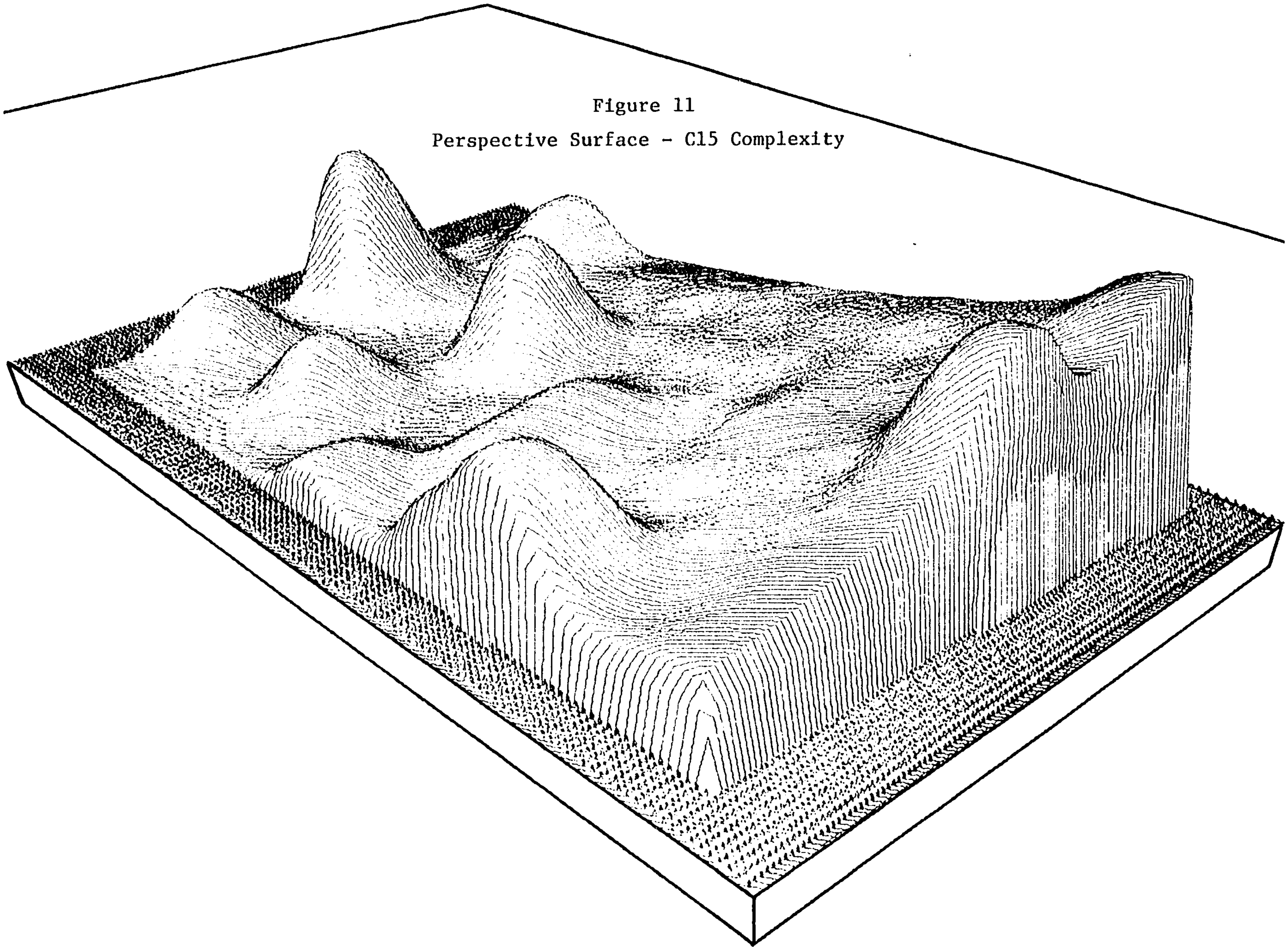
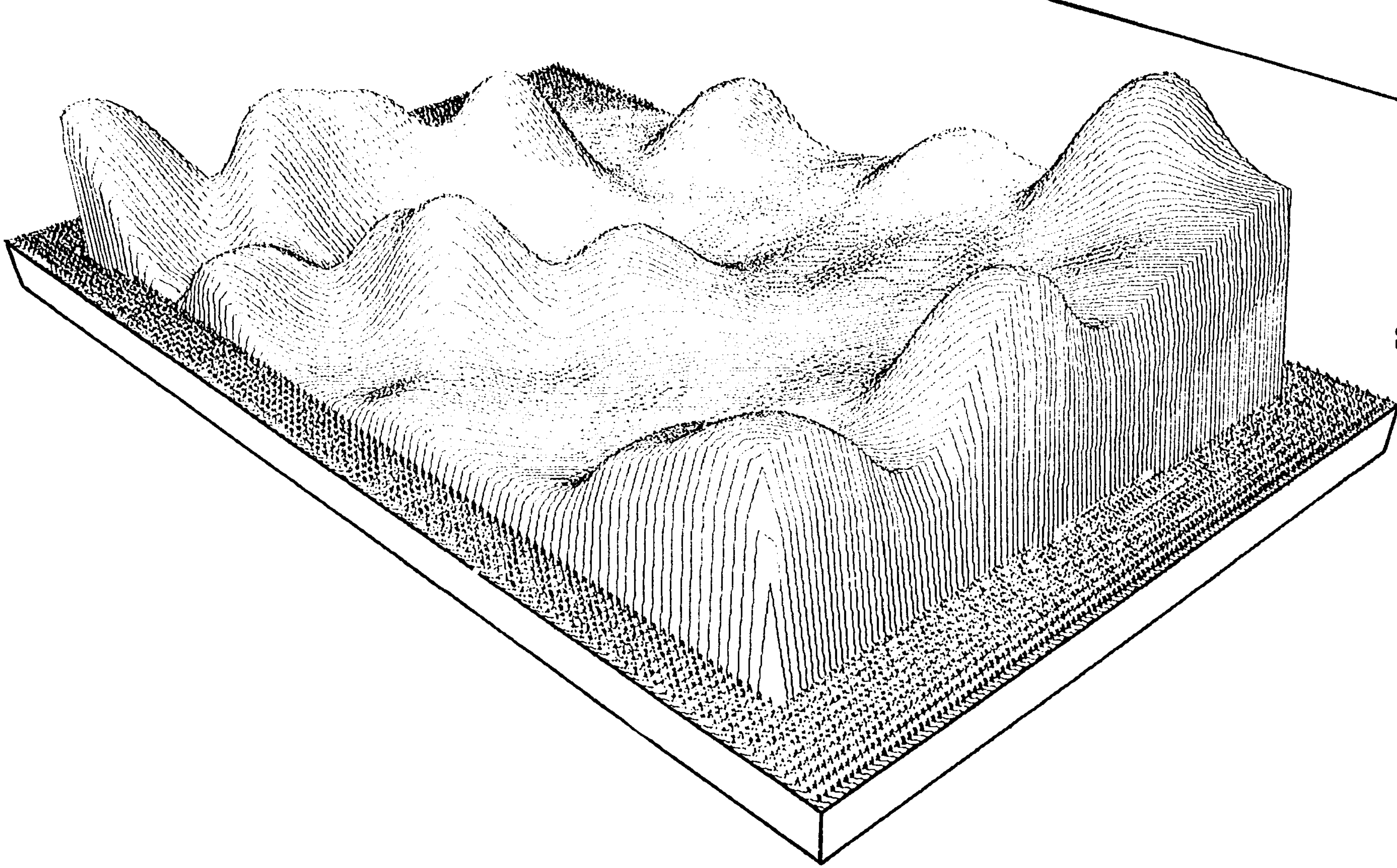


Figure 12

Perspective Surface - C20 Complexity



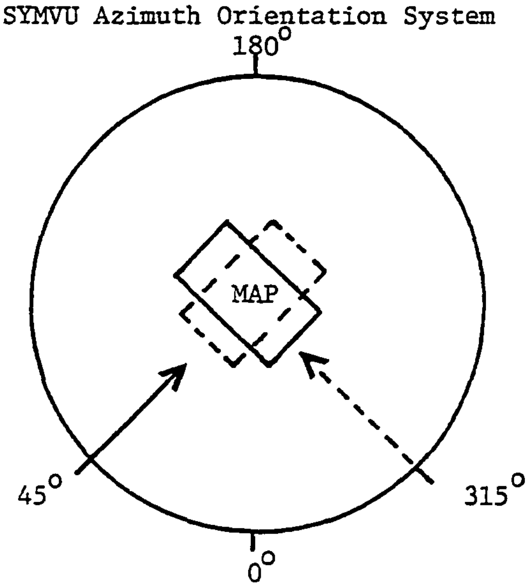
option to view the surface at any desired angle between 0 and 360 degrees. This is not unique, for a cartographer who would hand draw the perspective diagram would also have the same option. It had been hypothesized earlier how viewing angle can either enhance or hinder the intended transmission of information.

Cartographic research concerning the viewing angle and vertical exaggeration in perspective mapping was conducted by Jenks and Caspall (1967), Jenks and Steinke (1971), and Rowles (1976, 1978). Monmonier recently conducted a study which for the first time examined the selection of viewing angles for maximum clarity (Monmonier, 1978, 180-195).

Evaluation of this variable and its influence upon the transmission of information was controlled and assessed in the experimental design by selecting two viewing angles at azimuths of 45 and 315 degrees. A schematic of this SYMVU option is presented in Figure 13.

Figure 13

SYMVU Azimuth Orientation System



These angles were chosen to present the map reader the opportunity to perceive information from orthogonal orientations.[11]

Two additional factors were considered in the compilation of the perspective maps, viewing altitude and vertical exaggeration. A viewing altitude of 45 degrees was used on all perspective maps. This 45 degree altitude was selected based upon the guidelines offered by the developers of the SYMVU program.

> "For most cases, this gives an optimum view of the surface as well as a good relationship between the lines and white space which separate them. A zero to five degree view of a landscape topographic surface normally is quite close to eye level viewing whereas, those nearer to 45 degrees appear to the observer as birdseye views" (Goodrich, 1971).

Vertical exaggeration on perspective maps should be kept to a minimum and should never exceed a vertical to horizontal ratio of 6:1 (Schou, 1962). Research conducted by Jenks and Caspall (1967) indicated that vertical exaggeration was dependent upon the scale of the map. Furthermore, they concluded that final ratio selection should be based on three criteria: the relative nature of the surface (level or hilly), experimentation with different ratios by constructing vertical profiles, and aesthetics . . . "if it pleases the eye it will probably be accepted as 'realistic' by the map reader" (Jenks and Caspall, 1967, 31). Most cartographers have indicated that exaggeration be kept to a 2 or

[11]The two dimensional maps CONTUR maps were also oriented in the same manner. This was done for control purposes in the experiment.

3 to 1 ratio (Muehrcke, 1978, 111). SYMVU does not provide for an explicit exaggeration ratio, however the user can specify the input matrix width and height. This ratio was kept at 3:1. The width and height values were selected in such a way that the perspective maps were approximately the same size as the two dimensional maps, thus ensuring that the scale of the map did not influence the reader.

Twelve stimulus maps were generated for testing purposes as follows: three surface complexities (C10, C15, C20) based upon modification of a set of values which fit a 5th degree polynomial equation, each surface was drawn at a 45 and 315 degree viewing angle (V45, V315), and each map was drawn in two and three dimensions (2D, 3D). A complete set of maps is presented in the stimulus map booklet, Appendix I.

Experimental Procedure

Four factors were considered in the experimental design; the method of subject testing, presentation and order of stimulus maps, perceptual tasks for magnitude, gradient, and pattern information, and measurement of communication efficiency.

Testing Procedure

Several methods of testing, group, multiple subject, and single subject, were considered by the experimenter (author). It was concluded upon completion of the pilot study that multiple and group testing were unsatisfactory and presented an opportunity for measurement error. Additionally, having individuals other than the experimenter (lab assistants or teaching aids) administer the test instrument would likewise present an opportunity for error. Therefore, the author individually administered the perceptual tasks to each of the 78 subjects.

Each subject's response time was recorded for each perceptual task as the subject progressed through a replicated series of stimulus maps. To preclude any subject from "learning" task answers or anticipating the next stimulus map, a specific viewing order was established.

Stimulus Map Order

Kerlinger (1975, 40-43) discussed the importance of the experimenter being aware of certain intervening variables[12] in experimental research designs. One such variable is learning or practice effect. Control of this variable is normally achieved through incorporation of a Latin or Greco-Latin square design (Cochran and Cox, 1957; Fisher and Yeates, 1934, 1963; Winer, 1971, 685-752). A standardized square's design could not be used in this design because of the number of variables and repeated measures. Each subject viewed the twelve maps three times, each time responding to magnitude, gradient, and pattern tasks. To ensure that a subject would not view

[12]Kerlinger (1975, 40) defined an intervening variable "as a term invented to account for internal and directly unobservable psychological process that in turn account for behavior".

progressively more difficult surfaces a surface complexity/view matrix (Table II) was designed to establish a map viewing order.

Table II

Surface Complexity and View Matrix

Viewing Angle	Surface Complexity		
	C10	C15	C20
V45	A	B	C
V315	D	E	F

Source: Author's computations

Using the complexity/view matrix (Table II) a map sequence presentation matrix was developed (Table III).

Table III

Stimulus Map Presentation Matrix

Subject	Map Order					
Subject 1	A	C	E	D	F	B
Subject 2	D	F	B	A	E	C
Subject 3	B	D	F	E	C	A
Subject 4	E	A	C	B	D	F
Subject 5	C	E	A	F	B	D
Subject 6	F	B	D	C	A	E

Source: Author's computations

This presentation order eliminated any subject from receiving a like sequence of surfaces, that is, an A-B (C10-V45, C10-V315), C-D (C15-V45), C15-V315) or E-F (C20-V45, C20-V315) combination.[13] The order of presentation was repeated every six subjects in each of the two map reading groups. Two additional factors were controlled in the presentation order, the order of answering questions regarding magnitude, gradient, and pattern plus viewing order based on the dimension of the graphic. Table IV presents the matrix of question sequence for the perceptual tasks pertaining to the three types of information.

Table IV

Question Sequence Matrix

Order	Perceptual Task Sequence
Order 1	Magnitude, Gradient, Pattern
Order 2	Pattern, Magnitude, Gradient
Order 3	Gradient, Pattern, Magnitude

Source: Author's computations

[13] A standard 6 X 6 Latin square is arranged in the following manner (Cochran and Cox, 1957, 145):

A	B	C	D	E	F
B	F	D	C	A	E
C	D	E	F	B	A
D	A	F	E	C	B
E	C	A	B	F	D
F	E	B	A	D	C

This standard square could not have been used since like sequence of surface would be given to a subject (A-B, C-D, E-F, etc.) and therefore contaminate test results based upon potential learning effect.

One third of each group received order one, one third order two, and one third order three. This sequence was established to ensure that the order of perceptual task questions did not influence the reader.

Finally, it was important in the experimental design to vary the presentation sequence based on dimension. This was achieved by showing one-half of each group the two dimensional, and the remaining one-half of each group the three dimensional maps first. The sequence was established to ensure that the sequence of graphic format did not influence the map reader.

A complete presentation scheme for the stimulus maps is presented in Table V. The use of the presentation scheme acted as a counterbalance to any potential effects due to intervening variables based on presentation order. Each subject viewed twelve maps and responded to a perceptual task pertaining to magnitude, gradient, and pattern. This resulted in 36 time and accuracy scores for each of the 78 subjects.

Perceptual Tasks

A series of perceptual tasks were developed to measure the efficiency of two and three dimensional maps in transferring magnitude, gradient, and pattern information. The task for each type of cartographic information was based, in part, upon results of the pilot study. At least two different tasks were examined for each type of information in the pilot study.

Table V
Map Presentation Scheme

Subjects	Complexity/View Order	Task Order	Order Dimension
S11/21	A C E D F B	M-G-P	2-3
S12/22	D F B A E C	M-G-P	2-3
S13/23	B D F E C A	M-G-P	2-3
S14/24	E A C B D F	M-G-P	2-3
S15/25	C E A F B D	M-G-P	2-3
S16/26	F B D C A E	M-G-P	2-3
S17/27	A C E D F B	M-G-P	2-3
S18/28	D F B A E C	M-G-P	2-3
S19/29	B D F E C A	M-G-P	2-3
S110/210	E A C B D F	M-G-P	2-3
S111/211	C E A F B D	M-G-P	2-3
S112/212	F B D C A E	M-G-P	2-3
S113/213	A C E D F B	M-G-P	2-3
S114/214	D F B A E C	P-M-G	2-3
S115/215	B D F E C A	P-M-G	2-3
S116/216	E A C B D F	P-M-G	2-3
S117/217	C E A F B D	P-M-G	2-3
S118/218	F B D C A E	P-M-G	2-3
S119/219	A C E D F B	P-M-G	2-3
S120/220	D F B A E C	P-M-G	3-2
S121/221	B D F E C A	P-M-G	3-2
S122/222	E A C B D F	P-M-G	3-2
S123/223	C E A F B D	P-M-G	3-2
S124/224	F B D C A E	P-M-G	3-2
S125/225	A C E D F B	P-M-G	3-2
S126/226	D F B A E C	P-M-G	3-2
S127/227	B D F E C A	G-P-M	3-2
S128/228	E A C B D F	G-P-M	3-2
S129/229	C E A F B D	G-P-M	3-2
S130/230	F B D C A E	G-P-M	3-2
S131/231	A C E D F B	G-P-M	3-2
S132/232	D F B A E C	G-P-M	3-2
S133/233	B D F E C A	G-P-M	3-2
S134/234	E A C B D F	G-P-M	3-2
S135/235	C E A F B D	G-P-M	3-2
S136/236	F B D C A E	G-P-M	3-2
S137/237	A C E D F B	G-P-M	3-2
S138/238	D F B A E C	G-P-M	3-2
S139/239	B D F E C A	G-P-M	2-3

Where: A=C10-V45, B=C15-V45, C=C20-V45, D=C10-V315, E=C15-V315, F=C20-V315; M=magnitude, G=gradient, P=pattern; 2=two dimensional maps, 3=perspective maps.

$S_{1,1}$ to $S_{1,39}$=Berkeley Subjects, $S_{2,1}$ to $S_{2,39}$=Sonoma Subjects

Source: Author's computations

Magnitude tasks required ranking the three and five highest points on each surface, identification of the highest point, and identification of the minimum and maximum values. The gradient tasks required identification of the steepest slope by placing a pen mark at that location and by placing a pre marked, self adhesive line symbol at the same location. Pattern tasks included comparision of the surfaces to schematic diagrams representing the trend of increasing values of the surface, identification of the trend of increasing values based upon a letter and numbering indexing system, and a multiple choice selection system describing the trend of the surface.

Magnitude

The task selected to measure the transmission efficiency of magnitude data required each subject to rank order five surface point symbols and their associated values from highest to lowest. Subjects were instructed to place a "1" by the highest, "2" by the second, "3" by the third, "4" by the fourth highest, and "5" by the lowest point value. Subjects placed the numbers directly on both the two and three dimensional stimulus maps.

Selection of the five points was derived from the five highest values generated by the modified 5th degree polynomial equation and the three surface complexity matrices. The ranking test was selected because it required an interpretive type processing of magnitude information by the reader. It required each subject to scan the surface for sources of high information (the five symbols), determine the numeric values associated with each point, and assess how the five points were related in magnitude to one another.

Efficiency of the graphic in transmitting the intended message to the reader was defined and measured by accuracy and speed in which the subject perceived the intended magnitude information. Although no time limit was imposed, each subject was instructed to complete the task as accurately and quickly as possible. Theoretically, a map reader could view any map for an indefinite time period and eventually perceive the intended message, this however, would not be very efficient. The efficiency index, therefore, considered both a time and accuracy component.

Response time for each task was measured in seconds.[14] Descriptive statistics of these times indicated the distribution to be positively skewed. This is not unusual in research when a measure involves a time scale, for example, number of seconds to complete a task (Winer, 1971, 400). Consequently, all magnitude response times were logarithmically transformed.[15] This type of transformation is effective in normalizing the distribution when the dependent variable is a measure of reaction time and data are positively skewed (Bartlett,

[14] Time was recorded to 1/10th second accuracy.

[15] Times were transformed using the BIOMEDICAL computer program BMDO9S, Transgeneration (Dixon, 1973, 451-458).

1974, 39-53; Kirk, 1968, 64-65; Winer, 1971, 400). Descriptive statistics of the magnitude times and logarithmic transformations are presented in Table VI.

Table VI

Magnitude Response Time Characteristics

Statistic	Time	Log_{10}Time
Mean	27.400	1.371
Median	24.237	1.381
Mode	24.00	1.380
Variance	282.290	.060
Std. Deviation	16.801	.244
Skewness	2.864	-.131
Kurtosis	20.058	.147

n = 936

Source: SPSS (Statistical Packages for the Social Sciences) computer program CONDESCRIPTIVE Nie, 1975, 181-203)

The accuracy component based on rankings was measured by the correct number of answers that a subject identified. Subjects were asked to rank the five highest points on each surface therefore each could have identified zero to five correct pairs. Zero indicated a completely incorrect response while five indicated that all points were correctly ranked. The score of zero presented a mathematical problem since the score was to be divided into time. To preclude division by zero a constant of 1.0 was added to the correct pair's score. The effect of the constant was then eliminated by dividing the entire term by six. Mathematically stated:

$$\text{Efficiency index: } E = (T/(C+1.0))/6 \qquad (4.2)$$

where: $T = \text{Log}_{10}$ time in seconds

C = correct number of answers

This measure provided an index for each task response based upon a time and accuracy component. As the index value approached zero the reader had more efficiently perceived the intended magnitude information. This was demonstrated in Table VII with actual minimum and maximum times for all magnitude task responses.

Table VII

Efficiency Scores - Magnitude Responses

Minimum Time	Fast-Inaccurate		Fast-Accurate
Formula:	(.67209/1)/6	(.67209/3)/6	(.67209/6)/6
E =	.1120	.0373	.0186
Maximum Time	**Slow-Inaccurate**		**Slow-Accurate**
Formula:	(2.79007/1)/6	(2.79007/3)/6	(2.79007/6)/6
E =	.4650	.1550	.0775

Source: Author's computation from minimum and maximum times for all magnitude task responses.

Subjects who had fast response times and inaccurate answers had a larger index value (lower efficiency) than those who had the same time but were accurate (higher efficiency) in their responses. Subjects who were slow and inaccurate had a larger index value (lower efficiency) than those who had the same slow response but were accurate (higher efficiency).

Twelve magnitude efficiency scores were generated for each subject, six based upon the two dimensional surfaces and six upon the three dimensional. In total 936 efficiency index scores were generated[16] for the magnitude portion of the experiment.[17] Magnitude task instructions and stimulus maps are presented in Appendix I.

Gradient

In searching a surface for any gradient information, one source of high informational content is the location of the steepest slope from one point to another. The gradient task required each subject to identify the location of the steepest gradient on each surface (C10, C15, C20). This task required the subject to scan the map searching for visual fields which contained closely spaced isolines over a specified linear distance, compare these areas with other steep areas and make a decision as to the steepest.

The two dimensional gradient task required each subject to place a pre measured, self-adhesive line on the map. Opposite ends

[16]All efficiency scores were generated using the BIOMED computer program BMD095, transgeneration (Dixon, 1973).

[17]Other accuracy measures were considered but were determined to be inadequate. They included Kendal's and Spearman's correlation coefficients, number of incorrect pairs of rankings, and sum of the absolute rank difference.

of the line symbol touched the lower and upper isolines where the greatest change in gradient occurred. Different line lengths were used based upon the numeric distribution for each surface complexity. Line length was important because it required the subject to locate a specific slope (steepest) based upon a set linear distance on the map. In effect, a subject had to find the location where as many isolines as possible would "fit" between the end points of the line symbol.[18]

A similar task was required for the series of perspective maps. Subjects were required to place the line symbol unit directly on the edge of the steepest visible angle formed on the surface. This task required each subject to scan hills on the surface and assess their edges as to which has the steepest slope. Once located, the slope was identified by sticking the acetate unit over the edge of the hill.[19] This procedure is presented along with gradient task instructions and stimulus maps in Appendix I.

[18]The symbol (Paratype roll on self adhesive line) was placed on a piece of clear acetate. The acetate contained a piece of drafting tape which permitted the subject to attach the entire unit directly to the map. Subjects were given the acetate unit after each had read the task instructions.

[19]The length of the line symbol varied with surface complexity (C10, C15, C20) and viewing angle (V45, V315). Data values which were in front of hills blocked a portion of the hill's edge. This required six different line lengths for the perspective maps (three different surface complexities by two viewing angles). Subjects were given the acetate unit after each had read the task instructions.

Efficiency of the graphic in transmitting the intended message to the reader was again defined and measured by accuracy and time in which the subject perceived the intended gradient information.

Descriptive statistics indicated the distribution of gradient times to be positively skewed, as such, the times were logarithmically transformed. Descriptive statistics of the gradient times and logarithmic transformations are presented in Table VIII.

Table VIII

Gradient Response Time Characteristics

Statistic	Time	Log_{10}Time
Mean	17.673	1.161
Median	14.157	1.147
Mode	11.000	1.041
Variance	145.994	.076
Std. Deviation	12.083	.275
Skewness	1.898	.021
Kurtosis	5.769	-.178

n = 936

Source: SPSS (Statistical Packages for the Social Sciences) computer program CONDESCRIPTIVE (Nie, 1975, 181-203)

The accuracy component was based upon a correct or incorrect response. If correct, a value of 1.0 was assigned for the task; if incorrect, a value of zero was assigned. A constant of 1.0 was added to each score to preclude division into time by zero.

The effect of the constant was then eliminated by dividing by 2.0. Mathematically stated:

$$\text{Efficiency index: } (E) = (T/(C+1.0))/2.0 \qquad (4.3)$$

where: $T = \text{Log}_{10}$ time in seconds

C = correct score or incorrect score

This measure provided an index of efficiency based upon time and accuracy. The reader perceived the gradient information more efficiently as the index value approached zero, as demonstrated in Table IX with actual minimum and maximum times for all gradient task responses.

Table IX

Efficiency Scores - Gradient Responses

Minimum Time	Fast-Inaccurate	Fast-Accurate
Formula:	(.4149/1)/2	(.4149/2)/2
E =	.20745	.10372
Maximum Time	**Slow-Inaccurate**	**Slow-Accurate**
Formula:	(2.4449/1)/2	(2.4449/2)/2
E =	1.2224	.61122

Source: Author's computations from minimum and maximum times for all gradient task responses.

Twelve gradient scores were generated for each subject, six based upon the two dimensional and six upon the three dimensional maps. In total, 936 efficiency index scores were generated for this portion of the experiment. Gradient task instructions and stimulus maps are presented in Appendix I.

Pattern

The perceptual task for pattern was identical for both two and three dimensional maps. Subjects were asked to identify the trend of increasing values on each C10, C15, and C20 surface. This task required the subject to scan the surface and determine the arrangement and direction of increasing values of the surface, i.e., trend.

The task required that each subject compare the mapped surface to a series of five schematic diagrams representing the trend of increasing values on each surface. Subjects then ranked the five diagrams from one to five based upon how accurately it represented the actual trend of increasing values on the surfaces. Subjects placed their ranks (1 through 5) directly on the schematic diagrams.[20]

Efficiency of the graphic in transmitting the intended message was defined and measured by accuracy and time in which the subject perceived the intended pattern information.

[20]Schematic diagrams were constructed for each surface complexity and viewing angle. The diagrams consisted of five rectangles, oriented at the appropriate 45 or 315 degree angle, each containing five arrows indicating the direction of increasing values on each surface. Each rectangle contained a different combination of correct arrows. The most accurate, identified by (1), contained five arrows all in the correct direction. The second most accurate identified with a (2), contained four correct directional arrows. The third most accurate (3), with three correct arrows; the fourth (4), with two correct arrows; and the least accurate (5), contained only one correct arrow.

Descriptive statistics indicated the distribution of pattern times to be positively skewed, as such, the times were logarithmically transformed. Descriptive statistics of the pattern times and logarithmic transformations are presented in Table X.

Table X

Pattern Response Time Characteristics

Statistic	Time	Log_{10}Time
Mean	83.877	1.883
Median	77.227	1.887
Mode	120.000	2.079
Variance	1329.400	.036
Std. Deviation	36.461	.191
Skewness	1.061	-.308
Kurtosis	1.870	.460

n = 936

Source: SPSS (Statistical Packages for the Social Sciences) computer program CONDESCRIPTIVE (Nie, 1975, 181-203).

The efficiency index for the pattern task was mathematically computed in the same manner as the magnitude task efficiency index (equation 4.2). As the index value approached zero the reader had more efficiently perceived the intended pattern information as demonstrated in Table XI with actual minimum and maximum times for all pattern tasks responses.

Table XI

Efficiency Scores - Pattern Responses

Minimum Time	Fast-Inaccurate		Fast-Accurate
Forumula:	(1.0718/1)/6	(1.0718/3)/6	(1.0718/6)/6
E =	.1786	.0595	.0297
Maximum Time	**Slow-Inacurate**		**Slow-Accurate**
Formula:	(3.0409/1)/6	(3.0409/3)/6	(3.0409/6)/6
E =	.5606	.1689	.0844

Source: Author's computations from minimum and maximum times for all pattern task responses and times.

Twelve pattern efficiency scores were generated for each subject, six based upon the two dimensional and six based upon the three dimensional surfaces. There were 936 scores generated for the pattern section of the experiment. Pattern task instructions, schematic diagrams, and stimulus maps are presented in Appendix I.

Each subject viewed and responded to 36 maps; 12 maps, each viewed three times with a response to a task pertaining to magnitude, gradient, and pattern information. This resulted in compilation of 36 time, accuracy, and efficiency scores for each subject; 12 magnitude, 12 gradient, and 12 pattern.

Tesing Procedure

Each subject was provided a set of general instructions and definitions, a series of task instructions, and a series of 36 stimulus maps. The first page contained introductory statements concerning the experiment, a general and specific statement as to the types of maps they would view, procedures for answering task questions, a sentence to perform each task as accurately and quickly as possible, and a statement indicating that their task performance would not affect their course grade.[21] The second page contained definitions of the following terms: contour lines, contour map, contour interval, perspective map, magnitude, gradient, and pattern information. Each subject was asked if they understood the instructions and definitions, if not, they were clarified.

Subjects were individually tested by the author in two small rooms (one at Berkeley and one at Sonoma) which were void of maps and other distracting materials. Each subject was requested to voluntarily supply biographical data before the testing session began.[22]

[21]During the pilot study each subject was provided verbal reinforcement of the statement "answer each question as accurately and quickly as possible." This verbal reinforcement apparently caused anxiety (this was based upon interviews with the pilot subjects after they completed the experiment) and, therefore, a decision was made to delete the verbal restatement of that condition in the actual experiment. Additionally, the statement concerning test performance was included because several pilot subjects were concerned that their performance might lower their course grade.

[22]A separate response sheet was used for each subject which contained the following biographical data: subject identification code, major, class year in school, sex, race, lab participation, age, a statement whether or not the subject needed and was wearing glasses, and starting time of the test session.

Subjects were informed that they did not have to answer any or all of it; however, no one refused.

Subjects were given written instructions for each of the perceptual tasks. After a subject read the particular magnitude, gradient, and pattern task instructions, each was asked if they understood the instructions, if not, the author clarified any questions. In addition, the experimenter demonstrated each of the three tasks to the subject as they progressed through the stimulus maps. Likewise, each subject was informed that the experimenter could not answer questions once the particular task began. Finally, each was thanked for his participation upon completion. A complete set of instructions and stimulus maps is presented in Appendix I.

Analytical Method

A series of testable main effect hypotheses and interactions were stated in the previous chapter concerning the influence of graphic dimension, map reading ability, surface complexity, and viewing angle upon the transmission of magnitude, gradient, and pattern information. The dependent variable was defined and measured as the efficiency in which the transmitted information was perceived by the map reader. These 936 efficiency scores were then evaluated by the use of the factorial analysis of variance.[23]

[23]Separate analyses using the factorial design were also conducted on the 936 time and accuracy values.

This statistical method allows the investigator not only to evaluate the main independent effects but also the combined effects of two or more factors upon the dependent variable in a single experiment (Kirk, 1968, 18; Williams, 1968, 95; Winer, 1971). Each of the independent variables can have two or more levels of its own. In this research, dimension has two levels (2D and 3D); map reading ability, two levels (G1 and G2), surface complexity, three (C10, C15, C20); and viewing angle, two (V45 and V315). There are, however, basic assumptions using a factorial analysis of variance to test the research hypotheses and interactions presented in Chapter III.

Statistical Assumptions

Hypothesis testing based upon the statistical technique of analysis of variance involved three basic assumptions: 1) a normally distributed population, 2) homogenity of population error variance, and 3) additivity of effects. Descriptive statistics of the time responses for magnitude (Table VI), gradient (Table VIII), and pattern (Table IX) tasks indicated characteristics that the values were not normally distributed. As stated earlier, all response times were logarithmically transformed. This transformation is useful when the dependent variable is some measure of reaction time and the data are positively skewed (Bartlett, 1947, 39-52; Kirk, 1968, 65). Therefore, the logarithmic transformation ensured that the assumptions of normality, homogenity of error variance, and additivity of treatment effects were met (Kirk, 1968, 60-69). Although it is desirable to meet the assumptions wherever possible, several experimental design researchers have indicated that analysis of variance is robust enough to violation of any of its assumptions (Cochran and Cox, 1957, 91; Kirk, 1968, 60).

Computational Design

The computational design involved a five way factorial analysis of variance (ANOVA) for each set of efficiency scores, time responses and accuracy scores generated for magnitude, gradient, and pattern information. Each ANOVA, a 2 x 39 x 2 x 3 x 2 balanced subject design, was based upon two levels of map reading experience (G1 and G2), 39 subjects per group (S), two levels of dimension (2D and 3D), three levels of surface complexity (C10, C15, and C20), and two levels of viewing angle (V45, V315).

The factor of subject (S) was introduced into the design as a best estimate of within group variance. The error term in a multi factor design is important because this estimate of error becomes the denominator of the F ratio ((V_B/V_W) with whatever source of variation (experimental treatments) is being subjected to an hypothesis test. The degrees of freedom used in the design are based upon the number of treatment levels minus one (between d.f.) and the number of S's in each group times the number of groups (within d.f.). The main effect and interaction variables with their error terms are listed in Table XII.

Table XII

Main and Interaction Effects of Research Variables

Main Effects	Variable*	Degrees of Freedom
Map Reading Experience	(G)	1
Error	(GxS)+(S)	76
Graphic Dimension	(D)	1
Error	(SxD)	38
Surface Complexity	(C)	2
Error	(SxC)	76
Viewing Angle	(V)	1
Error	(SxV)	38
Two-Way Interactions		
Experience x Dimension	(GxD)	1
Error	(GxSxD)	38
Experience x Complexity	(GxC)	2
Error	(GxSxC)	76
Experience x View	(GxV)	1
Error	(GxSxV)	38
Dimension x Complexity	(DxC)	2
Error	(SxDxC)	76
Dimension x View	(DxV)	1
Error	(SxDxV)	38
Complexity x View	(CxV)	2
Error	(SxCxV)	76
Three-Way Interactions		
Experience x Complexity x View	(GxCxV)	2
Error	(GxSxCxV)	76
Experience x Dimension x View	(GxDxV)	1
Error	(GxSxDxV)	38
Experience x Dimension x Complexity	(GxDxC)	2
Error	(GxSxDxC)	76
Dimension x Complexity x View	(DxCxV)	2
Error	(SxDxCxV)	76
Four-Way Interaction		
Experience x Complexity x Dimension x View	(GxCxDxV)	2
Error	(GxSxCxDxV)	76
	Total	935

*Identification codes and levels of variables: 1) map reading experience (G) - 2 levels, 2) subject error term (S) - 39 levels, 3) surface complexity (C) - 3 levels, 4) graphic dimension (D) - 2 levels, and 4) viewing angle (V) - 2 levels.

Source: Author's computations

Summary

An experimental design was established which allowed the influence of graphic dimension, map reading experience, surface complexity, and viewing angle to be assessed upon the perception of cartographic information by map readers. Seventy-eight subjects from the University of California at Berkeley and Sonoma State University were individually tested by the author. Each subject progressed through a predetermined sequence of 36 maps (18 two dimensional and 18 three dimensional) responding to perceptual tasks pertaining to the cartographic concepts of magnitude, gradient, and pattern information. An efficiency index, involving a time and accuracy component, was computed for each subject for each perceptual task. This index became a measure for analysis of the efficiency of the map in transmitting the intended cartographic information to the reader. In total, 936 efficiency index scores were analyzed for each type of cartographic information. Additionally, 936 time and accuracy were analyzed separately for each type of information. In total, eight factorial ANOVAs were performed, three based on the efficiency index by information type, three based on response time and two on accuracy. The scores were analyzed utilizing a five-way factorial analysis of variance design. This design allowed the influence of the four main effects and series of two, three, and four interactions to be assessed. The results and interpretation of the analyses are presented in the next chapter.

CHAPTER V

EXPERIMENTAL RESULTS AND ANALYSIS

Eight ANOVAs were performed on the efficiency scores, response times, and accuracy scores by information type.[1] The main effect hypotheses and two, three, and four-way interactions were assessed from the analysis. The experimental results for magnitude, gradient, and pattern hypotheses are discussed and interpretations are provided.

Magnitude Information

Analysis of the ANOVA summary chart for magnitude efficiency scores (Table XIII) revealed that all four main effect independent variables did significantly influence the efficiency in which magnitude information was transferred to map readers. Graphic dimension, map reading experience, surface complexity, and viewing angle, each acting separately, influenced the efficiency of magnitude information transmission. If each main effect in an analysis of variance design is tested separately in the analysis and if each main effect is treated as if the other did not exist, they could be interpreted

[1]Each ANOVA was computed using the BIOMEDICAL computer program, BMDO2V, Analysis of Variance for Factorial Design (Dixon, 1973, 607-622).

individually without one variable conditioning the other (Williams, 1968, 101-111). However, variables seldom act individually. As such, any interpretation of the four main effects presented in Chapter III (equations 3.1-3.12) must include a discussion of interaction effects.

The ANOVA summary chart (Table XIII) indicated all four main effect variables were statistically significant; however, several interaction effects were evident. Four, two-way interactions were significant: map reading experience by surface complexity (GxC), map reading experience by graphic dimension (GxD), dimension by viewing angle (DxV), and surface complexity by viewing angle (CxV). Furthermore, one three-way interaction was significant, graphic dimension by surface complexity by viewing angle (DxCxV). The four-way interaction of map experience by graphic dimension by surface complexity by viewing angle (GxDxCxV) was not statistically significant.

The time analysis revealed that the main effects of graphic dimension and surface complexity were statistically significant (Table XIV); however, these variables were conditioned by two-way interactions between dimension and complexity (DxC) and complexity by view (CxV). Additionally, the main effects were conditioned by the three-way interaction of map reading experience by surface complexity by view (GxCxV).

The accuracy analysis (correct number of pairs of answers) revealed (Table XV) that all four main effects were significant,

Table XIII

ANOVA Summary Table - Magnitude Efficiency Scores

Source of Variation Main Effects		SS	d.f	MS	F	Tabled F	Sig. Level
Map Experience	(G)	.02797	1	.02797	5.93	3.98	.05
Error Term*	(S)+(G+S)	.35868	76	.00471			
Dimension	(D)	.71587	1	.71587	170.85	7.56	.01
Error	(SxD)	.15912	38	.00419			
Complexity	(C)	.41721	2	.20861	121.29	4.92	.01
Error	(SxC)	.13040	76	.00172			
View	(V)	.07616	1	.07616	37.89	7.56	.01
Error	(SxV)	.07628	38	.00201			
Two Way Interactions							
(GxD)		.01228	1	.01228	3.18	4.17	NS
Error	(SxGxD)	.14675	38	.00386			
(GxC)		.01631	2	.00815	6.08	4.92	.01
Error	(SxGxC)	.10150	76	.00134			
(GxV)		.00033	1	.00033	.29	4.17	NS
Error	(SxGxV)	.04317	38	.00114			
(DxC)		.33580	2	.16780	99.35	4.92	.01
Error	(SxDxC)	.12839	76	.00169			
(DxV)		.05295	1	.05295	50.91	7.56	.01
Error	(SxDxV)	.03948	38	.00104			
(CxV)		.03039	2	.01520	9.94	4.92	.01
Error	(SxCxV)	.11610	76	.00153			
Three Way Interactions							
(GxCxV)		.00048	2	.00024	.18	4.92	NS
Error	(SxGxCxV)	.10104	76	.00133			
(GxDxV)		negl.	1	negl.	negl.		NS
Error	(SxGxDxV)	.04830	38	.00127			
(GxDxC)		.00824	2	.00412	2.10	4.92	NS
Error	(SxGxDxC)	.14896	76	.00196			
(DxCxV)		.04568	2	.02284	21.55	7.01	.01
Error	(SxDxCxV)	.08080	76	.00106			
Four Way Interaction							
(GxDxCxV)		.00227	2	.00113	.72	7.01	NS
Error	(SxGxDxCxV)	.11829	76	.00156			
Total		3.53922	935				

*Error Term - Subjects (S) NS - not significant

Source: BIOMEDICAL computer program, BMD02V, Analysis of Variance for Factorial Design (Dixon, 1973, 607-622) and author's computations.

Table XIV

ANOVA Summary Table - Magnitude Response Times

Source of Variation Main Effects		SS	d.f.	MS	F	Tabled F	Sig. Level
Map Experience	(G)	.19706	1	.19706	1.03	3.98	NS
Error Term*	(S)+(G+S)	14.50775	76	.19089			
Dimension	(D)	15.95453	1	15.95453	227.82	7.56	.01
Error	(SxD)	2.66120	38	.07003			
Complexity	(C)	.54501	2	.27251	10.81	4.92	.01
Error	(SxC)	1.91472	76	.02519			
View	(V)	.01717	1	.01717	.65	7.56	NS
Error	(SxV)	.00815	38	.02653			
Two Way Interactions							
(GxD)		.00424	1	.00424	.08	4.17	NS
Error	(SxGxD)	1.99348	38	.05246			
(GxC)		.02010	2	.01005	.65	4.92	NS
Error	(SxGxC)	1.16591	76	.01534			
(GxV)		.01376	1	.01376	.93	4.17	NS
Error	(SxGxV)	.55784	38	.01468			
(DxC)		.49337	2	.24669	12.21	4.92	.01
Error	(SxDxC)	1.53549	76	.02020			
(DxV)		.02488	1	.02488	.77	7.56	NS
Error	(SxDxV)	1.22255	38	.03217			
(CxV)		.25223	2	.12612	3.76	3.13	.05
Error	(SxCxV)	2.54891	76	.03354			
Three Way Interactions							
(GxCxV)		.11934	2	.05967	4.69	3.13	.05
Error	(SxGxCxV)	.96521	76	.01270			
(GxDxV)		.00283	1	.00283	.20	4.17	NS
Error	(SxGxDxV)	.53630	38	.01411			
(GxDxC)		.02005	2	.01002	.49	4.92	NS
Error	(SxGxDxC)	1.54351	76	.02031			
(DxCxV)		.08236	2	.04118	1.81	7.01	NS
Error	(SxDxCxV)	1.72306	76	.02267			
Four Way Interaction							
(GxDxCxV)		.05204	2	.02602	1.25	7.01	NS
Error	(SxGxDxCxV)	1.57727	76	.02075			
	Total	53.26032	935				

*Error Term - Subjects (S) NS - not significant

Source: BIOMEDICAL computer program, BMDO2V, Analysis of Variance for Factorial Design (Dixon, 1973, 607-622) and author's computations.

Table XV

ANOVA Summary Table - Magnitude Accuracy Scores

Source of Variation Main Effects		SS	d.f.	MS	F	Tabled F	Sig. Level
Map Experience	(G)	39.38462	1	39.38462	13.31	7.01	.01
Error Term*	(S)+(G+S)	224.73077	76	2.95698			
Dimension	(D)	1574.56838	1	1574.56838	562.17	7.56	.01
Error	(SxD)	106.43162	38	2.80000			
Complexity	(C)	243.92308	2	121.96154	100.48	4.92	.01
Error	(SxC)	92.24359	76	1.21373			
View	(V)	20.34615	1	20.34615	15.06	7.56	.01
Error	(SxV)	51.32051	38	1.35054			
Two Way Interactions							
(GxD)		22.77351	1	22.77351	7.65	7.56	.01
Error	(SxGxD)	113.05983	38	2.97526			
(GxC)		11.71795	2	5.85897	5.42	4.92	.01
Error	(ScGxC)	82.11538	76	1.08097			
(GxV)		1.23504	1	1.23504	1.88	4.17	NS
Error	(SxGxV)	24.93162	38	.65610			
(DxC)		308.36752	2	154.18376	114.73	4.92	.01
Error	(SxDxC)	102.13248	76	1.34385			
(DxV)		7.53846	1	7.53846	7.82	7.56	.01
Error	(SxDxV)	36.62820	38	.96390			
(CxV)		2.15385	2	1.07692	.98	4.92	NS
Error	(SxCxV)	83.17949	76	1.09447			
Three Way Interactions							
(GxCxV)		3.82906	2	1.91453	2.77	4.92	NS
Error	(SxGxCxV)	52.50427	76	.69085			
(GxDxV)		1.70940	1	1.70940	2.07	4.17	NS
Error	(SxGxDxV)	31.29060	38	.82344			
(GxDxC)		9.29060	2	4.64530	2.69	4.92	NS
Error	(SxGxDxC)	130.87607	76	1.72205			
(DxCxV)		16.48718	2	8.24359	9.66	7.01	.01
Error	(SxDxCxV)	64.84615	76	.85324			
Four Way Interaction							
(GxDxCxV)		2.88034	2	1.44017	1.70	7.01	NS
Error	(SxGxDxCxV)	64.11960	76	.84368			
	Total	3526.61538	935				

*Error Term - Subjects (S) NS - not significant

Source: BIOMEDICAL computer program, BMD02V, Analysis of Variance for Factorial Design (Dixon, 1973, 607-622) and author's computations.

but were conditioned by reading experience and dimension (GxD), reading experience and surface complexity (GxC), dimension and complexity (DxC), and dimension by view (DxV). Additionally, a three-way interaction occurred between dimension, complexity, and view (DxCxV).

Meaningful statements concerning the main effects must be made with respect to the conditioning effects of the interactions. It is customary in a complex factorial design to first assess the results in light of the most complex significant interaction, in this case, the three-way interaction. Interpretation of results will focus primarily on the independent variable, graphic dimension and the efficiency index, the dependent variable. Comments regarding the test reuslts of the time and accuracy analyses are provided to help with the understanding of the information transfer process.

Dimension

Main Effects

The F value for the main effect of dimension in summary Table XIII indicated that indeed graphic dimension did significantly influence the transfer of magnitude data, however, the effect was the opposite of what had been hypothesized. Two dimensional maps were found to be superior to the perspective maps in conveying magnitude information as indicated by the lower mean (more efficient) for the efficiency measure in Table XVI. Furthermore, F values in

Table XVI

Magnitude - Main Effect Means

Dimension

Main Effect	Measure		
Dimension	Efficiency	Time	Accuracy
2D	.05452	1.51028	4.33547
3D	.10983	1.24916	1.74145

Source: BIOMEDICAL Computer Program BMDO2V Analysis of Variance for Factorial Design. Means cross verified with BMDO1D, Simple Data Description (Dixon, 1973; 67-73, 607-622).

Tables XIV and XV indicated that graphic dimension was significant when considering time and accuracy separately. Response time was faster for perspective maps (lower mean) but greater accuracy (higher mean) was achieved with the two dimensional maps (Table XVI).

The general statement that can be made is that two dimensional maps were more efficient primarily because of the greater accuracy provided with this type of map. Perspective maps were superior when time was considered separately; however the loss of accuracy with perspective maps made them less efficient. This conclusion must now be considered in view of the significant interactions.

Interaction Effects

The ANOVA results for efficiency scores (Table XIII) revealed a significant three-way interaction between dimension, complexity, and view (DxCxV). The individual treatment means for the levels of graphic dimension, surface complexity, and viewing angle acting in a combined three-way interaction upon efficiency can be observed in Table XVII. A graphic representation[2] of the dimension x complexity x

Table XVII

Dimension x Complexity x View Interaction Means

Magnitude - Efficiency Index

Dimension	Viewing Angle	Surface Complexity			View Means
		C10	C15	C20	
2D	V45	.0572	.0518	.0500	.0530
	V315	.0642	.0494	.0545	.0560
Complexity Means		.0607	.0506	.0522	.0545*
3D	V45	.1269	.0995	.0535	.0933
	V315	.1626	.1620	.0545	.1263
Complexity Means		.1447	.1307	.0540	.1098**

*Two dimensional mean
**Three dimensional mean

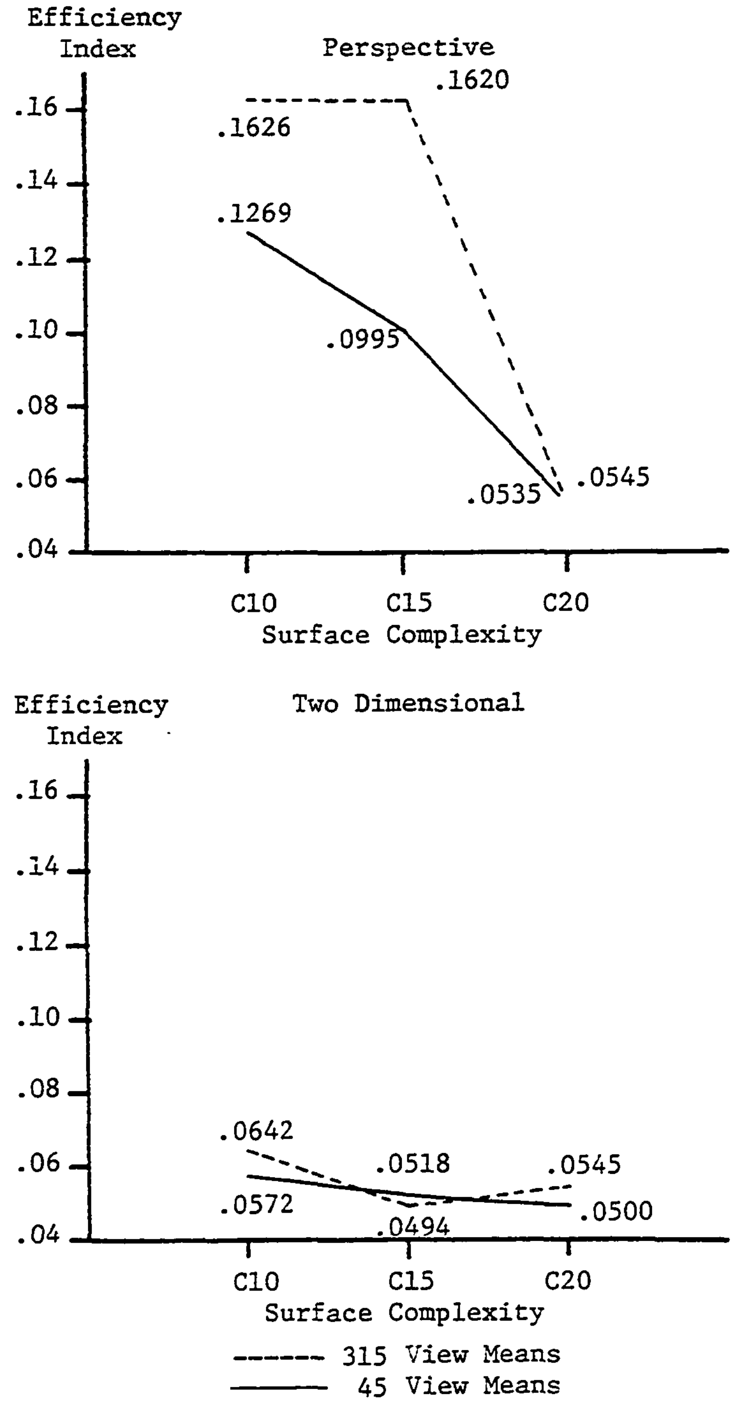
Source: BIOMEDICAL computer program BMD02V, Analysis of Variance for Factorial Design. Marginal treatment means cross verified with BMD01D, Simple Data Description (Dixon, 1973, 67-73, 607-622).

view (DxCxV) interaction means is presented in Figure 14.

[2]All interaction graphs were compiled and constructed with the Tektronix Extended Software Package for two dimensional plots (Tektronix, 1977) and a Tektronix 31 calculator interfaced with a 4661 Tektronix digital plotter.

Figure 14

Magnitude - DxCxV Interaction
Efficiency



This three-way interaction indicated that complexity and viewing angle made little difference with two dimensional maps. Performance was generally good as indicated by the relatively low treatment means (high efficiency) for all situations. With the perspective maps high complexity surfaces (C15 and C20) produced good performance, but the absence of surface complexity impaired performance, especially for the 315 degree viewing angle.

The increased number and specific arrangement of isolines on the more complex two dimensional surfaces represented redundant visual elements which supplied reference information to the reader in the search process for height information. There appears to be a clarifying effect with the perspective maps as the surface becomes increasingly complex as indicated by the low mean, especially for the most complex (C20) surface.

Height information can be estimated from the location of the five point symbols on the two dimensional surfaces by interpolating adjacent isolines. This can be a difficult task, especially if the height difference between two points was small, however, surrounding isolines do provide references for interpolation. Perspective maps do not usually contain height references on the surface. Estimated heights can be determined on a two dimensional surface but this becomes a more difficult process when viewing perspective maps since there are no specific reference isolines. The actual height values for the five data points used on the stimulus maps are presented in Table XVIII.

Table XVIII

Height Values For Stimulus Maps

Rank	Surface Complexity		
Highest to Lowest	C10	C15	C20
Highest	126	143	151
2nd highest	111	128	136
3rd highest	108	104	118
4th highest	106	100	113
Lowest	81	96	101

Source: Author's computations from RANDU modified 5th degree polynominal surface.

Height differences between several points were minimal, and apparently, these small differences were not clearly perceived from the perspective surfaces.

The results of this three-way interaction indicate that whenever exact height is to be transmitted, two dimensional maps are more efficient. However, perspective maps are efficient in transmitting relative height information when the difference between data points is great.

The decrease in accuracy was noticeable when the three-way interaction between dimension, complexity, and view (DxCxV) was examined. ANOVA Summary Table XV indicated that the DxCxV interaction for accuracy was statistically significant. The treatment means for this interaction are provided in Table XIX.

Table XIX

Dimension x Complexity x View Interaction Means

Magnitude - Accuracy Scores

Dimension	Viewing Angle	Surface Complexity			View Means
		C10	C15	C20	
2D	V45	4.3462	4.4744	4.3590	4.3932
	V315	4.1154	4.6026	4.1154	4.2778
Complexity Means		4.2308	4.5385	4.2372	4.3355*
3D	V45	1.0769	1.5256	3.3333	1.9786
	V315	.7692	.5513	3.1923	1.5043
Complexity Means		.9230	1.0384	3.2628	1.7414**

*Two dimensional mean
**Three dimensional mean

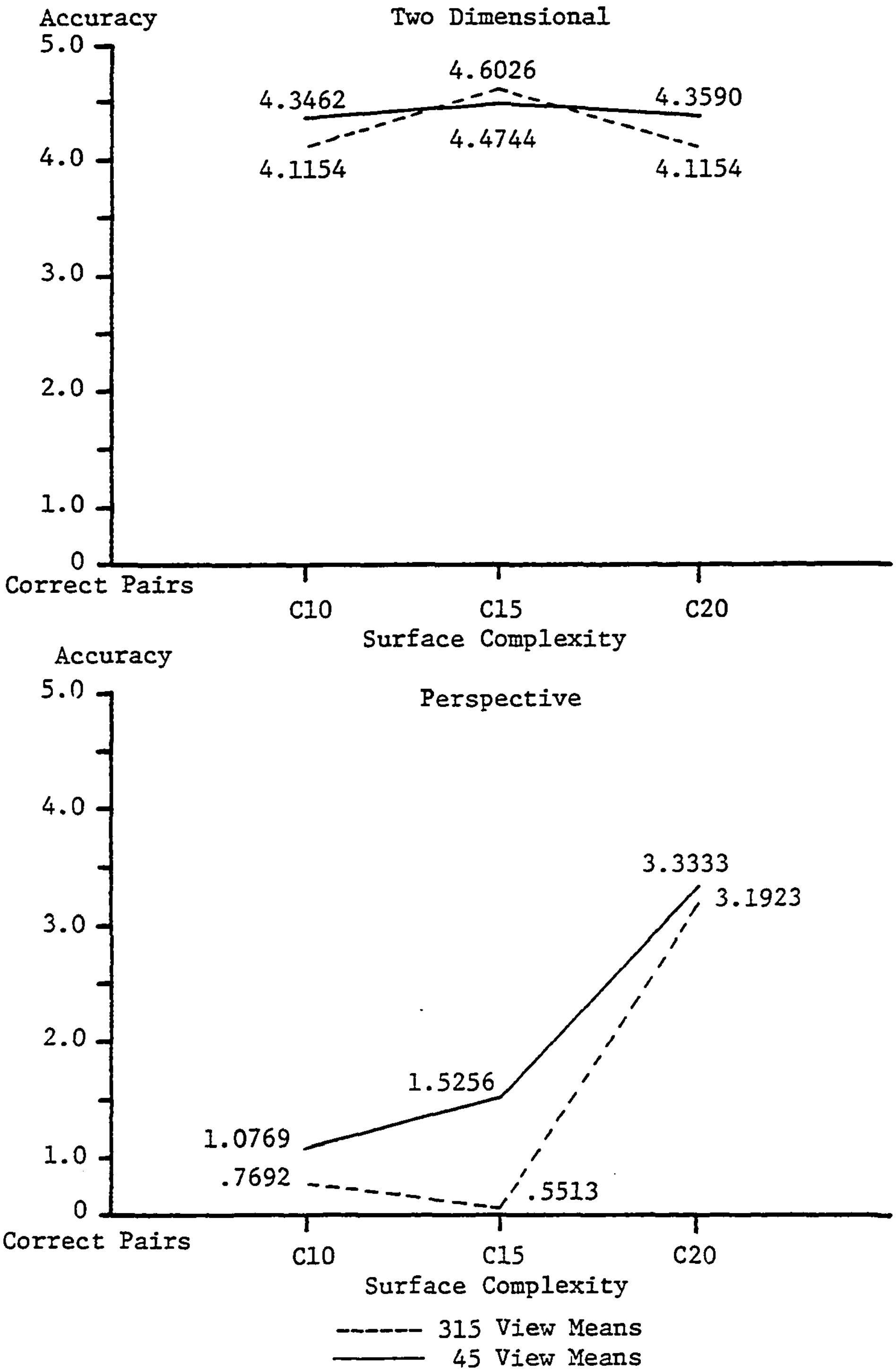
Source: BIOMEDICAL computer program BMDO2V, Analysis of Variance for Factorial Design. Marginal treatment means cross verified with BMDO1D, Simple Data Description (Dixon, 1973, 67-73, 607-622).

Graphs of this interaction (Figure 15) indicate that in general greater accuracy was achieved with the two dimensional maps regardless of surface complexity or map orientation. With perspective maps only the most complex (C20) surface produced good performance regardless of map orientation. When complexity was reduced accuracy was lower, especially with the 315 degree view for the C10 and C15 surfaces.

The time analysis did not yield a significant three-way interaction between dimension, complexity, and viewing angle (Table XIV).

Figure 15

Magnitude - DxCxV Interaction
Accuracy



Two-Way Interactions

The ANOVA of the efficiency measure indicated a significant two-way interaction (Table XIII) between dimension and surface complexity (DxC). As a graph of the treatment means reveals, the two dimensional maps were more efficient in transferring height information than perspective maps for all three surface complexities. With perspective maps only the most complex surface (C20) had good efficiency scores (Figure 16).

The time and accuracy ANOVAs (Table XIV and XV) indicated a similar significant interaction between dimension and surface complexity (DxC). The graphs (Figure 17) show again that higher accuracy was achieved with two dimensional maps regardless of surface complexity. With perspective maps only the most complex (C20) resulted in good performance as measured by efficiency. However, the graphs also showed that while greater accuracy was achieved with two dimensional maps, response time was generally fast for all surface complexities with perspective maps (Figure 17).

Interpretation of these results suggest strongly that isolines on the two dimensional maps create visual noise which slows response time. However, the isolines also acted as redundant visual elements that aided the viewer in determination of exact height values from the point symbols on the surface as indicated by the higher accuracy with the two dimensional maps.

Figure 16

Magnitude - DxC Interaction
Efficiency

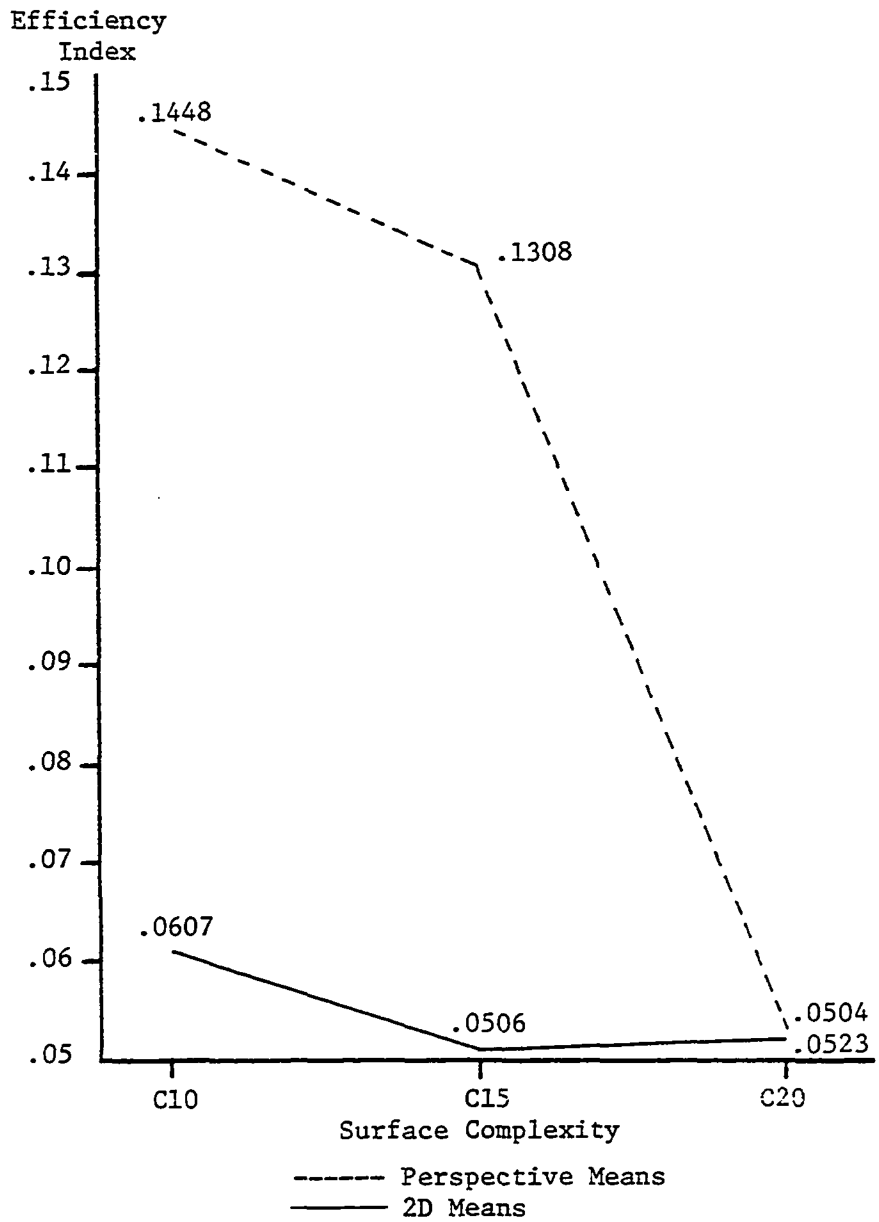
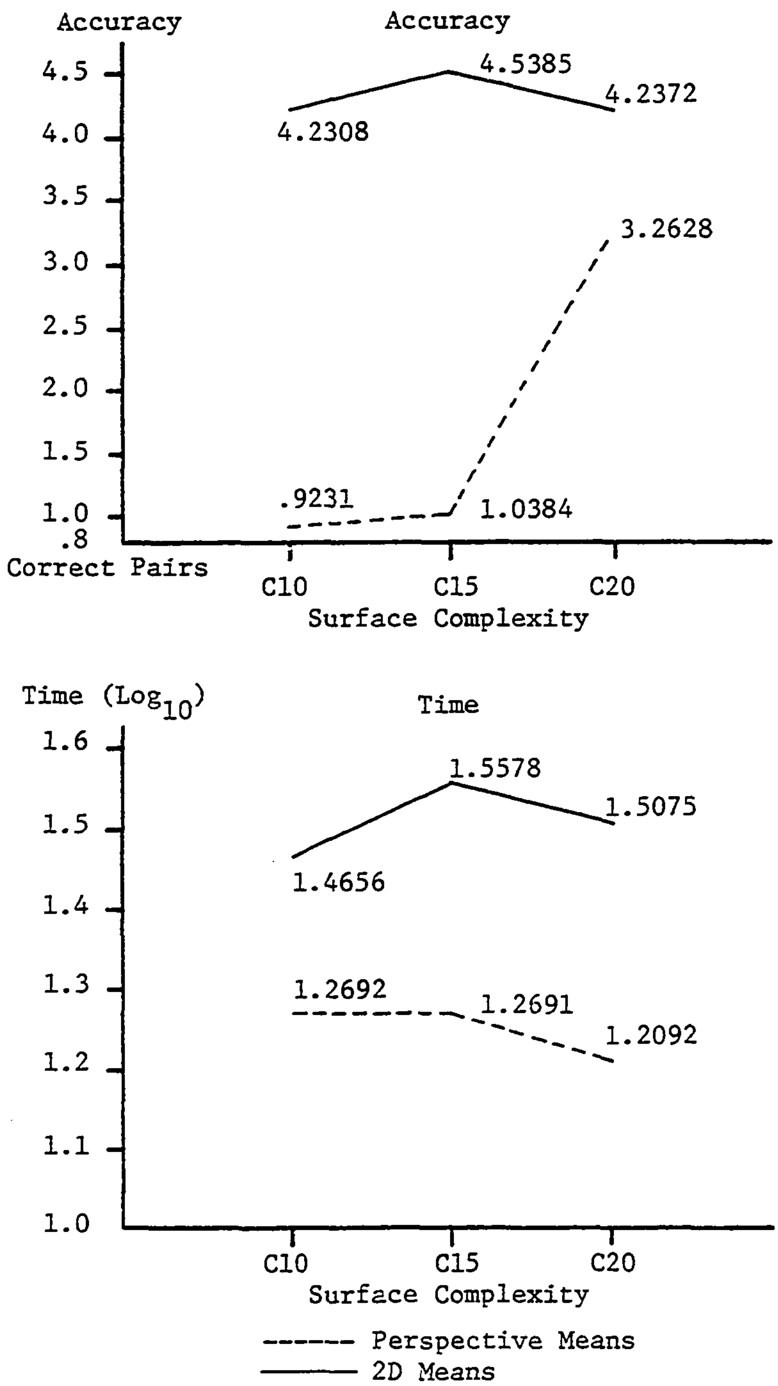


Figure 17

Magnitude - DxC Interaction
Time and Accuracy



Accuracy increased notably with the most complex (C20) perspective maps, as opposed to the two dimensional maps in which accuracy was good for all surface complexities. It was anticipated that overall efficiency, as well as accuracy, would decrease with increased surface complexity. Likewise, response time was anticipated to become slower with increased complexity. This, however, did not occur. Reasons for the particular results are provided in the next section which examines the surface complexity results.

Surface Complexity

Main Effects

The main effect of complexity was significant for the efficiency, time, and accuracy measures (Table XIII, XIV, and XV). The treatment means in Table XX indicate efficiency and accuracy increased with complexity while time generally decreases with complexity.

Table XX

Magnitude - Main Effect Means

Surface Complexity

Main Effect	Measure		
Surface Complexity	Efficiency	Accuracy	Time
C10	.10273	2.57692	1.367
C15	.09066	2.78846	1.410
C20	.05314	3.75000	1.358

Source: BIOMEDICAL computer program BMDO2V, Analysis of Variance for Factorial Design. Means cross verified with BMDO1D, Simple Data Description (Dixon, 1973, 67-73, 607-622).

These results are opposite from those hypothesized. One reason for this might be due to the arrangement of data points for the surfaces. The five data points on the various surfaces tended to be clustered, especially on the C15 and C20 surfaces. Points on the C15 surface were located along the bottom of the map with one exception at the upper center while all five points on the C20 surface were located along the lower boarder of the maps. The five data points on the C10 surface were more dispursed along a line from the bottom right to upper center of the map. (Appendix I - magnitude maps). Point locations were systematically assigned based on random values generated by the RANDU surface complexity matrices (Figure 6). This was done to simulate a surface which might actually occur with a real distribution. This may have resulted in faster times, especially for the most complex surfaces. A research hypothesis for future testing might focus on the effect clustering of data points has upon the transmission of information as the viewer scans the surface for height information. Interactions involving complexity are discussed in the sections under dimension, view, and map reading experience.

Viewing Angle

Main Effects

The main effects of view for efficiency and accuracy were statistically significant while the time measure was not (Tables XIII, XIV, and XV). Treatment means are provided in Table XXI.

Table XXI

Magnitude - Main Effect Means

Viewing Angle

Main Effect	Measure		
Viewing Angle	Efficiency	Accuracy	Time
V45	.07316	3.18590	NS
V315	.09120	2.89103	NS

Source: BIOMEDICAL computer program BMDO2V, Analysis of Variance for Factorial Design. Means cross verified with BMDO1D, Simple Data Description (Dixon, 1973; 67-73, 607-622).

As indicated by the means, the 45 degree view produced better performance for both the efficiency and accuracy measure. These main effects were, however, conditioned by the three-way interaction between dimension, complexity, and viewing angle (DxCxV) for both efficiency and accuracy. That interaction was discussed in the section on dimensional effects.

Two-Way Interactions

Significant interactions occurred between dimension by view (DxV) and complexity by view (CxV) for the efficiency analysis (Table XIII). Additionally, a significant interaction occurred between dimension and view (DxV) for accuracy[3] (Table XV).

[3]A two-way interaction also occurred between complexity and view (CxV) for time but is not discussed because it was only significant at the .05 level.

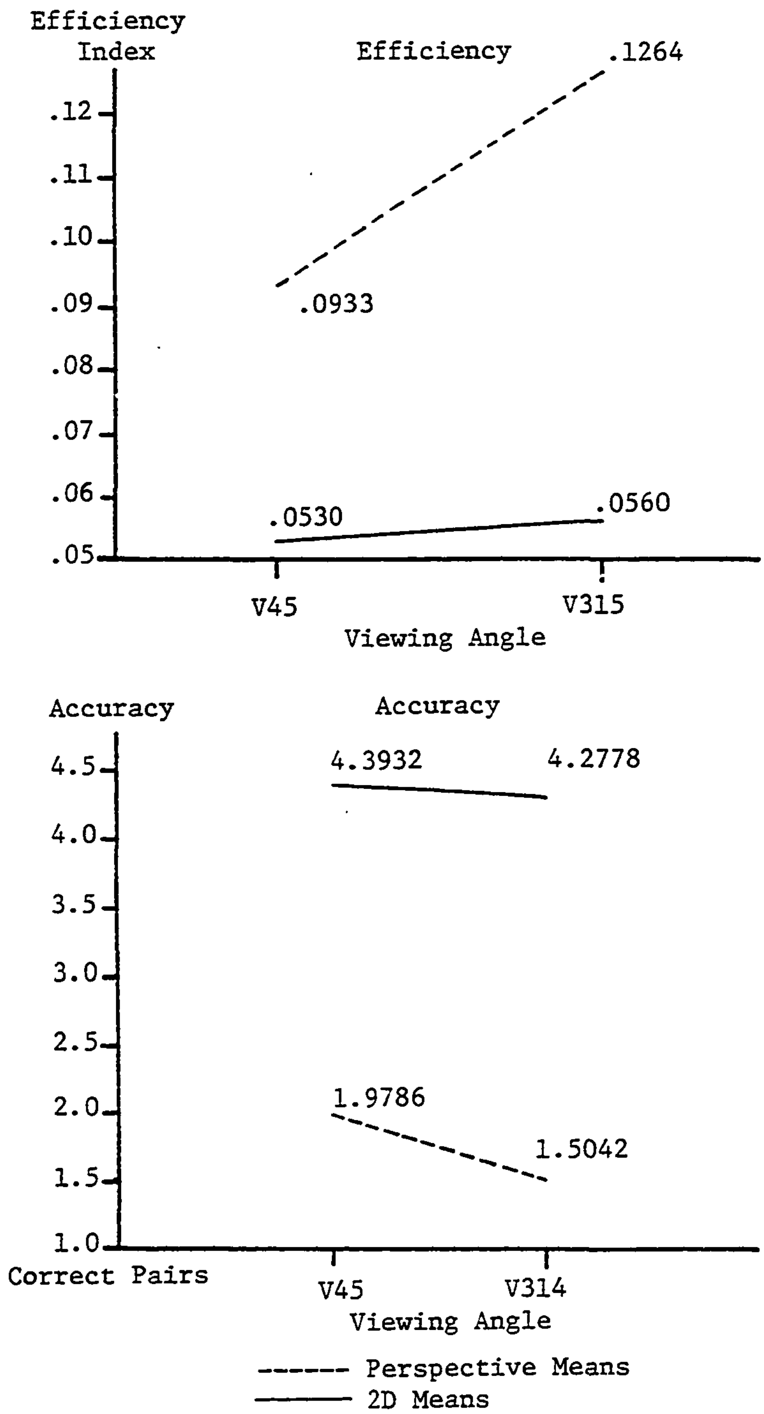
The graph of the DxV efficiency interaction means (Figure 18) indicated that performance was generally good with two dimensional maps for both viewing angles. The lack of parallelism in the data was noticeable with the perspective maps; performance seems to have been impaired with the 315 degree view because of the higher mean. The main effect means for view tend to support this; overall, the 45 degree view was better than the 315 degree view for both efficiency and accuracy (Table XXI).

The graph of the DxV interaction for accuracy revealed that two dimensional maps resulted in higher accuracy than perspective maps regardless of map orientation. With perspective maps the 45 degree view apparently provided better accuracy (Figure 18).

These results were not unexpected since two dimensional maps are seldom oriented to views other than the vertical edges of the map "pointing north" or "toward the top" of the map. Viewing angle is, however, more important in perspective mapping because the three dimensional technique has the potential to obscure or hide information. This was noticeable with the perspective maps, a lower (more efficient) mean for efficiency and a higher mean for accuracy with the 45 degree view. No statement was made at the outset of this research as to which view, 45 or 315 degrees, would enhance information, only that viewing angle could enhance or hinder the flow of information.

Figure 18

Magnitude - DxV Interaction
Efficiency and Accuracy



The reason for the higher efficiency and accuracy with the 45 degree view may be that it provided more of a profile in relation to the location of the five data points. The 315 degree view provided a frontal view of the five data points except on the most complex (C20) surface. A side profile may give the viewer the opportunity to compare several heights against an unobscured background and subsequently assess magnitude information, in effect, a better figure ground relationship than the 315 degree view provided. It then becomes important for the cartographer to assess the location and magnitude of potential information to be conveyed and select a viewing angle which best provides a side profile, and, if possible, one which has an unobscured background (Appendix I - magnitude perspective maps).

Map Reading Experience

Main Effects

ANOVA summary Tables XIII, XIV, and XV revealed that the main effect of map reading experience was statistically significant for efficiency and accuracy but not for time.

As anticipated, the more experienced readers could identify the intended height information more efficiently and more accurately than the less experienced group (Table XXII). The main effect of map reading experience on the assessment of height value was, however, conditioned by several two-way interactions.

Table XXII

Magnitude - Main Effect Means

Map Reading Experience

Main Effect	Measure		
Map Reading Experience	Efficiency	Accuracy	Time
G1 (inexperienced)	.08764	2.8333	NS
G2 (experienced)	.07671	3.2436	NS

Source: BIOMEDICAL computer program BMD02V, Analysis of Variance for Factorial Design. Means cross verified with BMD01D, Simple Data Description (Dixon, 1973, 67-73, 607-622).

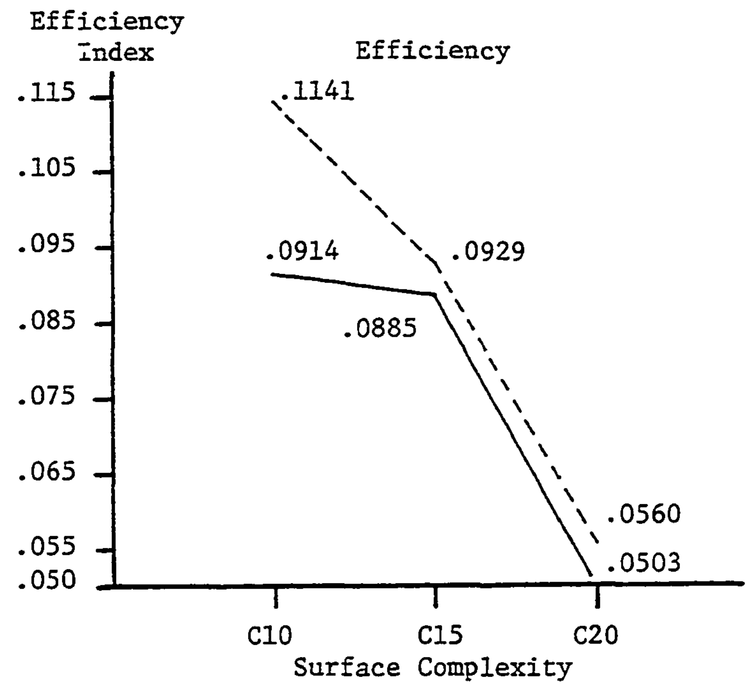
Two-Way Interactions

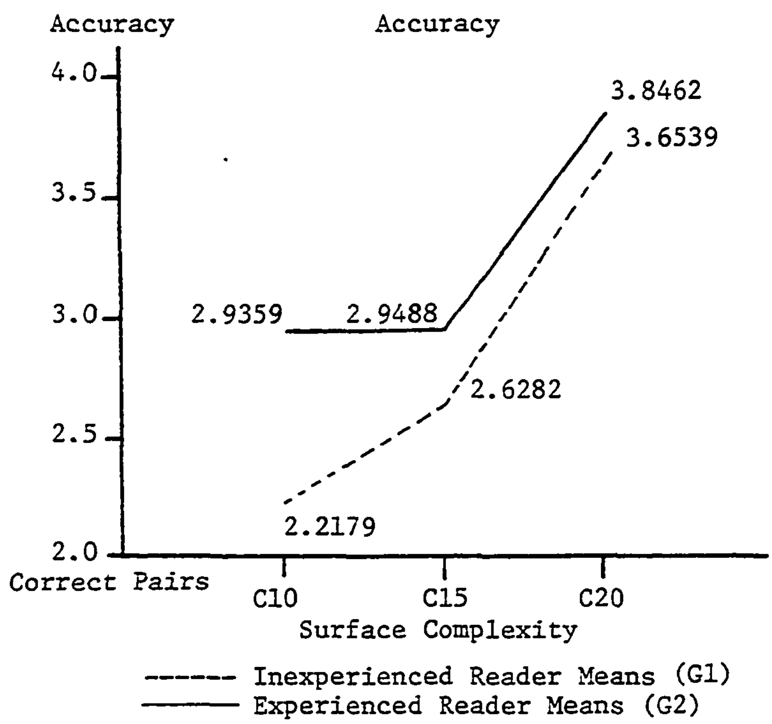
A significant two-way interaction occurred between experience and complexity (GxC) for both efficiency and accuracy. Furthermore, a two-way interaction occurred between experience and dimension (GxD) for accuracy. No significant two-way interaction occurred with map reading experience for the time analysis (ANOVA Summary Tables XIII, XIV, and XV).

Graphs of the GxC interaction (Figure 19) revealed that in all cases the more experienced group perceived the height information more efficiently and achieved greater accuracy than the less experienced group of map readers. The most complex surface (C20) resulted in higher efficiency and better accuracy for both groups of readers. An explanation was offered earlier that better performance with the

Figure 19

Magnitude - GxC Interaction
Efficiency and Accuracy





most complex surface may have been due to a cluster effect of the point symbols which resulted in quicker times and ultimately the low efficiency index for these surfaces.

The GxD interaction for accuracy (Figure 20) indicates both groups performed poorly with perspective maps and that two dimensional maps resulted in better performance primarily for the more experienced group of readers.

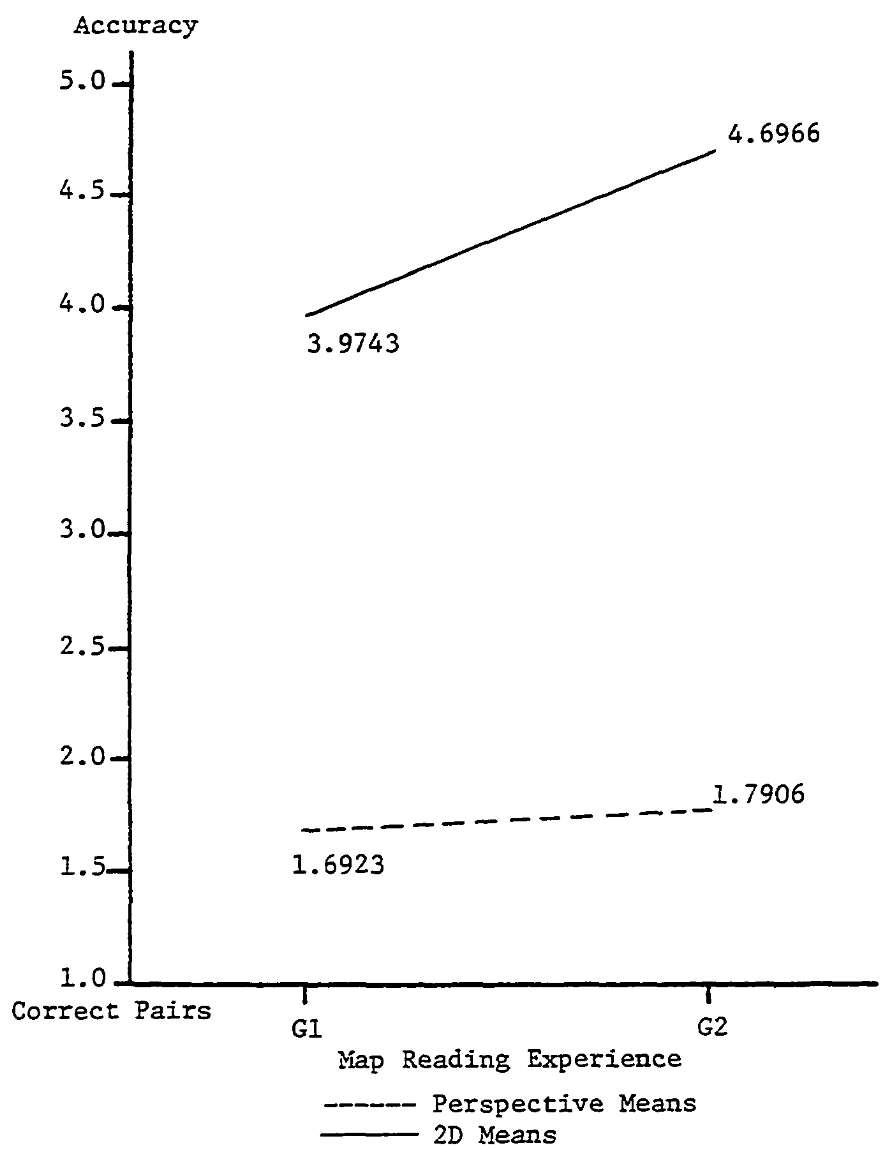
Summary - Magnitude

It can be concluded from the analyses of efficiency scores, accuracy, and response times that height information was more efficiently transferred from two dimensional maps than perspective maps. Greater accuracy was achieved with two dimensional maps while perspective maps produced quicker response times by the subjects. As such, two dimensional maps appear to transfer exact height information more effectively than perspective maps. If time alone is the most important factor, then perspective should be considered. This suggests that perspective maps provide an impressionistic view while the planimetric map provides exact height information for analytical purposes.

Efficiency scores and accuracy improved with increased surface complexity for both graphic dimension, but especially for the most complex perspective surfaces. Likewise, response time generally decreased as the surface became more complex, an unexpected result.

Figure 20

Magnitude - DxG Interaction
Accuracy



This can possibly be attributed to the clustering of the five point locations on the two more complex surfaces. This, however, is only a hypothesis and must be examined by testing at a later date.

The effect of viewing angle was more important with perspective maps, especially the 45 degree view which provided the reader with a better profile of the peaks representing the high values in the numeric distribution. Performance was generally good with two dimensional maps for both viewing angles. This was not unexpected since two dimensional maps are not usually oriented at directions other than "north" pointing "up".

Prior map reading experience resulted in higher overall efficiency and higher accuracy for both two and three dimensional maps. Response time, however, was not significant for either group of readers. Lastly, the more experienced group of readers achieved greater accuracy with the two dimensional maps than the less experienced group; likewise both groups' performance was poor in terms of accuracy with perspective maps.

Gradient Information

The ANOVA summary chart for the efficiency scores on the gradient measure (Table XXIII) indicates that the main effect of dimension, map reading experience, and surface complexity, each acting separately, did significantly influence the transmission of gradient information. Additionally, the following interactions were significant:

Table XXIII

ANOVA Summary Table - Gradient Efficiency Scores

Source of Variation Main Effects		SS	d.f.	MS	F	Tabled F	Sig. Level
Map Experience	(G)	.33672	1	.33672	6.65	3.98	.05
Error Term*	(S)+(G+S)	3.85048	76	.05066			
Dimension	(D)	3.94458	1	3.94458	108.94	7.56	.01
Error	(SxD)	1.37585	38	1.37585			
Complexity	(C)	11.71800	2	5.85900	344.65	4.92	.01
Error	(SxC)	1.29191	76	.01700			
View	(V)	.00026	1	.00026	.01	7.56	NS
Error	(SxV)	.59243	38	.01559			
Two Way Interactions							
(GxD)		.06599	1	.06599	3.37	7.56	NS
Error	(SxGxD)	.74525	38	.01961			
(GxC)		.30277	2	.15138	5.77	4.92	.01
Error	(SxGxC)	1.99592	76	.02626			
(GxV)		.00113	1	.00113	.01	4.17	NS
Error	(SxGxV)	.73117	38	.01924			
(DxC)		1.04433	2	.52217	39.90	4.92	.01
Error	(SxDxC)	1.07549	76	.01415			
(DxV)		.01577	1	.01577	1.22	7.56	NS
Error	(SxDxV)	.49341	38	.01298			
(CxV)		.27379	2	.13689	5.99	4.92	.01
Error	(SxCxV)	1.73683	76	.02285			
Three Way Interactions							
(GxCxV)		.01464	2	.00732	.50	4.92	NS
Error	(SxGxCxV)	1.10496	76	.01454			
(GxDxV)		.00201	1	.00201	.18	7.56	NS
Error	(SxGxDxV)	.43774	38	.01152			
(GxDxC)		.52929	2	.26465	15.90	4.92	.01
Error	(SxGxDxC)	1.26487	76	.01664			
(DxCxV)		.29603	2	.14801	14.20	4.29	.01
Error	(SxDxCxV)	.79206	76	.01042			
Four Way Interaction							
(GxDxCxV)		.04148	2	.02074	1.33	7.01	NS
Error	(SxGxDxCxV)	1.18804	76	.01563			
Total		3.53922	935				

*Error Term - Subjects (S) NS - Not significant

Source: BIOMEDICAL computer program, BMDO2V, Analysis of Variance for Factorial Design (Dixon, 1973, 607-622).

experience by complexity (GxC), dimension by complexity (DxC), complexity by view (CxV), experience by dimension by view (GxDxV), and dimension by complexity by view (DxCxV). The ANOVA for response time (Table XXIV) shows that only the main effects which were significant were dimension and viewing angle.[4] Significant two-way interactions occurred between experience and dimension (GxD), dimension and surface complexity (DxC), and dimension by viewing angle (DxV). One three-way interaction between dimension, surface complexity, and viewing angle (DxCxV) was significant.

Dimension

Main Effects

The analyses indicated that gradient information was more efficiently transferred by perspective maps than two dimensional maps and that response times were faster with perspective maps than two dimensional (ANOVA Summary Tables XXIII and XXIV). The main effect treatment means are presented in Table XXV.

[4]A separate accuracy analysis was not appropriate for the specific ANOVA design used in this experiment therefore it was not included. A non-parametric ANOVA or other appropriate analysis is anticipated for further research.

Table XXIV

ANOVA Summary Table - Gradient Response Times

Source of Variation Main Effects		SS	d.f.	MS	F	Tabled F	Sig. Level
Map Experience	(G)	.57281	1	.57281	2.17	3.98	NS
Error Term*	(S)+(G+S)	19.99757	76	.26312			
Dimension	(D)	7.29970	1	7.29970	116.38	7.56	.01
Error	(SxD)	2.38349	38	.06272			
Complexity	(C)	7.46324	2	3.73162	75.90	4.92	.01
Error	(SxC)	3.73586	76	.04916			
View	(V)	.07890	1	.07890	2.56	7.56	NS
Error	(SxV)	1.16814	38	.03074			
Two Way Interactions							
(GxD)		.32762	1	.32762	6.59	4.17	.05
Error	(SxGxD)	1.88810	38	.04969			
(GxC)		.02384	2	.01192	.30	4.92	NS
Error	(SxGxC)	2.97874	76	.03919			
(GxV)		.00105	1	.00105	.04	4.17	NS
Error	(SxGxV)	.98950	38	.02604			
(DxC)		1.15474	2	.57737	22.28	4.92	.01
Error	(SxDxC)	1.96892	76	.02591			
(DxV)		.10100	1	.10100	5.69	4.17	.05
Error	(SxDxV)	.67442	38	.01775			
(CxV)		.23391	2	.11696	2.02	3.13	NS
Error	(SxCxV)	4.38426	76	.05769			
Three Way Interactions							
(GxCxV)		.02050	2	.01025	.27	4.92	NS
Error	(SxGxCxV)	2.85267	76	.03754			
(GxDxV)		.01081	1	.01081	.77	7.56	NS
Error	(SxGxDxV)	.52679	38	.01386			
(GxDxC)		.03140	2	.01570	.62	4.92	NS
Error	(SxGxDxC)	1.90236	76	.02053			
(DxCxV)		.28694	2	.14347	8.05	4.29	.01
Error	(SxDxCxV)	1.35322	76	.01781			
Four Way Interaction							
(GxDxCxV)		.00814	2	.00407	.18	7.01	NS
Error	(SxGxDxCxV)	1.65356	76	.02176			
Total		66.07219	935				

*Error Term - Subjects (S) NS - Not significant

Source: BIOMEDICAL computer program, BMDO2V, Analysis of Variance for Factorial Design (Dixon, 1973, 607-622) and author's computations.

Table XXV

Gradient - Main Effect Means

Dimension

Main Effect	Measure	
Dimension	Efficiency	Time
2D	.4864	1.2626
3D	.3566	1.0861

Source: BIOMEDICAL computer program BMDO2V, Analysis of Variance for Factorial Design. Means cross verified with BMDO1D, Simple Data Description (Dixon, 1973, 67-73, 607-622).

Interpretation of these main effect results must be discussed in terms of the conditioning effects of the interactions.

Three-Way Interactions

A significant interaction occurred between dimension, map reading experience, and surface complexity (GxDxC) for the efficiency measure. Additionally, a significant interaction occurred between dimension, surface complexity, and view (DxCxV) for the efficiency and time measures (ANOVA Summary Tables XXIII and XXIV). Treatment means for this interaction for the efficiency and time measures are presented in Tables XXVI and XXVII.

Graphs of the dimension x surface complexity x viewing angle (DxCxV) interaction means for the efficiency measure and response times are provided in Figures 21 and 22.

Table XXVI

Dimension x Complexity x View Interaction Means

Gradient - Efficiency Index

Viewing Angle	Dimension	Surface Complexity			Dimension Means
		C10	C15	C20	
V45	2D	.3396	.4622	.6682	.4900
	3D	.2562	.2773	.5224	.3519
Viewing Angle Means		.2979	.3697	.5953	.4290*
V315	2D	.3059	.4816	.6610	.4828
	3D	.3178	.3278	.4381	.3612
Viewing Angle Means		.3118	.4047	.5459	.4220**

Table XXVII

Dimension x Complexity x View Interaction Means

Gradient - Response Time

Viewing Angle	Dimension	Surface Complexity			Dimension Means
		C10	C15	C20	
V45	2D	1.1556	1.3149	1.3764	1.2823
	3D	.9753	1.0143	1.2652	1.0849
Viewing Angle Means		1.0654	1.1646	1.3208	1.1836*
V315	2D	1.1104	1.2789	1.3402	1.2431
	3D	1.0527	1.0285	1.8080	1.2964
Viewing Angle Means		1.0815	1.1537	1.5741	1.2697**

*V45 (viewing angle - 45 degree) means
**315 (viewing angle - 315 degree) means

Source: BIOMEDICAL computer program BMDO2V, Analysis of Variance for Factorial Design. Marginal treatment means cross verified with BMDO1D, Simple Data Description (Dixon, 1973, 67-73, 607-622).

Figure 21

Gradient - DxCxV Interaction
Efficiency

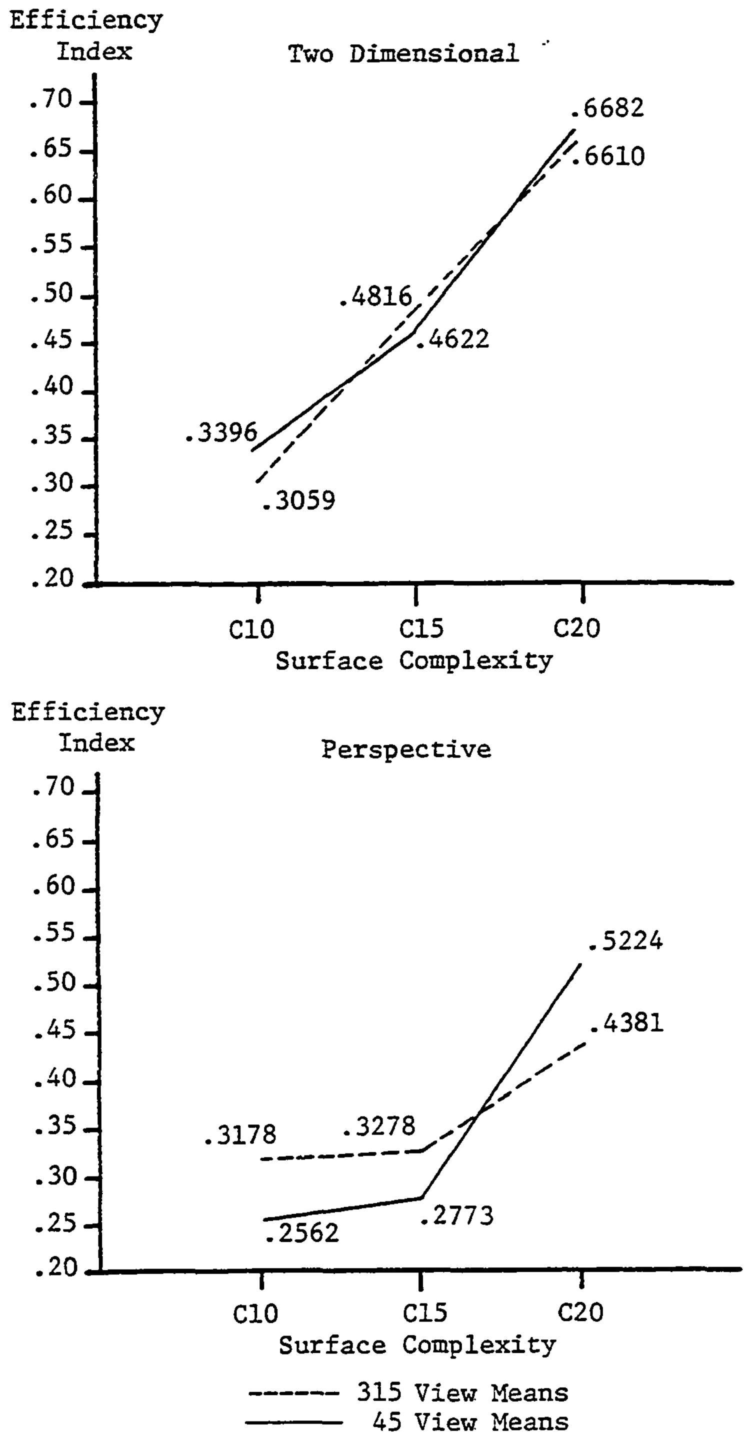
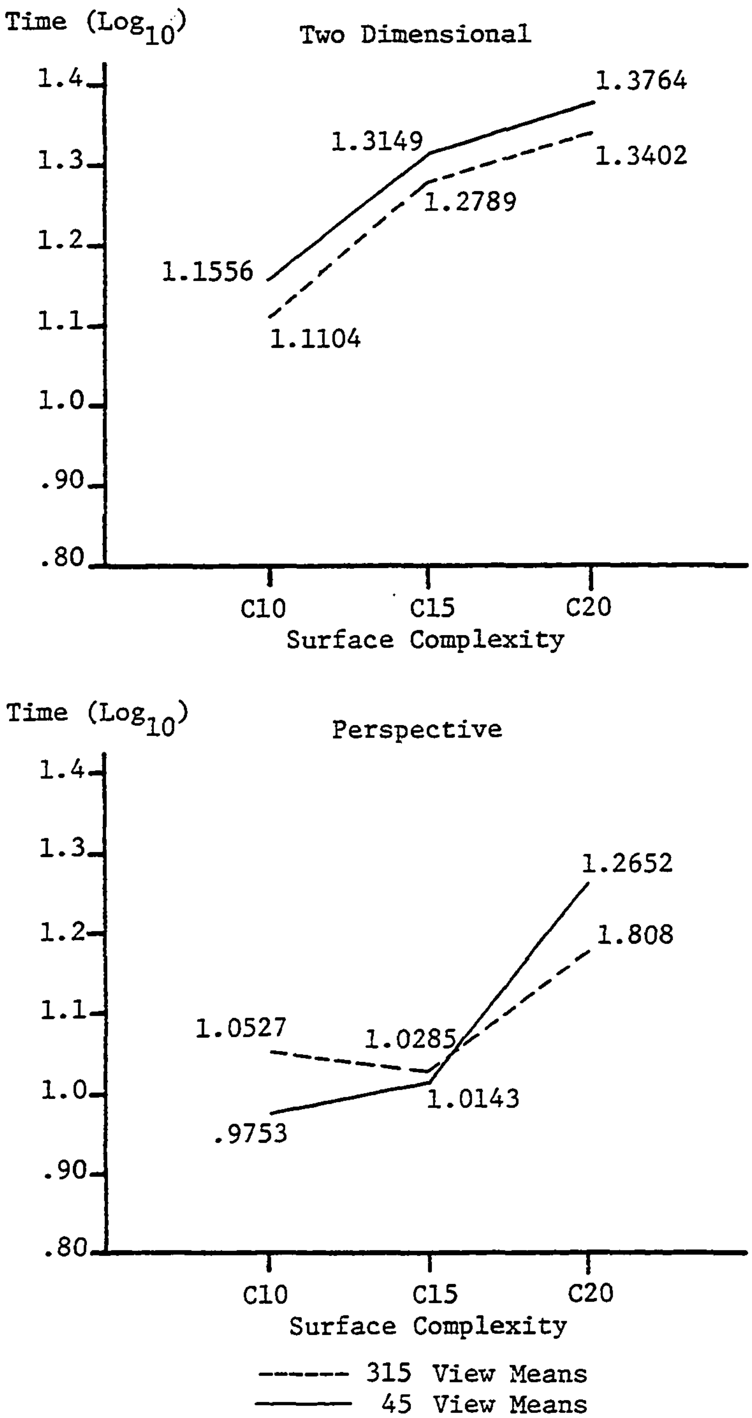


Figure 22

Gradient - DxCxV Interaction
Time



The graphs indicate that with two dimensional maps viewing angle made little difference on efficiency, but the increase in surface complexity impaired performance, especially for the most complex (C20) surface (Figure 21). As expected, viewing angle was more important with perspective maps. With perspective maps the less complex surfaces (C10 and C15) produced low scores while the efficiency scores for the most complex (C20) surface were poor, especially with the 45 degree viewing angle.

Higher efficiency was usually achieved with the 45 degree angle view (V45) on the perspective maps. The one exception was with the most complex surface. On the C20 perspective surface the steepest angle occurred at the left edge of the map. When viewed from 45 degrees the reader had a frontal view of the hill and associated angle. In the 315 degree view, even though data values in front partially hide the line formed by the steepest angle, the profile view of the hill enabled the reader to see the side of the hill and associated angle. The side profile apparently provided a better informational clue to slope than the frontal view (Appendix I - perpsective maps).

The graphs of the response times (Figure 22) for the DxCxV interaction indicate that with two dimensional maps response times were fast with less complex surfaces, especially the least complex (C10), and viewing angle made little difference. With perspective maps, however, the highly complex (C20) surface produced relatively slow response times, especially with the 45 degree viewing angle.

Interpretation of these relationships for the main and interaction effects involving dimension support the research hypothesis that the more direct pictorial characteristics of perspective maps aids in the transmission of gradient information over two dimensional maps. With two dimensional maps, because slope data is symbolized in the structure and arrangement of the isolines, it can become difficult to decode.

Surface Complexity

Main Effects

The analyses (ANOVA Summary Table XXIII and XXIV) revealed that both the efficiency means and response time means decreased with increased surface complexity. The treatment means are presented in Table XXVIII.

Table XXVIII

Gradient - Main Effect Means

Surface Complexity

Main Effect	Measure	
Complexity	Efficiency	Time
C10	.3049	1.0735
C15	.3872	1.1591
C20	.5724	1.2906

Source: BIOMEDICAL computer program BMDO2V, Analysis of Variance for Factorial Design. Means cross verified with BMDO1D, Simple Data Description (Dixon, 1973, 67-73, 607-622).

Interpretation of these main effects must be considered in terms of the significant interactions.

Three-Way Interactions

Summary Tables XXIII and XXIV indicated that the DxCxV interaction was significant for both efficiency and time measure. The results were discussed in the previous DxCxV interaction section.

The interaction between experience, dimension, and complexity (GxDxC) will be discussed later under the map reading experience section.

Two-Way Interactions

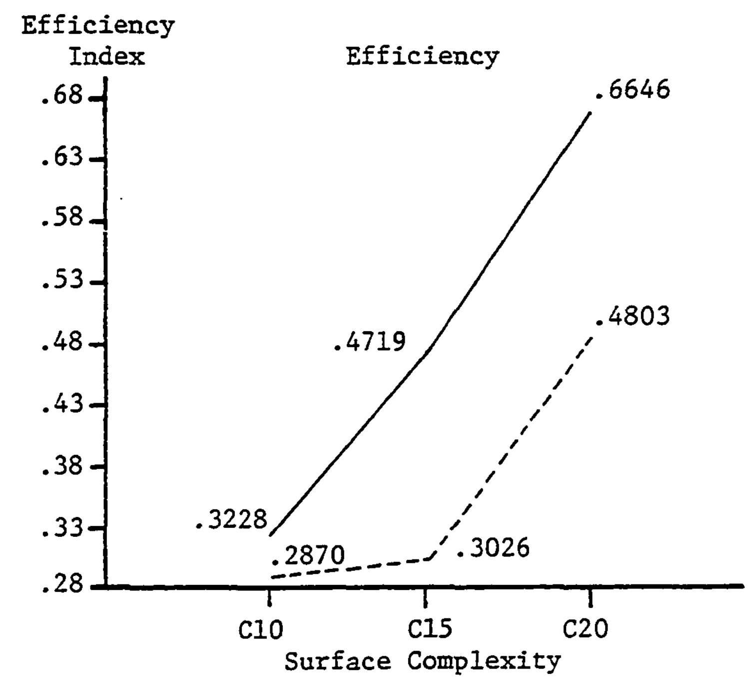
A significant interaction occurred between dimension and surface complexity (DxC) for both the efficiency and time measure (ANOVA Summary Tables XXIII and XXIV). Graphs of these interactions are provided in Figure 23.

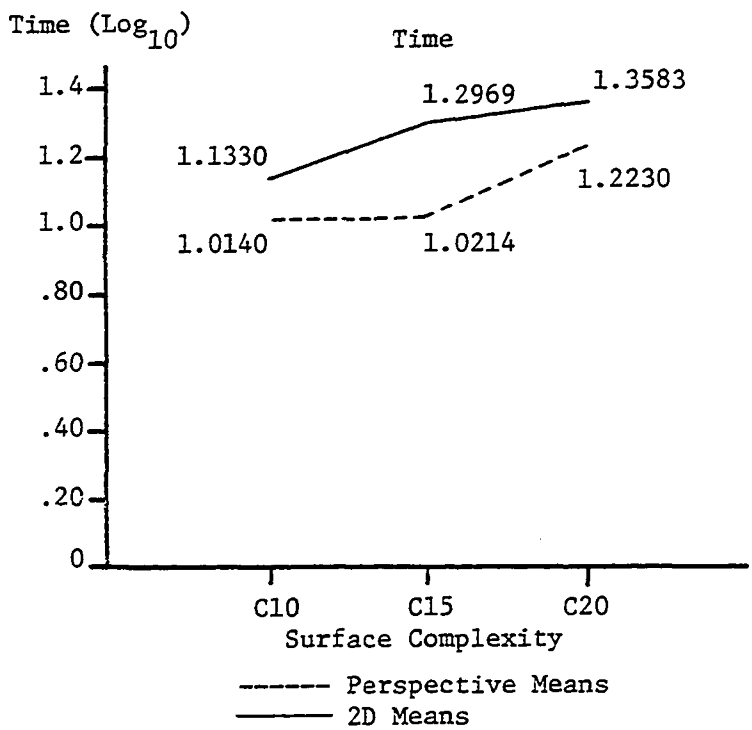
With perspective maps the highly complex (C20) surface impaired performance for the efficiency measure. Performance with the less complex surfaces (C10 and C15) was generally good. With two dimensional maps increased surface complexity impaired performance, especially for the highly complex C15 and C20 surfaces. Likewise, response time increased with surface complexity, most notably for the most complex (C20) perspective surfaces.

These results suggest that with two dimensional maps the increased number and arrangement of isolines on the highly complex surfaces provided more visual noise than the less complex surfaces

Figure 23

Gradient - DxC Interaction
Efficiency and Time





thus slowing response times and decreasing efficiency. Noise was also evident with the perspective maps. The increased number of hills and subsequent angles to be assessed as to which was steepest created more visual noise on the complex surfaces than the less complex perspective surfaces thus decreasing efficiency and slowing response times.

Surface complexity, as a noise element, must be evaluated with respect to the information to be conveyed. With height information, increased surface complexity resulted in faster response times and greater accuracy. Surface complexity did not act as noise but as a redundant visual element (isolines) which supplied informational clues which helped the reader assess specific heights on the surface.

Viewing Angle

Main Effects

Although the main effect of viewing angle was not significant for either the efficiency or time measures (Tables XXIII and XXIV), a significant two and three-way interaction occurred involving the variable of viewing angle. The DxCxV interaction was discussed earlier with the effects of graphic dimension. A two-way interaction occurred between surface complexity and viewing angle (CxV) with the efficiency measure. That effect is now examined.

Two-Way Interactions

The graph of the CxV treatment means (Figure 24) for the efficiency measure indicates that performance was generally good for the less complex surfaces (C10 and C15) at either viewing angle. Performance was impaired with the highly complex (C20) surface with indication that the 45 degree view, by providing more profile, produced better results.

A second two-way interaction occurred between dimension and view (DxV) for the time analysis but was only significant at the .05 significance level. Performance was good with either angle for two dimensional maps; with perspective maps the 315 degree view resulted in faster response times.

Map Reading Experience

Main Effects

The analyses indicated that prior map reading experience was significant for the efficiency measure but not for the time measure (Tables XXIII and XXIV). Treatment means are provided in Table XXIX.

Table XXIX

Gradient - Main Effect Means

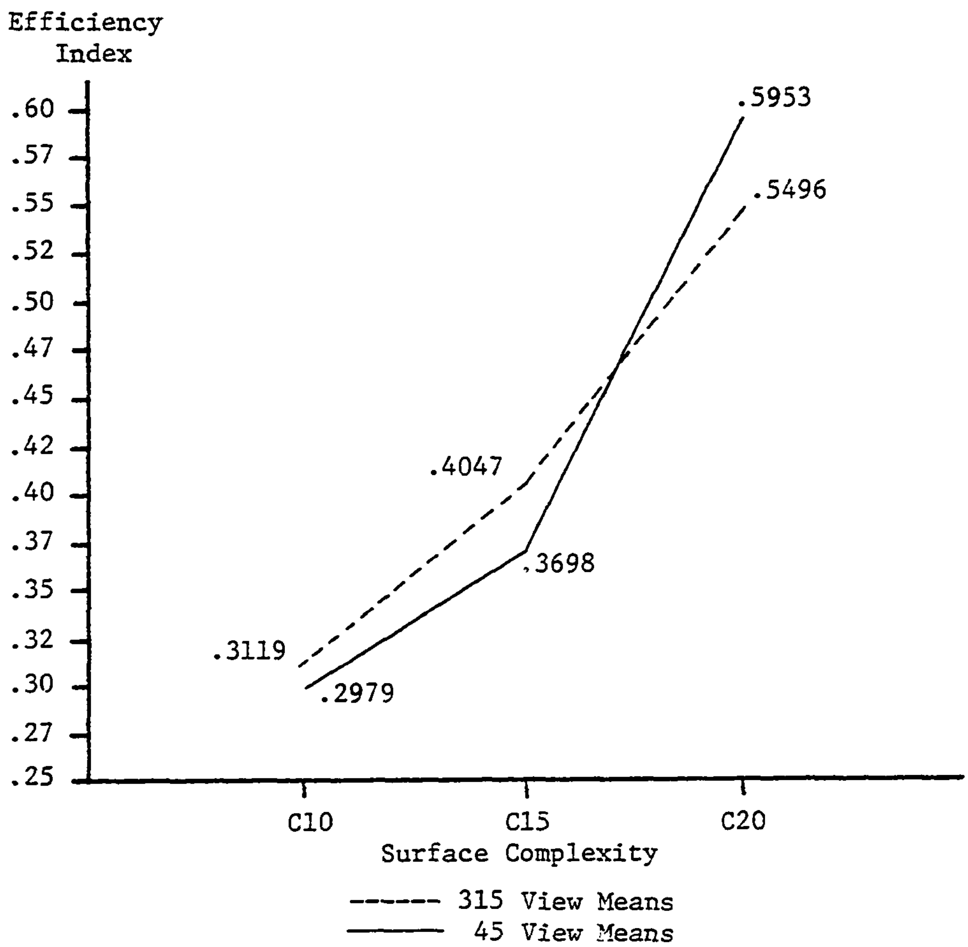
Map Reading Experience

Main Effect	Measure	
Experience	Efficiency	Time
G1 (inexperienced	.4405	NS
G2 (experienced)	.4025	

Source: BIOMEDICAL computer program BMDO2V and BMDO1D, (Dixon, 1973, 67-73, 607-622).

Figure 24

Gradient - CxV Interaction
Efficiency



As was anticipated, prior experience with map and air photo interpretation techniques aided the map readers in assessing slope information. This effect was, however, conditioned by several interactions.

Three-Way Interactions

A significant interaction occurred between experience, dimension, and surface complexity (GxDxC) for the efficiency measure (ANOVA Summary Table XXIII). The corresponding interactions for the time measure was not significant. Treatment means are presented in Table XXX and graphs of the interaction means are presented in Figure 25.

Table XXX

Map Reading Experience x Dimension x Surface Complexity Interaction Means

Gradient - Efficiency Index

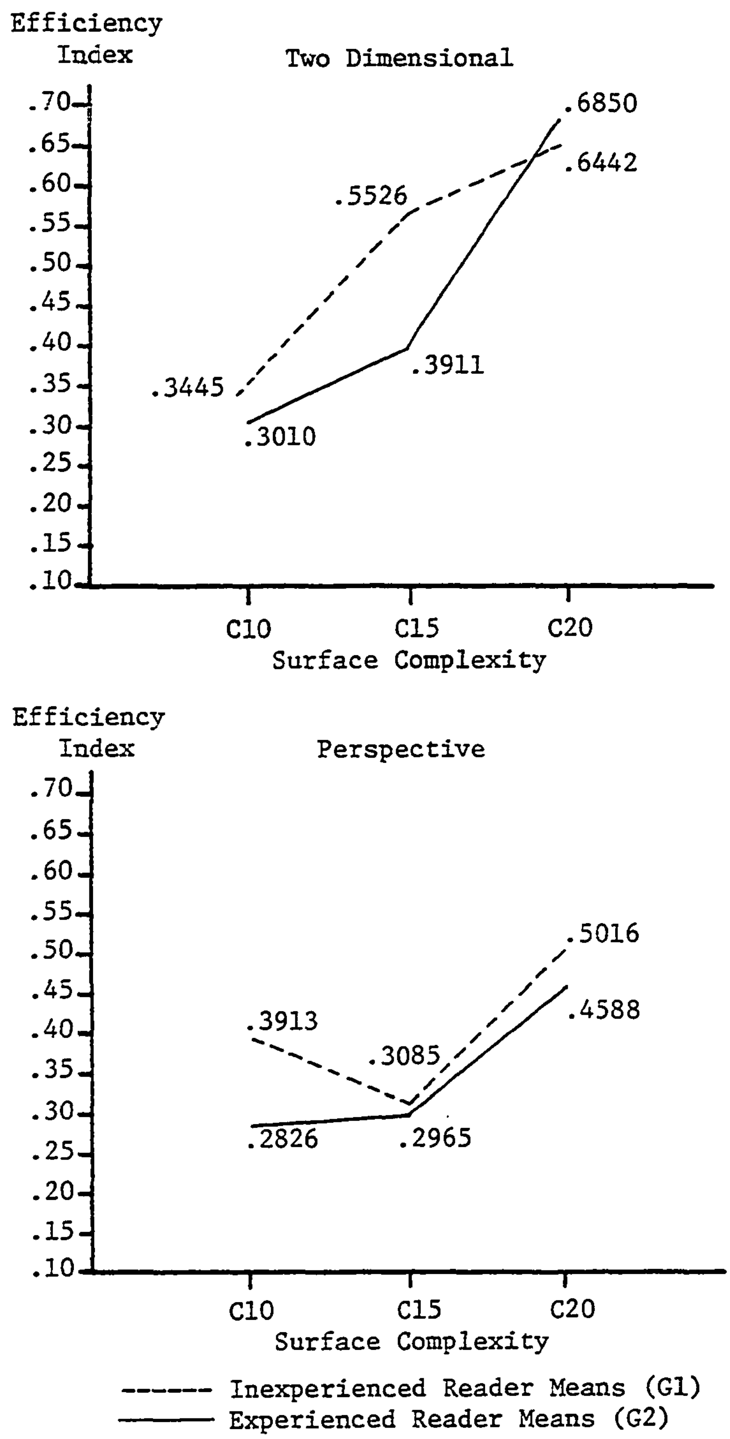
Map Reading Experience	Dimension	Surface Complexity			Dimension Means
		C10	C15	C20	
G1	2D	.3445	.5526	.6442	.5137
	3D	.3913	.3085	.5016	.3671
Complexity Means		.3179	.4305	.5729	.4404*
G2	2D	.3010	.3911	.6850	.4593
	3D	.2826	.2965	.4588	.3459
Complexity Means		.2918	.3438	.5719	.4026**

*G1 Inexperienced group mean
**G2 Experienced group mean

Source: BIOMEDICAL computer program BMD02V, Analysis of Variance for Factorial Design. Marginal treatment means cross verified with BMD01D, Simple Data Description (Dixon, 1973; 67-73, 607-622).

Figure 25

Gradient - GxDxC Interaction
Efficiency



The means illustrate that with two dimensional maps performance was good for both groups with the least complex (C10) surface. Efficiency decreased with increased surface complexity, especially with the less experienced group of map readers (G1). With perspective maps the least complex surfaces resulted in good performance, especially for the more experienced (G2) group of map readers, while the more complex (C20) perspective surface resulted in poor performance by both groups (Figure 25).

Based upon the results of the main effects and three-way interaction the relationships were not unexpected since existing theories of form perception suggested that the inclusion of depth to a surface provided a directly observable pictorial quality which enhanced the flow of information. All gradient information, including steepest slope information, was symbolized in a conceptual format on the two dimensional maps based upon the spacing and arrangement of isolines. The spacing and arrangement of isolines must first be mentally pre-processed before the information as to slope can be perceived. This resulted in lower efficiency and slower times for the two dimensional maps. Perspective maps, however, transfer slope information as a direct result of various surface forms displayed on the surface. Steepness was directly perceived from angles formed by various hills on the surface, thus greater efficiency and faster times for the perspective maps over the two dimensional (Table XXV).

As the perspective maps became more complex in visual structure the efficiency in transmitting slope information decreased probably because more slopes must be considered and the probability of near similar slopes increased. Each surface contained progressively more peaks, ten (C10), fifteen (C15), and twenty (C20). The increased number of peaks resulted in progressively higher means (lower efficiency), especially for the most complex (C20) perspective maps. As suggested by information theory, increased noise (peaks on the surface) apparently acted as a noise element which hindered the transmission of slope information.

Experienced readers (G2 - Sonoma group) were more efficient in perceiving steepest slope information from the perspective maps, even as the surface became increasingly complex, than the less experienced group (G1) of map readers from Berkeley. This was attributed to the map reading proficiency gained due to increased exposure and practice in map and air photo interpretation by the Sonoma (G2) group. Exposure to three dimensional models (stereo pairs) aids the reader in interpreting slope information from perspective maps.

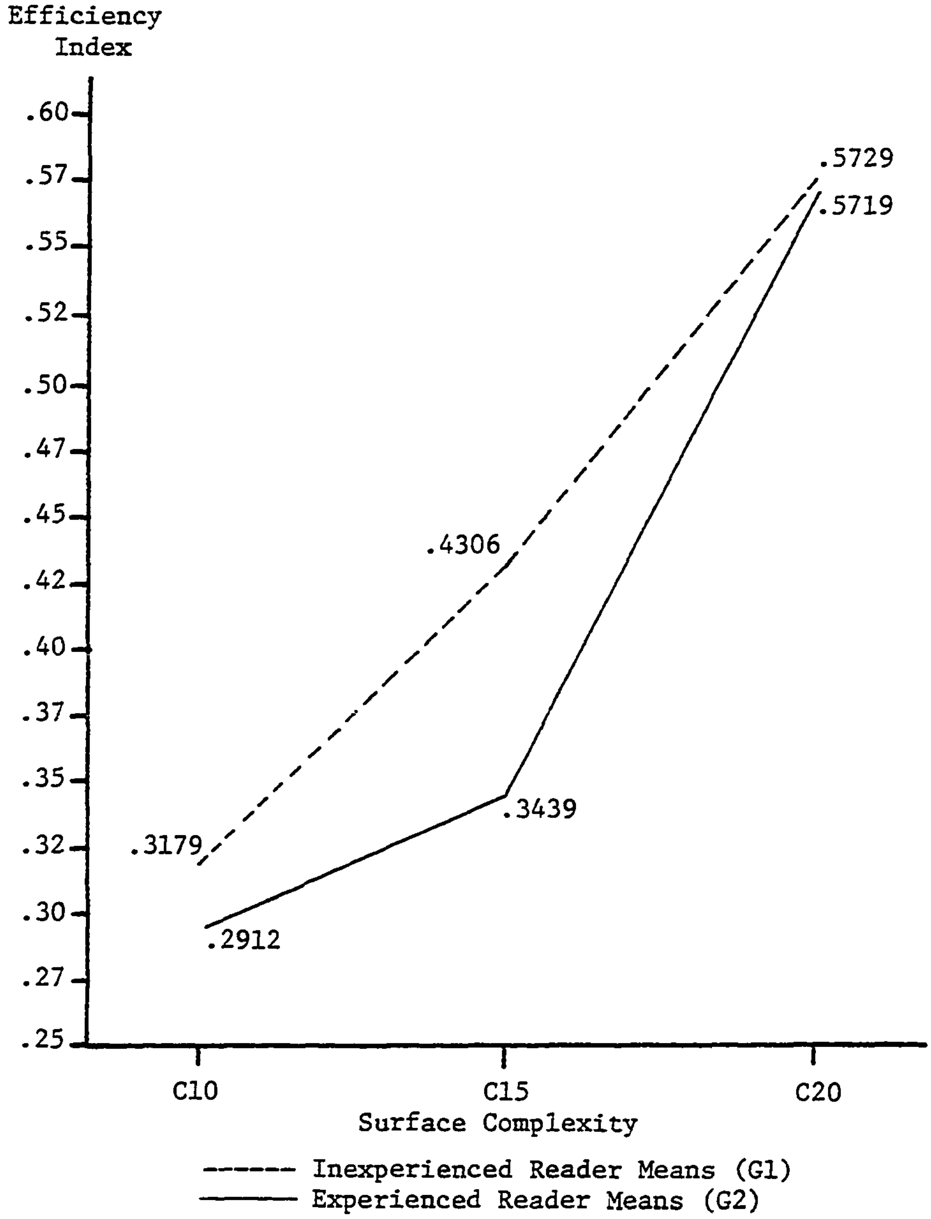
Two-Way Interactions

The two-way interaction between map reading experience and surface complexity (GxC) was significant for the efficiency measure (ANOVA Summary Table XXIII and Figure 26).

The results show that performance was generally good for both groups with the less complex (C10) surface and generally poor

Figure 26

Gradient - GxC Interaction
Efficiency



with the most complex (C20) surface. The more experienced (G2) group of readers performed considerably better with the higher complexity (C15) surface. Based on this interaction result and the overall main effect of prior map reading experience, the more experienced group (G2) were more efficient in perceiving steepest slope information than the less experienced (G1) group. Each group's efficiency decreased as the surface became more complex, in fact, their means were almost identical for the most complex (C20) surface (Figure 26). This result indicates that assessment of slope information becomes more difficult as surface complexity increases even for experienced map readers.

Summary - Gradient Information

The analyses revealed that perspective maps were indeed efficient in transferring steepest slope information to map readers. The use of perspective maps also resulted in faster response times than two dimensional for decoding gradient information. The more direct pictorial quality brought about by the addition of the third dimension provided an effective graphic format to convey a most difficult spatial concept, gradient.

The effectiveness of perspective maps in transferring steepest slope information decreased with increased surface complexity thus confirming the hypothesis that an increase in visual elements, that is, peaks on the surface produces a significant noise effect which hinders the decoding of slope information. Efficiency decreased probably because more slopes must be considered and the probability of near similar slopes increased. This also resulted in slower response times, especially for the high complexity surfaces. The same effect was noted with two dimensional maps; increased complexity produced a decrease in efficiency and slowness in response time.

The effect of viewing angle, as expected, was more critical with perspective maps. Selecting an orientation which provided a side profile of the intended peak which represents the data produced more effective results. Even when data values in front partially hide the line formed by the steepest angle, a profile view of the hill provides a substantial form perception clue to enable the reader to see the side of the hill and associated angle.

Lastly, prior training and experience with map and air photo interpretation principles aided the reader in decoding slope information. As anticipated, the experienced group of readers performed better than the inexperienced map reader. Prior experience with stereo models used in air photo interpretation provides map readers with basic interpretation skills which are used in the map reading process to decode slope information.

Pattern Information

All four main effect variables had a significant influence on the efficiency in which pattern information was transmitted to

Table XXXI

ANOVA Summary Table - Pattern Efficiency Scores

Source of Variation Main Effects		SS	d.f	MS	F	Tabled F	Sig. Level
Map Experience	(G)	.10345	1	.10345	11.14	7.01	.01
Error Term*	(S)+(G+S)	.70550	76	.00928			
Dimension	(D)	.03384	1	.00384	6.46	4.17	.05
Error	(SxD)	.19912	38	.00524			
Complexity	(C)	.06028	2	.03014	6.37	4.92	.01
Error	(SxC)	.35921	76	.00473			
View	(V)	.11149	1	.11149	24.13	7.56	.01
Error	(SxV)	.17573	38	.00462			
Two Way Interactions							
(GxD)		.00008	1	.00008	.02	7.56	NS
Error (SxGxD)		.13037	38	.00343			
(GxC)		.00729	2	.00365	.64	4.92	NS
Error (SxGxC)		.43586	76	.00573			
(GxV)		.01167	1	.01167	3.38	4.17	NS
Error (SxGxV)		.13107	38	.00345			
(DxC)		.16975	2	.08487	16.32	4.92	.01
Error (SxDxC)		.39558	76	.00520			
(DxV)		.00117	1	.00117	.35	7.56	NS
Error (SxDxV)		.12662	38	.00333			
(CxV)		.06732	2	.03366	7.18	4.92	.01
Error (SxCxV)		.35640	76	.00469			
Three Way Interactions							
(GxCxV)		.00764	2	.00382	.93	4.92	NS
Error (SxGxCxV)		.31139	76	.00410			
(GxDxV)		.00584	1	.00584	1.57	7.56	NS
Error (SxGxDxV)		.14136	38	.00372			
(GxDxC)		.01617	2	.00809	1.86	4.92	NS
Error (SxGxDxC)		.32973	76	.00434			
(DxCxV)		.07860	2	.03930	6.46	3.90	.05
Error (SxDxCxV)		.46214	76	.00608			
Four Way Interactions							
(GxDxCxV)		.01541	2	.00771	1.73	7.01	NS
Error (SxGxDxCxV)		.33856	76	.00445			
Total		3.53922	935				

*Error Term - Subjects (S) NS - not significant

Source: BIOMEDICAL computer program, BMDO2V, Analysis of Variance for Factorial Design (Dixon, 1973, 607-622) and author's computations.

Table XXXII

ANOVA Summary Table - Pattern Accuracy Scores

Source of Variation Main Effects		SS	d.f.	MS	F	Tabled F	Sig. Level
Map Experience	(G)	62.05235	1	62.05235	10.06	7.01	.01
Error Term*	(S)+(G+S)	468.58547	76	6.16559			
Dimension	(D)	15.12927	1	15.12927	8.49	7.56	.01
Error	(SxD)	67.66239	38	1.78059			
Complexity	(C)	12.39103	2	6.19551	2.41	4.92	NS
Error	(SxC)	195.02564	76	2.56613			
View	(V)	41.46261	1	41.46261	15.80	7.56	.01
Error	(SxV)	99.66239	38	2.62269			
Two Way Interactions							
(GxD)		2.16346	1	2.16346	1.41	7.56	NS
Error	(SxGxD)	58.12821	38	1.52969			
(GxC)		2.78419	2	1.39202	.45	4.92	NS
Error	(SxGxC)	233.63248	76	3.07411			
(GxV)		2.36004	1	2.36004	1.74	4.17	NS
Error	(SxGxV)	51.26496	38	1.34908			
(DxC)		128.89957	2	64.44979	24.10	4.92	.01
Error	(SxDxC)	203.18376	76	2.67347			
(DxV)		.77885	1	.77885	.36	7.56	NS
Error	(SxDxV)	81.51282	38	2.14507			
(CxV)		22.32265	2	11.16132	5.05	4.92	.01
Error	(SxCxV)	167.92735	76	2.20757			
Three Way Interactions							
(GxCxV)		.27137	2	.13568	.08	4.92	NS
Error	(SxGxCxV)	122.97863	76	1.61814			
(GxDxV)		.00107	1	.00107	Negl.	7.56	NS
Error	(SxGxDxV)	60.79060	38	1.59975			
(GxDxC)		1.42949	2	.71474	.34	4.92	NS
Error	(SxGxDxC)	157.65385	76	2.07439			
(DxCxV)		25.42949	2	12.71474	5.05	3.13	.05
Error	(SxDxCxV)	191.15385	76	2.51518			
Four Way Interactions							
(GxDxCxV)		7.46368	2	3.73184	2.14	7.01	NS
Error	(SxGxDxCxV)	132.11966	76	1.73842			
	Total	2616.22115	935				

*Error Term - Subjects (S) NS - not significant

Source: BIOMEDICAL computer program, BMDO2V, Analysis of Variance for Factorial Design (Dixon, 1973, 607-622) and author's computations.

Table XXXIII
ANOVA Summary Table - Pattern Response Times

Source of Variation Main Effects		SS	d.f.	MS	F	Tabled F	Sig. Level
Map Experience	(G)	.09678	1	.09678	.40	7.01	NS
Error Term*	(S)+(G+S)	18.00640	76	.23692			
Dimension	(D)	2.40120	1	2.40120	44.54	7.56	.01
Error	(SxD)	2.04832	38	.05390			
Complexity	(C)	.03483	2	.01742	1.05	4.92	NS
Error	(SxC)	1.25135	76	.01647			
View	(V)	.00087	1	.00087	.08	7.56	NS
Error	(SxV)	.38913	38	.01024			
Two Way Interactions							
(GxD)		.01966	1	.01966	.71	7.56	NS
Error	(SxGxD)	1.04003	38	.02737			
(GxC)		.00387	2	.00193	.14	4.92	NS
Error	(SxGxC)	.98078	76	.01290			
(GxV)		.00015	1	.00015	.01	4.17	NS
Error	(SxGxV)	.41892	38	.01102			
(DxC)		.09654	2	.04827	3.98	3.13	.05
Error	(SxDxC)	.91939	76	.01210			
(DxV)		.00740	1	.00740	.09	7.56	NS
Error	(SxDxV)	.29895	38	.00787			
(CxV)		.24044	2	.12022	4.86	3.13	.05
Error	(SxCxV)	1.87659	76	.02469			
Three Way Interactions							
(GxCxV)		.02009	2	.01004	.66	4.92	NS
Error	(SxGxCxV)	1.14315	76	.01504			
(GxDxV)		.01208	1	.01208	1.40	7.56	NS
Error	(SxGxDxV)	.32671	38	.00860			
(GxDxC)		.00388	2	.00194	.28	4.92	NS
Error	(SxGxDxC)	.52145	76	.00686			
(DxCxV)		.05903	2	.02952	2.51	3.90	NS
Error	(SxDxCxV)	.89322	76	.01175			
Four Way Interactions							
(GxDxCxV)		.00599	2	.00300	.35	7.01	NS
Error	(SxGxDxCxV)	.63533	76	.00836			
Total		33.75253	935				

*Error Term - Subjects (S) NS - not significant

Source: BIOMEDICAL computer program, BMDO2V, Analysis of Variance for Factorial Design (Dixon, 1973, 607-622) and author's computations.

map readers. However, three of the main effects were conditioned by two and three-way interactions.

The analysis of accuracy scores shows the main effects of dimension, map reading experience, and viewing angle to be statistically significant. For the analysis of the time measure only the variable of graphic dimension was significant (ANOVA Summary Table XXXI, XXXII, and XXXIII). Both two and three-way interactions conditioned the main effects for time and accuracy.

Dimension

Main Effects

All three measures for the main effect of dimension were statistically significant (Tables XXXI, XXXII, and XXXIII). Means are presented in Table XXXIV. On the basis of the efficiency and accuracy measures, it can be said that perspective maps transferred pattern information more effectively than two dimensional maps.

Table XXXIV

Pattern - Main Effect Means

Dimension

Main Effect	Measure		
Dimension	Efficiency	Accuracy	Time
2D	.1118	2.8440	1.8752
3D	.0998	3.0983	1.8955

Source: BIOMEDICAL computer program BMDO2V, Analysis of Variance for Factorial Design. Means cross verified with BMDO1D, Simple Data Description (Dixon, 1973, 67-73, 607-622).

Somewhat strangely, however, the analysis revealed that response time was slower for perspective maps than two dimensional maps. The main effect for the three measures were conditioned by several interactions.

Three-Way Interactions

A significant three-way interaction between dimension, surface complexity, and viewing angle (DxCxV) for the efficiency and accuracy measures (Tables XXXI and XXXII).

Based on the analysis of the DxCxV efficiency measure treatment means the following relationships were evident: 1) with two dimensional maps performance was generally good for the highly complex surfaces, reduced surface complexity impaired performance, especially with the 315 degree viewing angle; and 2) with perspective maps the more complex the surface the poorer the performance, especially for the 315 degree viewing angle. A graph of the DxCxV means is shown in Figure 27.

The accuracy analysis revealed that with two dimensional maps higher accuracy was achieved with the highly complex surfaces; decreased surface complexity impaired accuracy, espcially with the 315 degree viewing angle. With perpsective maps higher accuracy was achieved with the less complex surfaces; increased surface complexity impaired performance, especially with the 315 degree view. Treatment means are shown in Figure 28.

Figure 27

Pattern - DxCxV Interaction
Efficiency

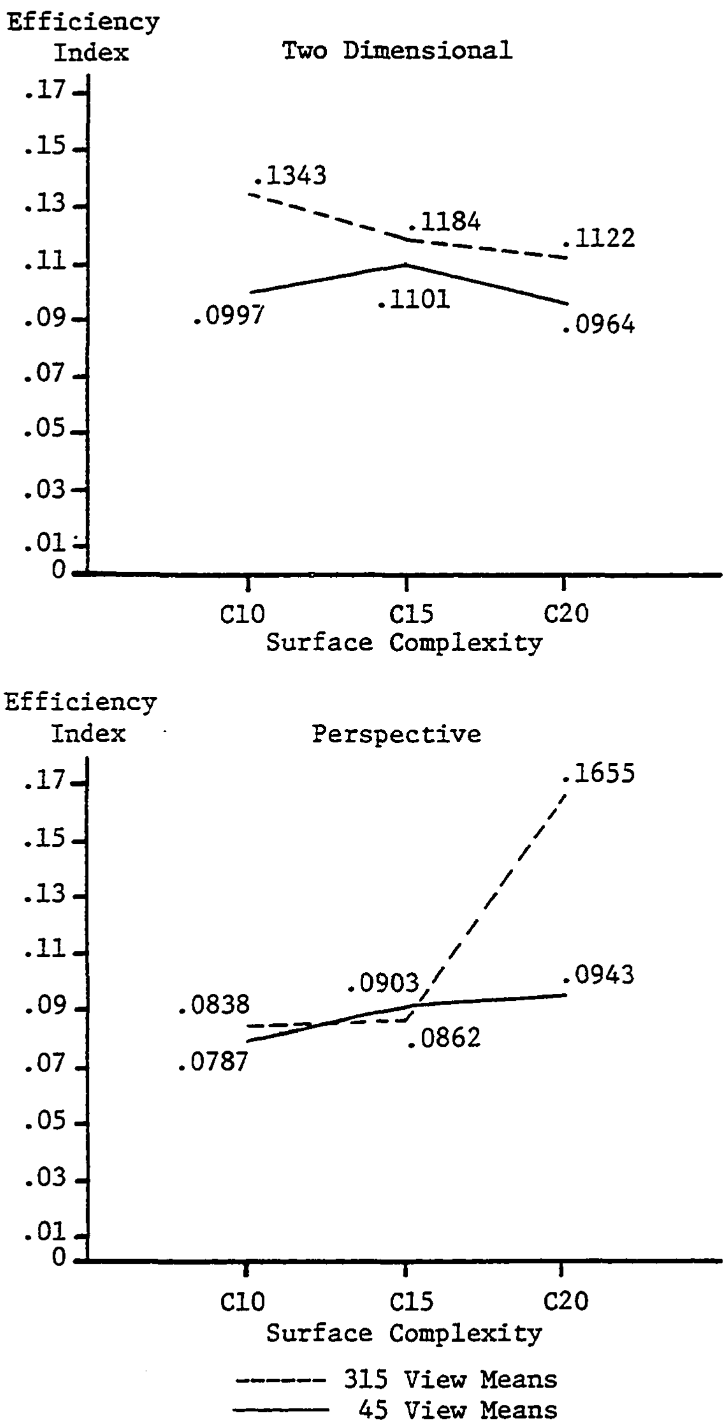
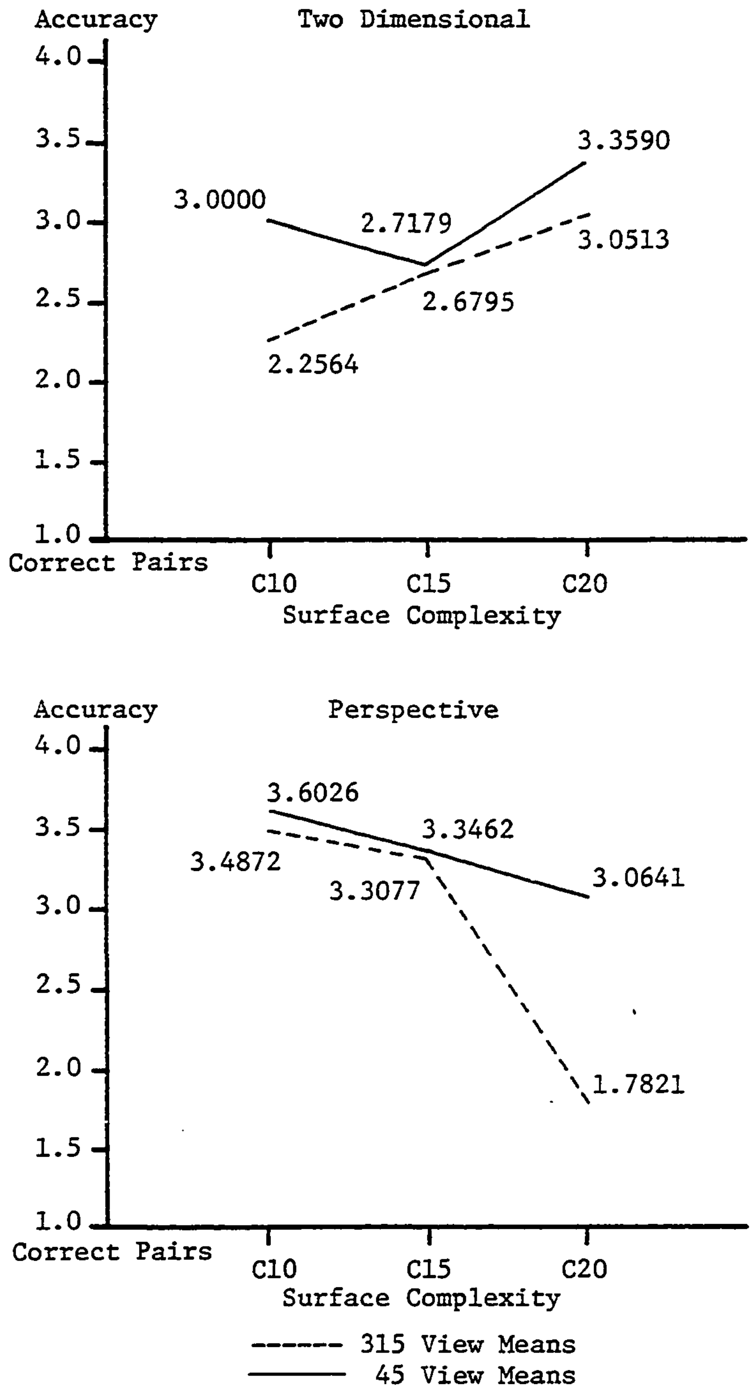


Figure 28

Pattern - DxCxV Interaction
Accuracy



On the basis of the results it appears that perspective maps provide a clarifying effect in transmitting pattern information, especially trend information to readers as reflected by the lower efficiency and higher accuracy main effect means. The clarifying effect diminished, however, with the high complexity perspective surfaces. The increased numbers of hills and other surface forms apparently provide visual noise which interferred with the intended pattern information as the surface became more complex. The increase in surface features on the highly complex surfaces obscurred surrounding features which acted as clues to the trend of increasing values on the surface. It may be that a threshold of surface complexity exists, beyond which, perspective maps become ineffective in transmitting pattern information (Table XXXV).

For two dimensional maps overall efficiency was poorer than for the perspective maps but efficiency generally increased as the surface became more complex when viewed from either angle. The isolines apparently provided exact height references. The direction of surface heights could be assessed from one point to another. This information was then probably used to determine the trend of increasing values. Perspective maps did not contain any reference elements, therefore, the noise values (additional peaks on the complex surfaces) blocked surrounding data which would have been used to help assess pattern information (Table XXXVI).

Table XXXV

Dimension x Surface Complexity x Viewing Angle Interaction Means

Pattern - Efficiency Index

Dimension	Viewing Angle	Surface Complexity			View Means
		C10	C15	C20	
2D	V45	.0997	.1101	.0964	.1020
	V315	.1343	.1184	.1122	.1216
Complexity Means		.1170	.1142	.1043	.1118*
3D	V45	.0787	.0903	.0943	.0877
	V315	.0838	.0862	.1655	.1118
Complexity Means		.0812	.0882	.1299	.0997**

Table XXXVI

Dimension x Surface Complexity x Viewing Angle Interaction Means

Pattern - Accuracy Scores

Dimension	Viewing Angle	Surface Complexity			View Means
		C10	C15	C20	
2D	V45	3.0000	2.7179	3.3590	3.0256
	V315	2.2564	2.6795	3.0513	2.6624
Complexity Means		2.6282	2.6987	3.2051	2.8440*
3D	V45	3.6026	3.3462	3.0641	3.3376
	V315	3.4872	3.3077	1.7821	2.8590
Complexity Means		3.5449	3.3269	2.4231	3.0983**

*Two dimensional mean
**Three dimensional mean

Source: BIOMEDICAL computer program BMDO2V, Analysis of Variance for Factorial Design. Marginal treatment means cross verified with BMDO1D, Simple Data Description (Dixon, 1973, 67-73, 607-622).

A viewing angle of 45 degrees (V45) appeared to have enhanced the pattern information for both two and three dimensional maps, however, the effect was more important with the perspective maps. Although the 45 degree view enhanced information, one exception was noted with (C15) surface; the 315 degree enhanced the pattern information more than the 45 degree view. For this particular perspective map and surface complexity (C15), the 315 degree view provided a better side profile of several peaks which formed a range extending from the upper right to the lower left section of the map. The 45 degree view did not provide this side profile but rather a frontal view, and subsequently the direction of the surface was more difficult to assess. The 45 degree view did not provide a better side profile on the (C10) and (C20) surfaces. It should be noted that one component of the overall trend of increasing surface values does extend from the upper left to lower right on all the stimulus maps (Appendix I - pattern maps).

Surface Complexity

Main Effects

The analyses revealed that only the measure of efficiency was statistically significant, time and accuracy were not (Tables XXXI, XXXII, and XXXIII). Means for this main effect are presented in Table XXXVII.

Table XXXVII

Pattern - Main Effect Means

Surface Complexity

Main Effect	Measure		
Complexity	Efficiency	Accuracy	Time
C10	.0991		
C15	.1013	NS	NS
C20	.1171		

Source: BIOMEDICAL Computer program BMD02V, Analysis of Variance for Factorial Design. Marginal treatment means cross verified with BMD01D, Simple Data Description (Dixon, 1973, 67-73, 607-622).

As anticipated, an increase in surface complexity resulted in a decrease in efficiency of the map in transferring pattern information. This effect, however, was conditioned by several interactions. The three-way interaction which occurred between dimension, complexity, and viewing angle (DxCxV) for both the efficiency and accuracy measure was discussed in the previous section. No other three-way interactions were significant.

Two-Way Interactions

Two-way interactions occurred between dimension and surface complexity (DxC) and surface complexity and viewing angle (CxV) for all three measures (ANOVA Summary Tables XXXI, XXXIII, and XXXIII). Although these three variables combined in the DxCxV three-way interactions, they are discussed here to more fully understand their separate relationships.

A graph of the DxC interaction (Figure 29) for the efficiency measure indicates that with two dimensional maps better performance was achieved with the high complexity surfaces. Increased surface complexity due to increased number, arrangement, and direction of isolines apparently provided additional form clues (Gestalt continuity and proximity) which was then used to assess the trend of increasing surface values.

The same graph revealed that increased surface complexity impaired performance with perspective maps. The higher complexity surfaces, especially the most complex (C20) surface, resulted in poor performance (Figure 30). The increased number of surface peaks (noise) apparently impaired the reader's ability to decode the intended pattern information by blocking surrounding surface features needed to assess trend information.

The accuracy graph of the DxC interaction means indicated that with two dimensional maps increased surface complexity improved accuracy, especially with the most complex (C20) surface. With perspective maps increased surface complexity decreased accuracy, again, most notably with the complex (C20) surface (Figure 30).

The time analysis indicated that with two dimensional maps response was generally slow for all three surface complexities. With perspective maps, however, response time was generally fast with a slight decrease for the most complex (C20) surface (Figure 30).

Figure 29

Pattern - DxC Interaction
Efficiency

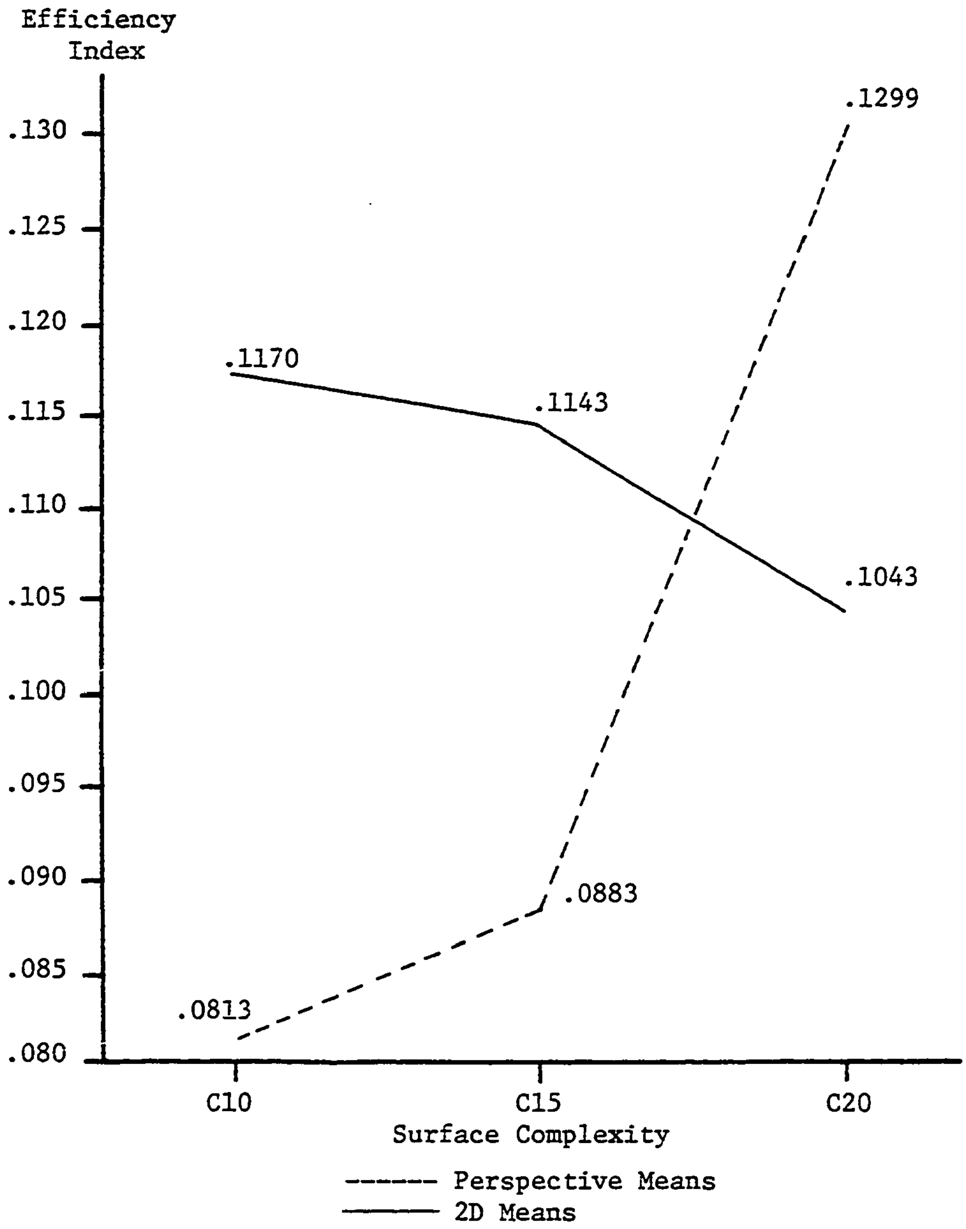
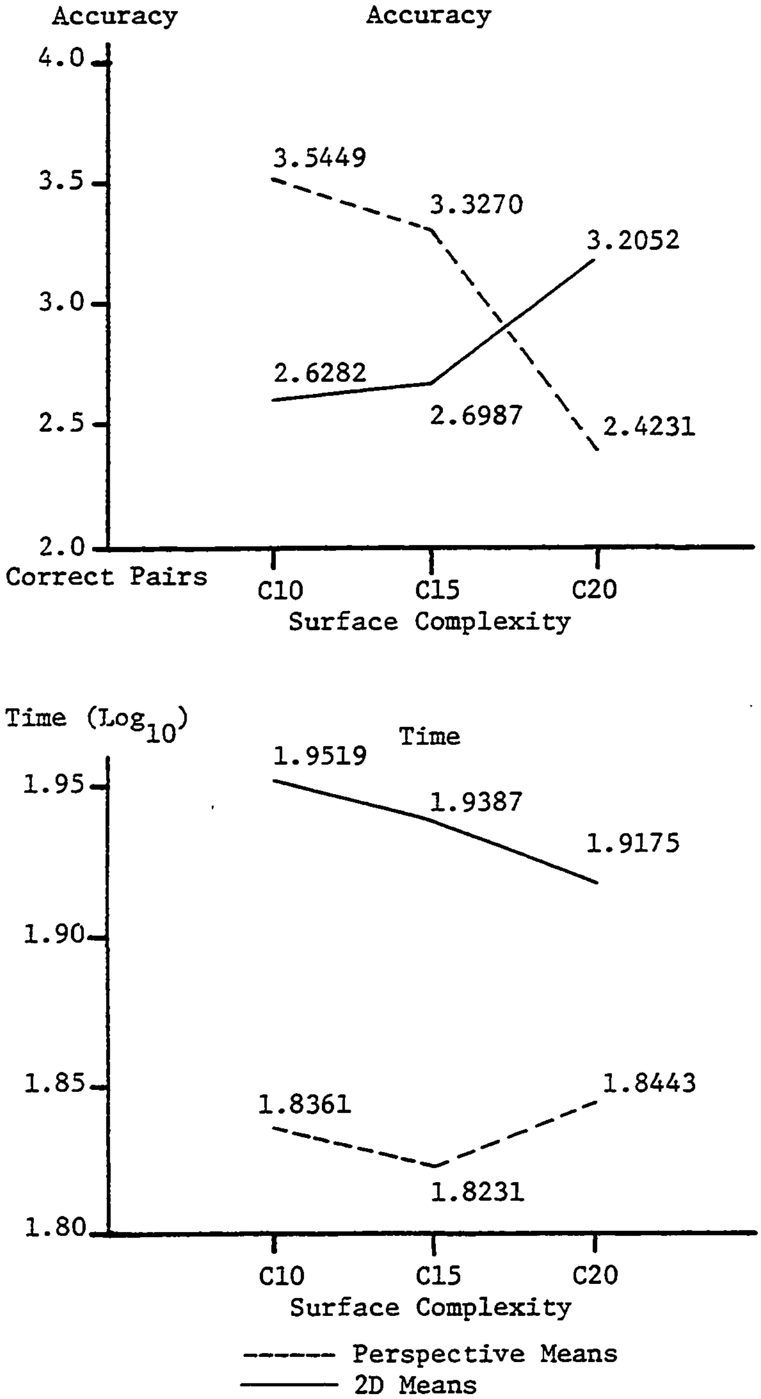


Figure 30

Pattern - DxC Interaction
Accuracy and Time



Viewing Angle

Main Effects

The viewing angle main effect was significant for the efficiency and accuracy measures, but not for response time (ANOVA Summary Tables XXXI, XXXII, and XXXIII). Treatment means are provided in Table XXXVIII).

Table XXXVIII

Pattern - Main Effect Means

Viewing Angle

Main Effect	Measure		
Viewing Angle	Efficiency	Accuracy	Time
V45	.0949	3.1816	NS
V315	.1167	2.7607	

Source: BIOMEDICAL Computer program BMDO2V, Analysis of Variance for Factorial Design. Means cross verified with BMDO1D, Simple Data Description (Dixon, 1973, 67-73, 607-622).

The means show that a 45 degree viewing angle provided better overall efficiency and better accuracy than the 315 degree orientation. The three-way interaction between dimension, surface complexity, and viewing angle (DxCxV) was examined earlier, but several two-way interactions are important.

Two-Way Interactions

A significant interaction occurred between dimension and surface complexity (DxC) which was discussed earlier. A second two-way interaction, surface complexity by view (CxV), was significant for all three measures (ANOVA Summary Tables XXXI, XXXII, and XXXIII).

Good performance by subjects was achieved with the least complex (C10) surface viewed from 45 degrees while poorer performance was noted with the more complex (C15) surface. Performance was especially impaired with the most complex (C20) surface viewed at 315 degrees (Figure 31). Little difference in accuracy was noted for the more complex (C15) surface at either view (Figure 32). Greater accuracy was achieved with the 45 Degree view for both the least (C10) and most complex (C20) surfaces. There was little difference in response time with the C10 and C20 surfaces, but considerable difference with the C15 surface; faster time was achieved with the 315 degree view (Figure 32).

Experience

Main Effects

The effect of prior map reading experience was significant for the efficiency and accuracy measure but not for response time (ANOVA Summary Tables XXXI, XXXII, and XXXIII). The experienced group of readers from Sonoma (G2) who had extensive training in map and air photo interpretation techniques achieved higher accuracy and were more efficiency than the less experienced group of map readers from Berkeley (G1) according to mean scores. Treatement means are presented in Table XXXIX.

Figure 31

Pattern - CxV Interaction
Efficiency

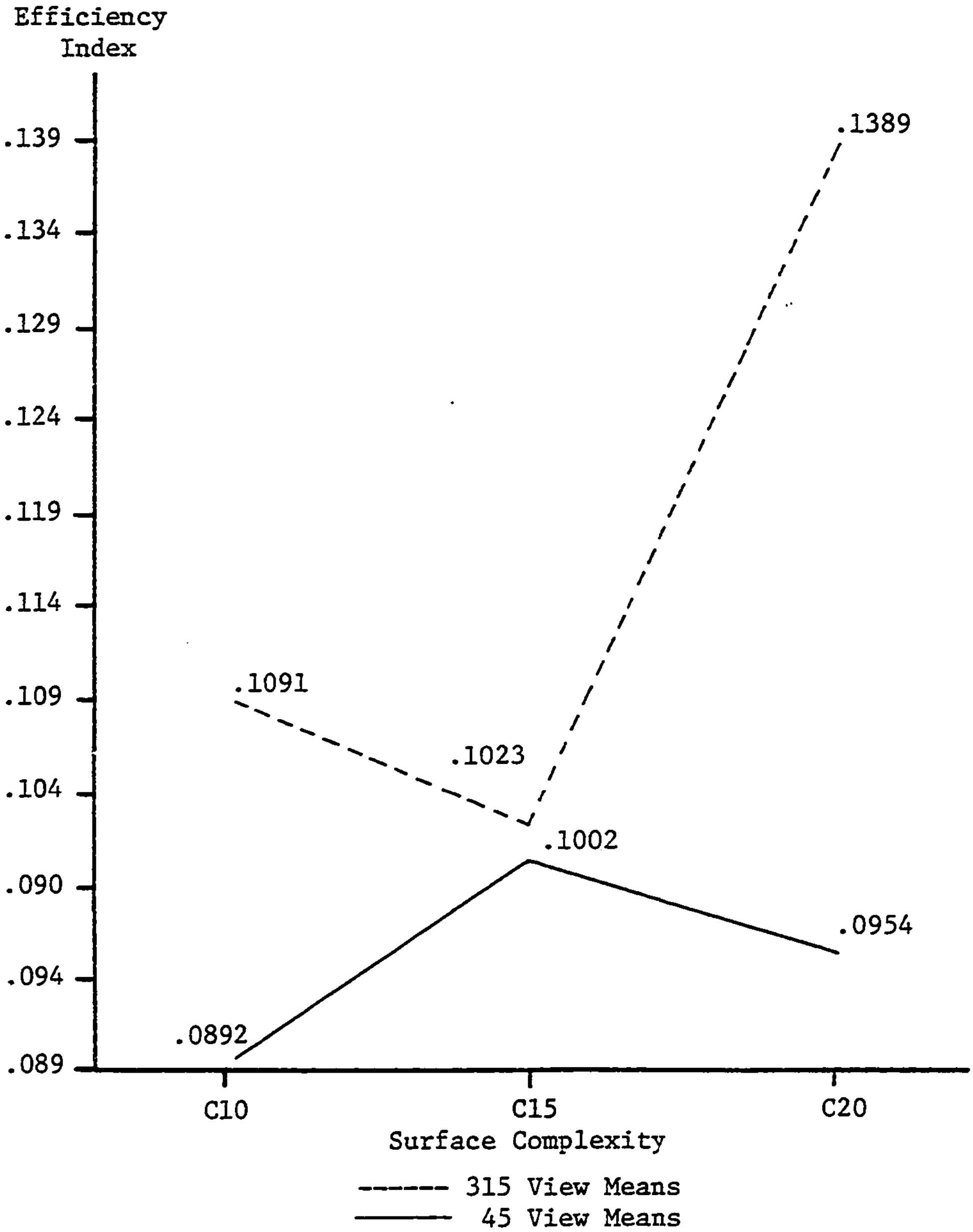


Figure 32

Pattern - CxV Interaction
Accuracy and Time

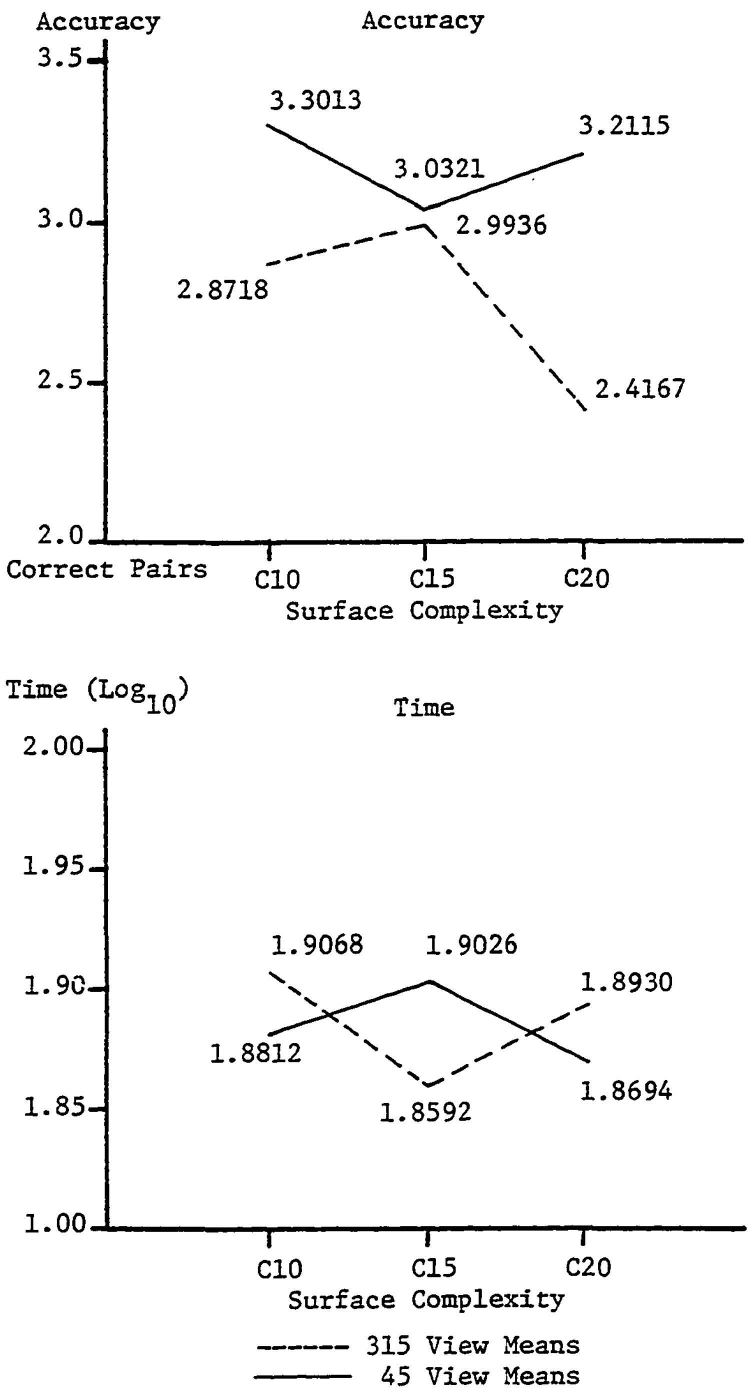


Table XXXIX

Pattern Main Effect Means

Map Reading Experience

Main Effect	Measure		
Experience	Efficiency	Accuracy	Time
G1 (inexperienced)	.1163	2.7318	NS
G2 (experienced)	.0953	3.2286	NS

Source: BIOMEDICAL Computer program BMD02V, Analysis of Variance for Factorial Design. Means cross verified with BMD01D, Simple Data Description (Dixon, 1973, 67-73, 607-622).

The effect of prior map reading experience was not conditioned by any other independent variables. The analyses did not produce any significant interaction between surface complexity, dimension, or viewing angle.

The results support the hypothesis that prior training in interpretation technique enables the map reader to more effectively decode pattern information from maps regardless of graphic dimension, surface complexity, or viewing orientation.

Summary - Pattern

Results revealed that perspective maps are effective in transferring pattern information to readers. Perspective maps were superior to the two dimensional maps for both the efficiency and accuracy measures, however, faster response times were achieved with the two dimensional maps. The direct pictorial quality of the perspective surface aides in the transmission of pattern, and specifically, trend information.

The clarifying effect of the perspective map diminished quickly with increased surface complexity. Surface complexity can produce noise which impeads the transmission of pattern information. Increased surface complexity results in considerable roughness on the high complexity surface which interrupts the underlying 5th degree polynomial trend surface. Peaks on the surface block surrounding areas which the reader needs to see to supply informational clues concerning the trend of the surface.

With two dimensional maps the arrangement and direction of isolines provided the reader with additional numbered reference isolines which provide information concerning elevation values across the surface from one point to another. This information was apparently then assessed to arrive at trend information concerning the surface.

As with other types of information, viewing angle was more important with perspective maps. Results indicated that those angles which provided more side profile enhanced the transmission of pattern information.

Lastly, prior training and experience with map and air photo techniques aided the reader in decoding pattern information regardless of graphic dimension, surface complexity, or viewing angle.

Summary - Magnitude, Gradient, and Pattern Information

Eight ANOVAs provided a statistical framework in which the variance in efficiency, time, and accuracy was assessed and evaluated.[5] The analyses indicated that the variables of graphic format, map reading experience, surface complexity, and viewing angle had significant, but different, influences based upon the type of cartographic information conveyed. Interpretation of the separate and combined effects of the independent variables were discussed as to their relative efficiency based upon the type of information. Additionally, interpretation of results concerning time and accuracy was conducted to provide a more in-depth analysis.

The following relationships exist between the grand means: 1) the magnitude task resulted in the lowest (most efficient) mean while the gradient task resulted in the highest (least efficient) mean, 2) a higher accuracy mean resulted from the magnitude task as opposed to the pattern task and, 3) the response time mean was lower (faster) for the magnitude task and highest (slowest) for the pattern task. Although comparison of means was not tested for significance it appears for this data that assessment of height information was less difficult that either gradient or pattern information. Table XXXX shows descriptive statistics for the various measures for each of the three types of information.

[5]Paired comparison tests for significance of individual treatment means was not performed in the analysis. These tests, such as Students T, Dunn's, Tukey's, and Scheffe's, are planned for future analyses of the separate effects reported in this research.

Table XXXX

Magnitude, Gradient, and Pattern Information

Descriptive Statistics

Information Type	Minimum	Maximum	Standard Deviation	Grand Means
		Efficiency Scores		
Magnitude	.0212	.3220	.0407	.0822
Pattern	.0298	.3726	.0701	.1059
Gradient	.1037	.9965	.1429	.4215
		Accuracy		
Magnitude	0.0000	5.0000	1.1892	3.0385
Pattern	0.0000	5.0000	1.5986	2.9711
Gradient	——	——	——	——
		Time		
Magnitude	.6721	2.3334	.1958	1.3797
Pattern	1.0719	2.4106	.0182	1.8853
Gradient	.4150	1.9956	.2308	1.1744

Source: Magnitude, Gradient, and Pattern Grand means BMD02V, Analysis of Variance for Factorial Design and descriptive statistics from BMD01D, Simple Data Description (Dixon, 1973, 67-73, 607-622).

This was not unexpected since identification and ranking of height values required no extensive processing of data, primarily recognition and subsequent ordering of the values. Pattern information not only required assessment of increasing values but additional decoding and processing of that data into a spatial arrangement, a more demanding process than just identification and ranking of high points. Gradient information was the least effeciently transferred. Here the reader had to identify and assess height values and determine their relationship to a linear distance on the surface before any slope information could be decoded. The high grand mean was suggestive of the difficulty in decoding this high level of interpretive information. The high gradient mean also suggests that this type of information is more difficult to efficiently convey than either pattern or magnitude information.

In summary, the analyses revealed that the variables of graphic format, map reading experience, surface complexity, and viewing angle had significant, but different influences on the transmission efficiency of the map based on the type of intended carotgraphic information to be conveyed. The statistical analysis has shown how the independent variables acted separately and in a combined manner to influence the dependent variables of transmission efficiency, accuracy, and response times. Chapter VI provides a summary of these findings and considerations for future research.

CHAPTER VI

SUMMARY, CONCLUSIONS, AND FUTURE RESEARCH CONSIDERATIONS

The old adage, "one picutre is worth a thousand words", is only partially true as it pertains to the communication efficiency of maps. It must be qualified by several factors: the type of information to be conveyed, the graphic dimension of the map, the complexity of mapped surface, the orientation at which the reader viewed the map, and prior map reading experience of the viewer.

The purpose of this research was to assess the influence of graphic dimension, as a design factor, on the communication of cartographic information. The research problem as presented in Chapter I asked the question--does the addition of height to a cartographic surface significantly increase the recognition and perception of magnitude, gradient, and pattern information, and furthermore, what effects do prior map reading experience, surface complexity and viewing angle have on the transmission efficiency of a map as the graphic dimension changes?

These parameters were selected because while their influence upon the perception of magnitude, gradient, and pattern information was unknown, communication and graphic theory suggested that they should be important in the communication process.

Experimental Design

Summary

The independent variables of graphic dimension, map reading experience, surface complexity, and viewing angle were controlled in a balanced experimental design and their influence on the dependent variable of transmission efficiency was assessed using a five-way factorial analysis of variance design. This procedure was used to assess the separate and combined influences of the independent variables on the efficiency in which magnitude, gradient, and pattern information were transferred to map readers.

Communication engineers measure efficiency as the quantity of data transmitted from one point to another; their measure, however, does not consider the intended meaning inherent in the transmitted message. This is, however, important in cartographic communication. Building upon the communication engineer's concept of information theory, cartographic efficiency in the experimental design and analysis was defined and measured as an index score based on each subject's number of correct answers and response time for a completed magnitude, gradient, and pattern task. Computational formulas were provided in equations 4.2 and 4.3 in Chapter IV. All total, 936 efficiency scores were computed for magnitude, gradient, and pattern tasks and subsequently assessed using a five-way, factorial ANOVA for each type of information. Additionally, five-way ANOVAs were used to assess the separate measures of accuracy and response time by information type. In total, eight, five-way ANOVAs were generated and subsequently assessed.

Seventy-eight subjects, 39 experienced map readers from Sonoma State University and 39 less experienced map readers from the University of California at Berkeley voluntarily participated in the experiment. Criteria for assignment to each of the two map reading groups was based upon completed course work involving minimal map reading training for the less experienced group and extensive course work in map and air photo interpretation techniques for the experienced group. Each subject viewed a controlled sequence of 36 stimulus maps and responded to magnitude, gradient, and pattern tasks.

The basic spatial structure of all stimulus maps was a representation of a fifth degree polynomial surface which was modified by the addition of noise values. Surfaces were generated with five, ten and twenty values. Each set of noise values and their locations on the surface was randomly generated and systematically assigned to the basic fifth degree surface. Each surface was then represented as a two dimensional isarithmic and three dimensional perspective map as a means of assessing the influence of graphic dimension. Each surface, in both graphic dimension, was constructed at two orthogonal viewing angles (45 and 315) in order that the influence of map orientation could be assessed. This procedure resulted in twelve, computer drawn, stimulus maps, six two dimensional and six perspective maps. Each subject viewed the twelve maps three times, each time responding to a perceptual task pertaining to magnitude, gradient, and pattern information. These perceptual task were developed to measure the efficiency of the map in transferring information the the viewer.

The magnitude task required a subject to search each surface for five point locations, assess their height, and rank them from highest to lowest. The gradient task required the identification of the location of steepest slope on each surface. Finally, the pattern task required each subject to identify the trend of increasing values on each surface. An efficiency score based upon accuracy and unit of response time was then computed for each task for each map. This resulted in the 936 (78 subjects, 36 scores for each) efficiency scores for each type of information. Eight separate five-way factorial ANOVAs were used to assess the variance of the efficiency scores, accuracy scores, and response times. The summaries and conclusions from these analyses are now presented.

Magnitude Information

Summary

Results of the analyses indicated a series of significant main effects and interactions for all three measures. A summation of the ANOVA results is provided in Table XXXXI.

These results revealed that height information was more efficiently transferred by two dimensional maps than perspective maps.

Table XXXXI

Summary of Magnitude ANOVA Results

Source of Variation	Measure		
Main Effects	Efficiency	Accuracy	Time
	Significance Level		
Map Experience (G)	.05	.01	NS
Dimension (D)	.01	.01	.01
Complexity (C)	.01	.01	.01
View (V)	.01	.01	NS
Two-Way Interactions			
GxD	NS	.01	NS
GxC	.01	.01	NS
GxV	NS	NS	NS
DxC	.01	.01	.01
DxV	.01	.01	NS
CxV	.01	NS	.05
Three-Way Interactions			
GxCxV	NS	NS	.05
GxDxV	NS	NS	NS
GxDxC	NS	NS	NS
DxCxV	.01	.01	NS
Four-Way Interaction			
GxDxCxV	NS	NS	NS

NS - not significant

Source: BIOMEDICAL computer program BMDO2V, Analysis of Variance for Factorial Design (Dixon, 1973, 607-622).

Greater accuracy was achieved with two dimensional maps, but perspective maps resulted in faster response times. Efficiency and accuracy increased with increased surface complexity for both dimensional surfaces, a result possibly brought about by a clustering effect of data points on the two most complex surfaces. Additionally, response time decreased with increased complexity, also a result probably due to the clustering of data points on the highly complex surfaces.

Viewing angle was more important with perspective than two dimensional maps. Both viewing angles resulted in good performance with the two dimensional maps while the 45 degree view resulted in better performance for the perspective surfaces.

Prior map reading experience resulted in better efficiency and higher accuracy for both two and three dimensional maps. Response time was not statistically significant for either group of readers. The more experienced group of readers also achieved greater accuracy with the two dimensional maps than the less experienced group of readers.

Conclusions

Graphic dimension, as a design element, did influence the transmission efficiency of intended height information to map readers. The fact that two dimensional maps were more efficiency was unexpected. Information theory suggested that increased noise would inhibit transmission of the intended message, thereby decreasing the overall communication efficiency of the entire system. Increased surface complexity, expressed by the complex arrangement and spacing of the isolines on the two dimensional maps, did not introduce excessive noise but supplied the reader with redundant line structure (more references isolines) which was used in assessing exact height values. The three dimensional had no reference clues to exact height information. This is not unusual since perspective maps do not usually contain surface reference symbols. This suggests that whenever exact height information is to be conveyed, two dimensional are more efficient.

The higher efficiency, accuracy, and quicker response times with the more complex surfaces may be attributed to a clustering effect of data points on these surfaces. Since data points were clustered on the complex surfaces less time was spent in scanning the entire map; only one section of the surface had to be scanned. This may have brought about the faster response times for the complex surfaces, especially for the perspective maps. It should be noted that whenever time alone is considered as the more important factor, perspective maps seem to be more efficient.

The inefficiency of the perspective maps may also be due to the particular data values assigned to the five control point locations and the inability of the reader to distinguish small differences between points. The most complex surface had the greatest difference between the five data points (Table XVIII). In effect, the most complex surface may have been the easiest surface to detect difference and rank height values. Rowles (1978, 43) reported in her research that two factors appeared to influence the perception of height information with perspective maps, height of the highest hill and the difference in height between hills. A conclusion can be drawn that wherever exact height information is to be transmitted, two dimensional maps are more efficient whereas perspective maps become efficient in transmitting relative height information when the difference between data points is great.

The third conclusion was that viewing angle had a more significant effect with perspective maps than two dimensional maps. Depending on surface complexity, map orientation enhanced height information. Two orthogonal azimuths of 45 and 315 degrees were used in the experiment and subsequently proved to significantly influence the transmission efficiency of magnitude information. Rowles' (1978) research indicated that viewing angle did not significantly influence the perception of height information, however the viewing angles she used were not orthogonal and only involved a total difference of 55 degrees for three views. It seems reasonable to conclude that the difference in viewing angle was important, especially as the surface became more rough. As shown in this research, a map orientation which provided more side profile of intended information enhanced transmission efficiency. Thus one conclusion would seem to be that the cartographer should consider those views which provide a clear, unobscured side profile. This is consistent with existing concepts in form perception, in particular, the value of a good figure-ground relationship. Such a relationship was achieved with the perspective maps as peaks were viewed from the side, as opposed to a frontal view. The result was an unobscured background which allowed the figure to stand out more clearly from its background and which allowed the reader to compare height from one hill to another.

The fourth and last conclusion was the beneficial effect of prior training and experience in map and air photo interpretation. It seems reasonable to conclude that training in map interpretation and air photo techniques, especially training in stereoscopy, enables a reader to evaluate height information more effectively than inexperienced readers.

Gradient Information

Summary

Results of the analyses indicated that the independent variables of dimension, map reading experience, and surface complexity did significantly influence the transmission of gradient information. A summary of ANOVA results for the efficiency means measure and response times is provided in Table XXXXII.

Table XXXXII

Summary of Gradient ANOVA Results

Source of Variation	Measure		
Main Effects	Efficiency	Accuracy*	Time
	Significance Level		
Map Experience (G)	.05		NS
Dimension (D)	.01		.01
Complexity (C)	.01		.01
View (V)	NS		NS
Two-Way Interactions			
GxD	NS		.05
GxC	.01		NS
GxV	NS		NS
DxC	.01		.01
DxV	NS		.05
CxV	.01		NS
Three-Way Interactions			
GxCxV	NS		NS
GxDxV	NS		NS
GxDxC	.01		.01
DxCxV	.01		.01
Four-Way Interactions			
GxDxCxV	NS		NS

*Not computed

NS - not significant

Source: BIOMEDICAL computer program BMDO2V, Analysis of Variance for Factorial Design (Dixon, 1973, 607-622).

The analyses illustrated that the use of perspective maps resulted in overall better efficiency and faster response times by readers in decoding steepest slope information. The effectiveness of the perspective map, however, decreased with increased surface complexity and especially at an angle which did not provide a great deal of side profile of the surface form. Additionally, response time increased with surface complexity.

Viewing angle was more important with perspective than two dimensional maps. The analyses show that those views which provide side profile enhance the transmission of slope information. Lastly, as anticipated, prior map reading experience aided the reader in decoding steepest slope information.

Conclusions

The first conclusion was that depth provided a valuable form perception clue for the recognition of slope information from perspective maps, but the transmission efficiency decreased with increased surface complexity. Even though perspective maps provided a more direct pictorial image of the concept of slope than the two dimensional map, as theories of form perception suggest, the increase in visual noise as the surface became more complex reduced the efficiency of the map. Efficiency decreased probably because more slopes must be considered and the probability of near similar slopes increased. The increased number of slopes to assess apparently became the noise factor which impeaded the transmission of slope information. This also resulted in slower response times, especially for the high complexity surfaces.

Noise accounted for the inefficiency of the two dimensional maps, however, noise was attributed to different factors. With two dimensional maps increased surface complexity brought about a more complex arrangement and spacing of the isolines. The resulting complex line structure of the optical array on the complex surfaces apparently introduced sufficient noise to decrease efficiency.

These results suggest that the cartographer must in some way, either visually or with a mathematical model, estimate surface complexity and use this as a design parameter if a perspective map is used to display gradient information.

If the surface is visually complex, then possibly two or more views of the perspective surface are needed to convey the intended slope information. When possible, a view that provides a side profile of peaks (high values in the distribution) increases the likelihood that gradient information will be more efficiently transmitted, especially as the surface becomes increasingly rough. Frontal views of hills symbolizing the intended slope information should be avoided as well as views which block figural form clues of the hill. This is consistent with theories of form perception, that is, recognition of figural shape is enhanced with a clear and unobscured background, however, surface specific characteristics might require that several maps at different orientations would best convey the intended information. This is not unreasonable since the cartographer will probably be using computer mapping routines to generate the perspective surfaces. The surfaces can then be previewed on a cathode-ray tube which would allow the cartographer a chance to assess the selected view, thus truly using map orientation as noise filter. Monmonier (1978) presented a methodology for evaluating surface characteristics which will aid in the selection of a viewing angle which provides maximum clarity of the surface. This methodology, plus ensurement of selecting an orientation which provides a side profile of the intended hill must be considered if viewing angle noise is to be reduced or eliminated.

A third conclusion was based on the beneficial results of prior map reading experience. Readers who received training in, and experience with aerial photographs, especially stereoscopy, decode slope information from both two dimensional and perspective maps more effectively than readers who have not had this training. One may speculate that the development of air photo interpretation skills provides a conceptual basis for a more proficient map reader.

Pattern Information

Summary

Results of pattern analysis indicated that all four independent variables, dimension, map reading experience, surface complexity, and viewing angle, did significantly influence the transmission efficiency of pattern information. However, the only variable that had a significant, but separate influence, was the variable of map reading. A summary of ANOVA results is provided in Table XXXXIII.

Results of the analyses revealed that perspective maps transferred pattern information more efficiently and accutarely than two dimensional maps, however, two dimensional maps resulted in slightly faster response times. Although the difference was small, it was statistically significant (Tables XXXIII and XXXIV).

With perspective maps increased surface complexity resulted in lower efficiency in transmission of pattern information. With two dimensional maps, however, increased complexity resulted in higher efficiency.

The analyses indicated that those viewing angles which provided side profile of the hill enhanced the transmission of pattern information. Lastly, prior training and experience with map and air photo interpretation techniques aided the reader in decoding pattern information regardless of graphic dimension, surface complexity, or viewing angle.

Conclusions

The first conclusion pertains to map reading experience. Since the variable of map reading experience was not conditioned by any other variable, it could be concluded that prior map and air

Table XXXXIII

Summary of Pattern ANOVA Results

Source of Variation	Measure		
Main Effects	Efficiency	Accuracy	Time
	Significance Level		
Map Experience (G)	.01	.01	NS
Dimension (D)	.05	.01	.01
Complexity (C)	.01	NS	NS
View (V)	.01	.01	NS
Two-Way Interactions			
GxD	NS	NS	NS
GxC	NS	NS	NS
GxV	NS	NS	NS
DxC	.01	.01	.05
DxV	NS	NS	NS
CxV	.01	.01	.05
Three-Way Interactions			
GxCxV	NS	NS	NS
GxDxV	NS	NS	NS
GxDxC	NS	NS	NS
DxCxV	.05	NS	NS
Four-Way Interactions			
GxDxCxV	NS		NS

NS - not significant

Source: BIOMEDICAL computer program BMDO2V, Analysis of Variance for Factorial Design (Dixon, 1973, 607-622).

photo interpretation experience greatly aided the viewer in decoding pattern information from both two and three dimensional surfaces, regardless of surface roughness or map orientation. This strongly suggests that prior training and experience with topographic maps aided the reader in assessing the spacing, arrangement, and direction of isolines, a relationship needed to decode pattern information from two dimensional surfaces. Furthermore, experience with aerial photographs, especially stereoscopy, provided the experienced reader with a broader base for decoding pattern information from perspective surfaces. It is noteworthy to emphasize that the more experienced group of readers decoded all types of information, magnitude, gradient, and pattern more efficiency than inexperienced readers.

A second conclusion was that the dimensionality effect of the perspective map did produce a clarifying effect as theories of form perception suggested but the clarifying effect diminished rapidly as the surface became more complex, thus emphasizing the influence of information overload as suggested by communication engineers. This suggests that if a surface is complex and rough, the value of the perspective map quickly diminishes.

A third conclusion was also reached pertaining to map orientation. As with magnitude, gradient, and pattern information, viewing angle became a more important factor with perspective maps. A view which offers an unobscured side profile of the high points provided the best informational clue to pattern recognition on the surface. This supports the value of good figure-background relationship as perceptual clue to form.

General Conclusions

Results of this research have indicated that perspective maps are efficient channels to transmit information but they do not represent a panacea for communicating all types and levels of cartographic information.

It appears that perspective maps are efficient information systems if the level of data generalization is broad and is not intended for detailed analytical purposes. As such, the transfer of information to map readers is based on an impressionistic attribute, the illusion of depth. Additionally, efficiency varies with the type of information to be conveyed.

If a quick, impressionistic view of magnitude data meets map reader requirements, then perspective maps should be considered as an effective display mode. If readers require exact height information of continuous spatial data for analytical purposes, then two dimensional isarithmic maps appear to be more efficient, especially if the reader has had prior experience with interpolation of contours from topographic maps.

There appears to be different thresholds of what map readers can perceive based on surface complexity for each information type.

With magnitude information efficiency and accuracy improved with surface complexity. When estimating height data, the number of peaks on the surface may not affect the reader, as with the highly complex surfaces, as much as absolute differences between data points for these surfaces. If differences are small, it appears that perspective maps become inefficient because readers cannot discriminate small differences between heights of hills.

An increase in surface complexity overloads the reader and hinders the communication of both steepest slope and pattern information with perspective maps. Although efficiency and accuracy decreased with increased complexity, perspective maps resulted in better performance than the two dimensional maps.

As with magnitude information, if exact slope information is to be conveyed, like degree or percent slope, then two dimensional maps should be used. This assumes, however, that the reader has a working knowledge of slope computation with isarithmic surfaces. If more generalized information is to be conveyed, like steepest slope, and the surface is not highly complex, then perspective maps should be considered as the display mode.

If perspective maps are to be used to convey steepest slope information the cartographer must determine the threshold of surface complexity for the map reading audience otherwise the map will not convey the intended information. Additionally, it becomes important that the cartographer select a map orientation that provides sufficient profile of the hill and associated angle. In fact, more than one view might enhance the information even further. This is not a difficult task given existing computer technology.

Although perpsective maps resulted in better accuracy and efficiency than two dimensional maps in transmitting pattern information, efficiency and accuracy decreased rapidly with increased surface complexity. It appears that surface roughness makes pattern information, especially trend, most difficult to decode. As with the other types of information perspective maps seem to provide an impressionistic view rather than one designed for analytical purposes. This is not to say that they do not convey information. The attribute of depth is not just a design element for visual effectiveness, but an element that enhances the transmission of pattern information if the surface is not highly complex.

Another conclusion is that prior map reading experience and training in air photo interpretation techniques aids readers in decoding all types of cartographic information. A current paradigm in cartography states that not only must the map be compiled to convey information, but proper map reading must take place by the viewer if the cartographic process is to be a complete information system. Experience with topographic maps provides necessary training with interpretation of contours which the reader can relate to quantitative isarithmic surfaces. If a reader was not familiar with interpretation of contours then the two dimensional isarithmic maps would be meaningless. It appears that readers decode information from perspective maps with little training. One might speculate that a reader with no map interpretation training might decode a minimal level of information with perspective maps. Future research must address this relationship between user needs and thresholds of perception of various types of information. If these levels can be ascertained by information type, then maps are more likely to become information systems.

Future Research Considerations

As with most research, it represents a starting point for future investigation. The research presented in this dissertation represents a springboard to investigations concerning questions relating to the communication aspects of two and three dimensional maps.

This research provided results which suggest that two dimensional were more effective in transferring exact height data than perspective maps. A hypothesis can be formulated as to what effect differences between heights have upon the perception of information. Likewise, what different thresholds exist with perspective maps.

Additional experimentation and testing is needed to ascertain the specific effects of clustered data points and the relationship to transferred height information from both two and three dimensional surfaces.

Research is needed to clarify the influence of viewing angle on the perception of gradient and pattern information. Only two orthogonal views were used in this research--can specific orientations be selected on the basis of surface specific characteristics? Monmonier's (1978) methodological assessment of surface clarity might be tested at angles which also provide side profiles of data points. Answers to these questions would provide specific guidelines for the cartographer in selecting an appropriate map orientation. Furthermore, what effect does viewing altitude have upon the transmission of height and gradient information? A 45 degree altitude provides an adequate "birdseye" view, but do other altitudes enhance particular types of information?

In general, research is needed to specifically identify and develop criteria for discriminating classes of map readers. Only through such as assessment can map reader needs be identified.

Cartographic research has not focused upon the communciation aspects of maps, much less, perspective maps, until very recently. As research in this area grows, a series of parameters will hopefully emerge in which the cartographer can accurately assess the needs of his map reading audience and use the most efficient graphic format to aid the viewer in becoming a map percipient rather than just a map reader. In a recent article on research in cartographic design the American cartographer Arthur Robinson (1977, 162) stated:

> "The realization that a great many maps are made with the objective of communication, such as most

> general maps, school maps, illustrative maps in books, and a large variety of thematic maps, has an important corollary. In order to design such maps so that their communication efficiency is as high as possible, it is necessary to understand the percipient, the uses of the map, and to be fully cognizant of the characteristics of his perceptual processes. In other words, it is necessary for the field of cartography to carry on research in cartographic design in order that some of the basic objectives of the map can be realized".

It is hoped that the findings of this research has added to the empirical data base of helping to understand the effects of design variables upon the transmission efficiency of cartographic information.

APPENDIX I

STIMULUS MAP BOOKLET*

INSTRUCTIONS

During this experiment you will observe a series of two dimensional contour maps and three dimensional perspective maps.

You will be asked to identify three types of information displayed on each map; information pertaining to magnitude, gradient, and pattern (trend).

You will be given a written question before each map series. The answer is to be placed directly on the question sheet or on the map itself. It is important that you answer each question as _accurately_ and _quickly_ as possible.

Your performance in answering these questions will in no way affect your grade for the course in which you are enrolled.

The following definitions are provided for your information; please read all of them carefully for you will not be able to return to these definitions once you proceed further in this exercise.

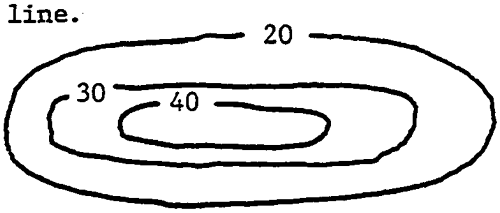
*Answers included

DEFINITIONS

Contour Lines: lines concerning points of equal elevation.

Contour Map: a map containing a series of contour lines.

Contour Interval: the constant difference in elevation between successive contour lines. If the contour interval is 10 and the contour line is marked 30, then the next line above represents 40, while the line directly below the 30 represents the 20 line.



Perspective Map: a three dimensional representation of a surface. These are diagrams which display height at well as length and width.

Magnitude: the range of values; the extent of values or series of values on a particular map.

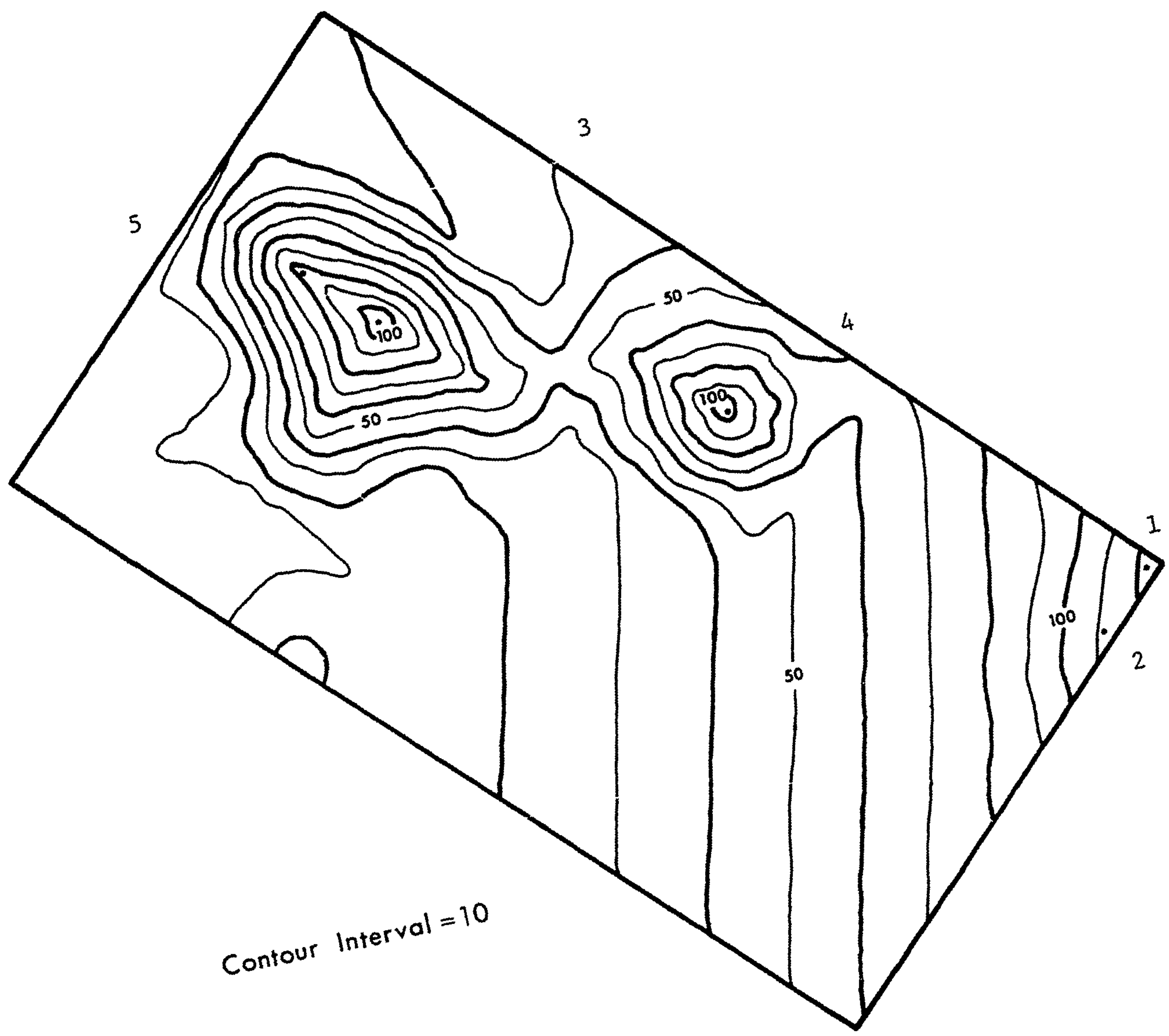
Gradient: the rate of slope between any two points on the map; the rate of change from one point to another on the surface of the map.

Pattern: the existence of regularities in texture or shapes; the orientation and arrangement of features on the map; the general trend of shapes on the map surface.

If you have any questions about these definitions, please ask now. Questions cannot be answered once you have begun work.

The following map contains five "dots" placed at various locations on the mapped surface. You are to place a "1" at the "." that indicates the highest point on the surface followed by a 2, 3, 4, and 5 at the 2nd, 3rd, 4th, and 5th highest point on the surface. Please mark all five "dots".

After placing your final mark on the map indicate verbally, "finished."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5
4
1
2
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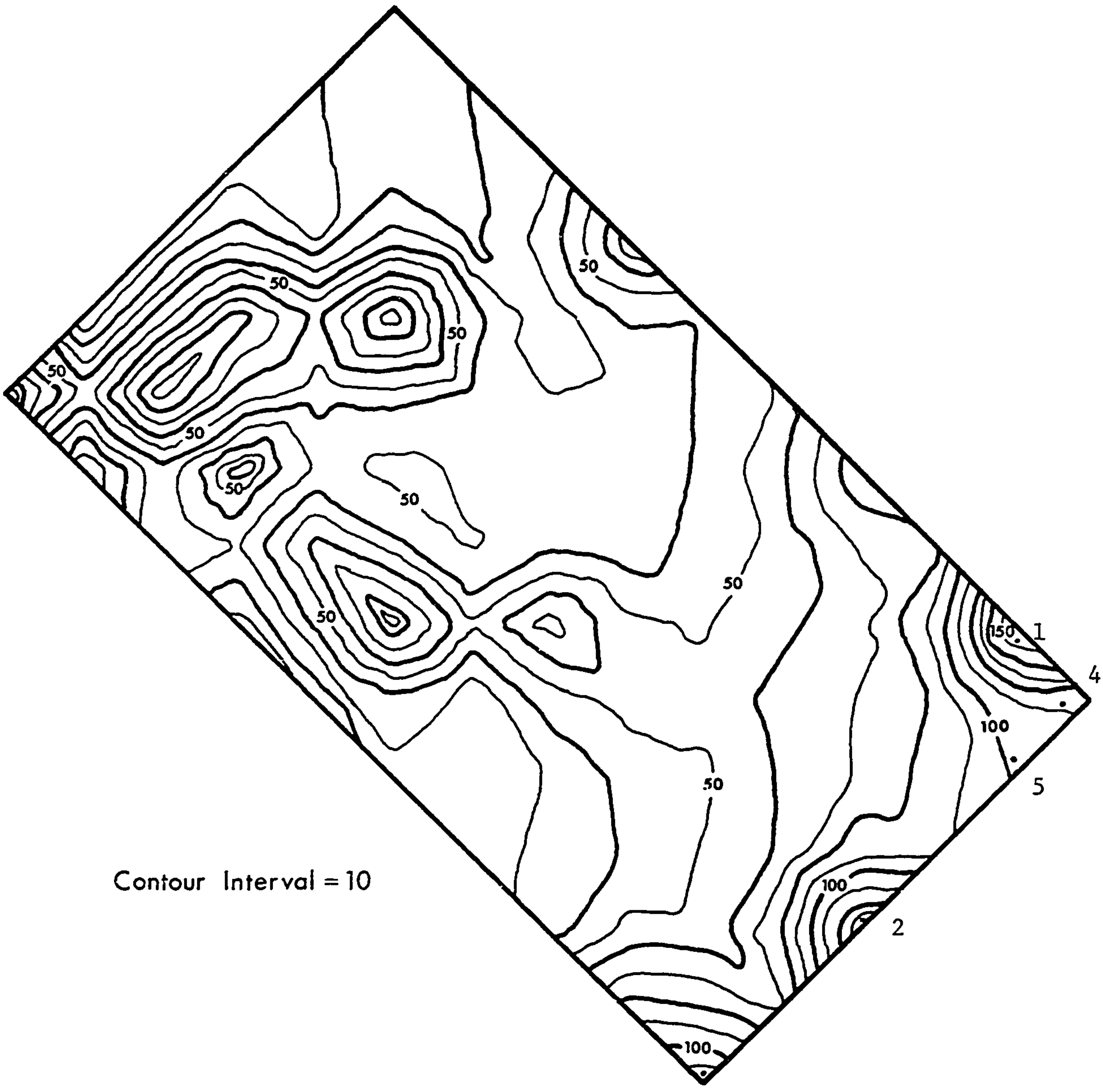
Contour Interval =10



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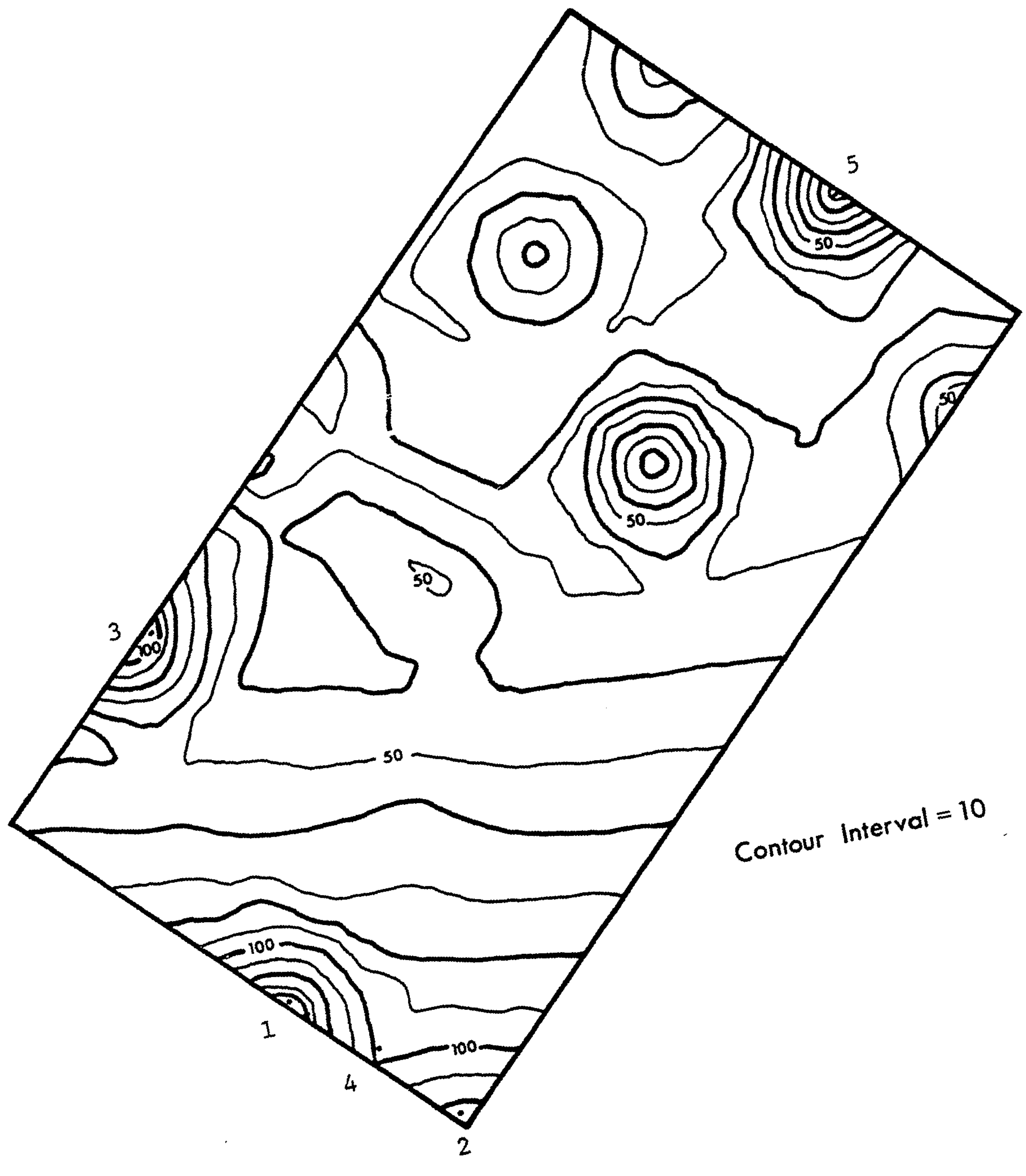
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50
50
50
3
100
50
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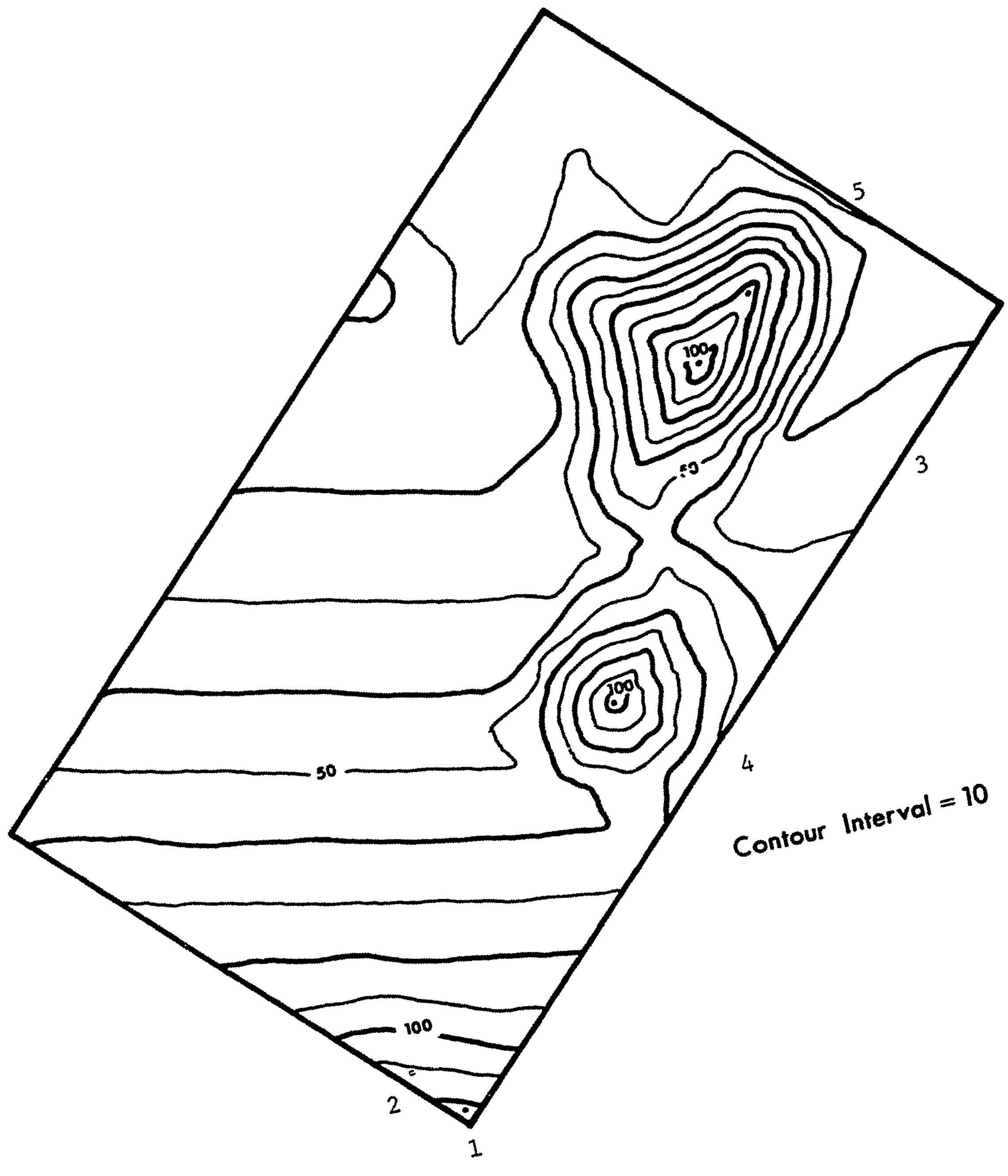
1
100
4
2
Contour Interval = 10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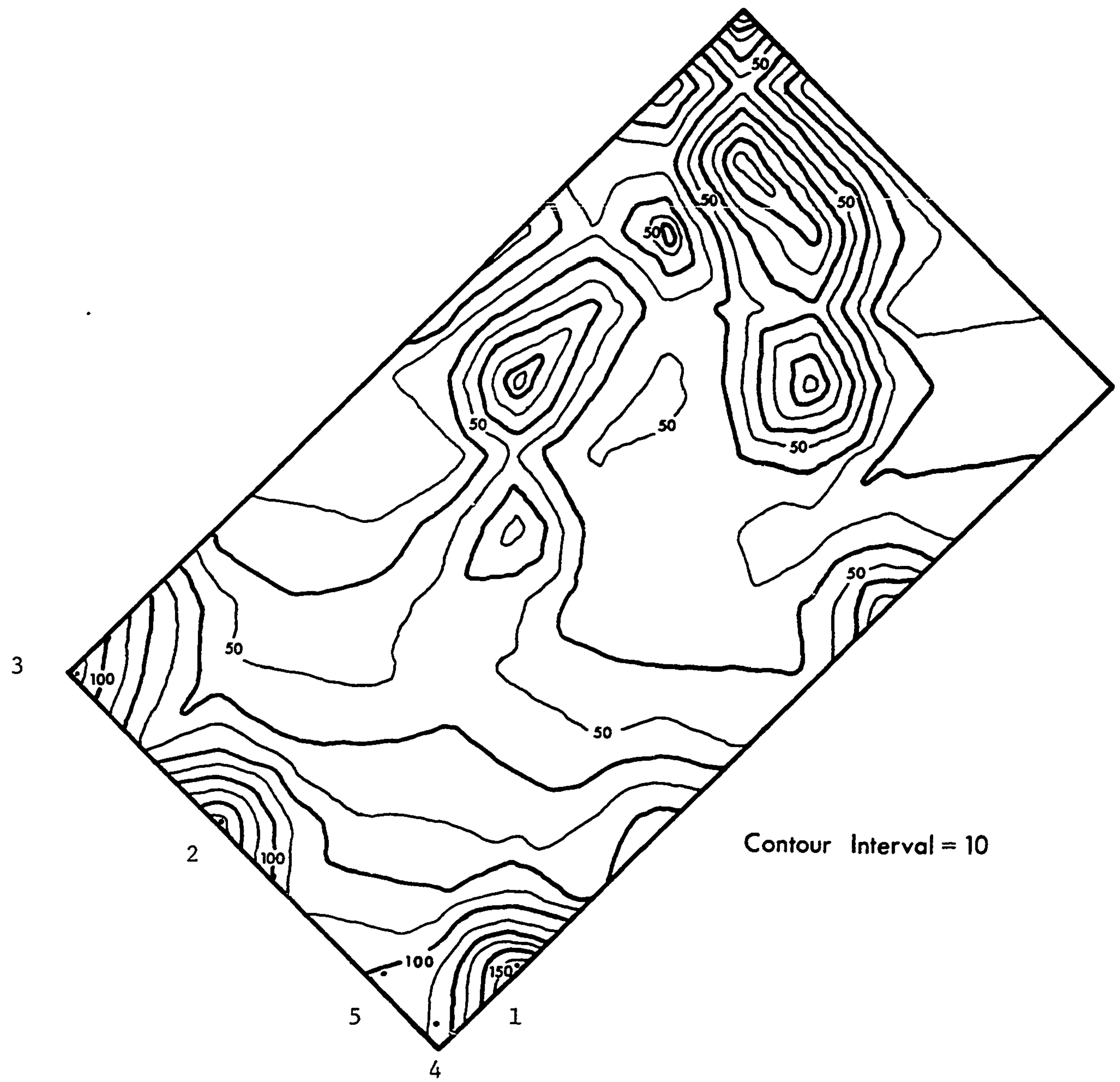
4
50
Contour Interval = 10
100
2
1



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3
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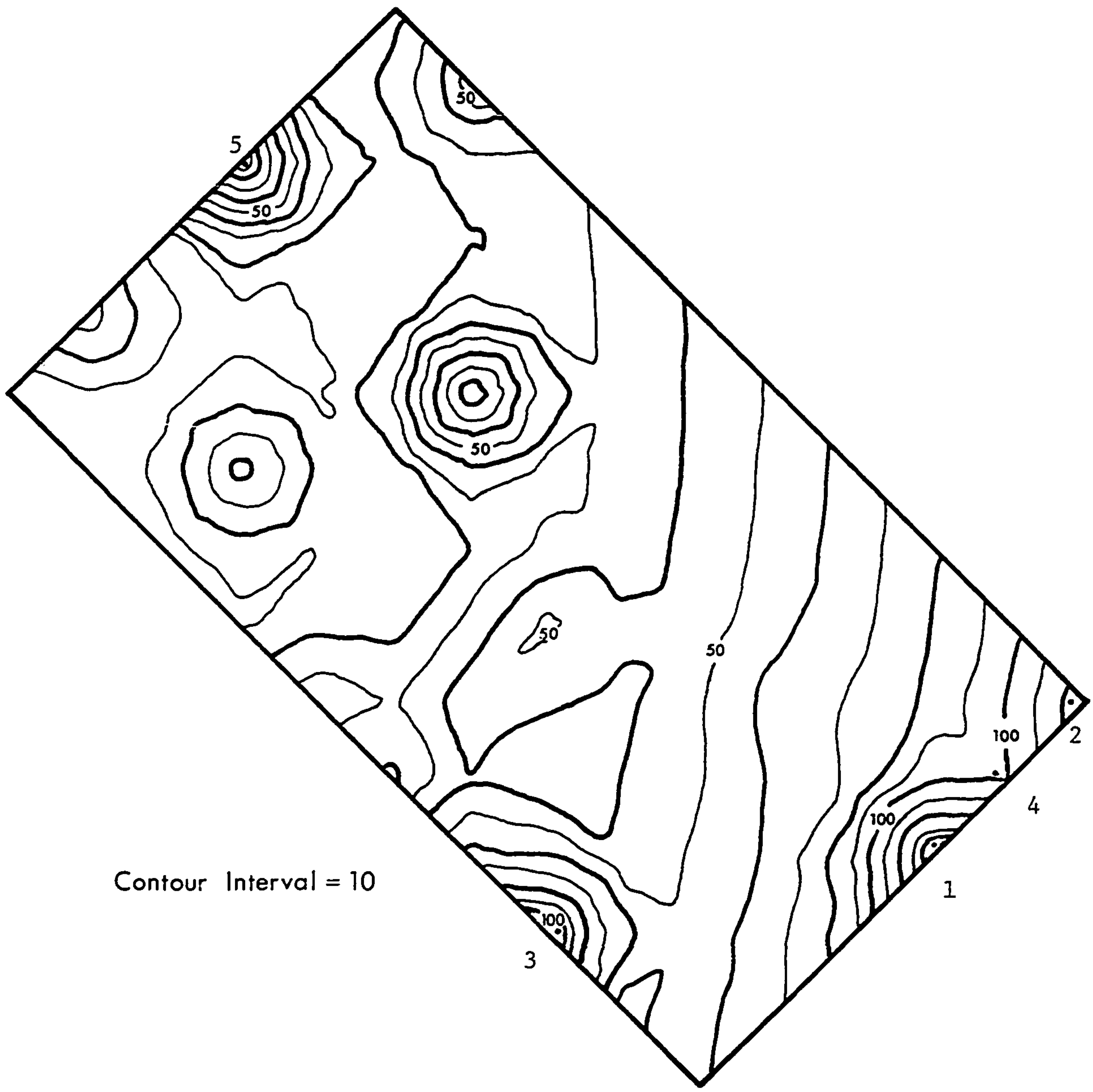
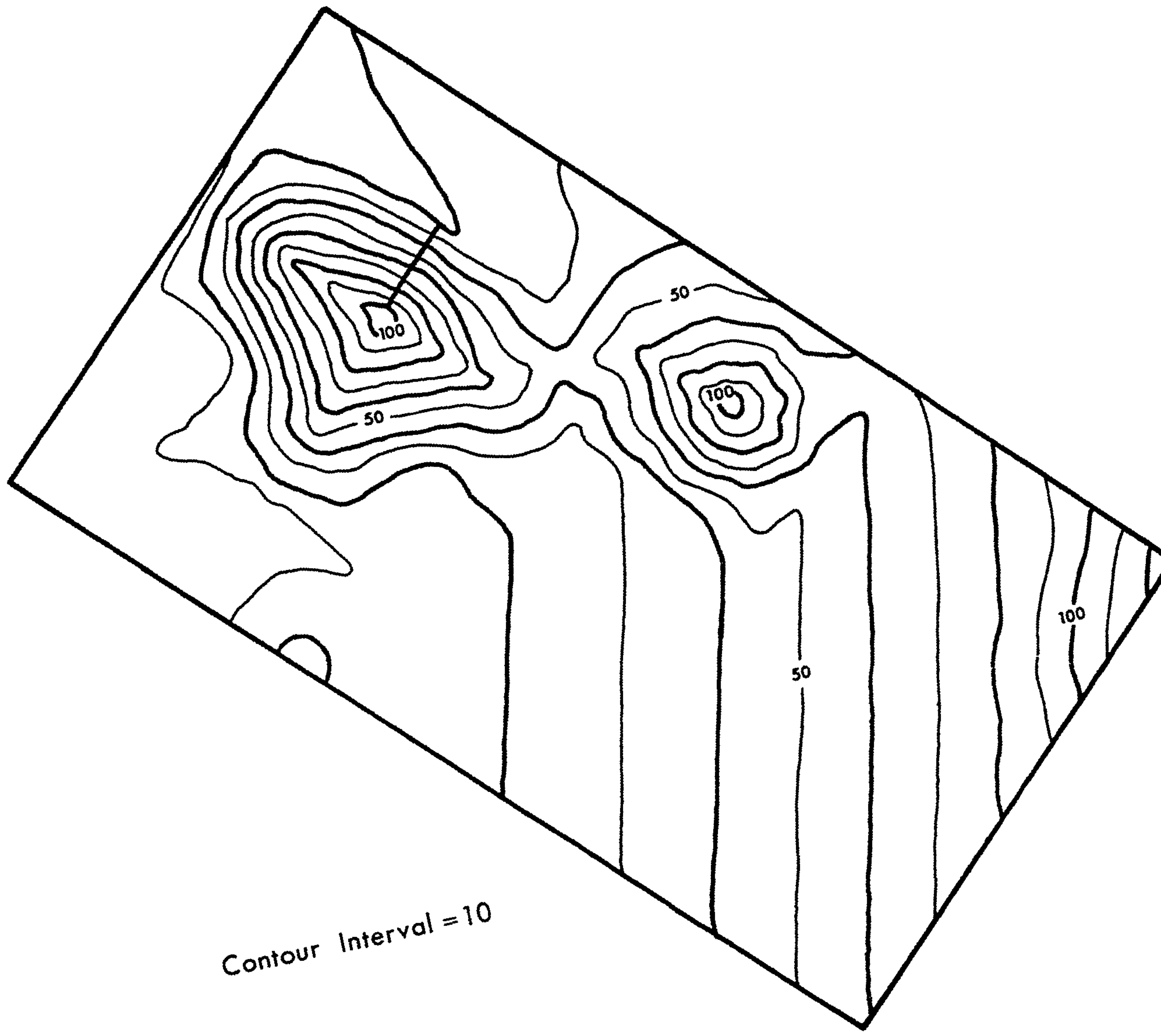
5
1
4
Contour Interval = 10



Contour Interval = 10

Using the pre marked measuring device with the black line, place the device so that the end points of the black line connect the points on two different contour lines representing the location of the greatest rate of change (the steepest slope) on the map.

When you have made your decision and placed the pre marked device on the map please indicate verbally, "finished."



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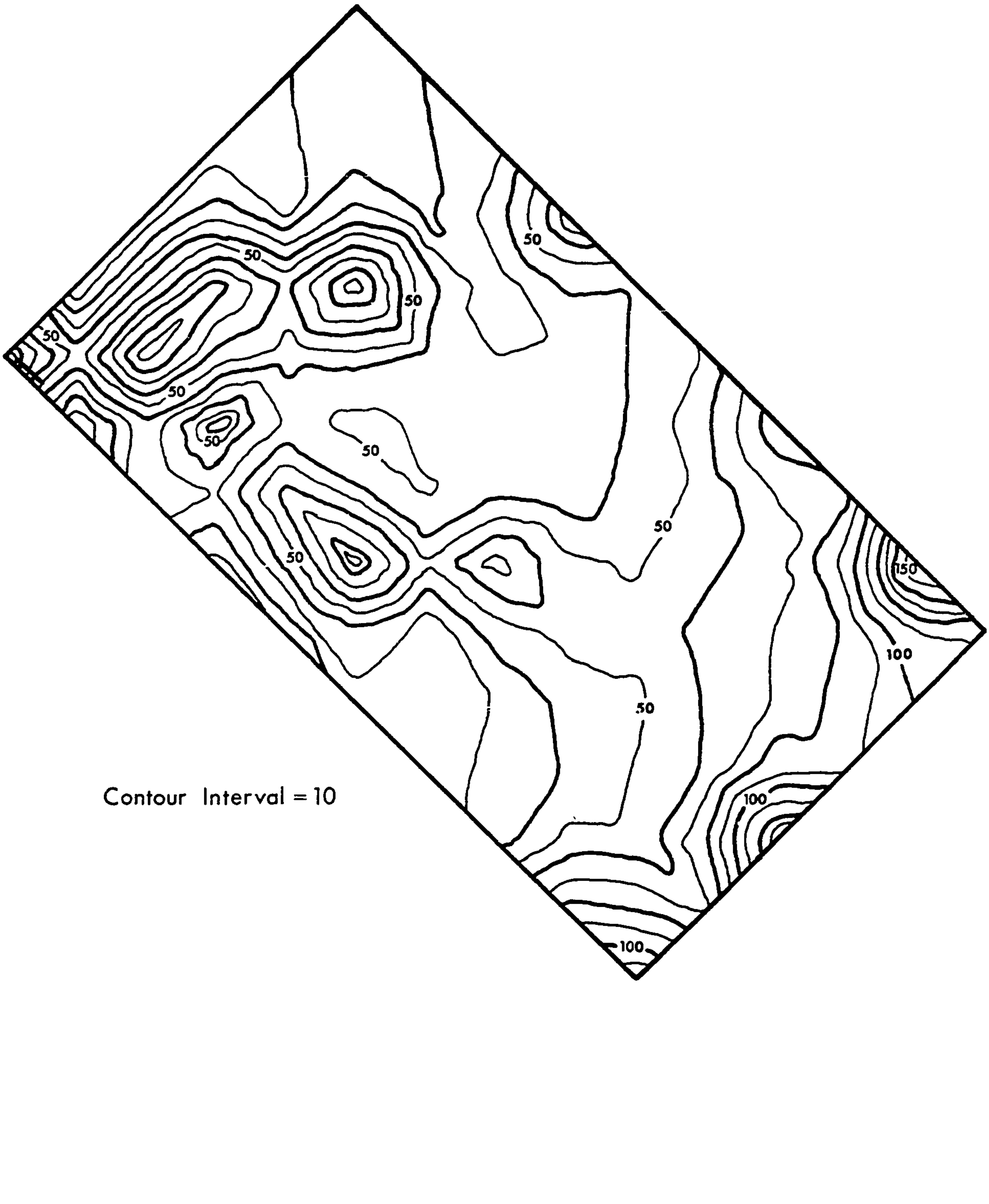

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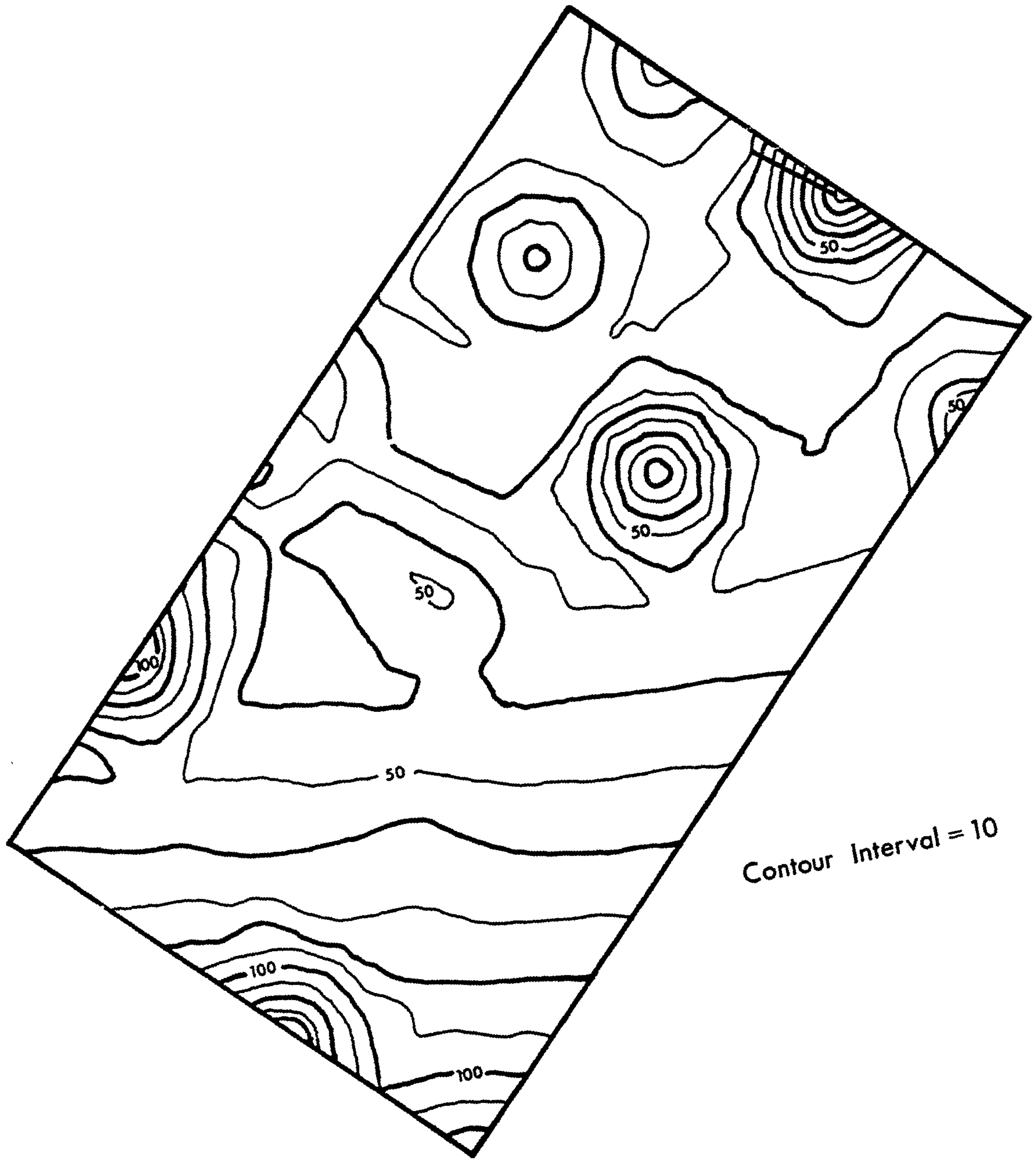
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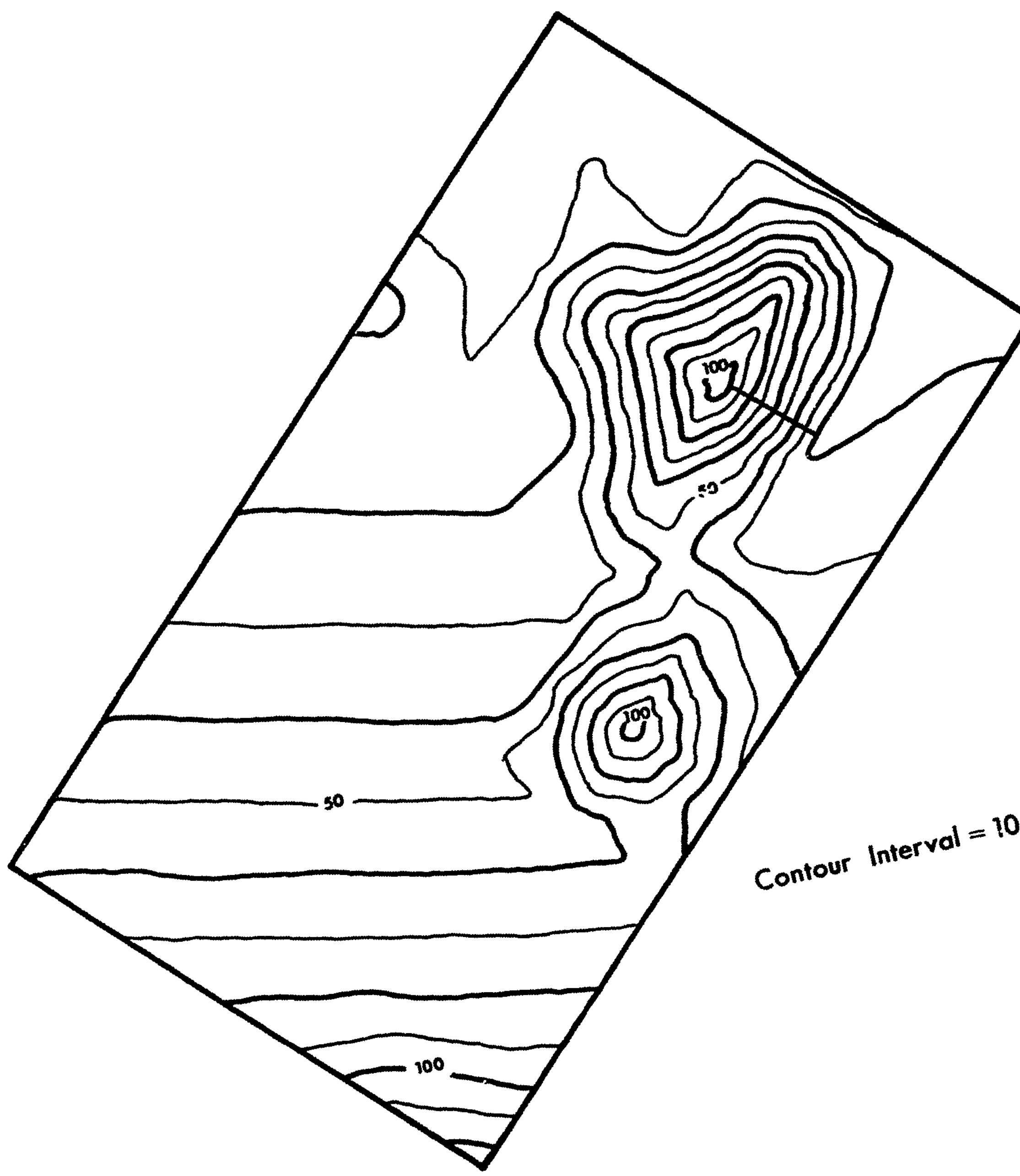
Contour Interval = 10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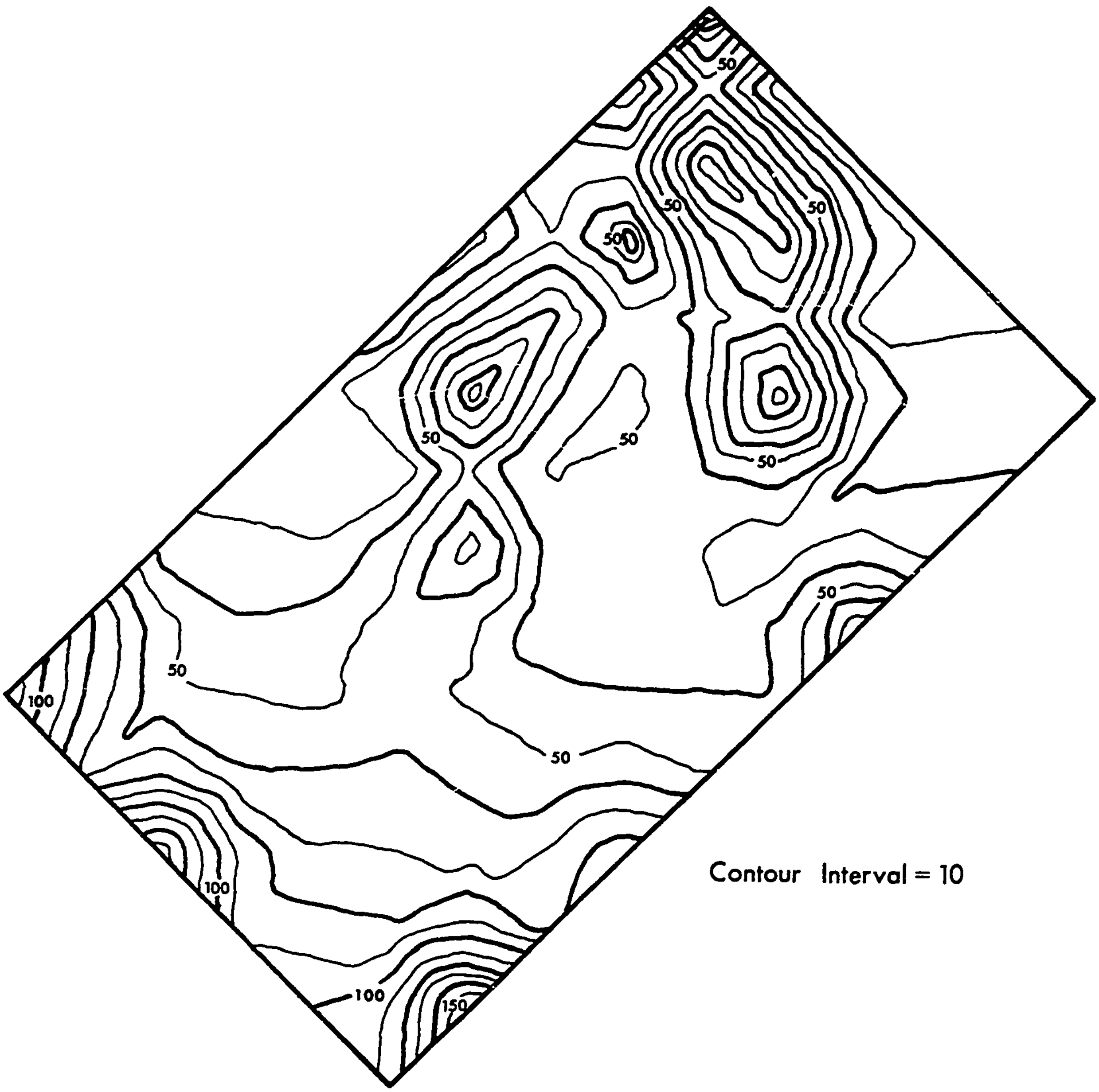
Contour Interval = 10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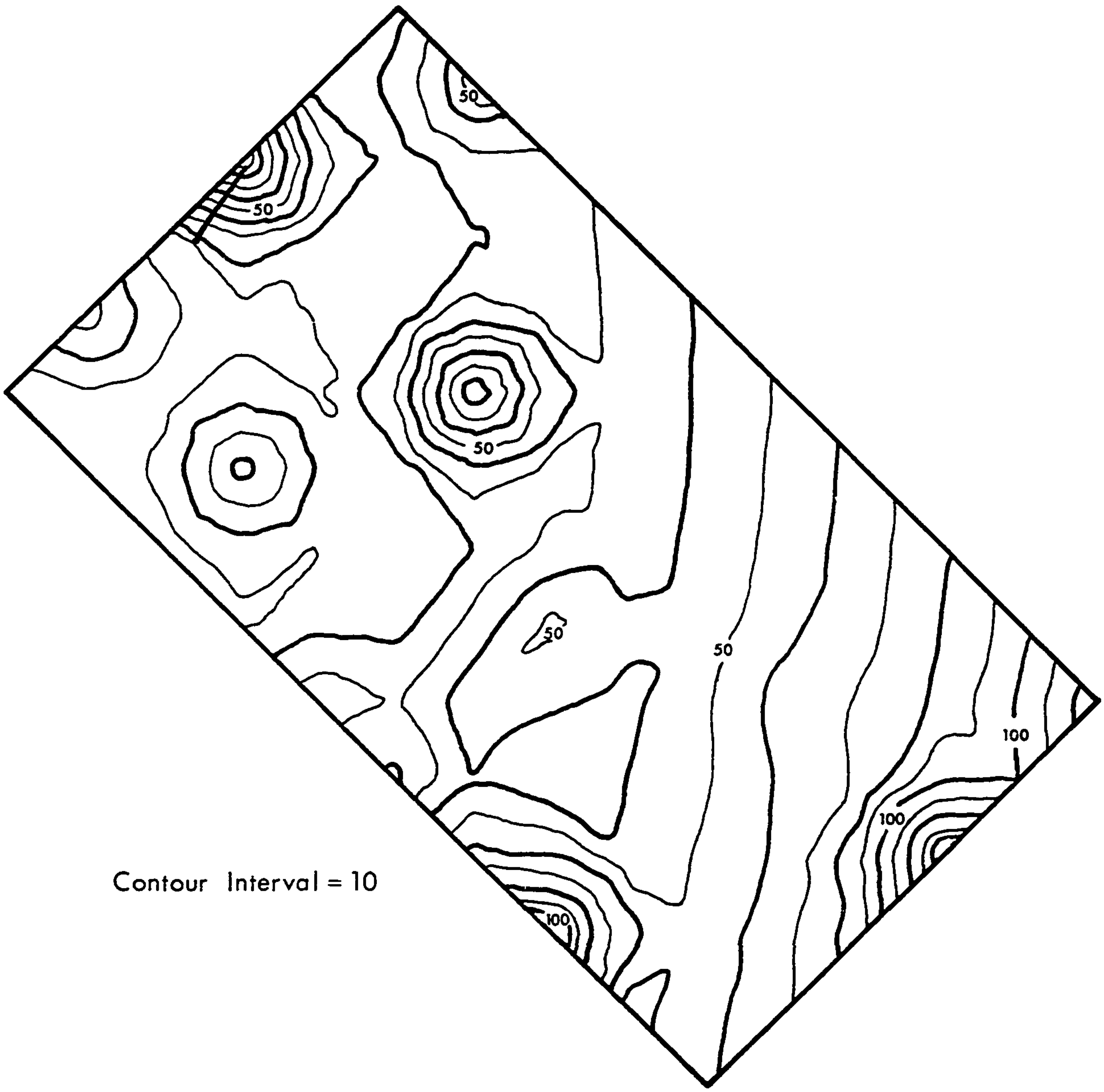
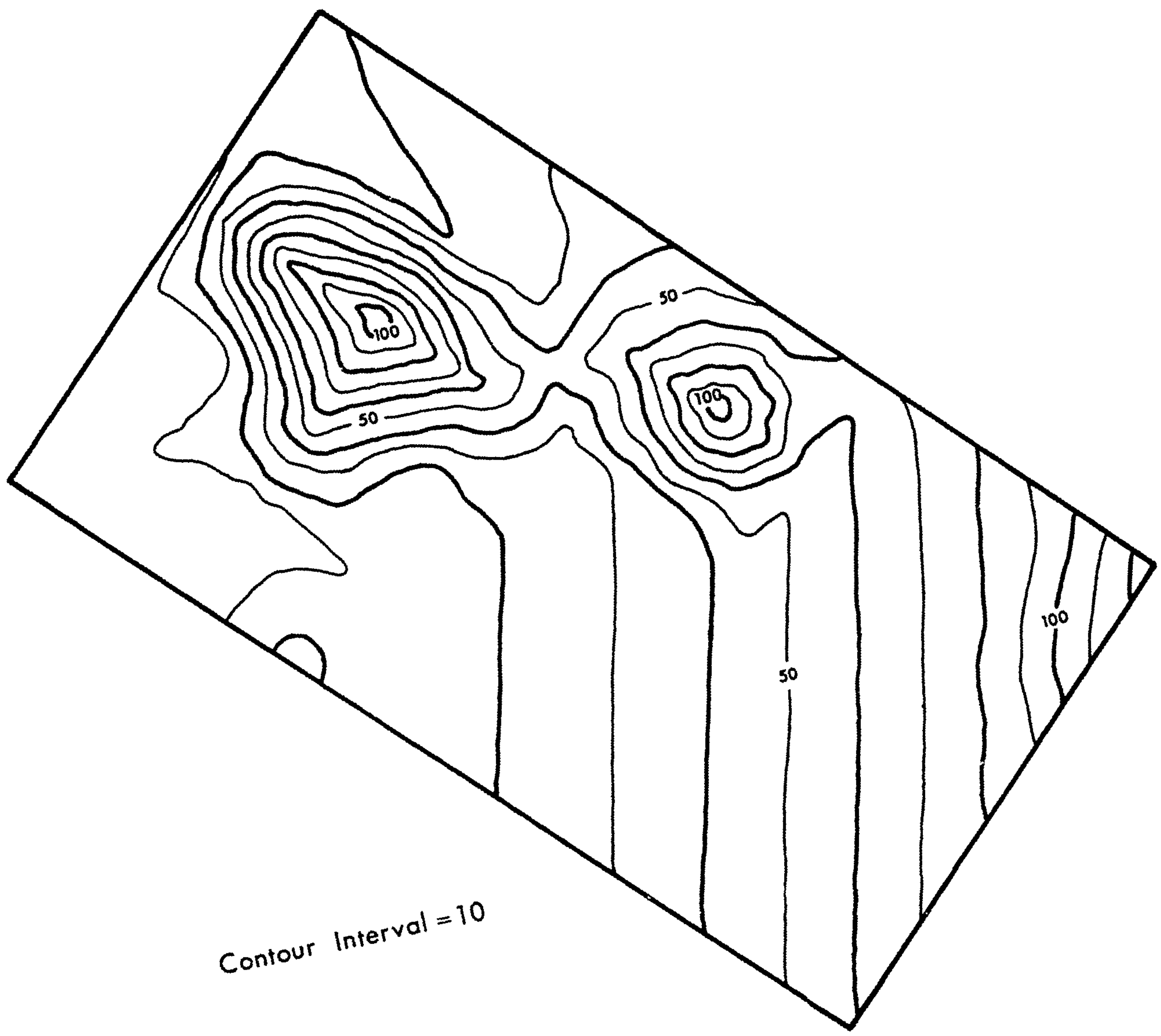
Contour Interval = 10



Contour Interval = 10

Rank the following maps by placing a 1 by the diagram which you feel most accurately represents the trend of increasing values on the surface, a 2 by the 2nd most accurate, 3 for the 3rd, 4 for the 4th and 5 for the least accurate representation. Arrows ⟶ indicate the direction of increasing values on the surface.

After placing the number on the final map indicate verbally "finished."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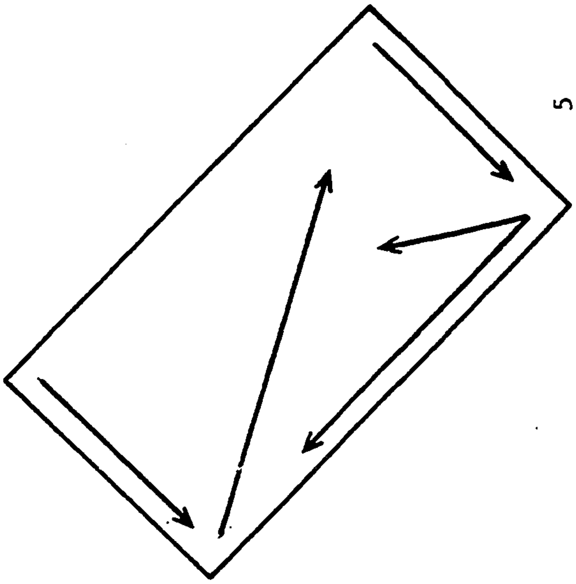
Contour Interval =10



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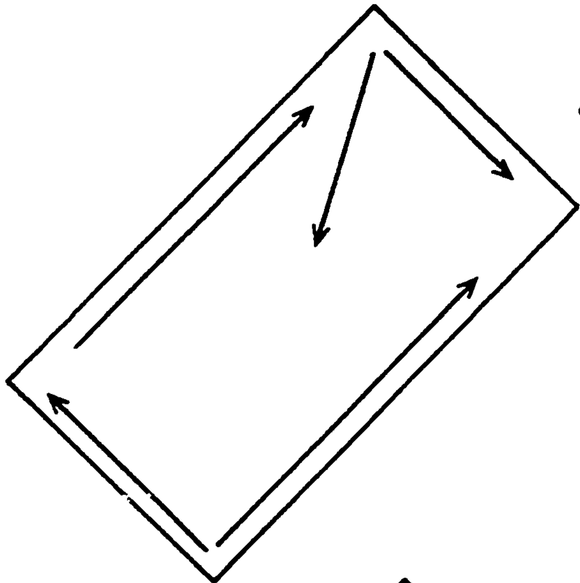

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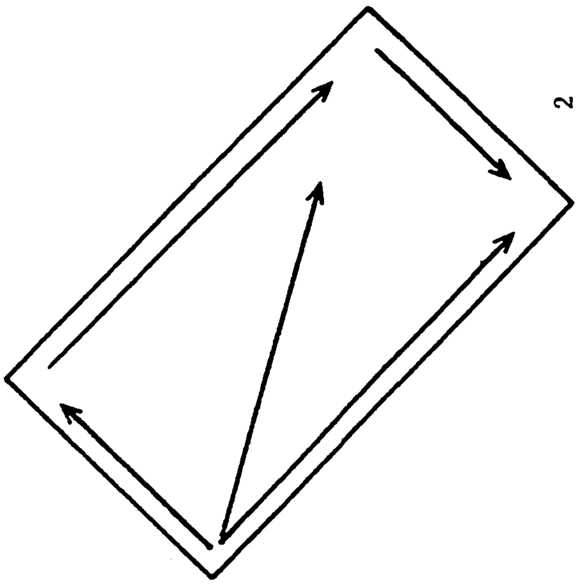

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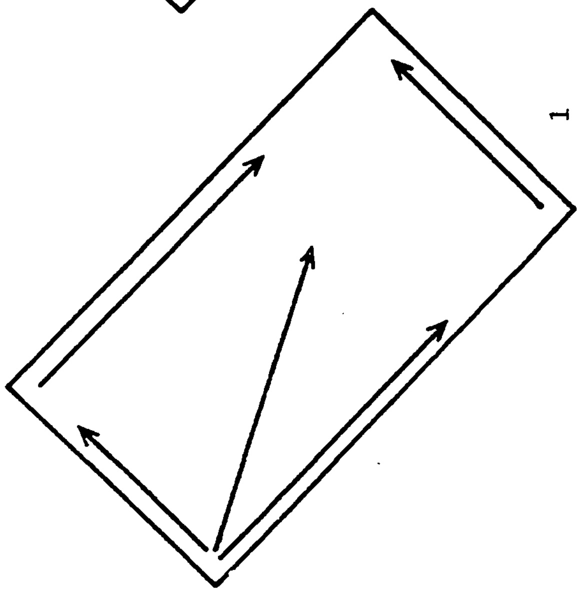

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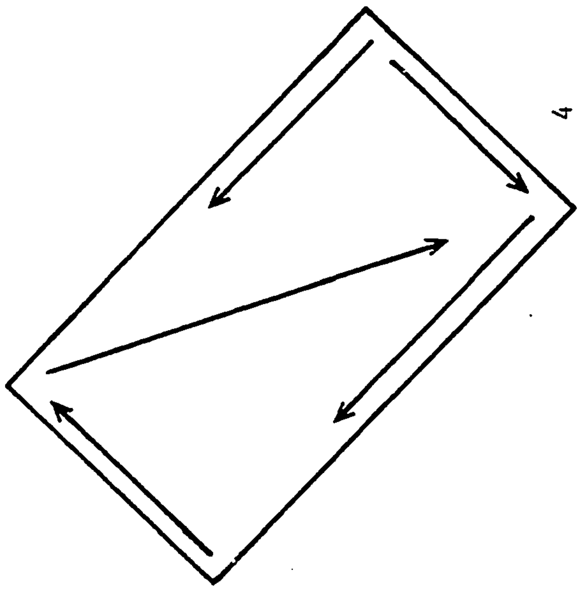

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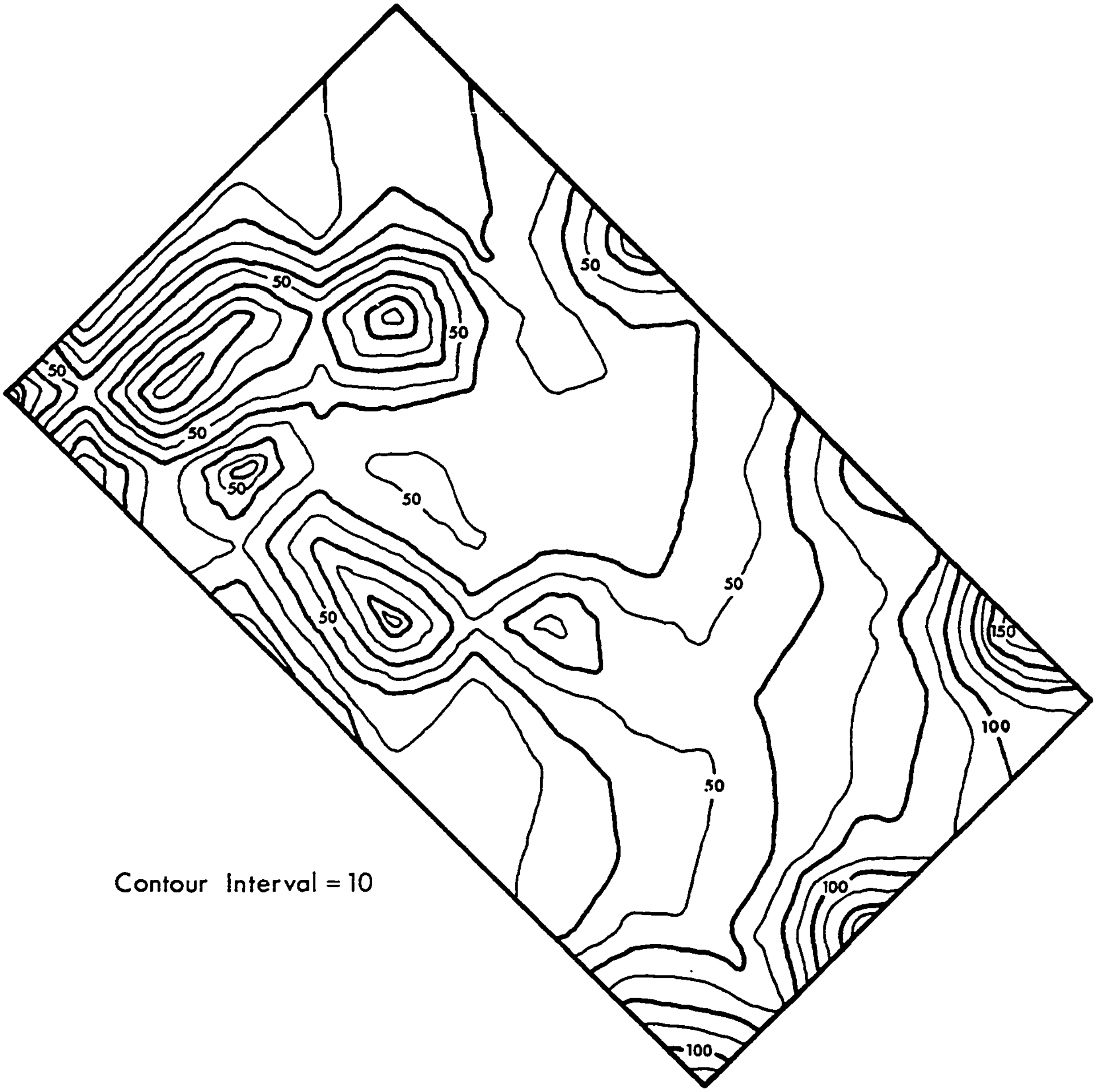
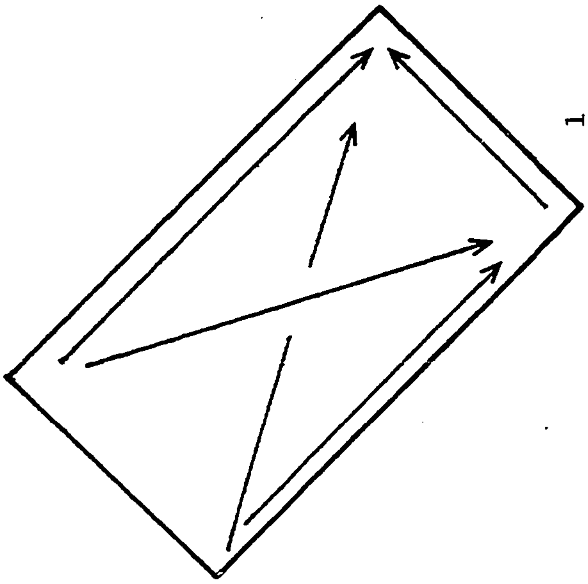


Contour Interval = 10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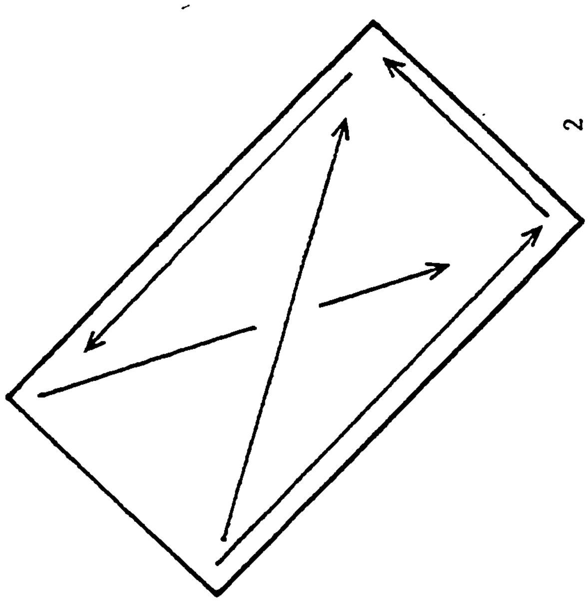
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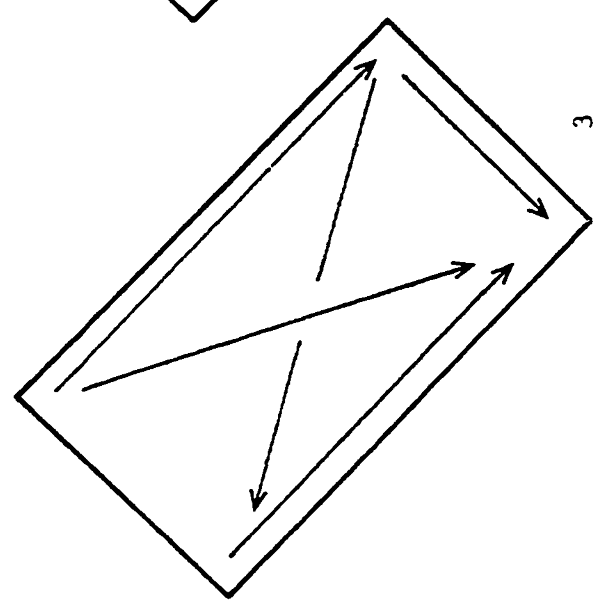
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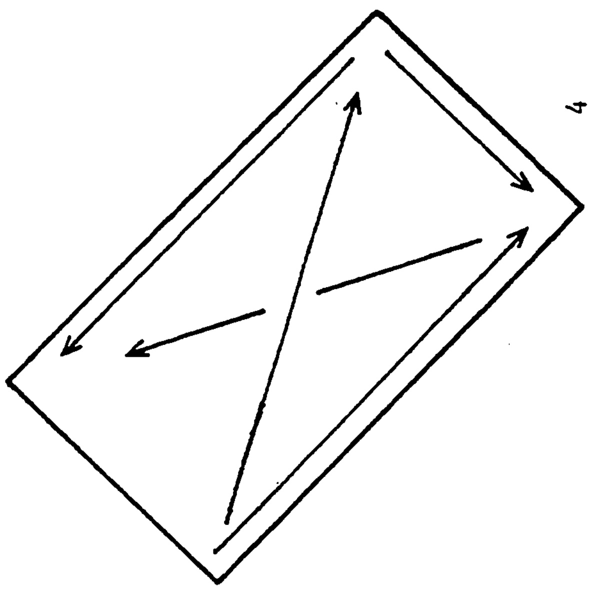
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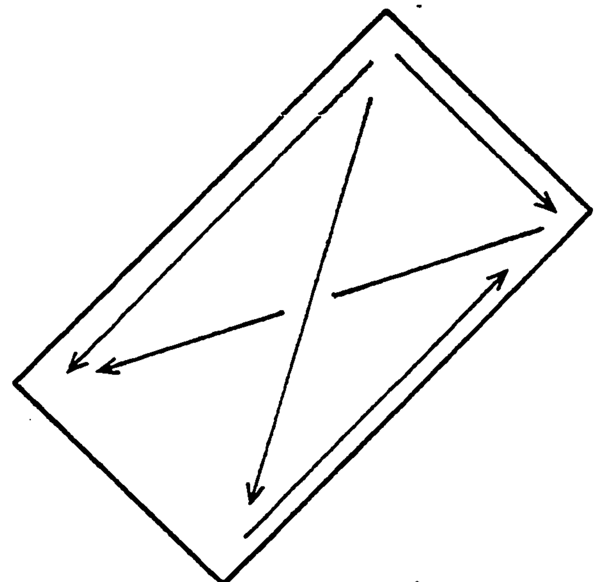
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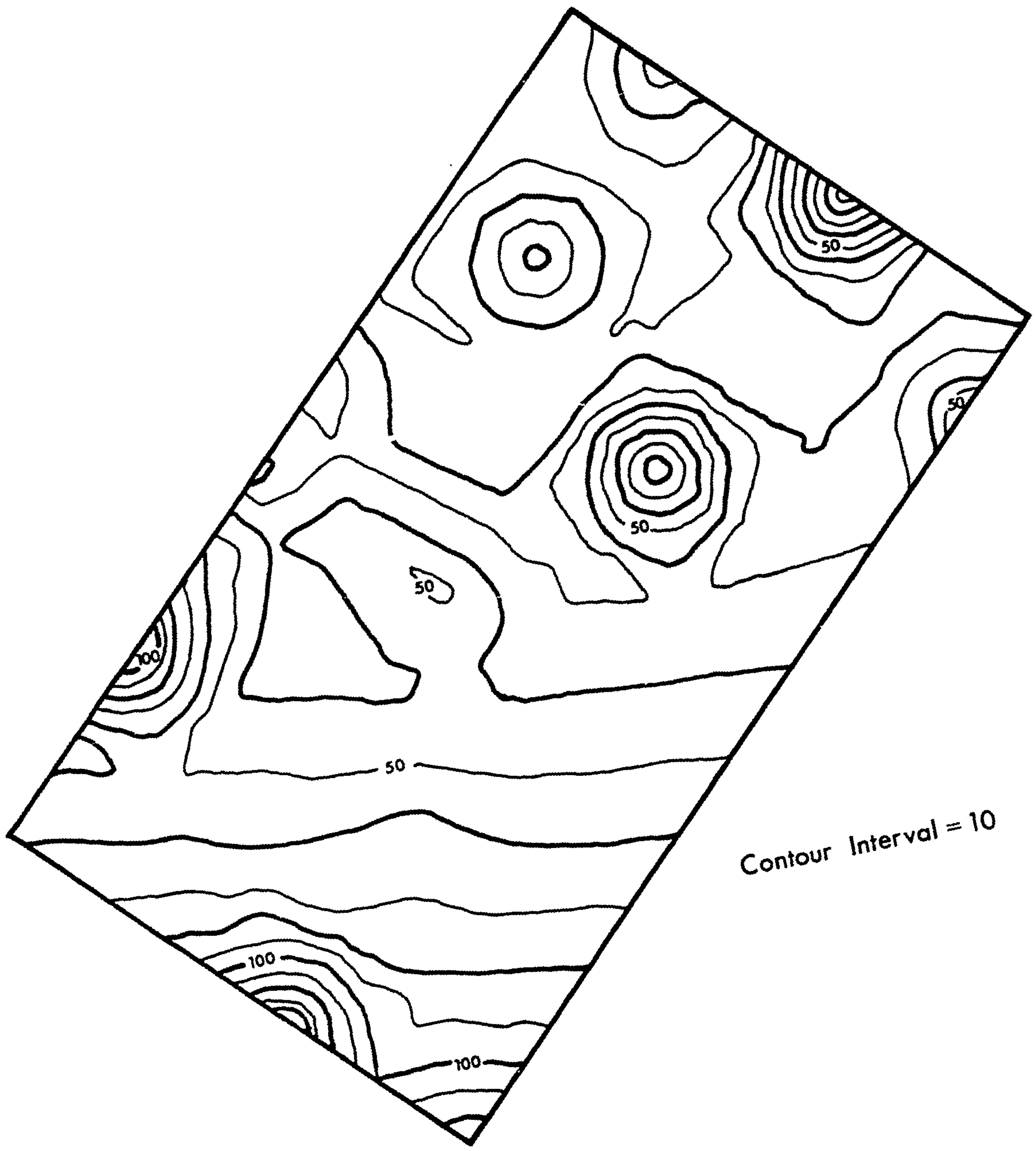
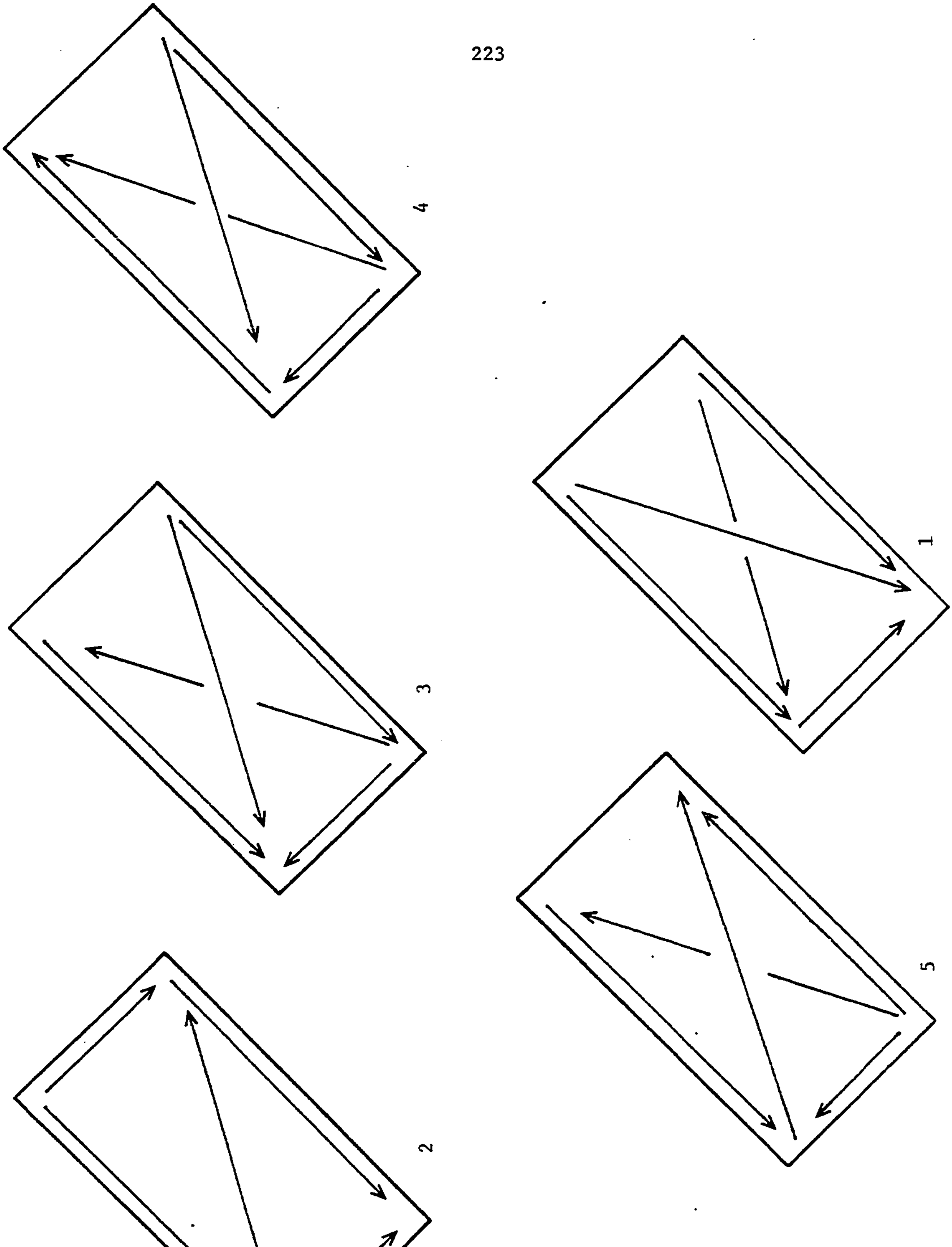


Contour Interval = 10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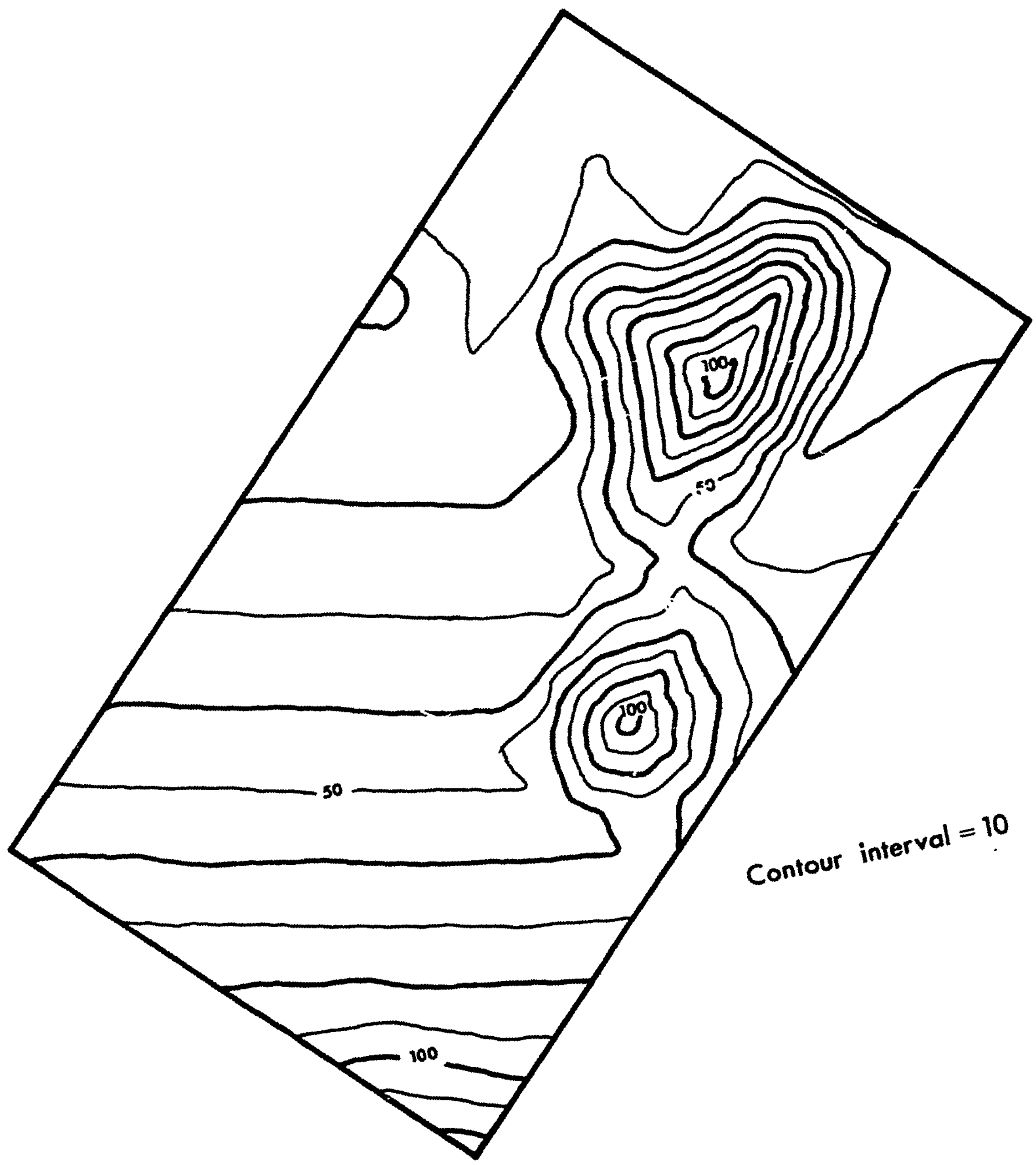
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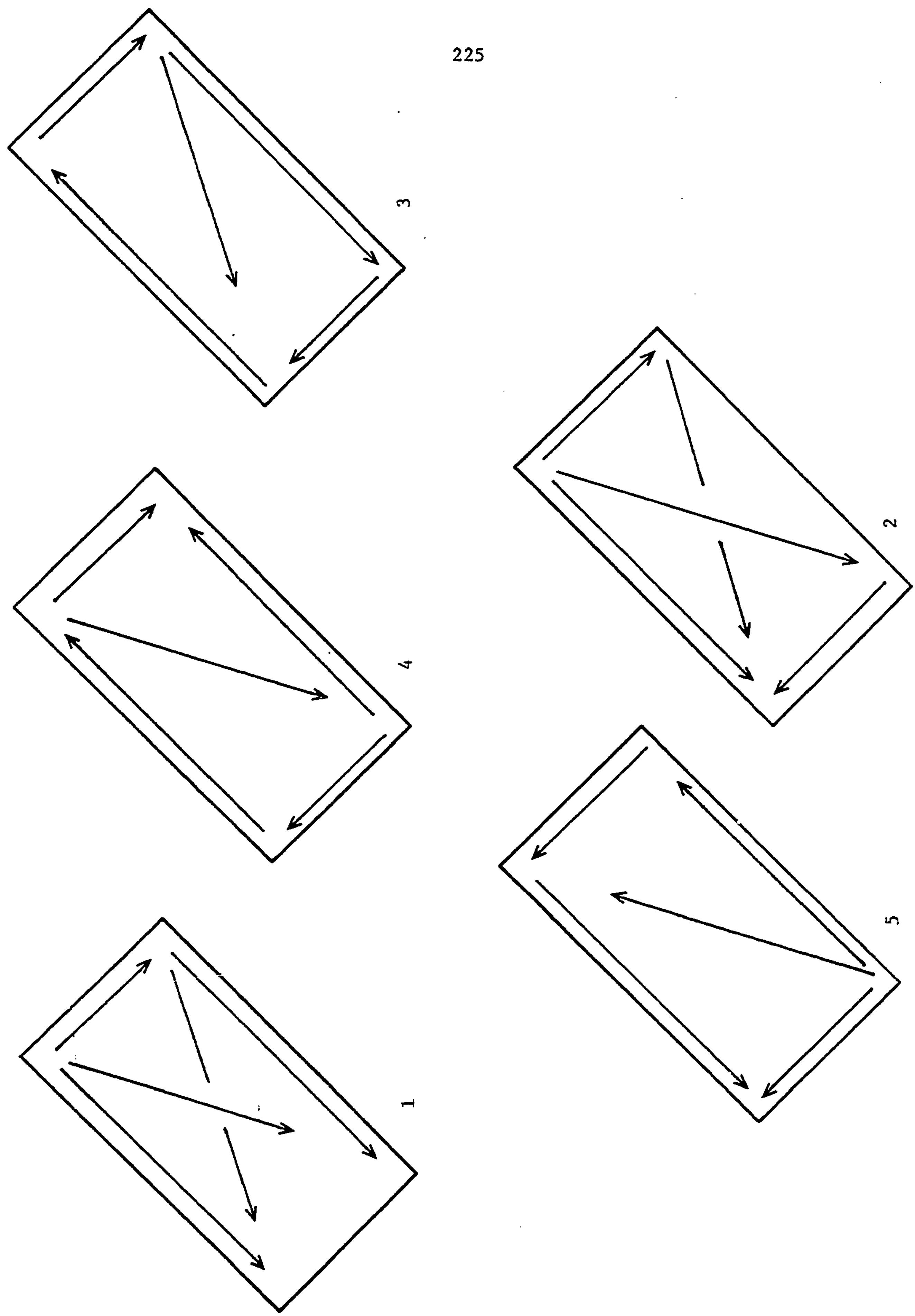
Contour interval = 10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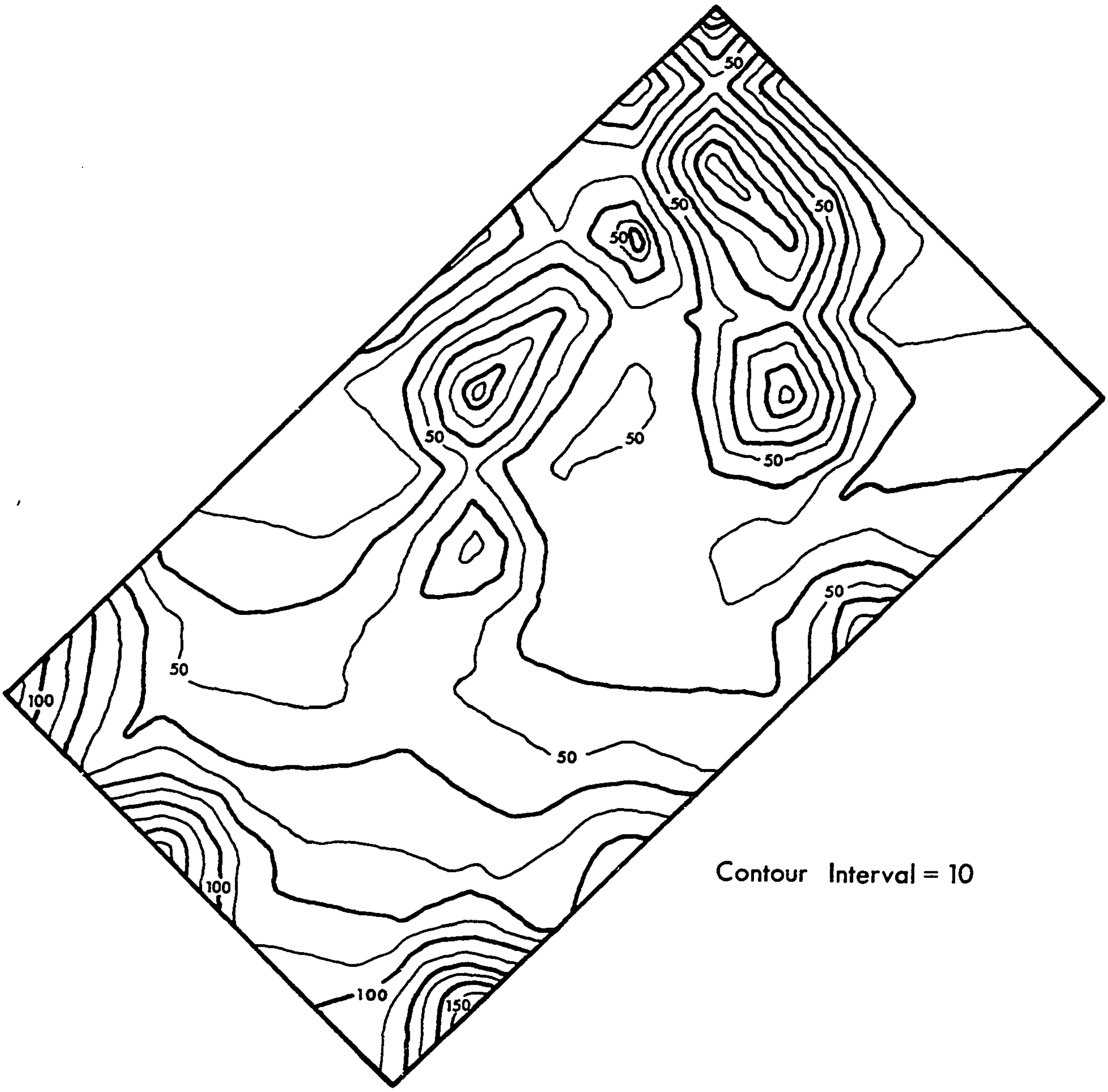
2
5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50
50
50
50
50
50
50
50
50
100
100
100
150
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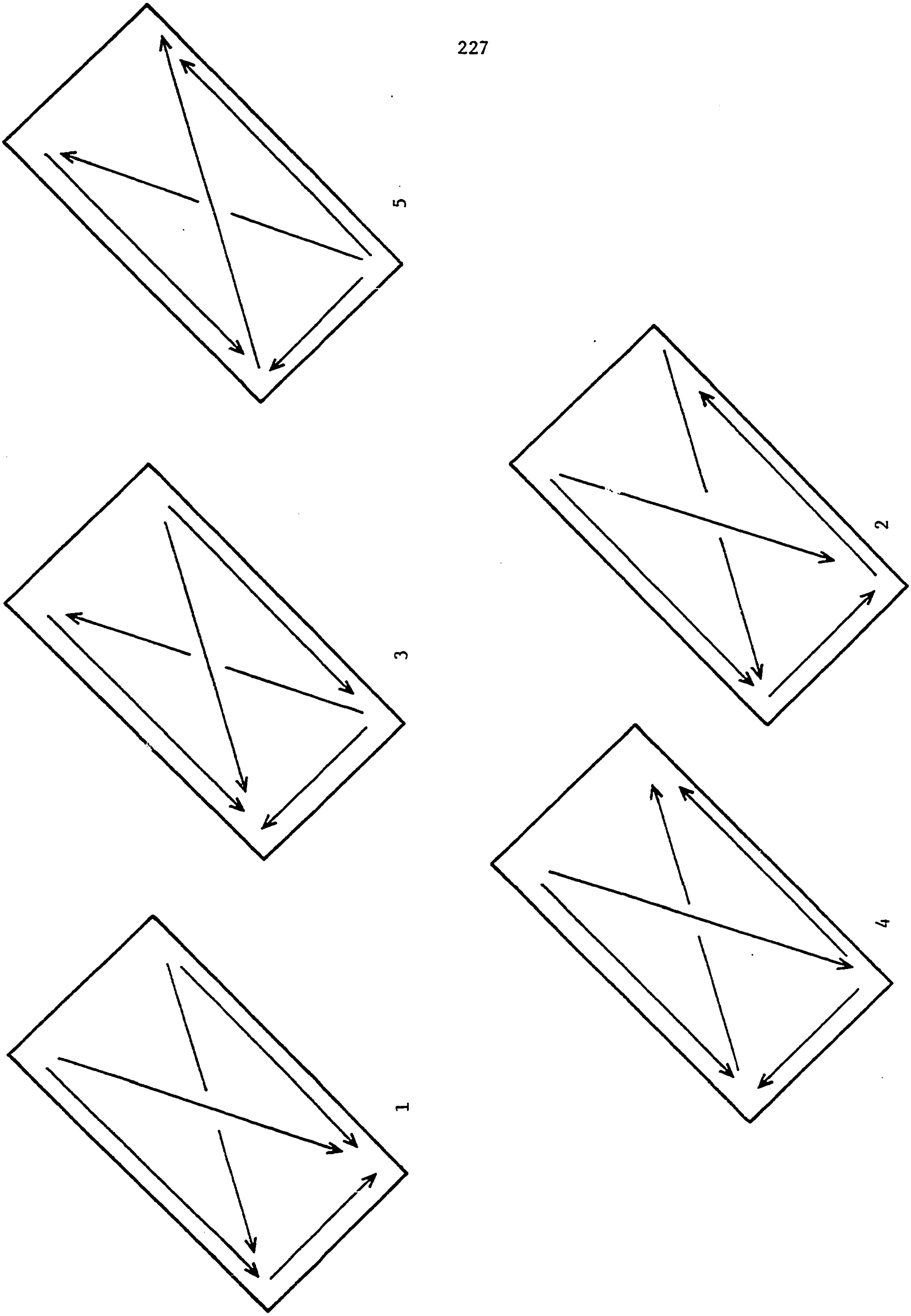
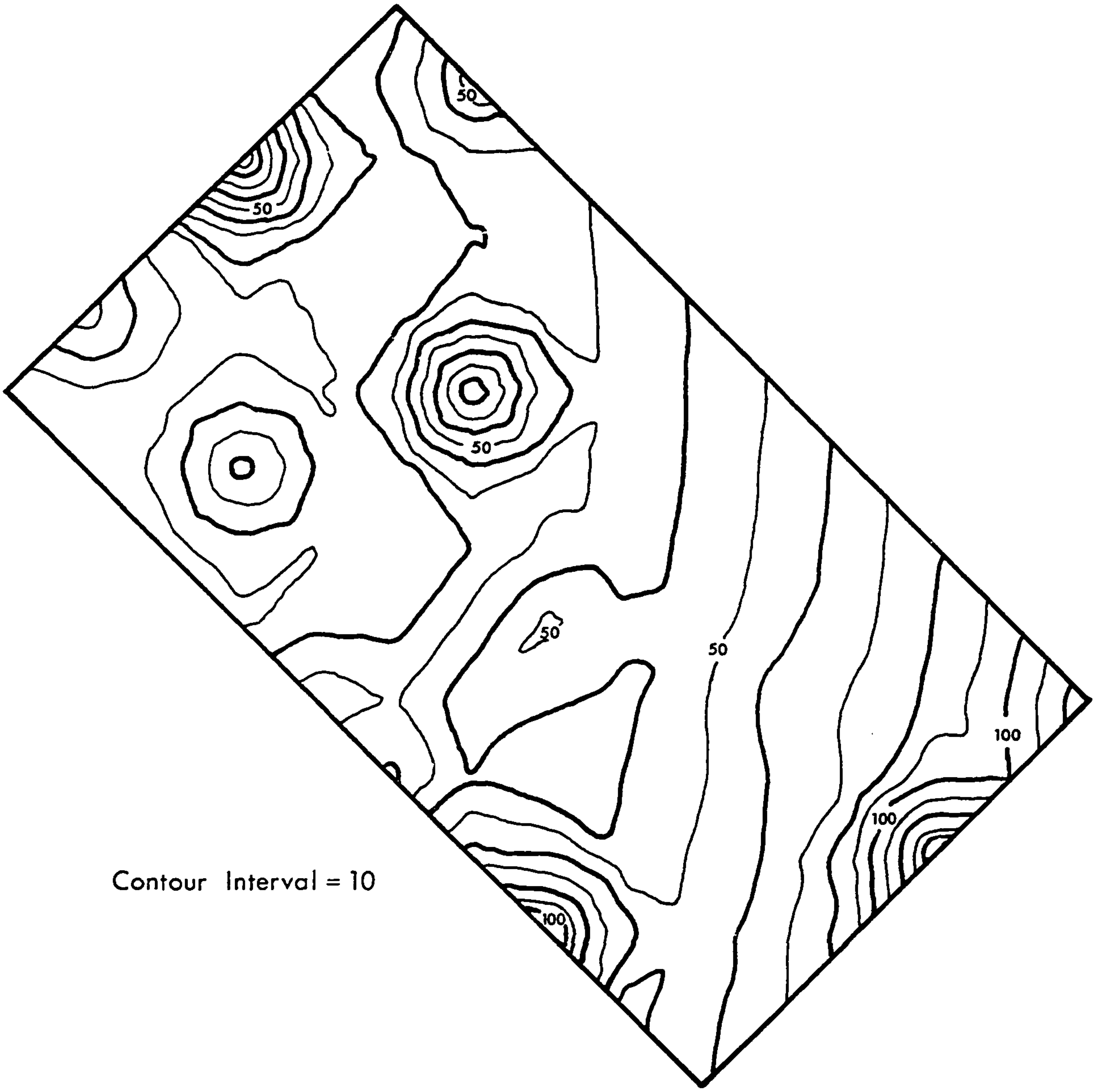

5
3
1
2
4



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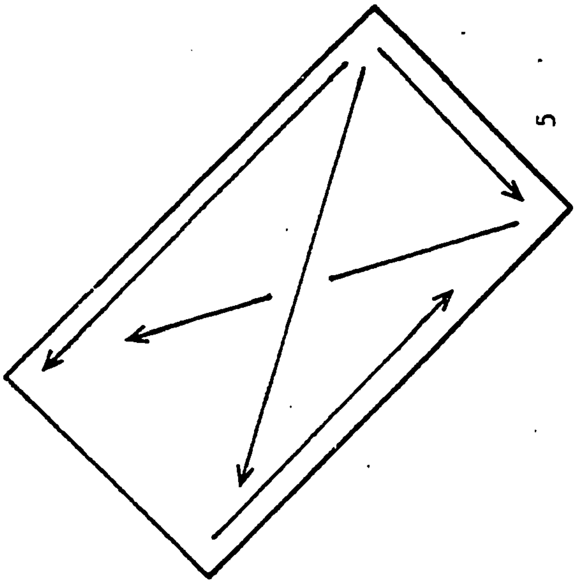

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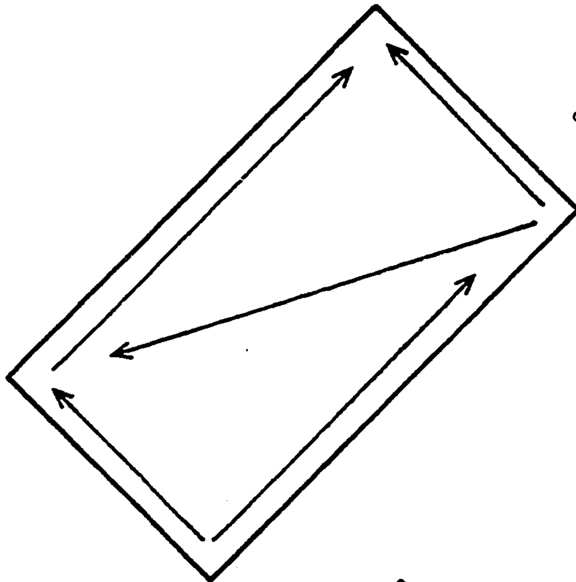

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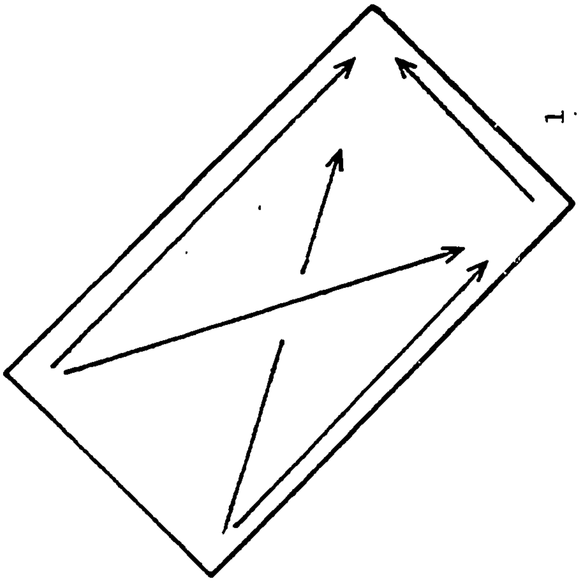
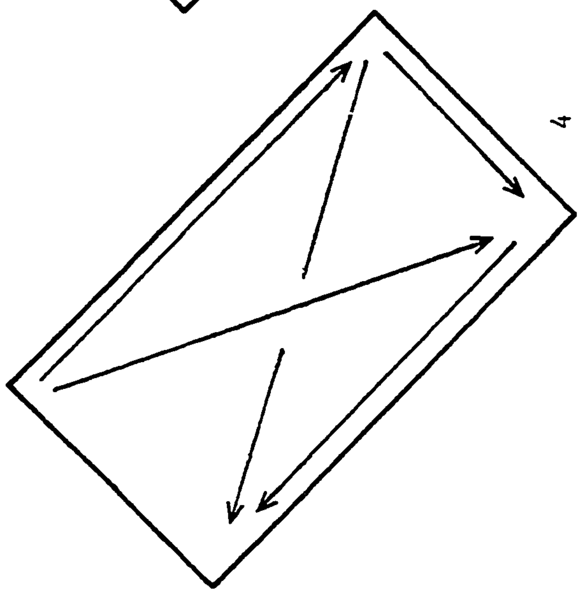


1



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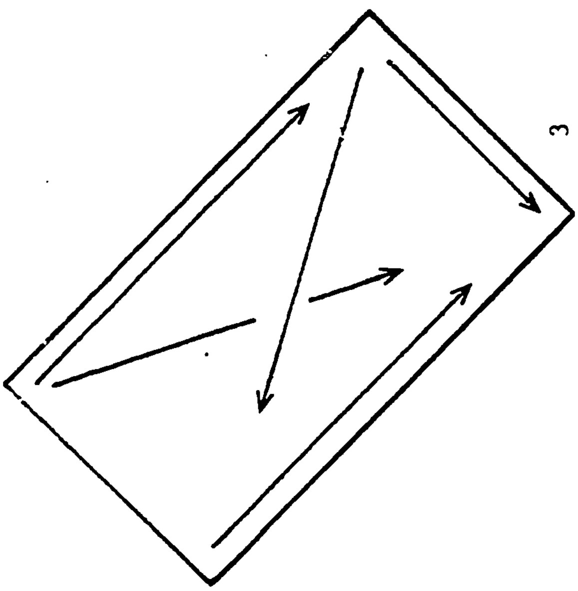
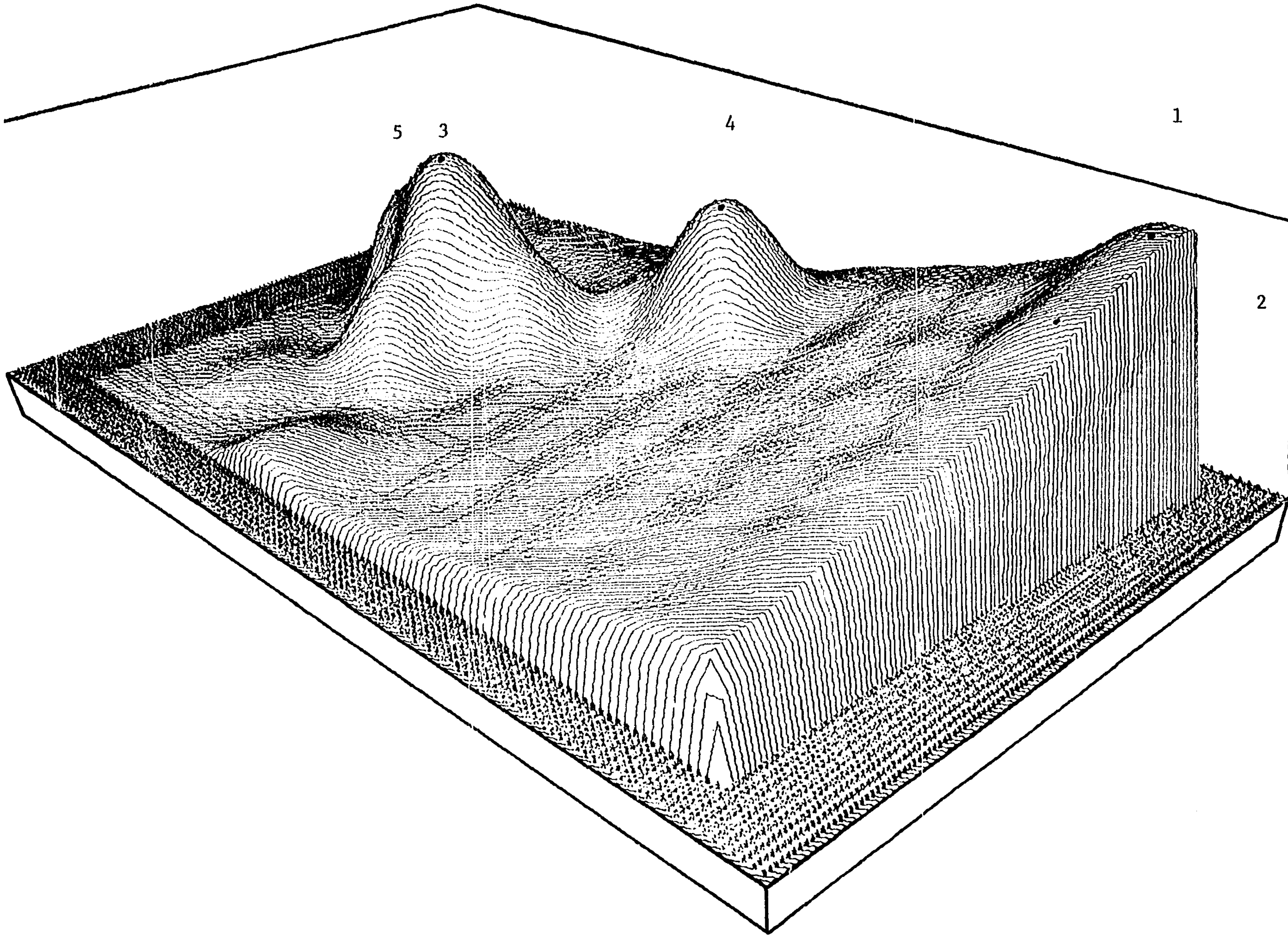
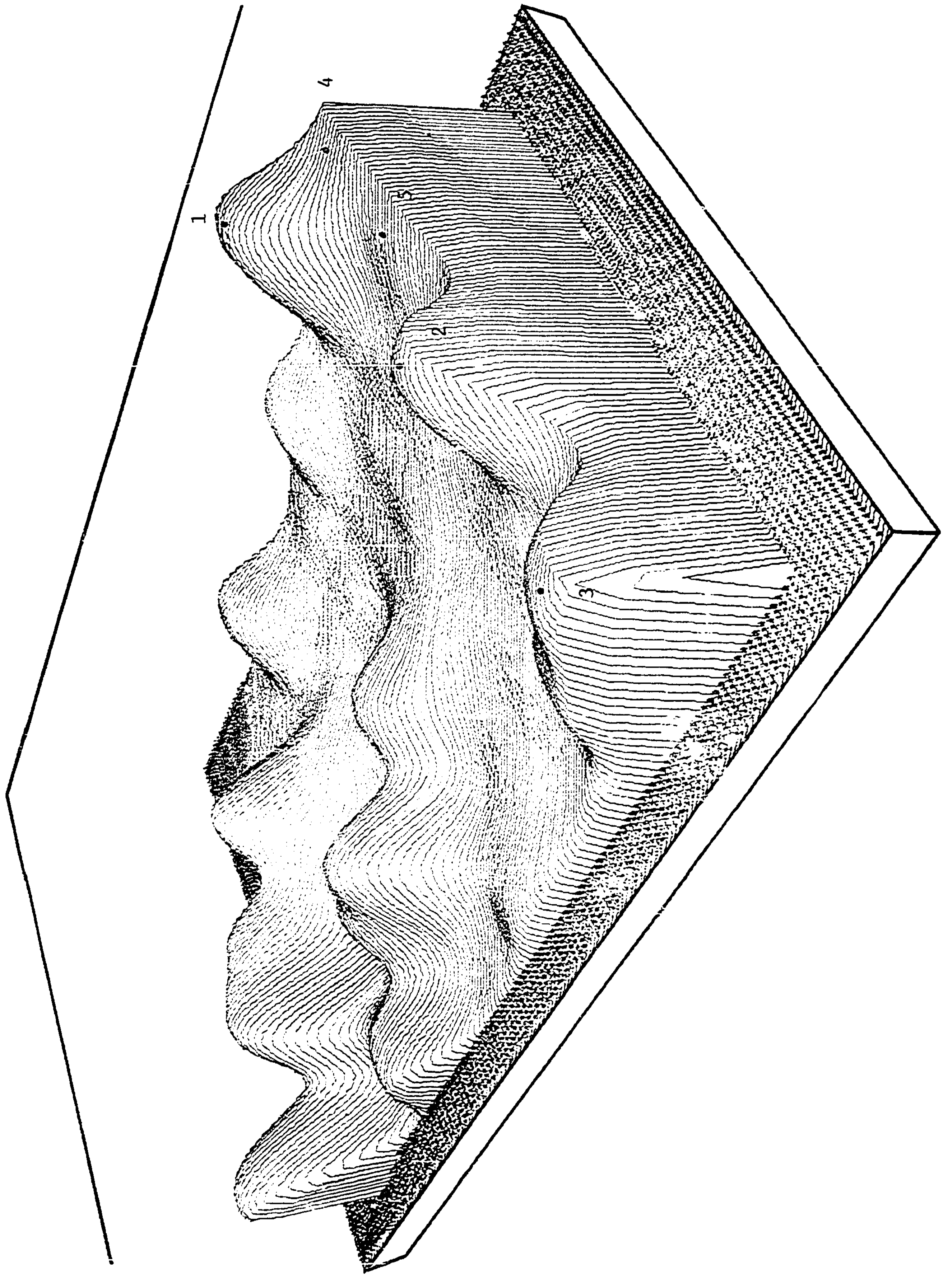


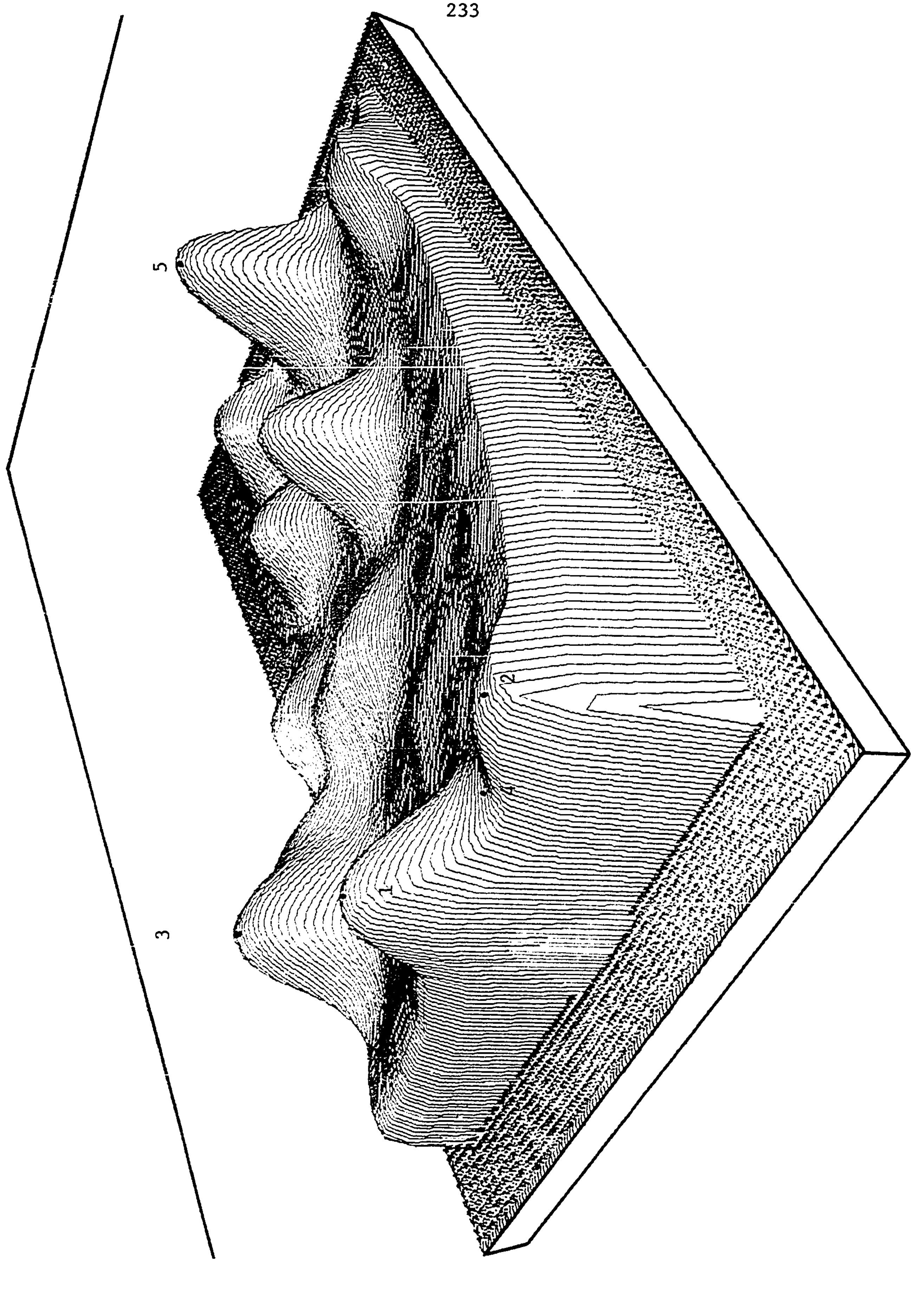
3

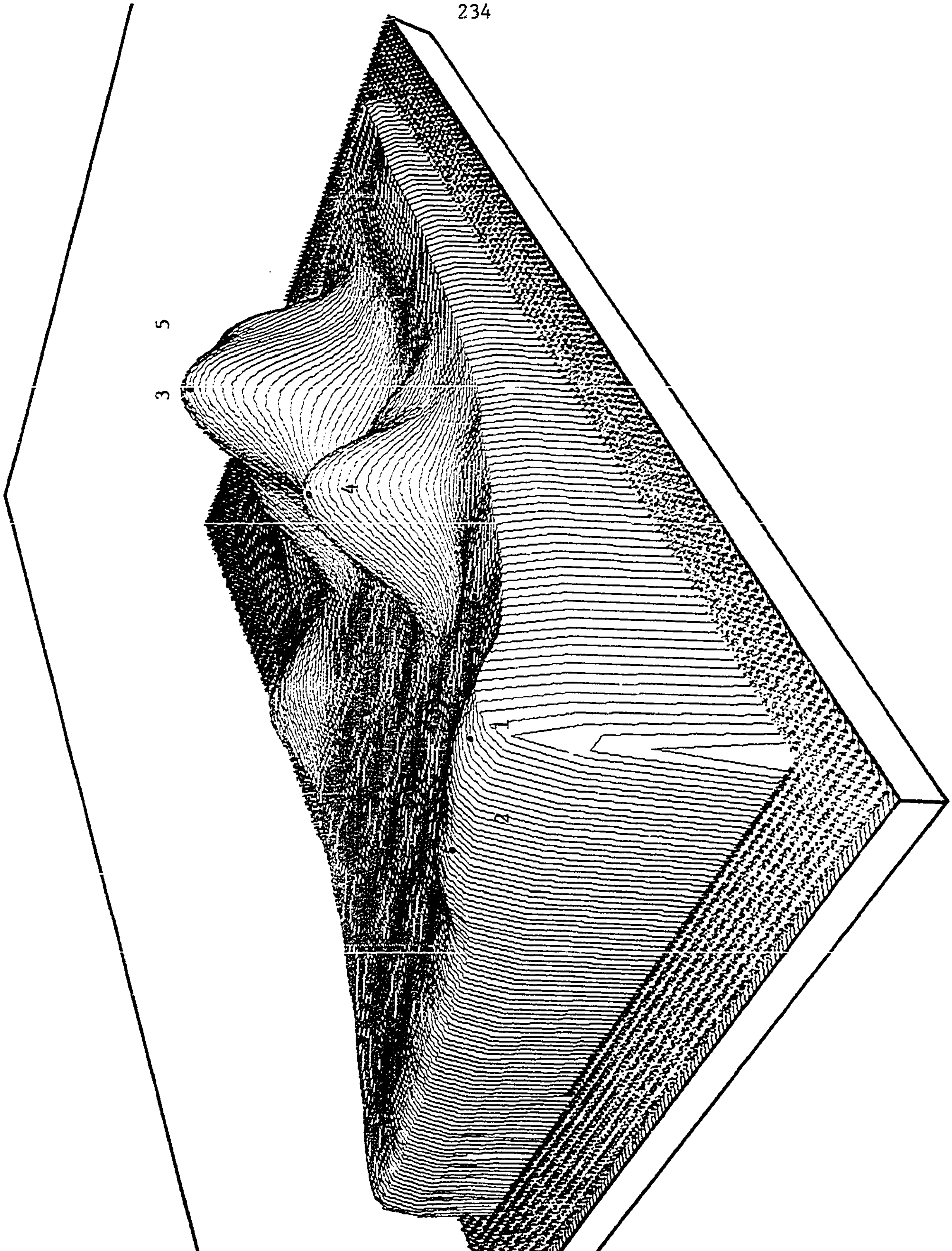
The following map contains five "dots" placed at various locations on the mapped surface. You are to place a "1" at the "." that indicates the highest point on the surface followed by a 2, 3, 4, and 5 at the 2nd, 3rd, 4th, and 5th highest point on the surface. Please mark all five "dots."

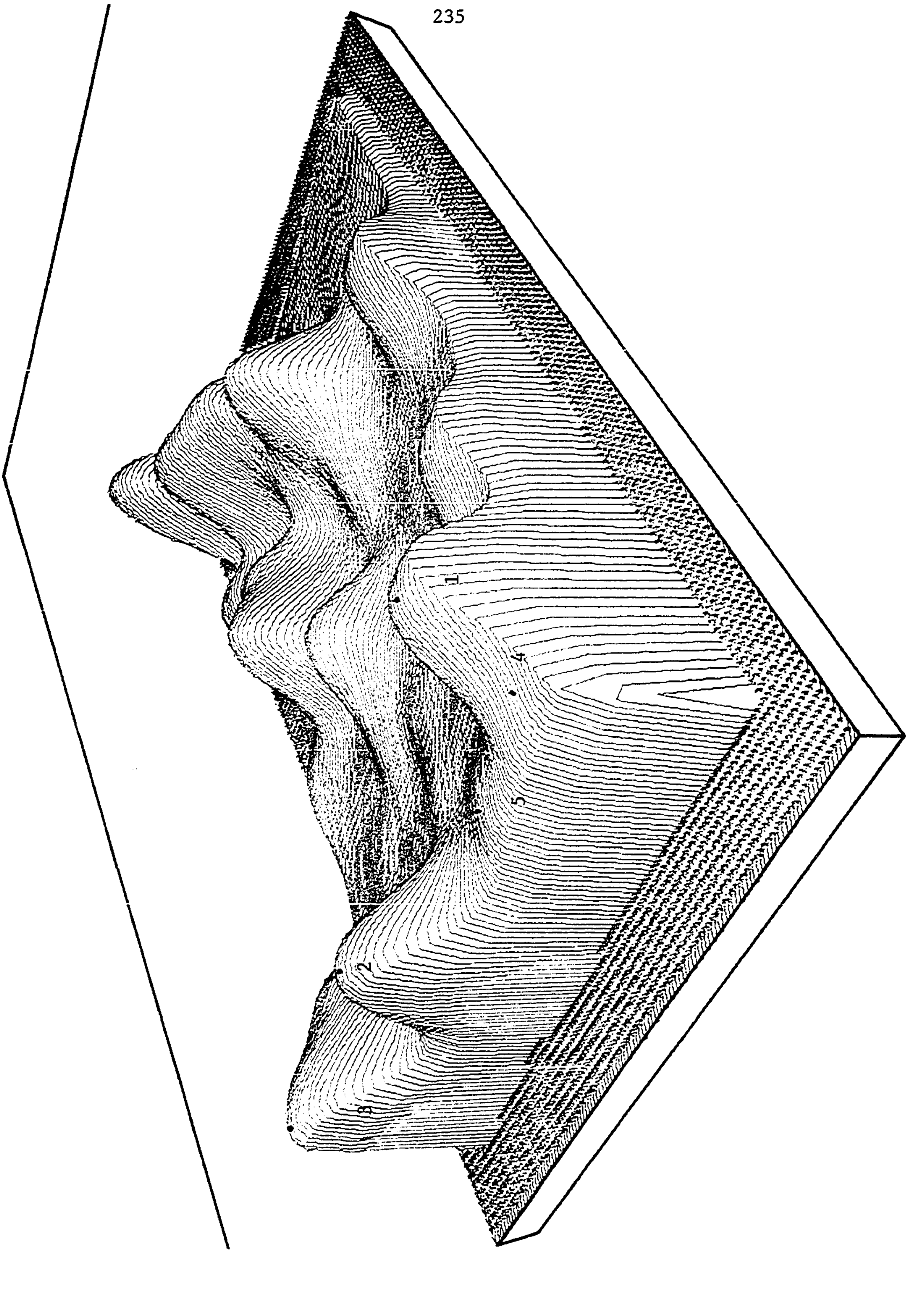
After placing your final mark on the map indicate verbally "finished."

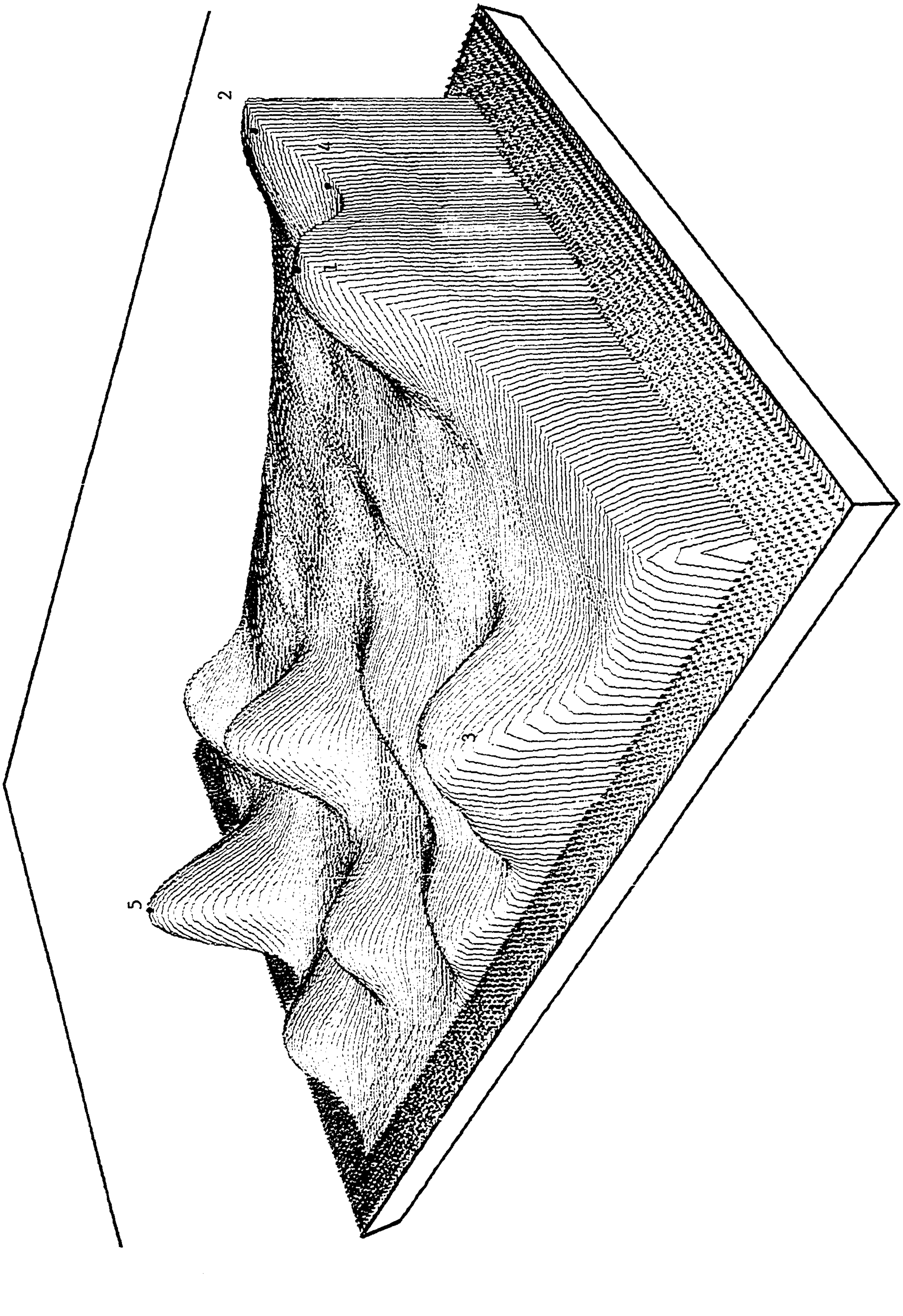

5
3
4
1
2


4
1
5
2
3


5
3
1
2

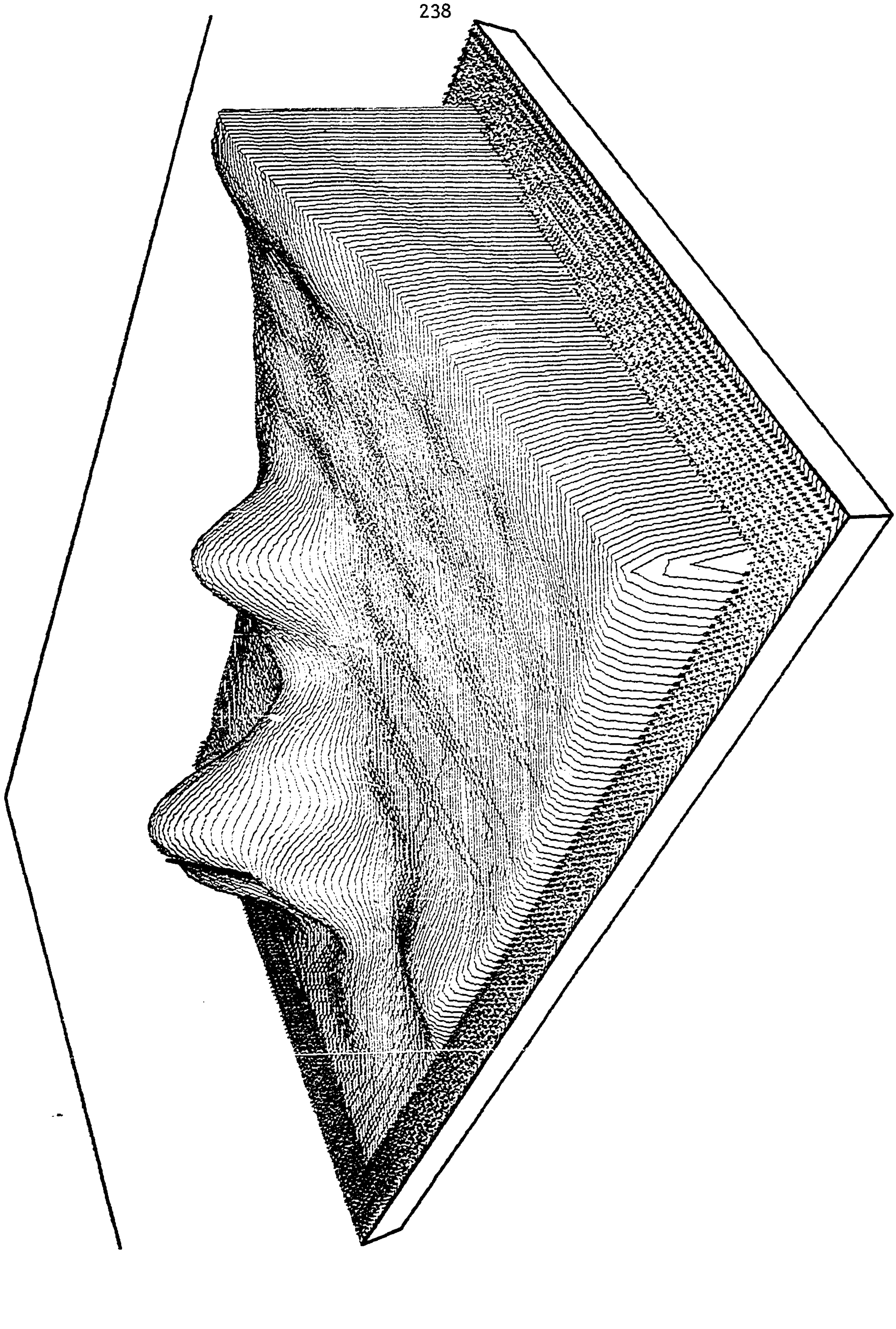

3
5

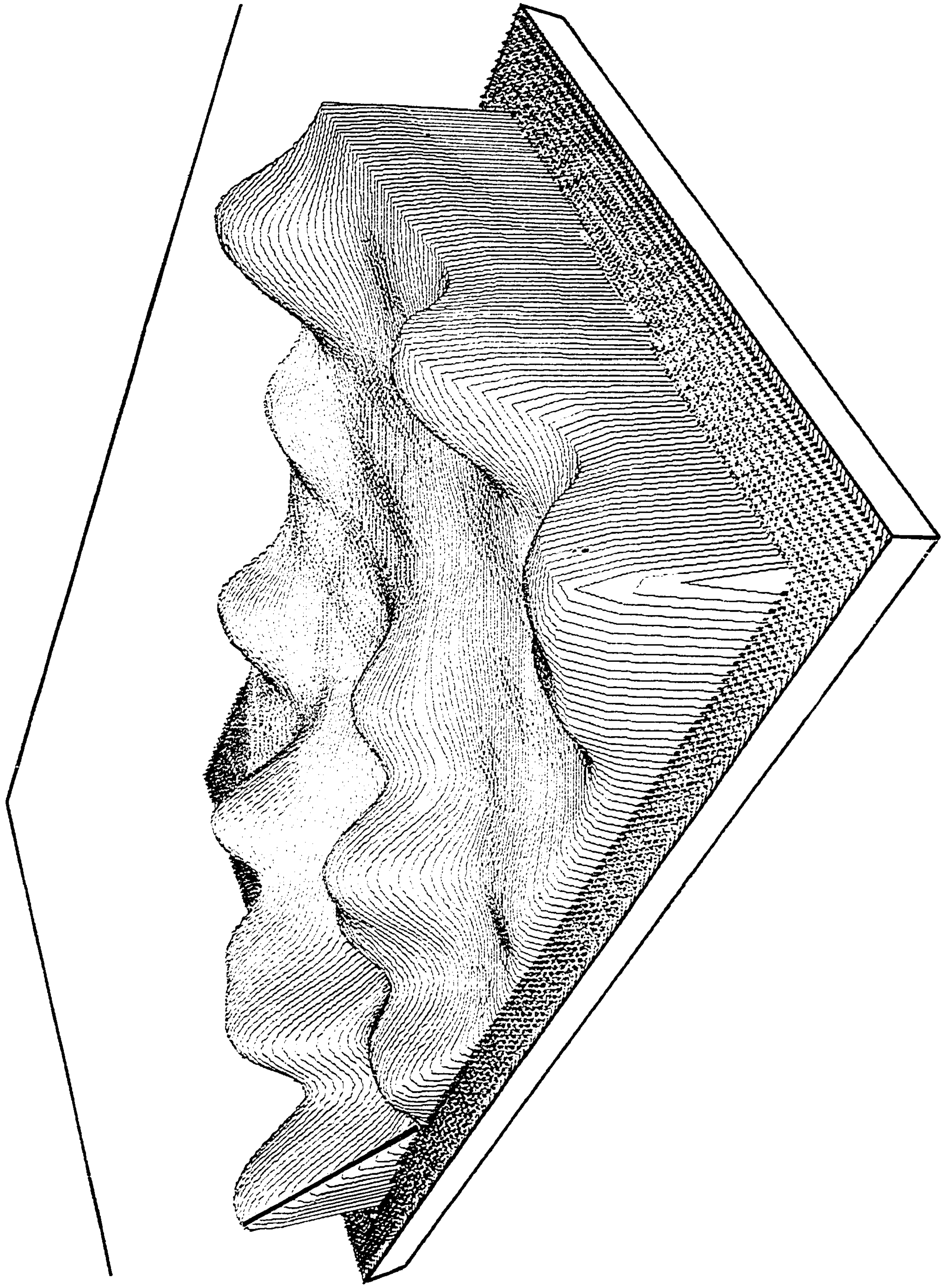

1
4
5
2
3

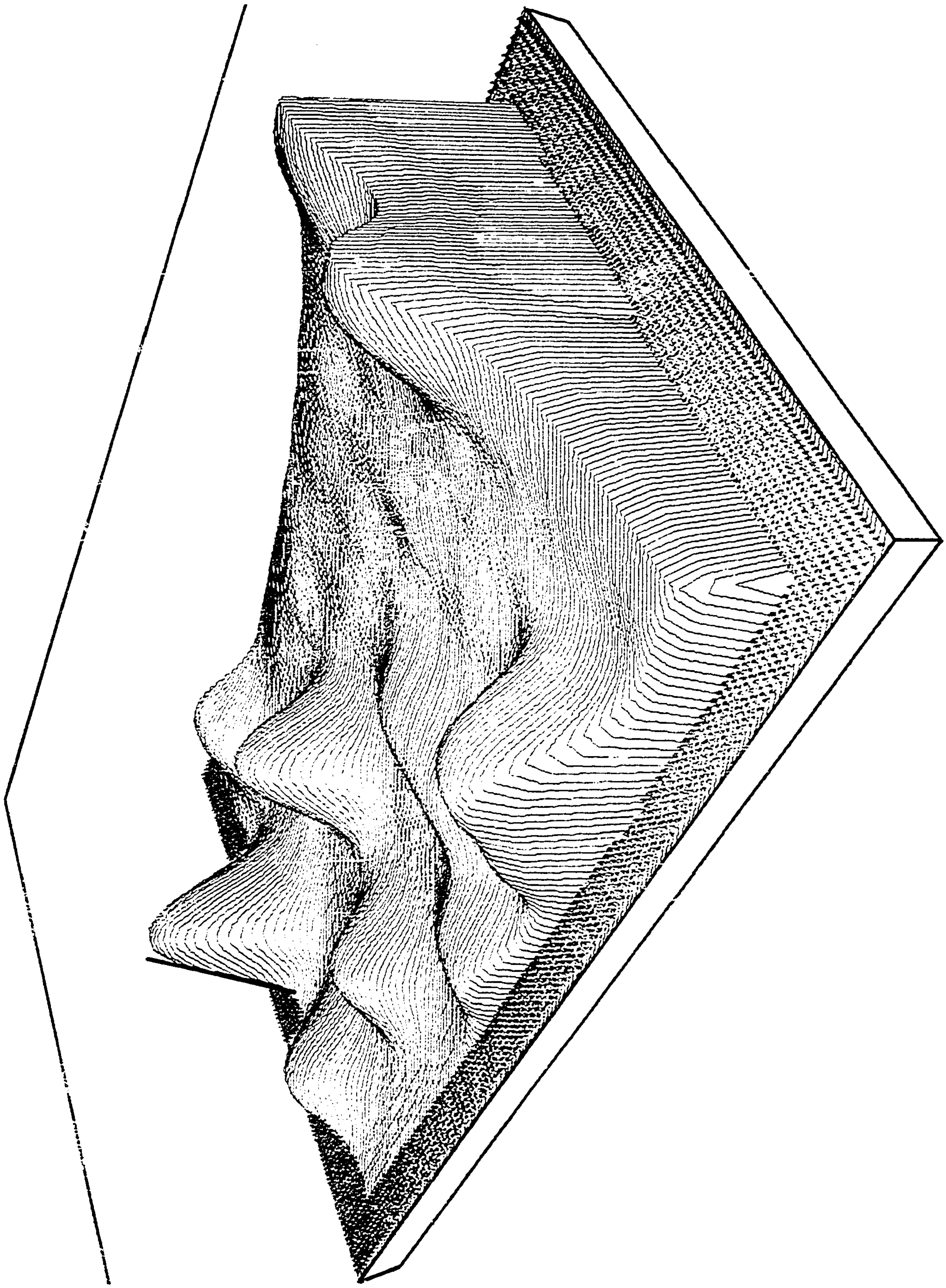

2
4
1
3
5

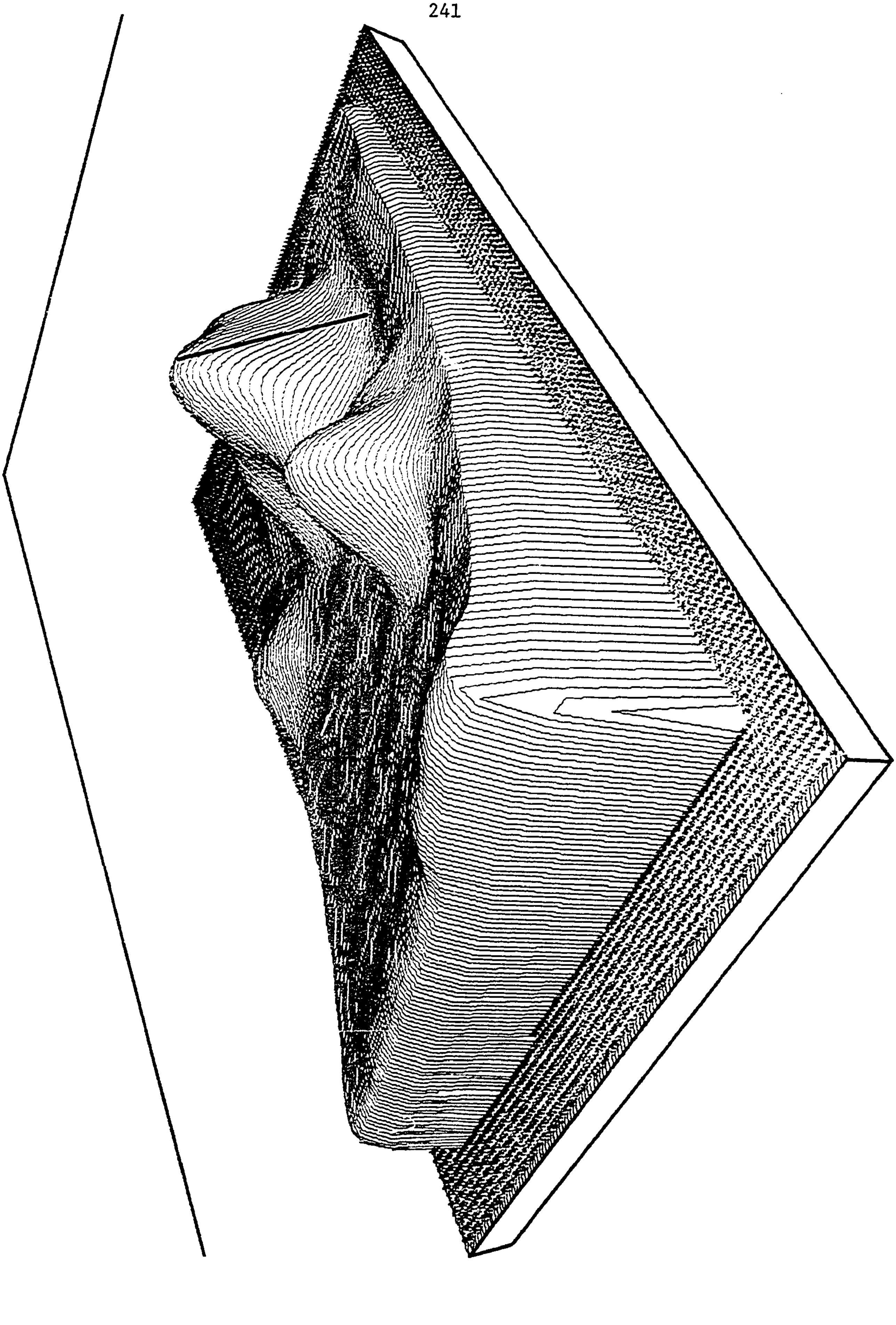
Using the pre marked device with the black line, place the device on the map so that the black line is directly over the location of the steepest visible gradient (the greatest rate of change over the shortest distance) on the map. Place the device so that the end points of the black line touch the top and base of the appropriate hill.

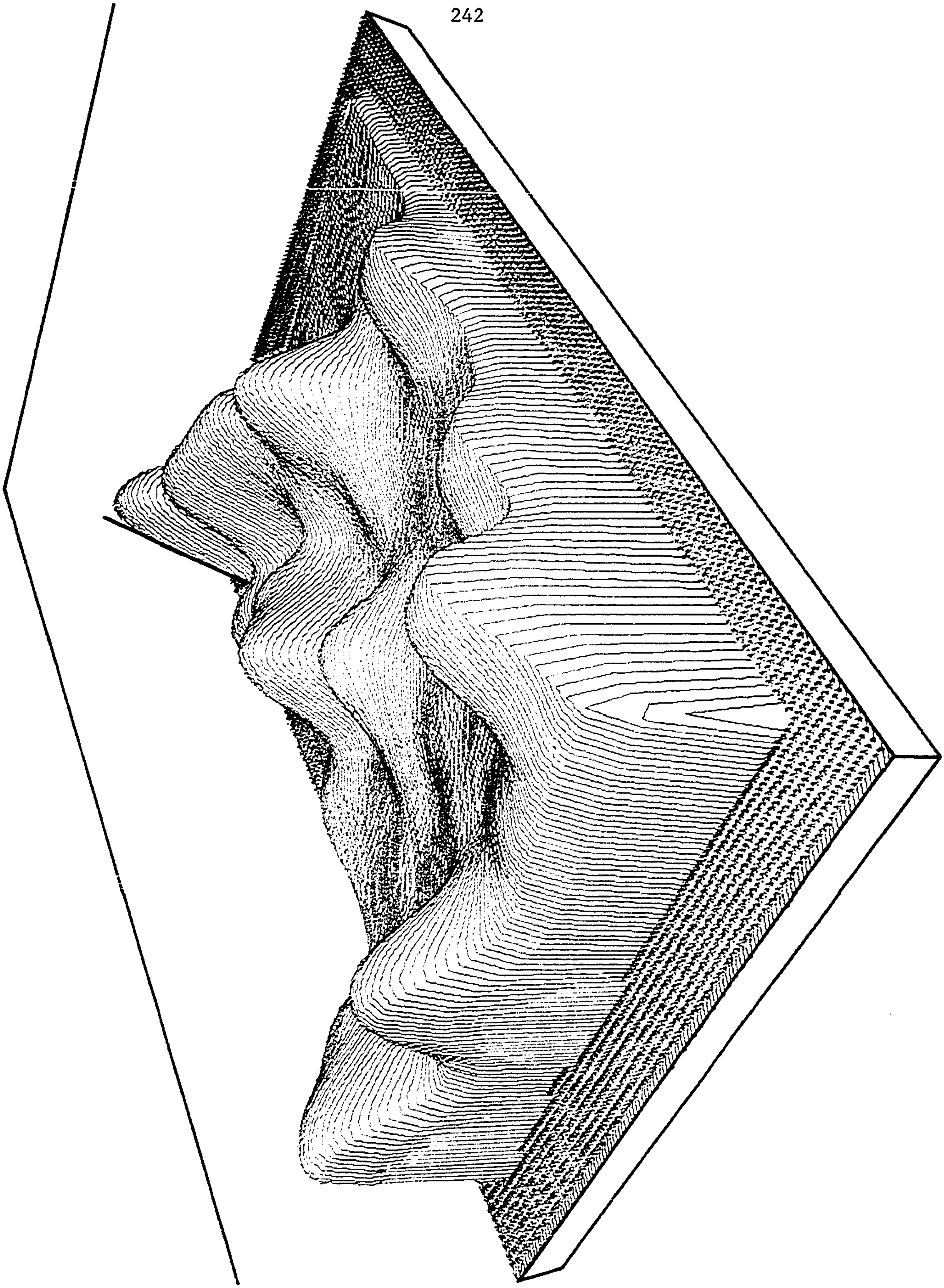
When you have made your decision and placed the pre marked device on the map please indicate verbally "finished."

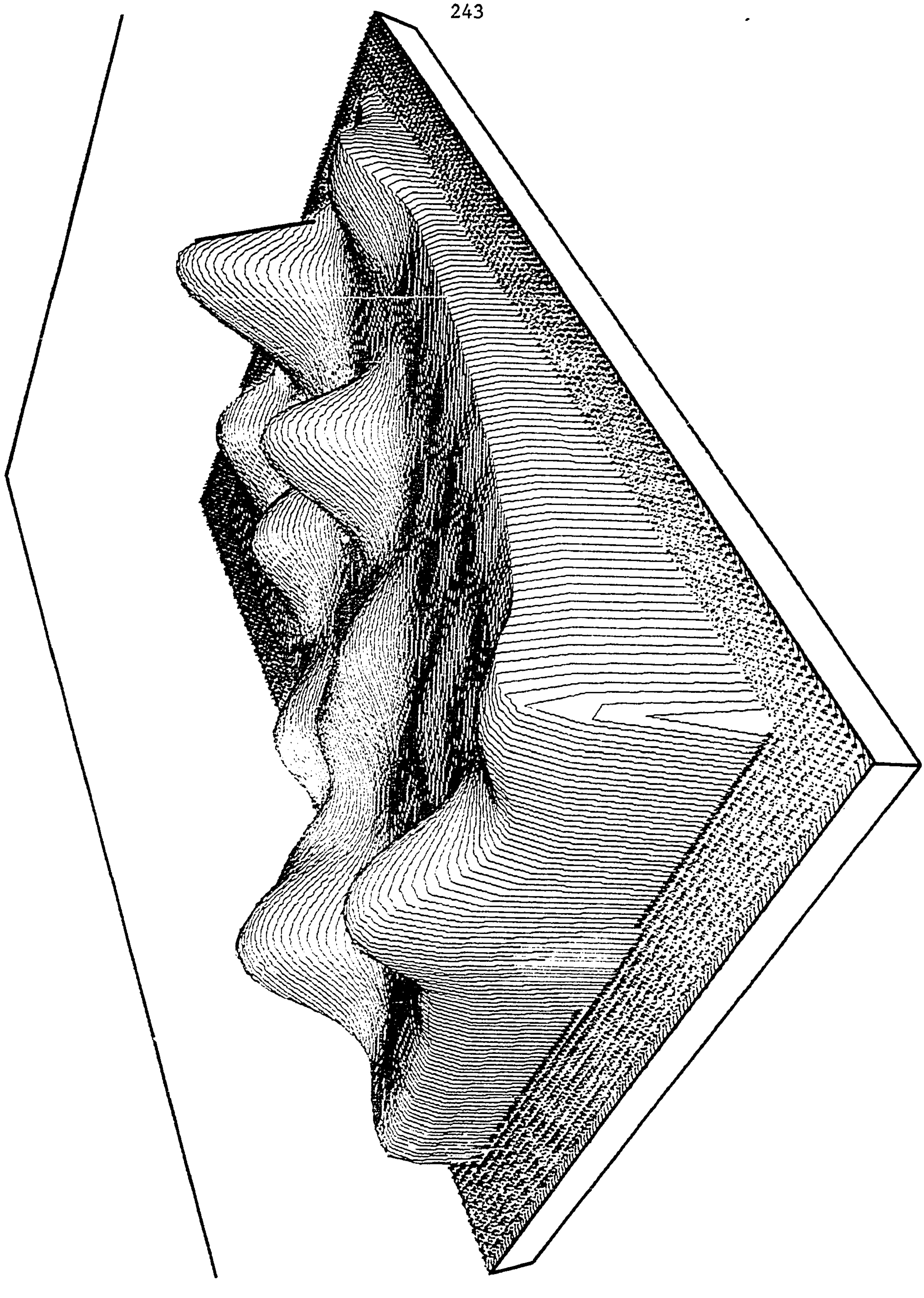






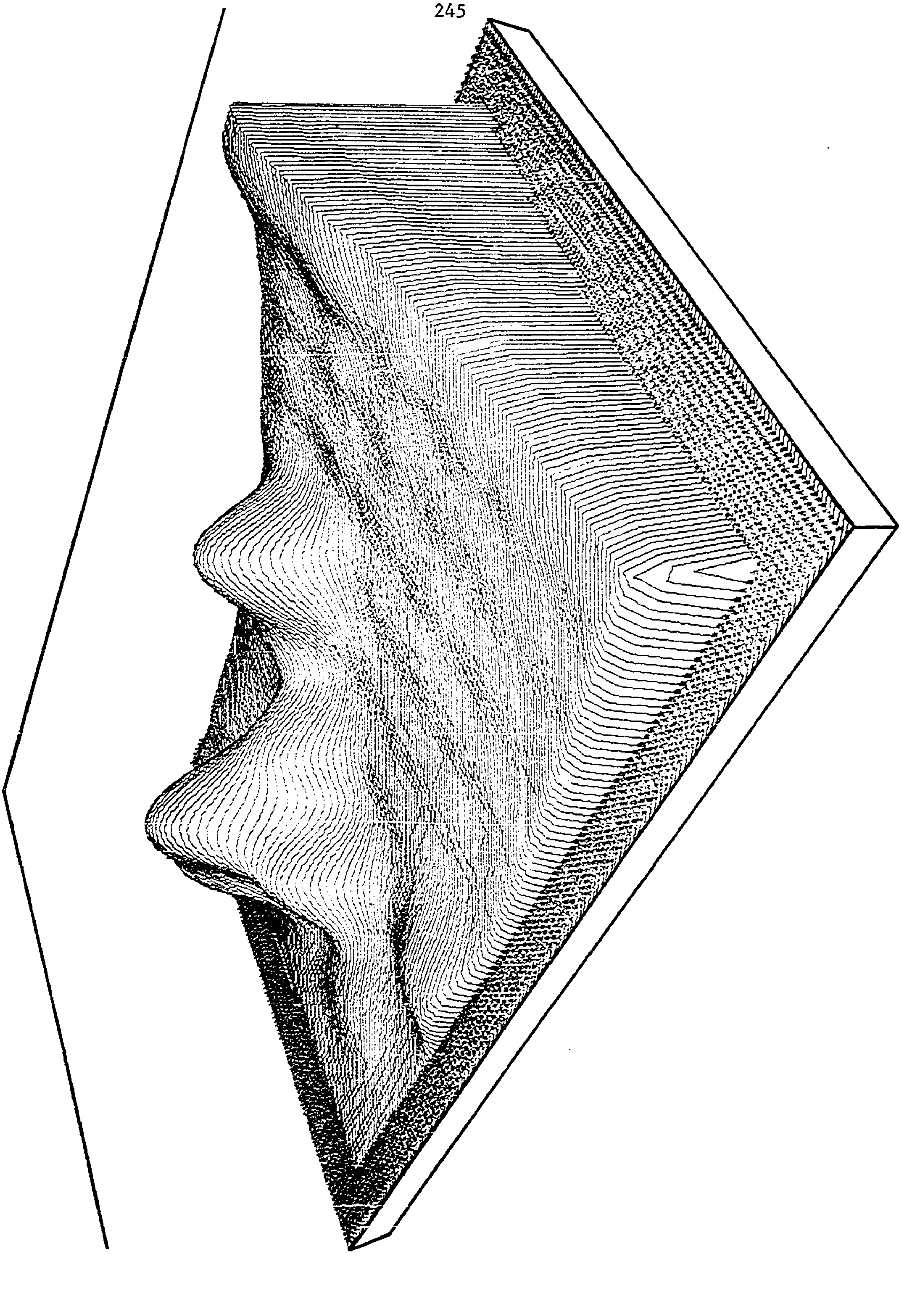


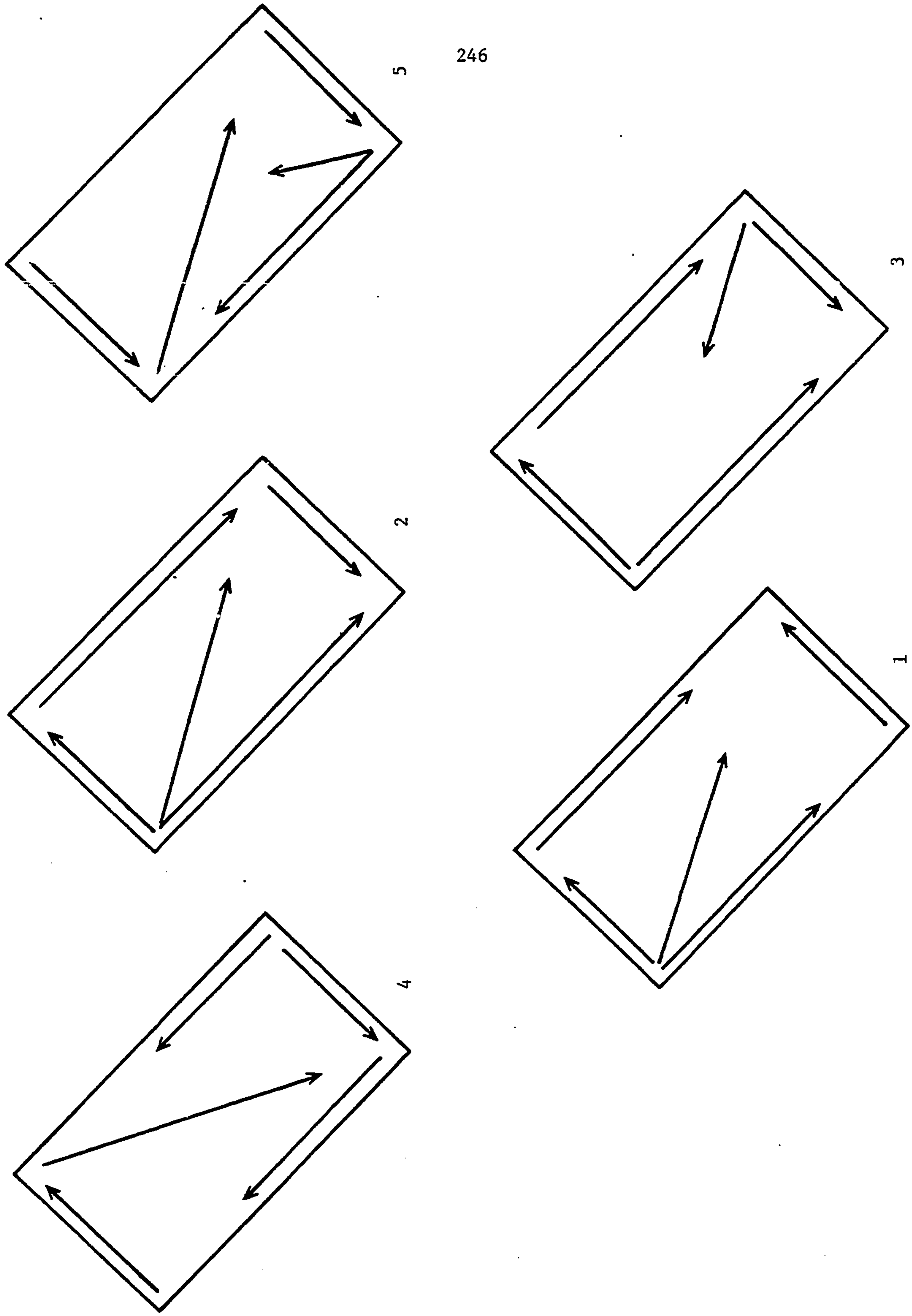


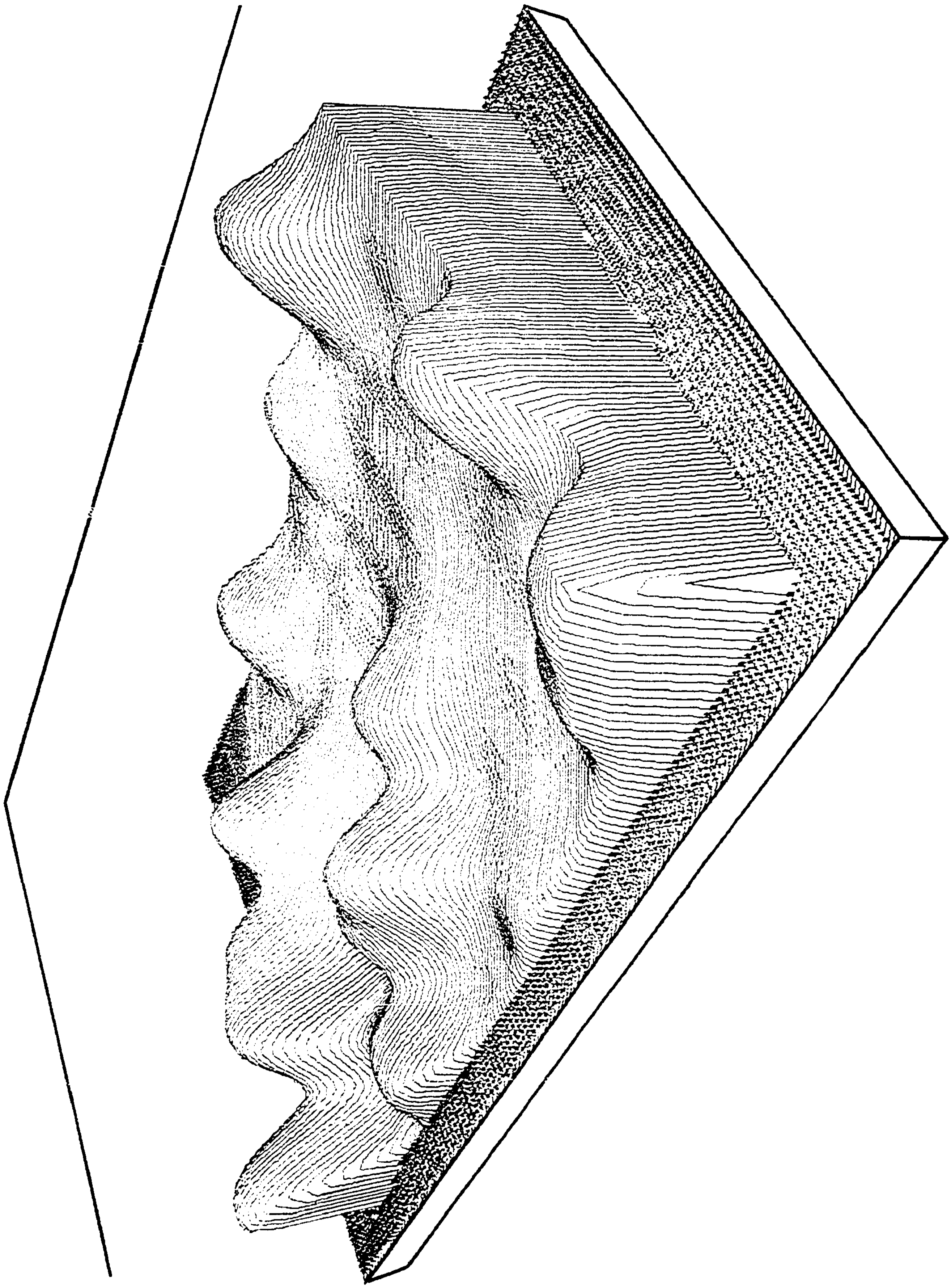


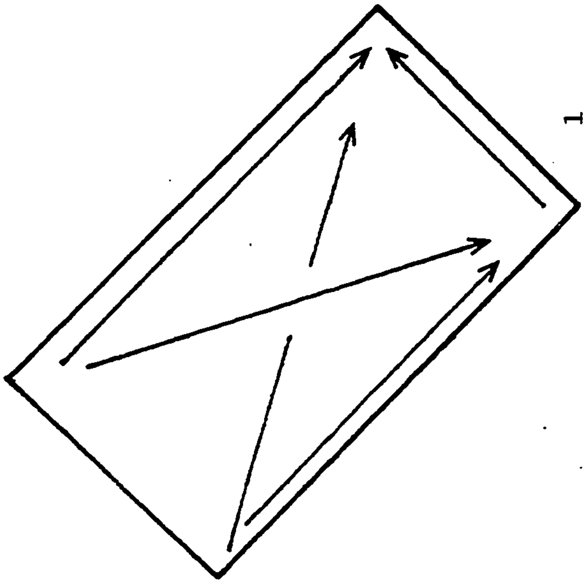
Rank the following maps by placing a 1 by the diagram which you feel most accurately represents the trend of increasing values on the surface, a 2 by the 2nd most accurate, 3 for the 3rd, 4 for the 4th, and 5 for the least accurate representation. Arrows ⟶ indicate the direction of increasing values on the surface.

After placing the number on the final map indicate verbally "finished."

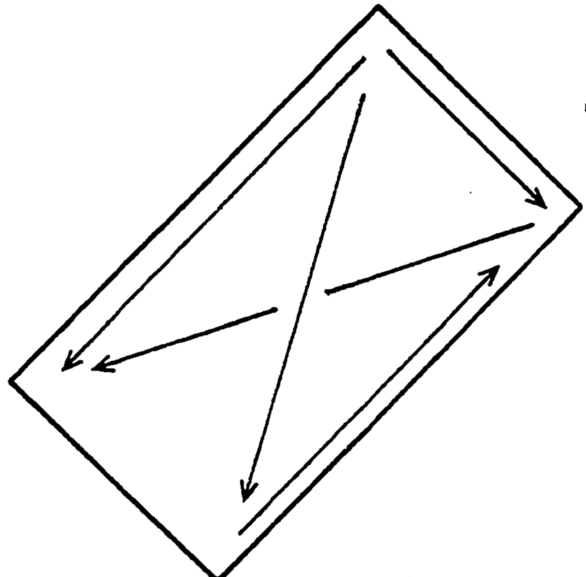



5
3
2
1
4

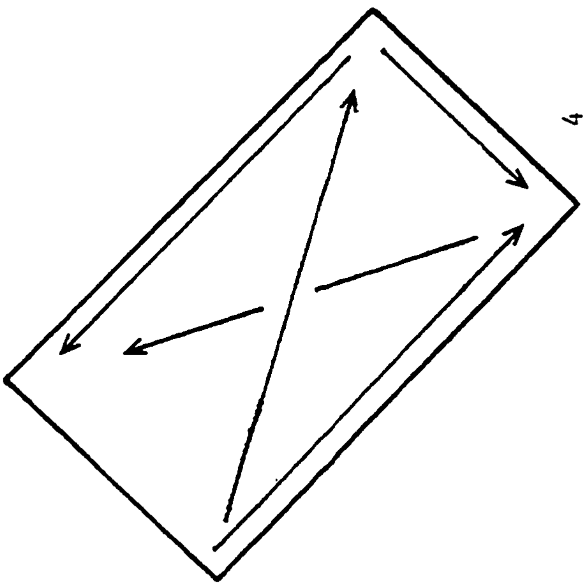




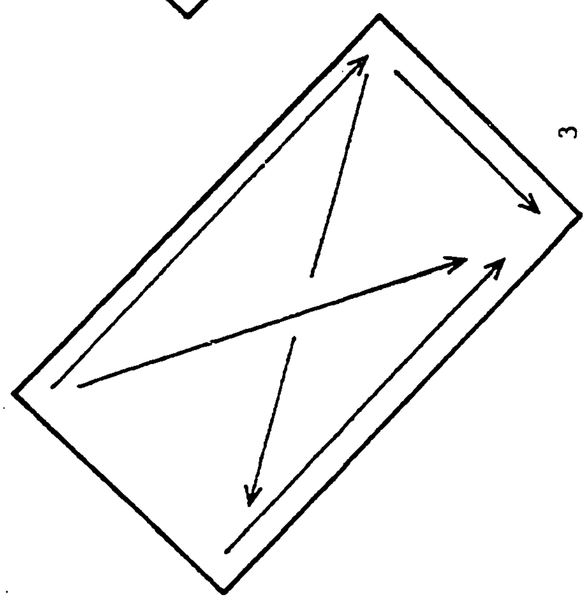
1



5



4



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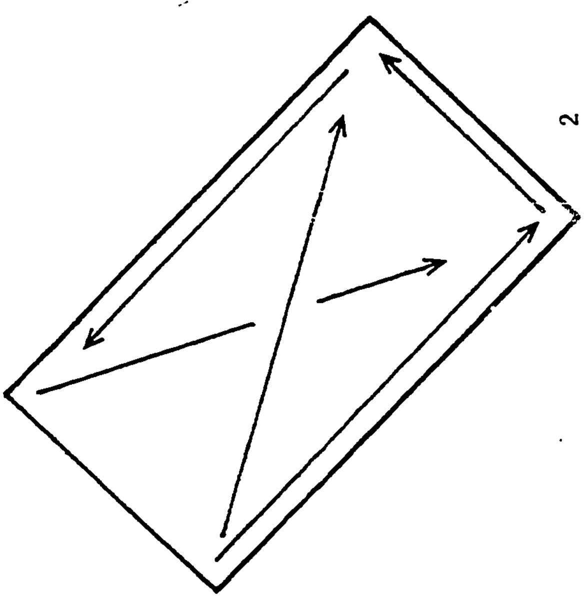
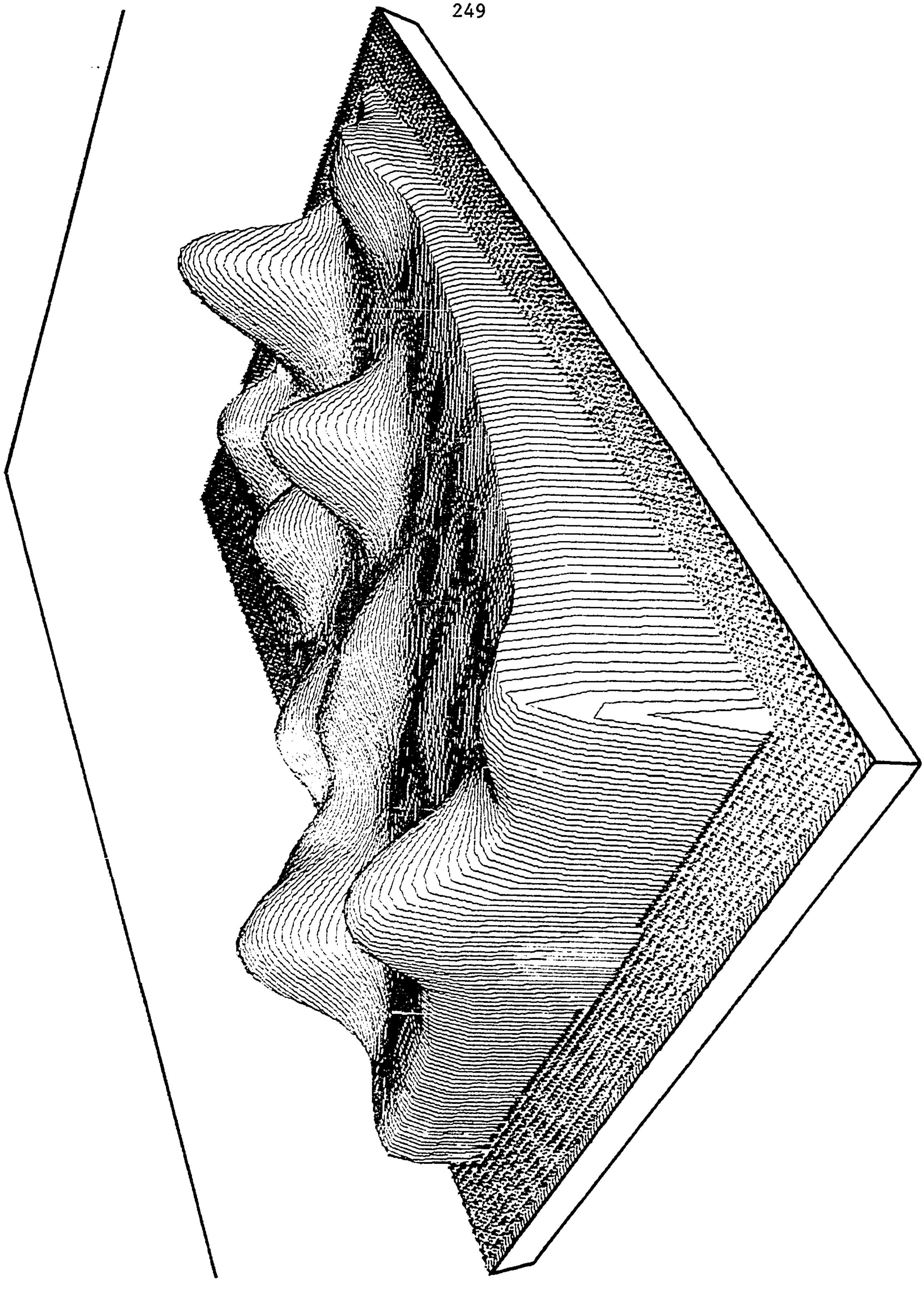
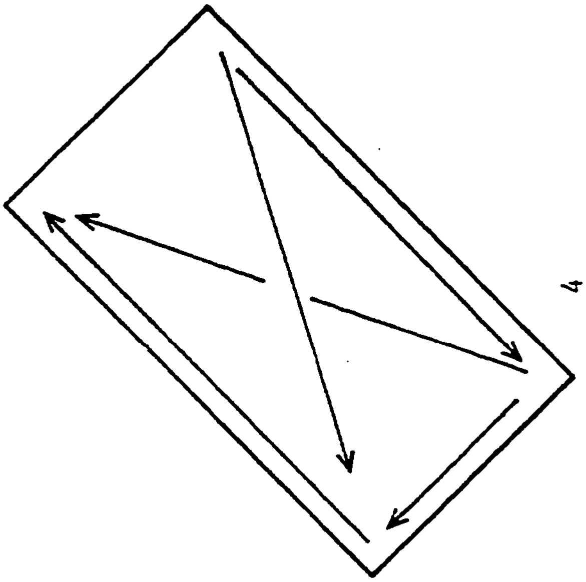


2





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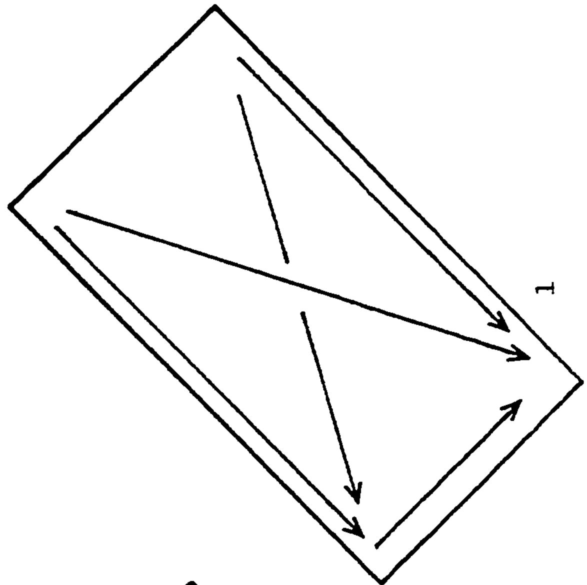

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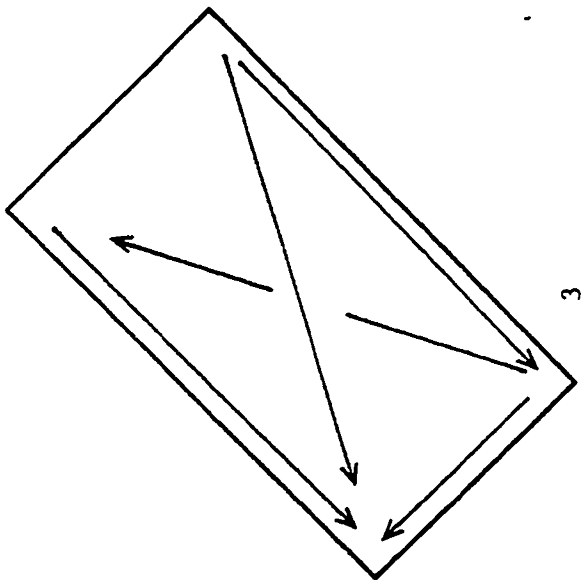

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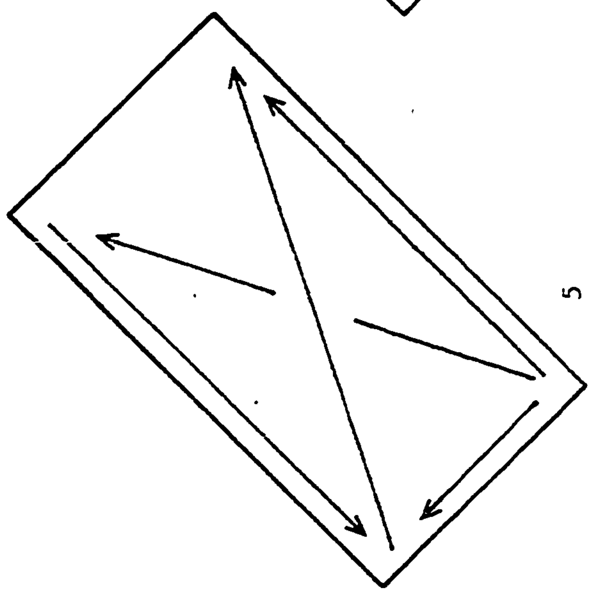

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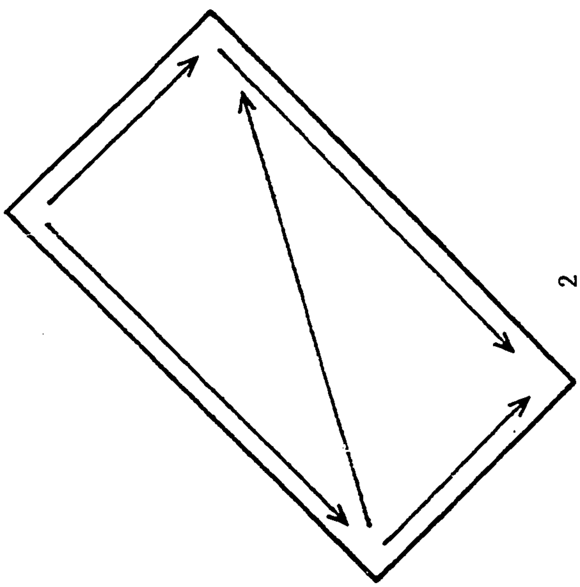

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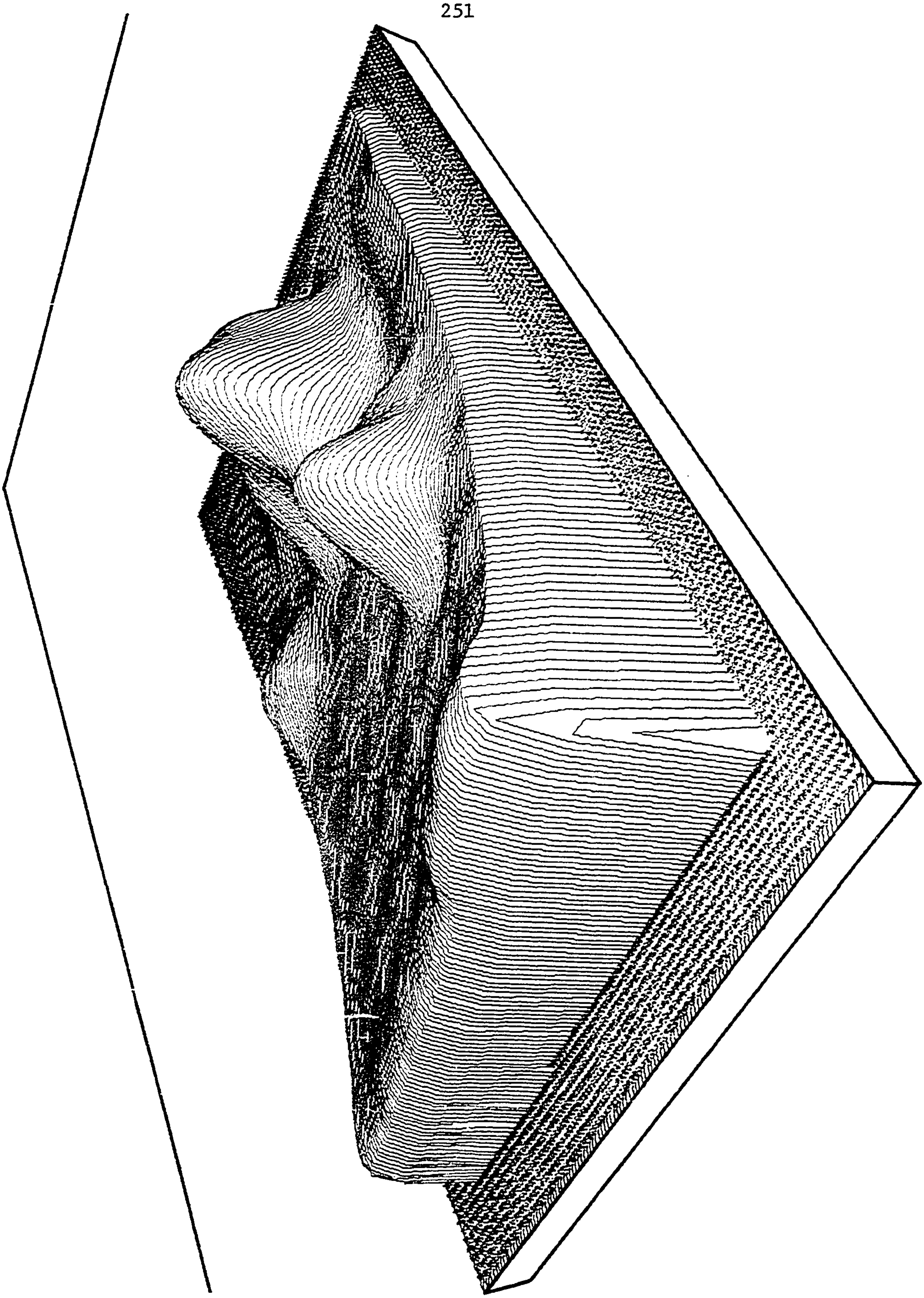

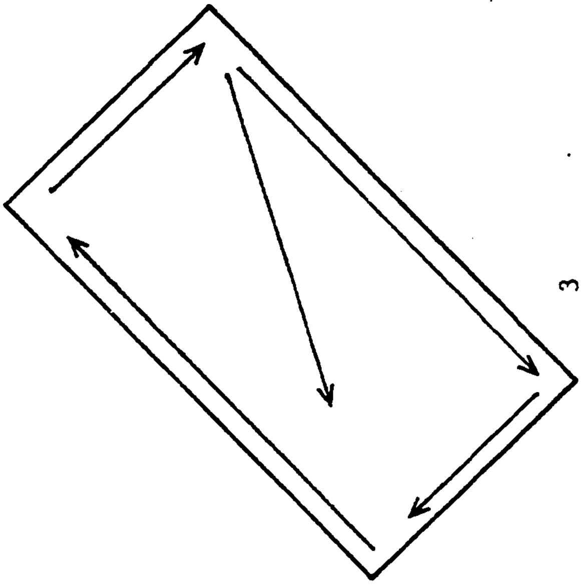

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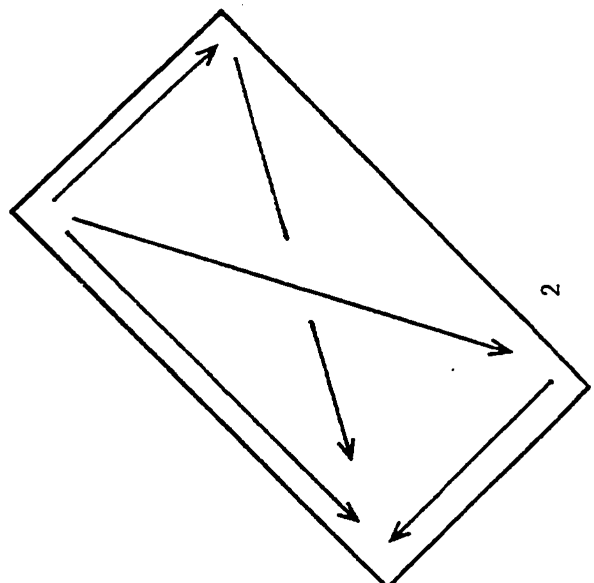

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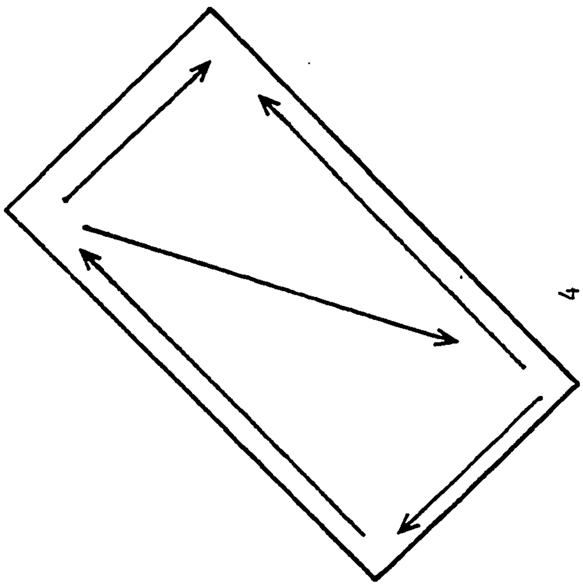

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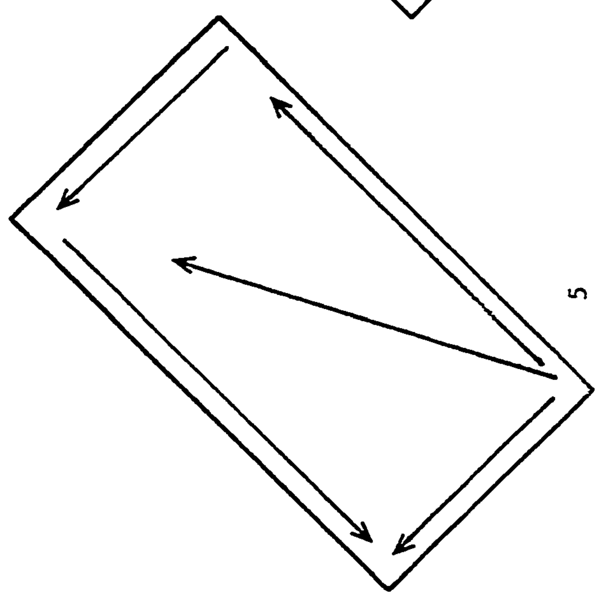

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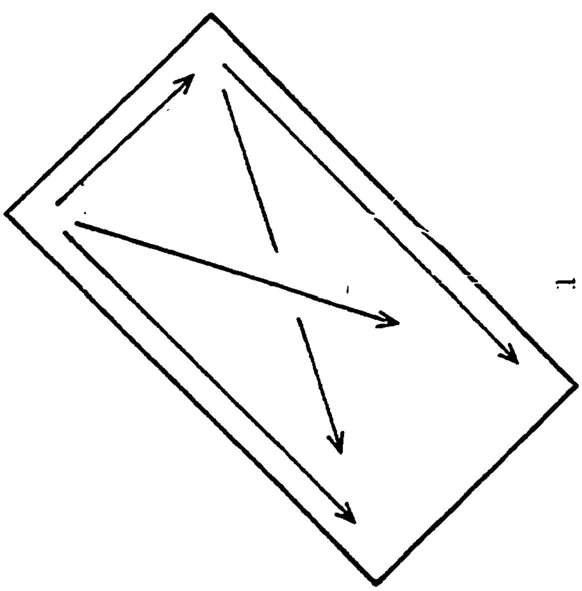

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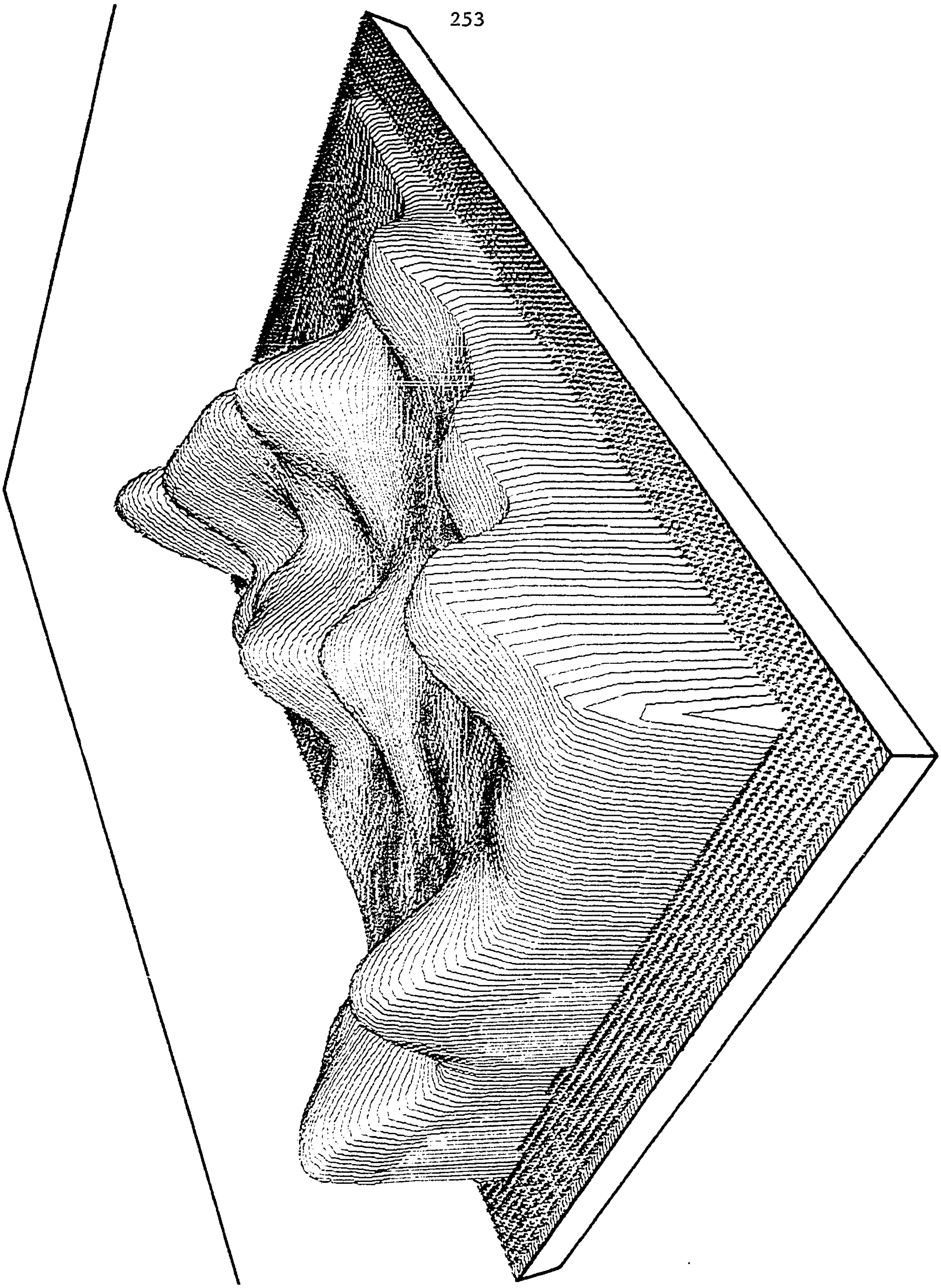

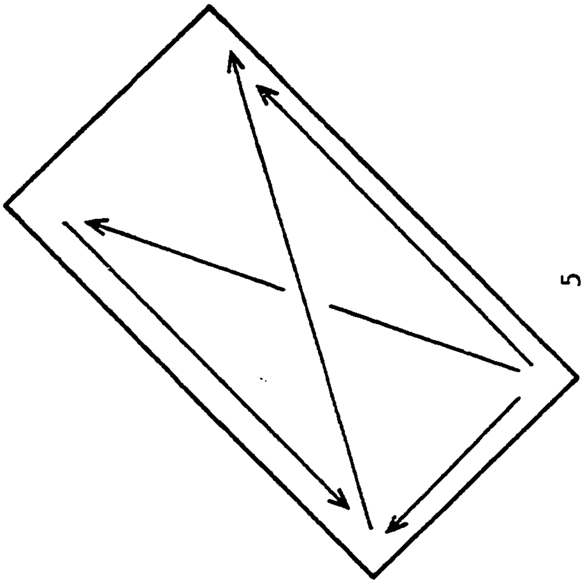

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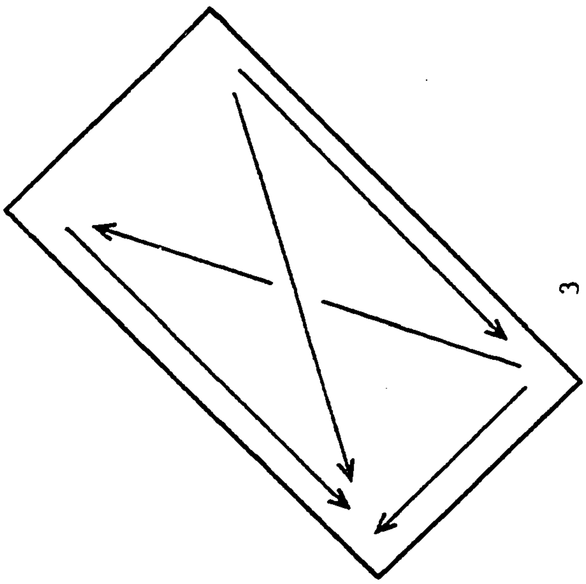

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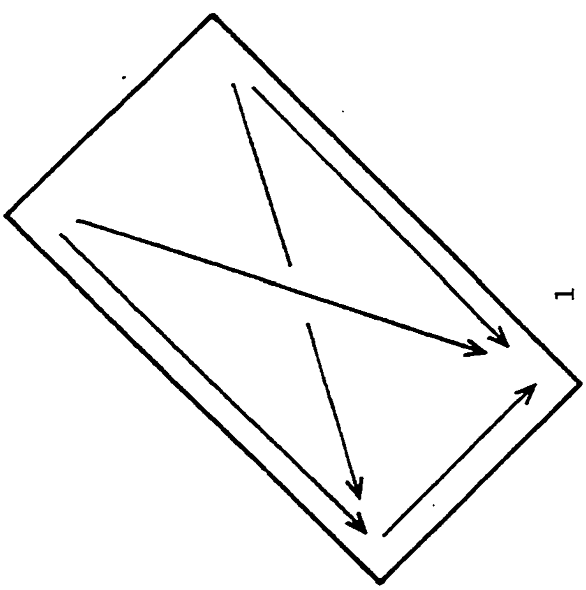

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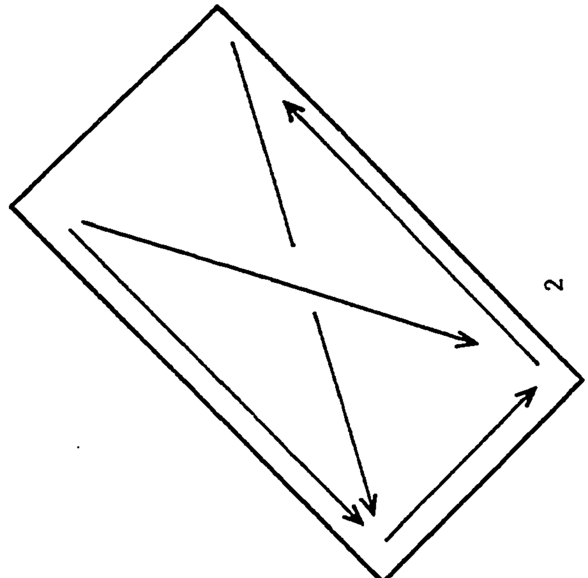

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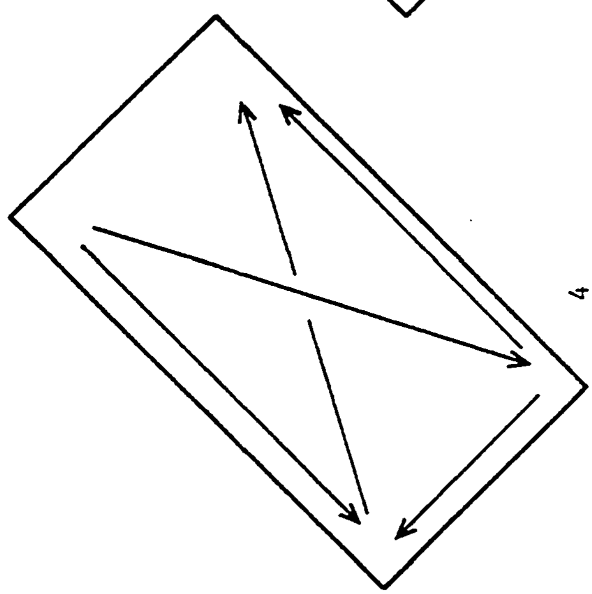
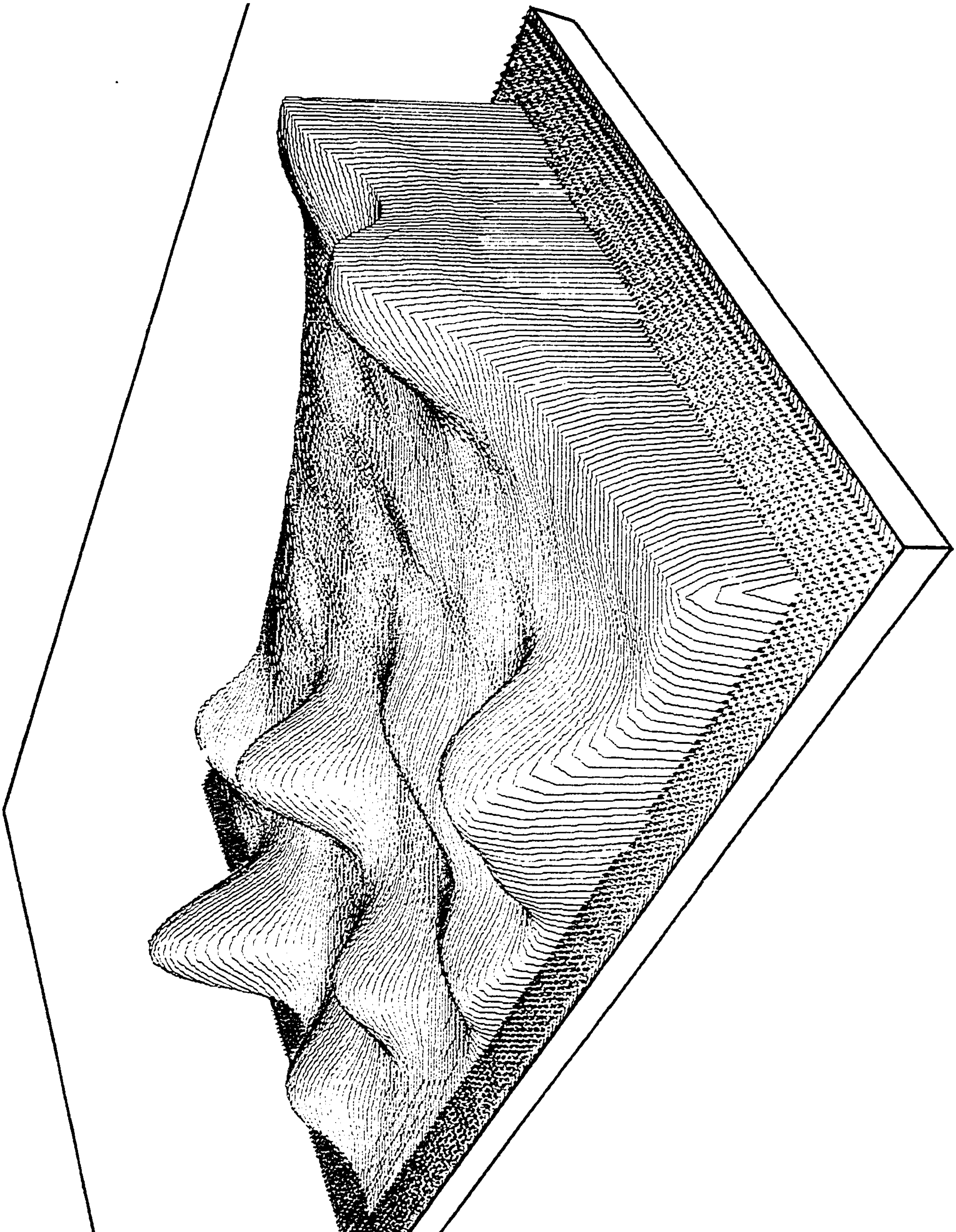
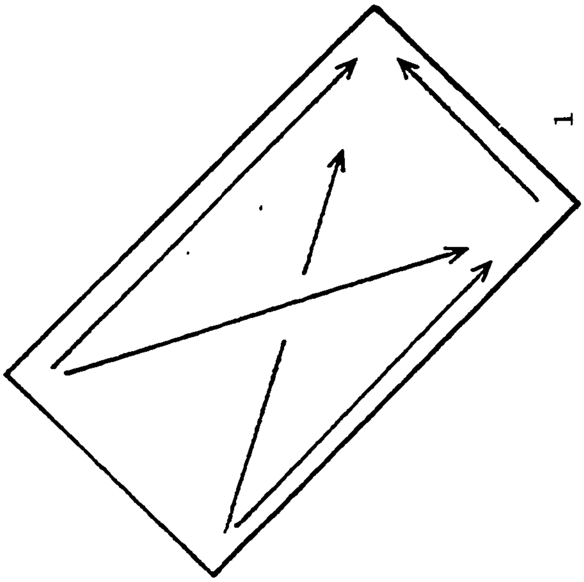
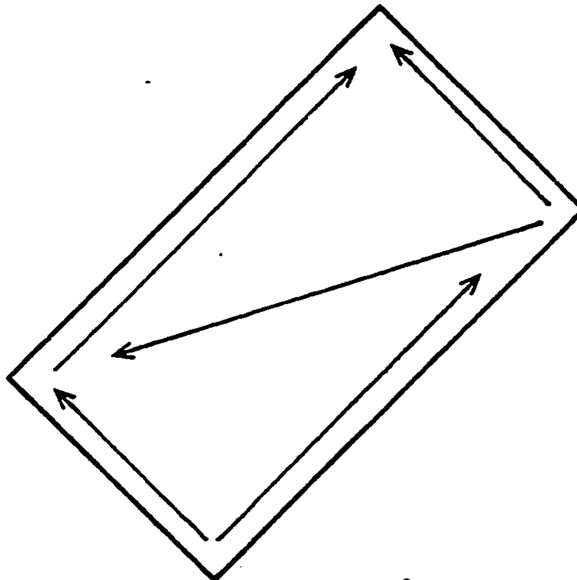


4

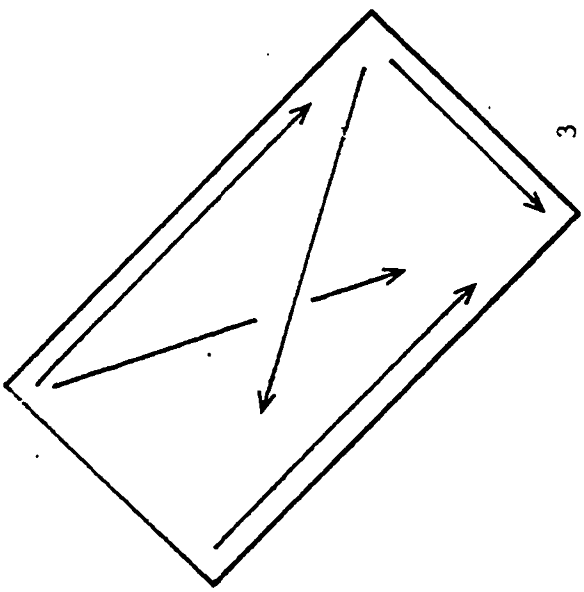




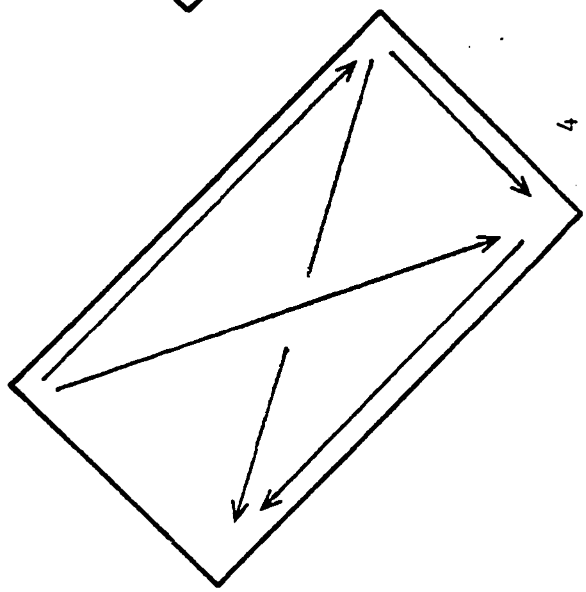
1



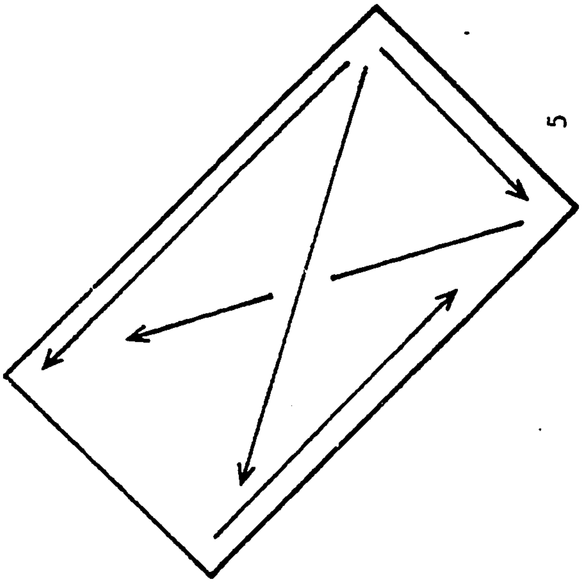
2



3



4



5

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